DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

STRESS ASSESSMENT USING FUZZY LOGIC TECHNIQUE

by
Büşra YAĞCI

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İZMİR

STRESS ASSESSMENT USING FUZZY LOGIC TECHNIQUE

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We have read the thesis entitled "**STRESS ASSESSMENT USING FUZZY LOGIC TECHNIQUE**" completed by **BÜŞRA YAĞCI** under supervision of **PROF. DR. EMEL KURUOĞLU KANDEMİR** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

....

Prof.Dr. Emel KURUOĞLU KANDEMİR

Supervisor

....

Prof. Dr. Çağın KANDEMİR ÇAVAŞ

(Jury Member)

....

Dr. Öğr. Üyesi Kadir DEMİR

(Jury Member)

Prof. Dr. Okan FISTIKOĞLU

Director

Graduate School of Natural and Applied Sciences

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STRESS ASSESSMENT USING FUZZY LOGIC TECHNIQUE

ABSTRACT

Individuals face many events during their lives. The human body reacts to all kinds of events that the individual encounters. This nonspecific response of the body to unexpected conditions and any change is called stress. Since human's perspectives on events are not the same, their reactions may not be the same. Therefore, the stress levels of individuals can be different. In order to minimize the damage caused by stress, which is an inseparable part of life, the first step is to determine the stress level of the person. Biomedical methods and scales are frequently used to determine the stress level. However, thanks to the development of technology, methods of determining the stress level have spread to fields such as artificial intelligence, machine learning, image processing, and neural network.

In this thesis, a model based on fuzzy logic techniques has been developed using photographs containing facial expressions in order to assess the stress levels of individuals. Basically, the difference between two photographs of the individual was used in the model. This difference was obtained from eye pair, mouth, forehead and eyebrow regions, which contain the important symptoms of stress on the human face and were detected using image processing. Fuzzy logic techniques used in the application are Fuzzy C-Means (FCM) clustering, Adaptive Neuro-Fuzzy Inference System (ANFIS) and Fuzzy Inference System (FIS). In the final result obtained from the model was determined so that the stress level of the individuals was included in one of the "None", "Low", "Moderate" and "High" levels.

Keywords: Stress assessment, fuzzy logic tecnique, image processing, FCM, ANFIS, FIS

BULANIK MANTIK TEKNİĞİ KULLANILARAK STRES DEĞERLENDİRME

ÖZ

Bireyler hayatları boyunca pek çok olayla karşı karşıya kalırlar. İnsan vücudu bireyin karşılaştığı her türlü olay karşısında tepki verir. Vücudun beklemediği koşullar ve herhangi bir değişim karşısında vermiş olduğu belirli olmayan bu tepkiye stres denir. Bireylerin olaylara bakış açıları aynı olmadığından tepkileri de aynı olmayabilir. Bu yüzden bireylerin stres düzeyleri farklı olabilir. Hayatın ayrılmaz bir parçası olan stresin verdiği zararları en aza indirebilmek için yapılması gereken ilk adım kişinin stres düzeyini belirleyebilmektir. Stres düzeyini belirlemek amacıyla biyomedikal yöntemler ve ölçekler sıklıkla kullanılmaktadır. Ancak gelişen teknolojiyle birlikte stres düzeyini belirleme yöntemleri yapay zekâ, makine öğrenimi, görüntü işleme gibi alanlara yayılmıştır.

Bu tezde bireylerin stres düzeylerini değerlendirmek amacıyla yüz ifadelerini içeren fotoğraflarını kullanan ve bulanık mantık tekniklerine dayanan bir model geliştirilmiştir. Temel olarak modelde bireyin iki fotoğrafı arasındaki fark kullanılmıştır. Bu fark stresin insan yüzündeki önemli belirtilerini içeren ve görüntü işleme kullanılarak belirlenmiş göz çifti, ağız, alın ve kaş bölgelerinden elde edilmiştir. Uygulamada kullanılan bulanık mantık teknikleri ise sırasıyla Bulanık C-Ortalamalar (FCM) kümeleme, Uyarlamalı Ağ Tabanlı Bulanık Çıkarım Sistemi (ANFIS) ve Bulanık Çıkarım Sistemi (FIS) dir. Modelden elde edilen nihai sonuçta bireylerin stres seviyesi “Hiç”, “Düşük”, “Orta” ve “Yüksek” seviyelerinden birine dahil olacak şekilde belirlenmiştir.

Anahtar kelimeler: Stres değerlendirme, bulanık mantık tekniği, görüntü işleme, FCM, ANFIS, FIS

CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

ABBREVIATIONS

COPD	: Chronic Obstructive Pulmonary Disease
EEG	: Electrocardiogram
FIS	: Fuzzy Inference System
ANFIS	: Adaptive Neuro-Fuzzy Inference System
FCM	: Fuzzy C-Means
GAS	: General Adaptation Syndrome
JAFFE	: The Japanese Female Facial Expression
AFHQ	: Animal Faces-HQ
MATLAB	: Matrix Laboratory
RGB	: True Color (Red Green Blue)
2D	: 2-Dimentional

CHAPTER ONE
INTRODUCTION

Humans, the most advanced living species on earth is known, are different from other living species thanks to their ability to think and express their thoughts by speaking. The ability of humans to think and express their thoughts by speaking has made it possible and even necessary to evaluate them not only from a physiological and biological point of view but also from a psychological point of view, unlike other living creature. Therefore, it is not enough to examine him/her only from the anatomical, biological and physiological point of view in order to understand the structure of human. In order to understand people, it is necessary to examine them with their emotions, thoughts and feelings.

It can be said that with the beginning of humanity the social life on earth began, too. Because human is a social being. They need other people and living things to continue their being in life. This need is met by the communication they establish with other people and living things around them. In this way, a connection is established between both their inner world and the outer world. Thereby, they become part of a society. Furthermore, they become an important factor affecting the lives of other people and living things in the society they are a part of.

People experience many events that involve both themselves and other people and living things around them in their daily lives. When approaching the events that people are likely to experience with their physiological and biological aspects, some examples can be given such as cold, hunger, thirst, injury, germ contamination, catching an epidemic disease, high fever, biomedical diseases, using smoking and alcohol, hormonal diseases, blood loss, cancer, organ loss and disability. All these listed events are phenomenon to which the body reacts directly or in result of their occurrence. For example; the metabolic rate increases by 10-12% for every 1 °C rise in body temperature above 37 °C. Accordingly, the need for fluid and calories in the body increases. Moreover, the workload of the heart and respiratory system increases (Uca, 2014). As a result of smoking, which is another example, carbon monoxide in cigarette smoke directly binds to hemoglobin, whose main task is to carry oxygen in the air to the lungs, reducing the oxygen carrying capacity of the blood. The nicotine in cigarettes directly affects the cardiovascular system in the body. Smoking causes cells of the immune system to overwork. Besides, it is also directly associated with respiratory system diseases such as lung cancer, chronic obstructive pulmonary disease (COPD) and asthma (Akdeniz, 2019). Bleeding occurs when the blood vessel wall is damaged and vascular integrity cannot be achieved, either spontaneously or due to trauma such as cut, shot with a firearm, falling, etc. (Celkan et al., 2006). The contraction of the smooth muscle in the blood vessel (vasoconstriction) is the first response to vessel damage (Ünal, 2018). At the same time, the body responds quickly to blood vessel damage by sealing the damage with fibrin clots (Aykar, 2019). These mentioned results are a clear indication that the body reacts to the events that people experience or may experience.

To approach the events that may occur in life from a psychological and sociological point of view, fighting with a sibling, moving to a new house, being appreciated by the teacher in the classroom, missing the bus, going to the cinema alone, retiring, graduating, seeing a very luxurious car while walking on the road, getting caught in the rain , having a child, chatting with a foreign tourist in a language that you do not fully understand, throwing garbage, taking an exam, traveling to a city you do not know at all, receiving news of the death of a relative, getting married, etc. are some of the situations that come to mind in a short time. Just as the human body gives a visible or invisible biological or physiological response to diseases, injuries, hunger, thirst, high fever, it also responds to environmental and psychological changes in the individual’s life. Someone who has a fight with her sibling may get upset and cry, and the retired person may lost her purpose of life and spend all her time sleeping because she will no longer work. A person who sees a very luxurious car may be angry and shout due to he does not have it, while another person may be happy to think that the reason he can throw garbage is because he has enough food in his house. A student who will take the exam may suddenly have a stomachache on the day of the exam or the groom may faint from excitement on the wedding day. Therefore, the human body reacts to all kinds of physiological, biological, psychological, sociological or environmental events and changes that an individual encounters. This reaction of the body in the face of unexpected conditions was named by Hans Selye, one of the many scientists working on it. According to Hans Selye (1976), stress is “the nonspecific response of the body to any demand” (p.15). Selye also defined stress as “the rate of wear and tear in the body” (p.16).

The word ‘stress’, which is frequently used by today’s people, was used in the meanings of hardship, straits, and affliction in the 14th century when the oldest known history (Lazarus & Folkman, 1984). In the 17th century, it continued to be used in the meanings such as disaster, trouble, and adversity, not far from its original purpose (Paşa, 2007). In the same century, the word stress ceased to be a word used only in social and daily life, and was used for the first time in the scientific field. In the scientific sense, stress was first used in the field of physics by a physicist-biologist Robert Hooke, one of the important scientists of the 17th century, to explain the relationship between an elastic object and the external force applied to it (Balcı, 2014). In the following centuries, the word stress has changed both in daily life and in the meaning of term. The word stress which was used for the first time in the field of physics has attracted the attention of different disciplines and has become a term used in many disciplines such as physiology, psychology, sociology, botany, and zoology.

Researches and studies that would achieve scientists to the definition of stress gained momentum at the end of the 19th century and the beginning of the 20th century. As a consequence of the studies about the internal balance of the body towards the end of the 19th century of the famous French physiologist Claude Bernard, who devoted himself to experimental medicine, the foundations of the stress concept were laid for the first time in the medicine. In the following years, Walter Bradford Cannon was the first scientist to use the term “homeostasis”, which was based on the works of Claude Bernad and which has a great importance in the identified of stress by developed these studies (Robinson, 2018).

In the middle of the 20th century, after many scientists who carried out their studies at about the same time, the word stress was first defined in its current meaning by the

Austrian-born medical doctor Hans Hugo Bruno Selye (Akdeniz, 2014; Fink, 2016). Selye who made observations and studies about stress while he was still a medical student at the German University in Prague in 1926, briefly mentions the concepts that will lead to the definition of biological stress in his short study which includes the results and observations of laboratory studies on rat published in 1936 (Fink, 2016; Selye, 1936; Szabo, Yoshida, Filakovszky, & Juhasz, 2017). Selye used stress for adverse conditions or stimuli, which are also encountered as “noxious agents” in the literature, as a result of which the body gives non-specific responses (Jackson, Ramsden, & Cantor, 2014; Viner, 1999). However, Selye’s first definition for stress is known as “the nonspecific neuroendocrine response of the body” (Szabo, Tache, & Somogyi, 2012, p. 474; Szabo, Yoshida et al., 2017, p. 4030). As a result of his studies, Selye observed that these responses of the body were not limited to the neuroendocrine area, and later on, he introduced new definitions of stress. The book named “The Stress of Life” includes Hans Selye’s works published between 1950-1956 when he focused his studies specifically on the concept of stress (Lazarus & Folkman, 1984; Selye, 1956). The definition of stress, which has changed over the years, is given by Hans Selye (1976) in the shortest form in this book as “the rate of wear and tear on the body” (p. 16). In the 1976 edition of the book, stress has become its form that widely accepted in the medical world with its current usage and has been defined as “the nonspecific response of the body to any demand” (Jackson et al., 2014, p. 47).

Although Selye’s definition of stress was a widely accepted definition both in his time and today, stress never had a general definition. Hans Selye who is known as the father of stress in the medical world as a result of his intense and successful studies on stress, has made stress even more popular (Fink, 2016; Jackson et al., 2014). Many scientists have made new definitions for stress through perspectives in their fields of expertise as well as research and studies on stress.

The famous psychologist Richard S. Lazarus who deal with stress from a psychological rather than physiological aspect, Robert W. Baker, Donald M. Broverman, and Joseph Mayer wrote “We reserve the term stress to refer to a state of the organism rather than the circumstances to which the individual is exposed" in their study called "Personality and Psychological Stress" (Selye, 1976, p. 16).

American physiologist John Wayne Mason whose definition of stress does not match Selye's definition, explained stress as 'may simply be psychological apparatus involved in emotional or arousal reactions to threatening or unpleasant factors in the life situation as a whole' in his study named "A re-evaluation of the concept of 'nonspecificity' in stress theory" (Selye, 1976, p. 20).

In his study published in 1974, the American social psychologist James S. House defined stress as a situation in which abilities cannot meet the desired demands, in other words, the demands or needs exceed the existing abilities and there is a clear obstacle to their satisfaction.

According to Prof. Dr. Doğan Cüceloğlu, stress is "the effort an individual spends beyond his/her bodily and psychological limits due to the incompatible conditions in the physical and social environment" (Cüceloğlu, 1994, p. 92).

Even looking at these definitions which are only a few of the hundreds of definitions of stress, it is possible to see that scientists who conduct research and studies on stress have different approaches to the subject. Perhaps the only agreed issue about stress which cannot have a single definition on account of the fact that it is examined by many different disciplines such as physiology, psychology, and sociology, is that it has a great importance in people's lives.

Stress which is called the *disease of the modern era* in many studies about it is generally used in a negative sense by people (Gökler, 2012; Özel & Karabulut, 2018). Stress, which is seen as the cause of failure, unhappiness, disagreements and many physiological or psychological diseases, often appears as a concept that people want to get rid of it. Although it is a well-known fact that the negative effects on human life and various diseases it causes Hans Selye "Complete freedom from stress is death. Contrary to public opinion, we must not-and indeed cannot- avoid stress, but we can meet it efficiently and enjoy it by learning more about its mechanism and adjusting our philosophy of life accordingly." clearly stated that stress cannot be completely eliminated with his words (Selye, 1973, p. 693). Stress is not a concept that should be eliminated with aspect all living things, especially people, need a certain level of stress to continue their lives. For this reason, scientists who define stress albeit with different approaches, have started to develop ideas about what stress is as well as how to cope with it, manage it and prevent the excess in time.

The sources that can cause stress in the person may be different from each other. Many criteria such as an individual's background, experiences, gender, age, job position, educational status, personality cause different perceptions and evaluations of events. Hence, on the grounds of the nature of being human, individuals do not react to every event in the same way (Özel & Karabulut, 2018). Individuals may even react differently to the same events at different times. Therefore, the first step to minimize the damage caused by stress, to cope with it and to manage it is to determine the stress level of the person (Yıldırım, 1991). For this purpose, stress scales developed by scientists appear as common tools used to measure the stress level of an individual (Eskin, Harlak, Demirkıran, & Dereboy, 2013).

The importance of technology is a fact that cannot be ignored in today's world which is the age of science and technology and is also called the information age and the third industrial age. Perhaps the greatest benefit of technology which we encounter in every aspect of human life that comes to mind or not such as transportation, information sharing, communication, sports, art, security, education etc. is its benefits in the field of health. Thus, the use of technology has been inevitable in determining the level of stress, the effect of which is a objective condition on human health. For this aim, studies have been carried out to determine and predict the stress level with many different methods such as artificial intelligence (Sharma & Gedeon, 2011), machine learning (Raichur, Lonakadi, & Mural, 2017), image processing (Failzal, V, V, C, & B P, 2021), neural network (Gavrilescu & Vizireanu 2019). In studies related with stress, data based on people's ratings of stress levels in medically validated scales as well as data obtained from behavioral manifestation, physiological signal, physical features, emotional manifestation, facial expression, and voice recognition are used (Shanmugasundaram, Yazhini, Hemapratha, & Nithya, 2019).

In view of the fact that the various symptoms and effects of stress on people, many different variables can be mentioned to determine stress. These are can be data which encountered in many studies, require various equipment to measure (electrocardiogram (EEG), electrodermal activity, respiration, humidity, and heart rate variability, speech), are obtained using thermal images (respiratory rate, number of blinks, skin temperature and blood flow), are obtained from pictures and videos (pupil size, head movements, changes in the eye, mouth, forehead, nose area) (Jeon, Bae, Lee, Jang, & Lee, 2020; Shanmugasundaram et al., 2019).

Sharma, Dhall, Gedeon, and Goecke (2014) proposed a stress recognition method that uses facial images and does not require body-contact sensors. The method covers two parts as data collection for stress recognition and analysis of the collected data. The dataset is called ANUStressDB in the study, includes 35 videos captured using the thermal and visual spectrum while the subjects watch movie clips which consist of stressful and non-stressful situations. The features procured from the videos in the dataset were used as input for the support vector machine and genetic algorithm techniques used in the study.

Raichur, Lonakadi and Mural (2017) stated, in their studies aiming to determine the stress levels of people who spend a lot of time in front of the computer, that these measurements are intrusive and less comfartable even though digital signal (galvanic skin response, blood volume, pupil dilation and skin temperature), physiological signals and visual features (eye closure, head movement) are used in many studies on stress detection. Instead, they proposed a method based on the change in eyebrow coordinates by using videos taken from the front while the person is working in front of the computer.

In the study titled “A Comprehensive Review on Stress Detection Techniques” published in 2019, it is mentioned that researchers have proven that stress level deduction can be made using heart rate, humidity response, temperature response and fuzzy logic algorithm. The authors have given information about the physical parameters used in the determination of stress and the sensors used in the measurements of these parameters. 12 studies published between 2007 and 2017 were examined and their contributions and limitations were given in the table (Shanmugasundaram et al., 2019).

In another study published in the same year considering the importance of real-time stress, a framework which monitor negative emotional stress instantly and warn the person to take a break when a certain threshold level is exceeded was proposed. The proposed framework detects stress using three facial expressions, anger, sadness, and fear which are sensitive to negative emotional stress. Three different datasets were used in this study, which is important in terms of the relationship between stress and anger, sadness and fear, which are accepted as three of the basic emotions. In conclusion part of study, the framework achieves high stress detection accuracy especially in database which consist of images are captured in an actual driving environment is mentioned (Zhang, Mei, Liu, Yuan, & Qian, 2019).

In a study published in 2020, the authors used the images obtained using a general camera while determining the stress, in contrast to the biological signal or thermal image data, which requires a device while to be obtained. In the stress recognition algorithm proposed in the study, face images and facial landmarks got from the first images were used. The results obtained are divided into 3 classes as no stress, weak stress and strong stress (Jeon et al., 2020).

Stress is of great importance in human life due to its potential to be encountered in every moment of life. Many studies and research on it reveal the importance of determining stress and stress level. Determining the stress level, which is thought to be of increasing importance in the near future, has already become a necessity today. So much so that even the smart watches we use in our daily life are measuring stress. It is very important to develop a method suitable for the daily life and the factors affecting stress, when assessment the level of stress that has taken such a place in human life. The aim of this thesis is basically to assess the stress level of individuals using images containing facial expressions.

This thesis consists of five chapters and the chapters in the thesis are organized as follows:

In Chapter One, the content of the thesis is introduced. The place of stress in the lives of living beings, especially people, the relationship between stress and people, and the basic definitions of stress are mentioned. The development process of the concept of stress has been examined. It is explained that this process is not only limited to the definitions of stress but also includes research and studies to determine the stress level. Examples of the techniques used in these studies are given and their purposes are mentioned. Thus, the literature review is summarized.

In Chapter Two, the concept of stress is explained in detail. In order to assess the level of stress, first of all, it is necessary to know what stress is, its history, developmental process, causes, results, and its effect on individuals. Therefore, stress has been examined extensively. The scientists who pioneered its development and their studies are included. In addition, the symptoms in humans were examined under three headings, and the being stress symptoms aspects of the variables used in application were underlined. Besides, the stress sources and the relationship between stress and emotions are explained.

In Chapter Three, fuzzy techniques used for stress assessment in the application developed within the scope of this thesis are explained. It has been observed that the fuzzy logic approach to the concept is more appropriate considering the structure and features of the concept of stress. The history and features of fuzzy logic, which forms the basis of fuzzy techniques, are given. Fuzzy techniques found suitable for assessing stress level were determined as Fuzzy Inference System (FIS), Adaptive Neuro-Fuzzy Inference System (ANFIS) and Fuzzy C-Mean (FCM) clustering. The structures and properties of these techniques, which form the basis of the application, are explained in detail.

In Chapter Four, the application proposed in this thesis to assessment the stress level is described in detail. The datasets and their properties used while developing the model are examined. In order to obtain the numerical values required by the techniques used in the application, images containing facial expressions, one of the most important signs of stress, are used. The eyes, mouth, forehead and eyebrow areas of individuals, in their images of neutral, fear, anger and sadness states are determined by image processing technique. The numerical values obtained from these regions were used as data in fuzzy techniques. Some results from FCM and ANFIS techniques have provided information for the FIS model. The stress assessment results obtained with the FIS model of the participants in the dataset are given in the table.

Finally, in Chapter Five, the results of the studies carried out within the framework of this thesis are explained. The percentage of success of the proposed model is given. Some determinations have been made to increase this percentage. Suggestions for the improvement of the model in future studies and its usage areas are presented.

CHAPTER TWO
STRESS

It is important to ask some questions to concept such as what, which, and why in order to understand and explain a concept. This chapter answers with explanations which include, the history and definitions about it to the question of what stress is, the changes in the person to the question of which symptoms it has, and the sources caused stress to the question of why stress occurs. Moreover, the terms related with stress are also included in order to understand it.

2.1 The History of Stress Definitions

Stress, which is a word that most people hear and use at least as often as the word "hello" in daily life, is a concept that is of great importance for people both scientifically and in daily life. What stress, which people define in their own way when asked what is and everyone has an opinion about it, really is, how it emerges and how it is defined has been the subject of many studies. Therefore, it is of great importance to examine the history of stress and the definitions made about it until now.

When analysed from an etymological perspective, the origin of the word stress is based on the words *'estrictia'* (Gök, 1995; Güçlü, 2001; Kırel, 1991; Osha, 2020) and *'estrica'* (Erdoğan, Ünsar, & Süt, 2009; Gökler, 2012) in Latin, and *'estrece'* (Recepoğlu & Recepoğlu, 2022) in French. Other opinions about the origin of the word stress are that the word is derivative of the Latin verb *strictus*, which means 'to draw tight' (Robinson, 2018, p. 334) and *stringere*, which means 'to bind tight' (Humphrey, 2002, p. 1). Moreover, the word strictus was incorporated into French as *estress*, which means 'narrowness, constriction, oppression', and *distress*, denoting 'hardship or force exerted on a person', into English (Robinson, 2018, p. 334). According to another view, the word *'distress'*, which is used in the same sense as today's definition of stress in ancient medical sources, is derived from the Latin word *'distringere'*, meaning "excessive pulling and stretching" (Kırel, 1991, p. 3).

According to Hans Selye stress is an ancient concept enough even prehistoric man to think the loss of strength and the sense of exhaustion that overpowers him after prolonged exposure to cold or heat, loss of blood, agonizing fear, or any illness, had something in common (Selye, 1973). According to some researchers, stress and its effects are an aware state by Aristotle, Hippocrates, and the other Ancients (Fink, 2016). However, the earliest known date for the use of the word stress is the 14th century. Stress, which was thought to have no programmatic focus in the 14th century, was used to mean hardship or adversity (Lazarus, 1993).

After a period of 300 years, the word stress has taken on the meanings of disaster, trouble, calamity, affliction, grief, and sorrow in the 17th century (Gökler, 2012; Güçlü, 2001). However, the importance of the 17th century from the development of the concept of stress point of view is that it was used scientifically for the first time rather than in daily life. Robert Hooke, the name that coined the word stress in the physics literature, was interested in how it was possible to build structures that are designed by humans to carry heavy loads in a manner to resist natural events that could shake or destroy them. In this process, he introduced three new definitions, including the stress definition. The definitions made by Hooke have been stated in the work of R. Lazarus as "*Load* referred to a weight on a structure, *stress* was the area over which the load impinged, and *strain* was the deformation of the structure created by the interplay of both load and stress" (Lazarus, 1993, p. 2). In other words, Robert Hooke used the concept of stress to explain the relationship between an elastic object and the force exerted on it from the outside, (Gökler, 2012; Recepoğlu & Recepoğlu, 2022) and he discovered the law of elasticity, also known as Hooke's law, in 1660 (Kültz, 2020).

About a hundred years later, the famous physicist Thomas Young used stress in a formula in conjunction with Hooke's law (Paşa, 2007). Young, who is one of the pioneers of the use of stress in the field of physics, defined stress as the ratio of the force that existed to balance the externally applied force inside the elastic body to the region where the externally applied force acts (Brantley & Thomason, 1995; Engel, 1985). According to this definition, stress is a situation that exists spontaneously within the substance but arises under the influence of a force applied from outside. According to the information obtained from different sources, Young has argued that matter reacts and resists the force applied from outside only as much as the force within itself. If the force inside the elastic material is strong enough to balance the external force, it responds by bending and leaning; and tries to adapt. Otherwise, matter undergoes a qualitative or quantitative change in proportion to the magnitude of the external force (Gökler, 2012; Paşa, 2007).

After its scientific use in physics for the first time, the word stress which changed semantically was used in the 18th and 19th centuries to mean power, pressure, hard, and difficulty for the object, the individual, the organ, and the individual's mental state (Güçlü, 2001). Perhaps the most important pioneer of usage for the individual and organ concepts in the 19th century of the word stress, known to have been used in areas such as social life, physics, and engineering in previous centuries, is Claude Bernard who is considered as the father of experimental medicine (Robinson, 2018). Continuing his studies in Paris towards the end of the 19th century, Bernard has observed that the internal environments of living things not only provide the intercellular nutrient exchange, but also act as a buffer through biochemical methods (Fink, 2016). As well as, he has discovered the condition in which blood vessels dilate and narrow to maintain the body's internal temperature. As a result of his studies, he made the concept of stress a subject for the first time in the medical world and developed the theory of *milieu intérieur* which means 'the environment within' and is thought to be the basis of the development of the stress concept (Robinson, 2018, p. 335).

When the literature is examined, studies (Dantzer, 2001; Türk, 1997) arguing that the word stress (as a term) emerged from the works of Cannon and Selye as well as sources stating that stress was also defined by Bernard have been encountered. According to these studies, the word stress in the field of medicine was first used by Bernard and was defined as 'stimuli that disrupt the balance of the organism' (Gök, 1995, p. 3). In the same century, stress, on which other physiologists besides Bernard, made statements, was explained by the German physiologist Eduard Pfluger as 'the protection of the organism from harmful factors in order to feed and meet the needs of life' (Görgülü, 1988, p. 5).

The works, that laid the groundwork for the stress definition, of scientists began to gain momentum at the beginning of the 20th century. One of the foremost of these studies is the American physiologist Walter Bradford Cannon's detailing Bernard's milieu intérieur theory and putting forward the definition of homeostasis. While Cannon was examining the peristaltic movements in a cat, he coincidentally observed that the peristalsis stopped when the cat was distressed and alarmed. As a result of this observation, the emotional effect of the stimuli affecting the internal system of the living organism became a subject that attracted Cannon's attention. Another event that guided his work was that he was assigned to France to observe the "shell shock" situation that occurred in the soldiers who served in the First World War (Robinson, 2018). Continuing his studies on the response of the internal system of the living organism to trauma and fear after the war, Cannon named "The coordinated physiological reactions which maintain most of the steady states in the body" as *homeostasis* in 1926 (Cannon, 1929, p. 400; Robinson, 2018). Homeostasis, which is formed by the combination of the Greek words *homoios* meaning "like, similar" and *stasis* meaning "position, standing", is defined in another word as "the ability to stay the same or static" (Selye, 1973, p. 697).

Cannon (1929) gave examples such as the amount of glucose and calcium in the blood, water in the body, the temperature value of the body, the hydrogen-ion concentration of the blood, and explained their importance to the body in his study. In the same study, he detailed homeostasis by describing the optimum level of these values, the harm they can cause to the body when these values change, and the body's reactions to ensure internal balance as a result of the change. Cannon, who also used stress to explain homeostasis, was the first person to use the word stress in the medical world according to some sources. In addition, stress was first used by Cannon in 1915 to describe a nervous strain and tension (Türk, 1997). According to Lazarus and Folkman, Cannon viewed stress as a state that disrupts homeostasis under adverse conditions such as cold, lack of oxygen in 1932 (Lazarus & Folkman, 1984). However, he did not use the word stress in his works until his article titled “Stresses and Strains of Homeostasis”, published in 1935, in which he did not include the definition and reference about stress (Robinson, 2018).

Another term that Cannon who Selye referred to as ‘one of the greatest physiologists not only of this century, but of all time’ in 1975 introduced to the literature was *fight or flight* (Fink, 2016; Jackson et al., 2014, p. 28). Cannon mentioned in 1915 that the purpose of the body’s responses, through methods such as the nervous system and hormone secretion, in case of deterioration of homeostasis, is to prepare the ground for the behavioral response of the animal or human in this situation (Cannon, 1994). According to the concept of fight or flight, living organisms can react in two ways to the stimulus: they either face and fight the stimulus or flee from it (Fink, 2016; Kırel, 1991).

Hans Selye is one of the scientists working on stress whose popularity has increased in the 20th century in the medical world, especially in branches such as physiology and psychology, and perhaps the most important of them on the grounds that he defined stress for the first time in its current meaning. The basis of Selye’s stress studies was the observations he made in 1926 when he was a second-year medical student. Selye, who was taught that the symptoms are related to and specific to certain diseases throughout his education life, observed that people with different diseases have many common signs, symptoms, and complaints (Tan & Yip, 2018). Selye, who gave as an example of the fact that people suffering from different diseases such as excessive blood loss, an infectious disease, and cancer are faced with common consequences such as loss of ambition to succeed, muscle strength and weight; called this situation “syndrome of just being sick” in those years (Selye, 1973,1976).

After completing his doctorate at the university where he studied medicine, Selye was trying to find a new hormone with his studies on rats while working at the Biochemistry Department of McGill University (Jackson et al., 2014) Selye, who observed three main changes in rats during his experiments, namely adrenal enlargement, lymphatic structures shrinkage, and deep, bleeding ulcers in the stomach and duodenum, initially thought that the reason for these changes was a new sex hormone. However, when Selye discovered that rats had the same physiological responses to different stimuli, such as various toxic substances, extreme cold, injury, and excessive muscle exercise; he realized that there was an experimental explanation of the situation which he called the "syndrome of just being sick" about 10 years ago (Selye, 1973, 1976).

Selye, who described his experiments on rats and the results he obtained in his article titled "A Syndrome Produced by Diverse Nocuous Agents" published in Nature in 1936; stated that the responses of the body against the stimuli, which he referred to as "acute non-specific nocuous agents", were the same and a typical syndrome emerged. Selye said that this syndrome, which and is most commonly known as "General Adaptation Syndrome" (GAS), develops in three stages (Selye,1936).

The first stage of GAS, which is also known as "biologic stress syndrome" (Selye, 1973, 1976) and "Selye's Syndrome" (Tan & Yip, 2018) in the literature, is the *alarm reaction* named by Selye. Alarm reaction is the stage where the first reaction to stimuli is given. Selye stated that, in addition to the three basic reactions he observed in his experiments at this stage, events such as loss of adipose tissue, formation of edema, decrease in body temperature, increase in tears and saliva secretion occurred, and also that the organism could not remain in a state of alarm all the time (Selye, 1936).

Depending on the severity of the agent and the exposure time, the animal may die in the alarm reaction, if it survives, the second step of the syndrome, the *stage of resistance,* is passed. The changes that occur in the second phase of the syndrome are often the opposite of those that occur in the alarm reaction phase or these changes disappear completely. Therefore, the changes in the two stages are different from each other. At the stage of resistance, the organism shows resistance to adapt to the stimulus. So, the resistance of the body is above normal. However, since the body directs all its resistance to the stimulus it is trying to adapt to, its defense against other stimuli is low. In cases where the applied stimulus disappears or the body adapts to the stimulus, all changes in the body return to their normal state and the energy lost until this stage begins to be regained.

If the stimulus is continued to be applied even if it is constant, the body inevitably enters the third and final stage, the *stage of exhaustion.* Although the tendency to return to normal state and start gaining energy in the resistance phase suggests that the body can cope with the stimulus applied at a constant level depending on its severity, Selye said that the ability of a living organism to adapt to the surrounding conditions, in other words, the ‘adaptation energy’ is a finite quantity. While explaining his GAS in his study (Selye, 1973), Selye cited the gradual aging of an inanimate machine over time and said that the human body would have the same end as a result of wear and tear. For this reason, the body which cannot overcome the stimulus in the stage of resistance shows fatigue in the stage of exhaustion, its resistance decreases and the symptoms that occur in the alarm reaction reappear. At the end of this stage, the body takes serious damage and becomes susceptible to diseases, and the last point is death. All stages of GAS is given in Figure 2.1.

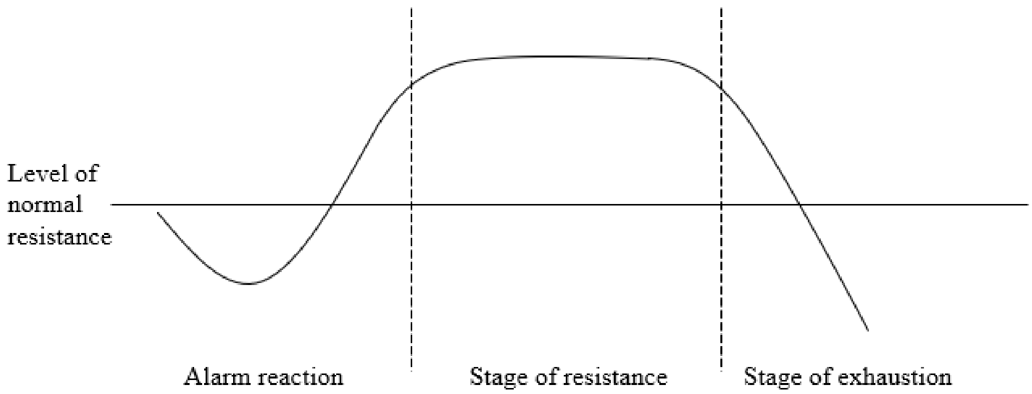


Figure 2.1 Three stages of GAS (Selye, 1976)

Selye, who explained GAS in detail in the following years, used the word stress for the first time to describe the adverse conditions that laboratory animals were exposed to during the experiments that led to his discovery of GAS (Jackson et al., 2014). However, he did not include the concept of stress in his work (1936). Selye, who initially used stress to name the noxious agent that caused non-specific reaction, changed the use of the term stress after defining GAS and defined it as “the state of an organism in adaptation and response the environment” (Viner, 1999, p. 393).

According to scientists who had the opportunity to work together with him like Sandor Szabo, Selye, who often worked long hours seven days a week, including traditional holidays, used the term stress in his first monograph which is named “Stress” published in Montreal in 1950 (Szabo, Tache et al., 2012; Szabo, Yoshida et al., 2017). After this 822-page monograph, which refers to more than 8,000 references, the “Annual Reports of Stress” series was published for five years, one year apart (Selye, 1956; Szabo, Tache et al., 2012; Viner, 1999). Selye, who introduced stress to the literature as it is used by the majority today, often underlined that, according to his students, he was not the first to use this term (Robinson, 2018). In his study titled “Stress and The General Adaptation Syndrome” published in 1950, he explained stress “is the interaction between damage and defense, just as in physics tension or pressure represents the interplay between a force and the resistance offered to it” from a biological perspective (Selye, 1950, p. 1384).

Unlike previous uses, Selye’s first definition of stress is accepted as “the nonspecific neuroendocrine response of the body” (Szabo, Tache et al., 2012, p. 474; Szabo, Yoshida et al., 2017, p. 4030). However, Selye’s research and studies on stress have led to changes in the findings about stress over time. Selye realized that the body’s responses were not only related to the neuroendocrine system but also to almost all other organ systems. In his studies (Selye 1973, 1976), he explained that stress is not the same as emotional arousal or nervous tension, and that it can occur in some situations where the nervous system is ineffective, and even in lower animals and plants that do not have a nervous system. Based on these reasons, he removed the word “neuroendocrine” in the definition of stress and redefined the concept.

Selye, whose works have reached wider audiences with the translation of his works into many different languages such as Italian, Spanish, German, Japanese and French, defined stress as ‘the state manifested by the specific syndrome which consists of all the nonspecifically induced changes within a biologic system. Thus stress has its own characteristic form, but no particular specific cause.' in his book titled "The stress of life" published in 1956. In the same book, stress is also defined 'the sum of all nonspecific changes caused by function or damage' (Selye, 1976, p. 16). The final version of Selye's definition of stress is "the nonspecific response of the body to any demand" (Selye, 1976, p. 15).

Hans Selye, in his book "Stress in Health and Disease" published in 1976, included the studies and definitions with quotations made by many scientists of his time about stress in order to explain the historical formation of stress. According to Selye, Beier defined stress in his work in 1951 as 'the perception of threat, with resulting anxiety' (p. 16). Pronko and Leith 'considered as synonymous with such setting factors as are related to the disintegration of the behavioral response configuration of the organism' in 1956 (p. 16). According to Wolff, stress is 'that state within a living creature which results from the interaction of the organism with noxious stimuli or circumstances' in 1960 (p. 17). Another quote in the book is 'For this paper stress is broadly defined as any stimulus or stimuli, experienced consciously or unconsciously, which is potentially harmful or threatening to the individual', which Scotch included in a 1963 study (p. 18). Selye, wrote that Bugard used stress instead of both the pressure from the environment and the individual's reaction to this pressure in 1974.

When the definitions of stress in the literature are examined, we can see many definitions that have common points, completely overlapping or completely different from each other, depending on the profession of the scientist defining the concept, the discipline in which the concept is used, and even the century in which it is used. Whatever the definitions, the term stress has been used for two main purposes throughout its ongoing historical development. These purposes appear as a stimulus that harms the organism or reaction of the organism to this stimulus. Giving examples from daily life may help to explain this distinction. The term stress is used in the sense of events or situations that harm the individual, (stimuli) in sentences such as "I have a very stressful life.", "I am under stress at work.". In sentences such as "I am very stressed lately", "You should take a walk to get rid of your stress", it is used in the meaning of the individual's reaction to the stimulus. This common use, which can cause confusion even in daily life, was much more important for scientific studies. Selye, who is known to use the term stress in his works to mean both cause and reaction, also suffered from this problem (Szabo, Tache et al., 2012). Therefore, he coined the term "*stressor*", which he defined as "the stress producing factor", to the literatüre (Selye, 1973, p. 692).

Selye, who carried out his first studies when the subjects were under physical stressors, said that problems such as emotional arousal, mental effort, fear, and concentration could also be stressors in his later studies. He stated that stressors can cause stress in the body, regardless of whether they are physical or psychological, but the effect of this stress on the body is not the same. Therefore, he split stress into two as *distress* (dis, come from Latin, translated bad) and *eustress* (eu, come from Greek, translated good). He named the harmful, destructive and unwanted stress that damages the body as distress, and he used the word eustress to describe the constructive and demanded stress that is beneficial to the body (Selye, 1976).

Many scientists in the medical world, such as Selye, who was one of the pioneers of the development of the concept with his intense studies on stress in the 20th century, were working on this subject. One of these scientists, cognitive psychologist Lazarus, proposed in 1966 to consider it as a regulatory concept for understanding events that play an important role in human and animal adaptation (Lazarus & Folkman, 1984). Lazarus, who deals with stress from a psychological rather than physiological point of view, drew attention to this distinction he made while dealing with stress. According to him, a factor that can cause physical stress is not the same as one that causes psychological stress. He criticized Selye's theory of GAS in that the stimuli are only physiological, and said that this syndrome can be thought of as the physical manifestation of the process called coping in psychology. He argued that the unique feature of psychological stress is that it includes the meanings and evaluations attributed by individual as well as the emotions. According to this understanding, a situation that is perceived as stressful by one individual may not be perceived as stressful for another. As a result, he emphasized the importance of the individual's perception and evaluation on his reaction when faced with a stressful situation (Lazarus, 1993; Robinson, 2018).

Lazarus and Folkman defined psychological stress as “is a particular relationship between the person and environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being” (Lazarus & Folkman, 1984, p. 19). In the same book, three types of stress, namely harm/loss, threat and challenge, whose distinctions Lazarus mentioned in 1966, are given in detail. Accordingly, *harm/loss* refers to a psychological damage such as an irreversible injury or illness that has already happened to the individual, or the loss of a loved one. *Threat* is a type of stress that has not yet occurred but is thought to will cause harm as a result. The third and final type of stress, *challenge*, is one in which all available resources are used to overcome and one is confident that they will be overcome (Lazarus & Folkman, 1984).

Thomas Holmes and Richard Rahe, who explained the relationship between stressful life events and physical illnesses, defined stress as a “stimulus event” in 1967 (Gadzella, 1994). Mandler defined stress in 1976 as the response of the organism to harmful stimuli, the danger sign they reveal (Kırel, 1991; Timuroğlu & Yılmaz, 2019)

The study, published in 1981, co-authored by Menaghan and Mullan, said there was probably general consensus for the following definition; “stress refers to a response of the organism to conditions that, either consciously or unconsciously, are experienced as noxious” (Pearlin, Menaghan, Lieberman, & Mullan, 1981, p. 341). In the same study, the authors suggested that the events experienced by people may affect the person negatively, and that if they persist, it may lead to a detrimental change in the sense of self, resulting in stress.

Hann expressed stress in 1984 as a situation in which people perceive the events they experience as bad and think that they cannot overcome them (Timuroğlu & Yılmaz, 2019). According to Magnusson, stress is a person’s reaction to the difference between the life they live and the life they want to live (Recepoğlu & Recepoğlu, 2022).

Ivancevich, Matteson and Konopaske stated that stress is the result of the interaction between the stimulus and the individual’s response. Moreover, the clear definition they give for stress in the same book is “stress as an adaptive response, moderated by individual differences, that is a consequence of any action, situation, or event that places special demands on a person” (Ivancevich, Matteson, & Konopaske, 2014, p. 232).

In his book, which deals with stress from many aspects, Harrington defines stress as “is the constellation of cognitive, emotional, physiological and behavioral reactions the organism experiences as it transacts with perceived threats and challenges” (Harrington, 2012, p. 8).

Stress, which has a history of 86 years when the starting point is accepted as the definition of biological stress, has been defined by many scientists and have been the subject of many studies and research in this short time. It is of great importance to examine the historical development of this important concept, whose popularity is increasing day by day, in order to understand the point it has reached today. Perhaps the sentence that best summarizes this development was established by Hans Selye: “Everybody knows what stress is and nobody knows what it is.” (Selye, 1973, p. 692).

2.2 Stress Symptoms

Human beings have the same anatomical and physiological structure as a requirement of being a species. Any people are not the same, despite the fact that they are made up of the same organs and systems. Therefore, it cannot be expected that the reaction they give in the face of any situation that disrupts the normal flow of life will be the same. For example, a person who has spent most of his/her life in a city with a continental climate may not feel cold in weather that is cold according to locals in the winter months after moving to a city with a temperate climate. Because the temperature at which his/her body shows signs of feeling cold is much lower than that of the people he/she has just moved to. Another example is the fear of clowns, which has named in the literature as Coulrophobia. The clown, which makes most of us smile when we see it, is a reason for some people to fear.

In addition to giving the different reactions of individuals, the individual may even react differently to the same situation at different times. For example, the reaction a person gives when watching a movie for the first time may not be the same as when watching it for the tenth time. Sometimes, a situation that causes distress in one individual may lead to eustress in another individual. The word “non-specific” in Selye’s definition of stress has also a qualification of proof that individuals give uncertain reactions to situations.

People give also common reactions to the situations they experience. These reactions are important guides for understanding what kind of situation a living thing is in. Most of the time, we can interpret that someone who laughs is happy, someone who cries is unhappy, someone whose eyes are red and itchy is allergic to anything, someone who coughs and has a runny nose has the flu, and someone with red spots on their body has measles. What causes us to make these comments is that the person gives reactions and symptoms specific to the situation he/she is in. So, it is possible to detect the presence of stress, which we encounter at every point of our lives, that most people suffer from, with the symptoms they have.

Stress affects the organism as a whole. Therefore, its symptoms are also multifaceted. Stress may show much more serious symptoms such as a heart attack depending on the stressor and its duration as well as mild symptoms such as headaches and backaches, stiff neck, increased sensitivity of the person, shouting at people for no reason, fatigue (Özel & Karabulut, 2018; Sarp, 2000).

While wide variety of stress symptoms were examined, they have divided into different categories. When the literature is examined, it is seen that the symptoms are gathered under two groups as physiological and psychological symptoms in the most basic form (Kaba, 2019). In some studies (Gökler, 2012; Özel & Karabulut, 2018), behavioral symptoms were added to these categories, and the symptoms were divided into three categories. In a study that dealt symptoms other than physiological symptoms from different aspects, the symptoms were divided into four groups as physical, emotional, mental and social (Güçlü, 2001). Symptoms were classified under five groups at most, and the groups were named as physical, emotional, mental, social and spiritual symptoms (Recepoğlu & Recepoğlu, 2022). Even though they are examined under different headings, these categories are intertwined with each other, in that human beings are a whole in terms of all aspect.

Stress has been used for many different purposes in studies on it. It is sometimes expressed as the stimulus, sometimes the body's response to this stimulus, and sometimes an adaptation process. Due to the reasons thought to be related to this in the studies, it was seen that the events indicating the presence of stress in the individual were examined under the headings such as "stress responses" (Yıldırım, 1991) or "stress conclusions" (Özcan, 2021) instead of "stress symptoms"(Güçlü, 2001). In some studies, both stress symptoms and stress consequences are included. Although the conclusion part has similarities with the symptoms, the situations that are caused in the long term by stress which are divided into groups such as individual and organizational are explained. Irrespective of which word is used, the meaning to be expressed in essence is common. The presence of stress affects the individual in every aspect and some changes occur.

In this study, as a result of the examinations, the title of "symptom" was used because stress is commonly used in the sense of the body's response to stimuli. At the same time, stress symptoms are grouped under three headings: physical symptoms, psychological symptoms, and behavioral symptoms.

2.2.1 Physical Symptoms

Stress manifests itself in individuals with various signs. Physical symptoms of stress include those that can sometimes be seen from the outside, such as changes in facial expressions, and sometimes that can be detected by medical methods, such as heart diseases (Kaba, 2019; Zhang et al., 2019).

As it gives instant information, the change in facial expression caused by stress is perhaps one of the most important signs of the presence of stress. Facial expressions are a very easy and fast source of stress symptoms, as they can be understood simply by looking at the face of the person with whom are communicating without resorting to any medical method. Faced with a negative and distressing situation, the individual reacts such as squinting, wrinkles on the forehead, bending of the face, and stretching the lips (Mengi, 2013).

One of the most important indicators of stress is asymmetric lip and eyebrow movements (Metaxas, Venkataraman, & Vogler, 2004). Mouth shape, lip deformation, lip corner puller, lip pressor are shown as stress-related facial features types (Giannakakis et al., 2017). An obvious change is observed in the eyebrows. Although eyebrow movements do not have a universal pattern, the change in an individual's eyebrows is a symptom used to detect the presence of stress (Raichur et al.,2017).

Stress manifests itself in and around the eye in various ways, such as blinking frequency, eye aperture, eyelid response, and pupil size variation (Giannakakis et al., 2017). The pupils of the stressed individual are observed to dilate compared to their normal state (Recepoğlu & Recepoğlu, 2022). Since this symptom is occurred by the autonomic nervous system in a way that the individual cannot control, it provides an important advantage (Baltaci & Gokcay, 2016).

Alongside the physical symptoms vary according to the duration of the stressor, the severity of the symptoms increases as a result of the prolongation of the duration. Sarp (2000) divided the extensive and common symptoms of stress into two groups as short-term symptoms (early symptoms) and long-term symptoms. She listed short-term physical symptoms as headache, stomach problems, loss of appetite, overeating, irregular sleep, constant fatigue, muscle aches, skin problems, gnashing of teeth, muscular twitching, mild chronic diseases, sexual problems, diarrhea, constipation. In the same study, hypertension, heart problems, stroke, diabetes, ulcers, infectious diseases, intestinal problems are given as examples for long-term physical symptoms.

Some physical signs of stress can be listed as fatigue, headache, backache, muscle aches, chest pain, dizziness, fainting, loss of balance, tinnitus, heart palpitations, high pulse, rapid, shallow and short breathing, dryness in the throat and mouth, loss of appetite, bulimia, sudden weight change, indigestion, stomach cramps, heartburn, jaw spasm, excessive sweating, frequent urination, cold hands and feet, arthritis, constipation, diarrhea, tremor, twitching, stuttering and speech difficulties, hyperactivity, sleep disorders such as sleeping too much or not being able to sleep, sensitivity to loud sound and light, allergies and itching (Gökler, 2012; Güçlü, 2001; Kaba, 2019; Özel & Karabulut, 2018; Recepoğlu & Recepoğlu, 2022).

Another symptom of stress, which manifests itself in various ways, is neural reflexes. Nail biting, clicking fingers, make fist and clench hands, grinding teeth, hunch, touching some areas of the skin, especially on the face, and tearing off parts, tearing the skin around the fingernails, touching hair are examples of reflexes that the individual performs involuntarily (Recepoğlu & Recepoğlu, 2022).

Research has revealed that there is a relationship between stress that occur in order to adapt to an unfamiliar situation and to maintain the normal balance of the body and physical discomforts. In case of stress, the body’s immune system weakens and the individual becomes vulnerable to diseases (Hovardaoğlu, 1997). Stress, which is seen as the cause of many diseases today, is seen as a reason that;

- Circulatory system diseases and heart diseases such as tachycardia, hypertension, hypotension, heart attack,
- Respiratory system diseases such as bronchial asthma,
- Digestive system diseases such as nausea, vomiting, anorexia,
- Skin diseases such as hair loss, psoriasis, eczema and urticaria,
- Endocrine system diseases such as hyperthyroidism and diabetes,
- Central nervous system diseases such as migraine, neurotic reactions, and weakness

- Reproductive system diseases such as menstrual irregularities (Görgülü, 1988).

At the same time, the presence of these diseases is one of the important symptoms of stress.

2.2.2 Psychological Symptoms

The first studies on stress in the medical world were mostly done by physiologists. Accordingly, researches and experiments were carried out under physical stressors such as heat, fatigue, injury, injecting toxic substances. However, with the change in the size of the studies, it has been observed that stress is not only dependent on physical stimuli, but also occurs in the face of psychological stimuli such as life events, emotional arousal, mental effort, and fear (Selye, 1973, 1976).

Sarp (2000), who also examined the psychological symptoms in two groups as in the physical symptoms, listed the short-term symptoms as forgetfulness, anger, irritability, anxiety, problems with family members, increasing useage of alcohol and cigarettes, depression, increasing usage of drugs and sleeping pills, feeling of powerlessness, problems with co-workers, problems at work. She said that severe depression, accidents, domestic violence, suicide attempts, excessive use of alcohol and drugs, and psychological disorders are long-term symptoms of stress.

The psychological symptoms of stress are not as clear and precise as we know that his/her hand of a person whose hand is cut off will bleed. Because these symptoms depend on many variables, especially people's experiences, ideas and personalities. However, it is of course possible to list common situations that are accepted as symptoms of stress. Psychological symptoms, which are very common in stress, are touchiness, incompatibility with people around, thinking that everything is meaningless, not enjoying life, being afraid of being sick, constantly thinking that one is sick, lack of self-confidence, losing one's self-respect, being pessimistic, excessive sensitivity, crying suddenly, sudden change in mental state, aggression, nervous laughter, hopelessness, loss of excitement, stagnation, indifference to events (Güçlü, 2001; Kaba, 2019; Özel & Karabulut, 2018; Recepoğlu & Recepoğlu, 2022).

When it comes to stress, most people usually think of negative thoughts. Although it is known that positive situations and emotions can also be a sign of stress or cause stress, it is often associated with emotions such as anger, fear, sadness (Zhang et al., 2019). Moreover, emotions, feelings and situations such as worry, anxiety, irritability, tension, outburst of anger, uneasiness, nervousness, anger, inadequacy, worthlessness, abandonment, impatience, hostility, restlessness, panic, tension, which are also evaluated as emotional symptoms in some other studies, are among the psychological symptoms of stress (Gökler, 2012; Görgülü, 1988; Yıldırım, 1991).

Psychological symptoms of stress also occur cognitively and mentally. Accordingly, symptoms such as lack of concentration, indecisiveness, forgetfulness, obsession with a single thought, inability to remember things to do, people and events, daydreaming frequently, loss of sense of humor, low productivity, difficulty in reasoning, thinking about death and suicide, making mistakes in mathematical operations can be observed (Güçlü, 2001; Özcan, 2021; Özel & Karabulut, 2018). Even if we prefer to get rid of our thoughts and sleep to renew, relax and rest, there are also symptoms of stress such as grinding teeth during sleep, talking in sleep, having fearful dreams (Görgülü, 1988). In the long run, it can also cause diseases such as depression, anxiety and irritable bowel syndrome (Kaya, 2019; Uzbay, 2004).

2.2.3 Behavioral Symptoms

Stress manifests itself in people behavioral symptoms as well as physically and psychologically. The presence of stress causes people to exhibit attitudes that affect all living and non-living beings around them. It is possible to have information about the stress situation by observing the behaviors that affect the relations of the individual with other people.

Individuals may exhibit behaviors that are grouped as assertive, passive and aggressive as a symptom of stress or in other words, as a stress response. The person exhibiting the behaviors called assertive faces the problem in order to solve the problem. On the contrary, the person who avoids facing the situation that causes stress exhibits behaviors called passive and aggressive. This situation can lead to deterioration of psychological health (Yıldırım, 1991).

Blaming other people, canceling the meetings a short time before or not going to them at all, offending the people around with words, being on the defensive all the time, getting offended with many people, not speaking, constantly making negative criticisms, not being able to empathize, shouting or speaking fast, ignoring self-care related with appearance, restlessness, being constantly on the move, or acting very slowly and sluggishly, crying fits, indulging in alcohol and cigarettes can be given as examples for behavioral signs that indicate the presence of stress in the individual include (Güçlü, 2001; Özcan, 2021; Özel & Karabulut, 2018). In addition, situations such as lack of concentration, inability to focus, and distraction, which are among the symptoms of stress, lead the person to exhibit behaviors that are prone to accidents (Kırel, 1991).

Neural reflexes, which are included in the physical symptoms of stress, are also behavioral manifestations of stress. Furthermore, in a study in which these involuntary movements are called body language, it is explained that the individual exhibits behaviors such as clasping his/her hands on his/her chest, rubbing the palms, yawning, speaking quickly, and closing his/her mouth with his/her hands (Mengi, 2013).

2.3 Stress Sources

Every outcome in life needs a cause. A small child cries because his mother is angry, it rains because humid air or clouds have encountered a cold layer and moisture has condensed, the patient has oral cancer because he has smoked for many years, the seasons occur because the Earth revolves around the Sun. Just as there is at least one reason for these situations, which are given as examples, stress, which is briefly and superficially defined as the reaction of our body, also has causes, and factors that lead to its formation.

Stress is not a situation that occurs spontaneously in a static process, without any reason. In order for stress to occur, a number of events, situations or changes must occur in the life of the individual that disrupts the order, forces him/her, and requires his/her body to react (Güçlü, 2001). Hunger, noise, injustice, birth, death, economic troubles, business life, interpersonal conflicts, unemployment, bright light, loneliness, age crisis, family problems, cheating, abandonment, chronic diseases, unpaid bills, exams, natural disasters such as fire, earthquake, flood are just some of the stress sources that a person may encounter in his daily life (Özel & Karabulut, 2018).

Underlining that stress is not a situation to be avoided, Selye also has emphasized that it cannot be avoided even if desired. If everything goes well in life, even if external factors do not change, the heart will continue to pump blood, the intestines will digest the eaten food. In other words, there is a need to produce the energy required for the continuity of life, to resist and adapt to external factors. This need ends only with death (Selye, 1973). This means, that there is no environment, condition or place where living things can hide from stress throughout their lives. In parallel with this point of view, every event, situation, condition, place and even other living things in life are a potential source of stress for the individual.

Getting a promotion, having a child, pregnancy, neighbor noise, getting married, getting divorced, breaking up with a loved one, approaching the assignment due deadline, being ignored, going on vacation, setting unrealistic goals, generational conflicts, falling in love, graduating, wedding, starting a job, leaving the job, moving from the family home, moving to the family home, friendlessness, heavy workload, ignoring their own wishes are sources of stress for individuals. When these examples are examined, the most striking situation is that among the stressors, there are events that arouse positive emotions in most people. Contrary to popular belief about stress, it does not only arise as a result of negative situations and emotions. On the contrary, the individual may face stress in the result of happy events such as getting a promotion, having a child, pregnancy, getting married, falling in love, graduating, wedding, starting a job, going on vacation. It is even known that there are patients who have had a heart attack due to intense stress in the face of some happy events (Yıldırım, 1991).

Selye’s quote ‘Stress is not what happens to you, but how you react to it’ summarizes the fact that the events gain to being stressful qualification depends on the individual (Szabo, Yoshida et al., 2017, p. 4032). If we need to examine it in depth, for any stimulus to turn into a stressor, regardless of which part of the body it affects, it must exceed the existing comfort threshold and disrupt the balance of the system (Güçlü, 2001). However, not every situation has the same importance for the individual. So, the same situation may be stressor for one person but not for another. For example, some children may embarrass to ask for money, thinking that they are a burden to their parents. By contrast, according to another part, their families are responsible for taking care of them, so they have to give money. While the winter season brings heating problems for a family living in a slum, it can mean a visual feast together with snowfall for a family living in a luxury house. Traveling abroad sometimes means more work and fatigue for a business man, and new discoveries and fun for a world traveler. These examples, which are given in a limited number, clearly state that the same situation is a source of stress for some individuals and not for others.

Since the beginning of the world, change has been continuing without stopping. The events people experience and their responses to these events change with this change. This means that events and situations that cause people to get stressed change. Therefore, stress factors are not only dependent on the individual but also depend on the time, country and culture. For people who are struggling with disasters such as war, hunger and thirst in the country where they live, the disasters in their countries are a serious stress factor. People living in a country with a high level of welfare and no worries about the future, due to do not experience such problems, their sources of stress are very different. While smallpox, which caused the death of an estimated about 300-500 million people, was both a deadly disease and a source of stress for the people of the period, it lost these qualities today with the discovery of its vaccine in 1976 and the announcement of its eradication in 1980 (Parıldar, 2020).

The general characteristics of stressors, which is a very important concept for stress-related studies, are grouped under five main items (Görgülü, 1988). These items are the following;

1. Stressors do not affect individuals in the same way. Different individuals are affected by stressor in different ways. This difference is due to some factors. These factors are;
   1.1. The stressor itself: The intensity of the stressor and how long it continues is important in terms of the defining stressor. For example, a low-strength chronic stressor that is repeated often can be more damaging than a very strong but short-term stressor.
   1.2. The response to stressor: This response may depend on the individual's adaptability to previous stressors and their genetic makeup.
   1.3. The importance of the stressor: The importance that an individual attaches to the source of stress varies depending on variables such as his/her perception, experiences and environment.
2. Whatever the stressor is, the first option is to adapt to it. If it is successful, the disturbed balance is restored. Otherwise, the individual may become ill.
3. The stress that occurs in the individual can turn into another source of stress.
4. The stressor alone is not the cause of the disease, but it can be the starting point of the process, the result of which may be disease.
5. If the source of stress is very severe and long-lasting, the individual is affected by this source, regardless of its structure.

Stress sources may have different characteristics in terms of interaction areas even though they have common characteristics in terms of they are reveal stress in the individual. Accordingly, they were divided into different categories in studies. In the literature, it has been seen that they are mainly examined under two groups as organizational stressors and non-organizational stressors (Güçlü, 2001). In another study, it was written that stress factors were tried to be separated as organizational, individual, and social sources (Okutan & Tengilimoğlu, 2002).

In another approach, Wilkinson classified stress factors in 2004 according to the level of stress severity they reveal (Gökler, 2012). The details of this classification are tabulated and given in Table 2.1.

Table 2.1 Wilkinson’s categories of stressors

Level of Stress Caused	**Stress Factors**
Very High	• Death of close relatives such as mother, father, spouse • Divorce, break up with the lover • Being put in jail • Being tortured • Diseases • Marital problems • Being fired from job • Obligation to change house and environment
High	• Reconciliation after break up • Being retired • Illness of a family member • Getting pregnant • Sexual problems • Having a children • Changing job • Economic troubles • Friendship loss
Moderate	• Family quarrels • Large amounts of debt and subsequent legal actions • Excessive workload • Children’s leaving from home

Table 2.1 Continues

	• Starting or leaving a job (especially for women) • Starting or graduating from school • Unexpected and rapid change in living conditions • Changing personal habits • Employee-employer problems
Low	• Change in business hours and conditions • Changing school • Variation in lifestyle • Changing in religious activities • Changing in social activities • Small amount of debt • Changing in sleeping habits • Family relations • Changing in eating habits • Violations of the law that have not severe penalties

As seen in Table 2.1, Wilkinson divided stress factors into four different groups according to the level of stress they cause. This approach of Wilkinson clearly shows the effect of stress sources on the stress level.

2.4 Relation between Stress and Emotions

When viewed from the outside, the effects of the events they experience on people can only be observed in the physical dimensions. However, human is not just a physical body. Every moment lived without exception creates an impression in the inner world of the individual. These impressions that a certain object, event or person evokes in the inner world of the individual are called emotions (Turkish Language Association, 1974). For example; a person may be happy when he/she receives a gift from someone, sad when he/she misses the bus, angry at a rude behavior, worry when his/her child is late for home, disgusted when he/she smells a foul smell, excited when speaking in public, surprised when meeting a friend he/she haven't seen in years, afraid of dogs, embarrassed when he/she makes a mistake and also feel insecure when being with people in higher positions. Such situations can also be sources of stress -as discussed in detail earlier in Section 2.3- for the individual. So, there is an inevitable relationship between emotion, which is also defined as "a state of physiological arousal accompanied by changes in facial expressions, gestures, posture, and subjective feelings" and stress (Ivancevich et al., 2014, p. 79).

There is an intertwined structure between stress and emotions. A complex series of physiological changes occur in the body with stress. The central nervous system, endocrine system, autonomic nervous system and pituitary have important functions during stress (Görgülü, 1988). In this process, hormones such as cortisol, also known as stress hormone, oxytocin, known as love hormone, adrenaline, noradrenaline, are released. As a result of fear and stressful situations, first of all, oxytocin release decreases. However, oxytocin, which is known to its secretion increases as a result of happy events, is secreted in order to maintain the homeostasis of the body (Kaba, 2019). For this reason, it can be concluded that the body gives similar physiological responses in situations of fear and stress.

At the same time, noradrenaline activates a structure in the brain called the amygdala, which is the starting point of emotions (Özel & Karabulut, 2018; Siegrist, Bellingrath, & Kudielka, 2018). After many physiological events like these, the body gets ready for the fight or flight situation, which is the first response to the stressor. Emotion and emotional changes can occur as a result of changes in the systems functioning during this and all subsequent stress phases (Siegrist et al., 2018). In this process, feelings such as fear, anger, sadness, and even happiness in the case of eustress, which are among the symptoms of stress, can be observed.

On the other hand, since it is known that getting rid of stress completely will occur with death, there is actually stress under every emotion. From this point of view, emotions, in a way, include stress. However, stress may not be clearly noticeable under every emotion. The psychological aspect of stress is mostly composed of negative emotions such as fear, anxiety and anger (Siegrist et al., 2018).

Considering stress as a subset of emotions, Lazarus mentioned 16 emotions, nine of which are negative (anger, fright, anxiety, guilt, shame, sadness, envy, jealousy, and disgust), four of which are positive (happiness, pride, relief, and love), and three of which are of uncertain value (hope, compassion, and gratitude) (Lazarus, 1993). According to Ekman and Friesen, there are six universal emotions as anger, happiness, fear, surprise, disgust and sadness. These emotions have basic facial expressions of universal nature that are easily recognizable in many different cultures (Batty & Taylor, 2003). The relationship between emotions and stress establishes a connection between facial expressions- are both symptoms of stress and facial manifestations of emotions- and stress.

CHAPTER THREE
FUZZY LOGIC TECHNIQUES

Life is a collection of precise and imprecise situations. The fact that the shape of the Earth is geoid, and water freezes at 0 °C and boils at 100 °C under normal conditions are proven constant phenomena. It is clear and certain that -1 is a negative integer and 5 is less than 6. These expressions do not change from person to person. The meaning of these expressions is the same for everyone. However, there are uncertainties as well as certain things in human life. For example, the expressions of frying the onion until it turns pink and kneading the dough until it reaches the consistency of an earlobe, which can be seen frequently in recipes, are not perceived by everyone in the same way. When a child who can count to only 10 is asked how much he loves his mother, being of the child’s answer is 10 means a lot for the child. Because the number 10 is the greatest value that the child knows. However, for adults who know that natural numbers are infinite, a value of 10 is too small to answer this question. As another example, the sentence “The exam was *difficult*.”, which is often encountered in daily life, can be given. The meaning of the word *difficult* in this sentence is instinctively understood by everyone, but it does not mean the same thing to everyone. The word difficult may mean not being able to solve two questions in a 20-question exam for a hardworking student, and for a lazy student, being unable to solve 19 questions. As can be understood from the examples, the fact that some words, events and situations have various meanings for individuals causes uncertainty. This uncertainty is defined fuzzy (Şen, 2004).

People encounter many fuzzy situations throughout their lives. The approach to fuzzy situations encountered and the approach to exact and clear situations are different from each other. For example, the amount of rain that falls or the duration of rain does not matter when the advice “If it rains you should take your umbrella.” is approached classical. Even if a single drop of rain falls, it is understood that the umbrella must be taken. However, when the same proposal is considered as a fuzzy situation, the rainfall and the duration of rain gain importance. It may not be taken if it rains a little. Therefore, it is difficult and insufficient to express fuzzy situations with a classical approach.

In order to understand, explain and draw conclusions about fuzzy situations, it is necessary to first understand the fuzzy logic. For this reason, firstly, fuzzy logic is explained in this chapter. The definition of fuzzy logic, the difference between it and classical logic, its history, development, fuzzy set theory, which are the basis of fuzzy logic, and membership values are included. Then, what FIS, ANFIS and FCM techniques are based on fuzzy logic, their structures and properties are explained in detail.

3.1 Fuzzy Logic

Human beings have the ability to think and make decisions by nature. Thinking is based on some principles, rules and systems. Reasoning based on certain rules is called logic (Turkish Language Association, 2015). Another definition of the concept of logic is the science that deals with the rules that determine the consistency of propositions and the validity of inferences (Turkish Language Association, 1976). Also, logic is the art and science of correct thinking (Turkish Language Association, n.d).

Although the previous studies are not ignored, the first systematic studies on logic were carried out by Aristotle (Karataş, 2018). Aristotle's logic, which is shaped around the studies of Aristotle and the reasoning principles he adopted, is also called classical logic (Özmen, 2019). Classical logic, the foundation of which was laid by Aristotle, is generally accepted to have three main principles (Gültekin, 2021). The first principle is the principle of identity. According to this principle, a thing is only itself. In other words, something is not something else, it is what it is. The second principle is the principle of contradiction (or non-contradiction). According to the principle of contradiction, something either exists or it does not. A thing cannot be both itself and its opposite. According to this principle, it cannot be said that the same thing both is and is not. The third and final principle of classical logic is the principle of excluded middle. This principle only mentions the existence of two situations. Accordingly, a thing is either itself or its opposite. A third option is not possible in any situation. For example, something is either beautiful or ugly, good or bad, right or wrong. According to this principle, there is no expressions that includes degree such as somewhat good, very bad, partially correct.

Considering the principles of reason on which it is based, classical logic can be defined as a two-valued logic (Özmen, 2019). In this logic, propositions have one of two values such as yes-no, right-left, old-young. In other words, when these values are considered as a set or a group, anything belongs to only one of these two groups and must belong to one of these two groups. In the symbolized form of classical logic, this belonging is represented by the numbers 0 and 1. Any element has the value of 1 in the set it belongs to, and 0 in the set it does not belong to. In other words, the true propositions and the false ones are represented by the values 1 and 0, respectively (Gültekin, 2021). However, every situation in life has not such sharp boundaries. To illustrate, generally children resemble their parents in physical and characteristic features. A child’s eyes may resemble his mother, his nose may resemble his father’s, or some physical characteristics may resemble his father, while some characteristics may resemble his mother’s. In such cases, it can be inferred that the child resembles both his mother and father, more like his mother, or less like his father. However, classical logic does not allow such inferences. According to this approach, the child has to resemble either only his mother or only his father. Since it is known that children receive their genetic information from both their parents, it can be clearly stated that classical logic is insufficient to explain these and similar ambiguous situations.

Classical logic allows systems to be modeled by assuming that systems operate the same in all cases, have precise and clear information about them, and do not change over time. In this way, all exact situations can have a mathematical modeling. However, because of the inability of classical logic to explain uncertain situations, there were also philosophers who opposed this logic. For example, Heraclitus argued that something can be both true and untrue at the same time. Plato contradicted the principle of excluded middle of classical logic and said that there is a third situation or region apart from two situations such as true-false. This discourse of Plato is accepted as the basis of fuzzy logic. Alongside philosophers who supported this idea, such as Georg Wilhelm Friedrich Hegel, Karl Marx, and Friedrich Engels, Jan Łukasiewicz was the first to offer a systematic alternative to Aristotelian logic (Hellmann, 2001). Due to his rejection of the two-value logic, he named the new logic he developed as "three-valued logic" and added a new one to the 0 and 1 values in classical logic. Łukasiewicz has often shown the third case with the fraction ½ (Woleński, 2019). Finally, in 1965, the concept of fuzzy sets, which forms the basis of fuzzy logic which is the polyvalent logic that enables the modeling of uncertainties, was introduced by Azerbaijan-born Prof. Lotfi A. Zadeh (Lütfi Aliasker Zade) (Seising, 2015; Zadeh, 1965).

Lotfi A. Zadeh, who said that he believed that the techniques required for the analysis or modeling of almost any man-made or natural system were based on set theory and two-valued logic, realized that classical logic was insufficient to explain complex or uncertain systems while writing a book on systems theory. After this awareness, Zadeh, who carried out his studies in order to find what is closer to the real world, proposed concepts such as fuzzy logic, fuzzy sets and fuzzy systems that allow for defining and modeling situations with uncertainty (Seising, 2015). According to Zadeh's statements summarizing fuzzy logic and fuzzy sets theory, there is no concept of certainty. Nothing can be considered with absolute certainty. The mathematical expression of anything is not limited to 0 and 1. This expression is variable between 0 and 1 (Işıklı, 2008). In Zadeh's own words, the definition of fuzzy logic is "a kind of logic using graded or qualified statements rather than ones that are strictly true or false" (Zadeh, 1984).

The recommendations such as think logically, use your logic, decide logically, which we often hear in daily life, advise to clearly distinguish situations such as right-wrong, good-bad, beautiful-ugly, yes-no, long-short, high-low. However, it is not always possible to make these clear, precise, defined and unambiguous distinctions. For example, a person who is cold in a room with an open window may ask a friend to close the window a little. In a situation where daily life is completely governed by classical logic, this request is meaningless. Since the word a little has no equivalent in classical logic. In this logic, the window can be either open or closed. On the other hand, fuzzy logic makes sense of the window is open or closed with a degree, as well as being open and closed. The amount of closing the window depends on the perception of the person who will close the window. Here, the decision may vary depending on the individual and how the individual perceives the word “a little”, but again, the request is largely met with ease. When the same request is handled with classical logic, the amount of closing the window must be clearly expressed. For example, It is necessary to use sentences that contain certainties that are difficult to apply in daily life such as “Can you close the window at a 20° angle?” or “Can you close 80% of the open part of the window?” instead of “Can you close the window a little bit?”. However, this usage is far from making people’s lives easier. Contrary to this approach, fuzzy logic makes human life easier thanks to its ability to define ambiguous expressions that people use in their daily lives and its applicability to real life. Moreover, it enables simplification and modeling of complex systems.

Contrary to the two-valued logic, fuzzy logic is a multi-valued logic that allows the definition of intermediate values such as less slightly, quite, enough, and much, very, extremly etc. In real life, it is not always possible to have precise information about events, situations, people or systems. For example, when describing an individual, fuzzy expressions such as quite tall, extremely slim, not very young are used. Since the working of human logic is not limited to only two situations, unlike classical logic. Fuzzy logic aims to work just like the logic functioning that enable people to describe uncertain situations and make decisions in situations where there is a lack of information (Zadeh, 1988). Thus, fuzzy logic acts as a bridge between daily life, linguistic variables and their mathematical description. In other words, fuzzy logic is a mathematical system based on the concept of fuzzy set, which takes the working system of the human brain as a model (Özmen, 2019).

Although they have many fields of study and application today, the concepts of fuzzy logic and fuzzy set were not considered in the first years of their introduction. Moreover, they were met with great suspicion and criticism by especially in the western world, which adopted Aristotle’s logic. The concept of fuzzy logic has been limited to theoretical studies since it has not been applied in any field from the first years it was developed until the 1970s (Şen, 2004). The first application of fuzzy logic was carried out in 1974 by Ebrahim Mamdani, a control engineer at Queen Mary College in London, and his research student Seto Assillan, in order to develop a model that could control the steam engine. This application was pioneered many applications and fuzzy logic gained importance. Its use for the control of cement kilns by F.L.Smidth & Co. firm in Copenhagen was one of the first commercial applications of fuzzy logic. The developed controller was first marketed in 1980 (Zadeh, 1984).

Fuzzy logic has become more widespread in eastern countries, especially in Japan, than western countries, thanks to the ease it provides in applications and the success it has achieved. In the early 1980s, Dr. Sugeno, N. Nishida, and Tomohiro Tagaki developed a fuzzy logic controller that recommends a change of direction to the car based on certain parameters at the Tokyo Institute of Technology in Japan. In the same years, Hitachi company developed an automatic train operation using fuzzy logic, which they proved in field tests to be as successful as an experienced operator. Applications in Japan were not limited to this, but expanded to areas such as robot control, speech recognition, universal controller and stabilization control (Zadeh, 1988). Fuzzy logic, whose usage area is increasing day by day, is used in various fields such as internet technologies, face recognition systems, space vehicles, military technologies (Özdemir & Kalınkara, 2020), robotics, automation, machine learning, image processing (Gültekin, 2021), clustering, electronic equipment (air conditioner, washing machine, dishwasher, vacuum cleaner, refrigerator, oven, camera, etc.), finance (Özmen, 2019), geophysics (Kaftan, Balkan, & Şalk, 2013) etc. at the present time.

3.1.1 Fuzzy Sets

Fuzzy sets are the basis of fuzzy logic. In 1965, Zadeh put forward the theory of fuzzy sets in his work called “Fuzzy Set”, and in his later works, he detailed the fuzzy logic that he based on this concept. In the introduction to his work, Zadeh mentioned that in the real world, clusters do not have strictly defined membership values. In support of these words, he gave the classification of living things as an example and said that living things such as dogs, horses, birds are definitely included in the group of animals, and things such as rocks, liquids, and plants definitely do not belong to this group. However, the inability to make a definite interpretation about things like starfish and bacteria showed that the real world cannot always be expressed with classical sets, which are the basis of classical logic, and a new concept is needed when working with indefinite classes, as in this example (Zadeh, 1965).

Fuzzy set theory is not completely different from the classical set concept. Moreover, classical sets are considered special cases of fuzzy sets (Klir, 1995). From this point of view, fuzzy sets are a more comprehensive version of classical sets. On the other hand, the need for a broader and more comprehensive new concept, fuzzy sets, that can better express the real world in the presence of classical sets shows that classical sets are insufficient for some cases and there is a difference between them. Therefore, in order to understand fuzzy sets, first of all, it is necessary to explain the concept of classical set and its properties.

Informally, a *set* is any collection object. For example, “people living in Izmir”, “students with glasses in the classroom”, “provinces in Turkey” are sets. Object contained in a set are called *members* or *elements* of the set. Sets are usually represented by uppercase letters and elements of sets are represented by lowercase letters. If a is an element of a set A, then it is denoted by $a \in A$ otherwise it is denoted by $a \notin A$. The set containing all possible elements in a certain discussion, context or application is called the *universal set*. The universal set is not unique. It depends on the context. It may contain discrete object or continous space. According to its elements, it is called a *discrete universal set* or a *continuous universal set*.

Formally, a classical, ordinary, nonfuzzy, crisp set or set A is defined as

$$A=\{x|\ p(x)\}, \tag{3.1}$$

where $p(x)$ is designates a proposition of the form "x has the property p", if it satisfies the following property. According to this property in Equation 3.1 for any object a, $p(a)$ must be either true or false. It must not be both of them. If for any object a, $p(a)$ is true then a is an element of the set A otherwise a is not an element of the set A (Klir & Yuan, 1995). In other words, any object either provides or does not provide the condition given for the classical set. A third case, such as providing a little, quite, a lot, is not possible. In the case of providing the condition expressed as true, the object is a member of the set, and in case of not providing the condition expressed incorrectly, it is not a member of the set. For example, the classical set A, consisting of 18, 28 and the integers between them, can be expressed such that

$$A = \{x |\ 18 \leq x \leq 28\}. \tag{3.2}$$

As can be clearly seen in Equation 3.2, the boundaries of set A are exact and do not contain any uncertainty. In view of the classical set definition, the elements belonging to set A and the elements not belonging to this set can be determined precisely. According to this definition, all integers x greater than or equal to 18 and less than or equal to 28 are members of the set A. However, any integer that falls outside this range, that is, less than 18 or greater than 28, cannot be a member of the set A.

Another method of defining classical sets is to use a function that maps object to a value according to whether it is a member of the set or not. Assuming that X is a universal set that includes the set A, this function takes each element in the set X to either 0 or 1 depending on whether it is an element of the set A, and this function is called a *characteristic function* (Klir, 1995). The classical set A is defined by

$$\chi_A(x) = \begin{cases} 1, & for\ x \in A \\ 0, & for\ x \notin A \end{cases} \tag{3.3}$$

where χ_A is the characteristic function, X is the universal set and $x \in X$.

The value of the characteristic function of a classical set, in other words, is called the *membership degree* or *membership value*. As shown in Equation 3.3, the element belonging to the set takes the value 1, the element not belonging to the set takes the value 0. For example, for the set in Equation 3.2, all integers greater than or equal to 18 and less than or equal to 28 take the value 1, and all remaining integers take the value 0.

Definitions of classical sets can be embodied with examples from real life. For example, people do not always use an exact number when talking about each other's ages. Instead, expressions such as child, young, middle-aged, old are used. When the age range of 18 and 28 is considered young, this set, named with the letter Y, is mathematically defined as in Equation 3.2. Universal set is positive integers and x represents age values. According to the classical set definition, all integers in this range, including 18 and 28, are members of Y, while the others are definitely not. As seen in Figure 3.1, while an 18-year-old individual is definitely young, a 17-year-old individual is definitely not young, or a 28-year-old individual is definitely young while a 29-year-old individual is definitely not young. However, the concept of youth in real life does not have such sharp boundaries.

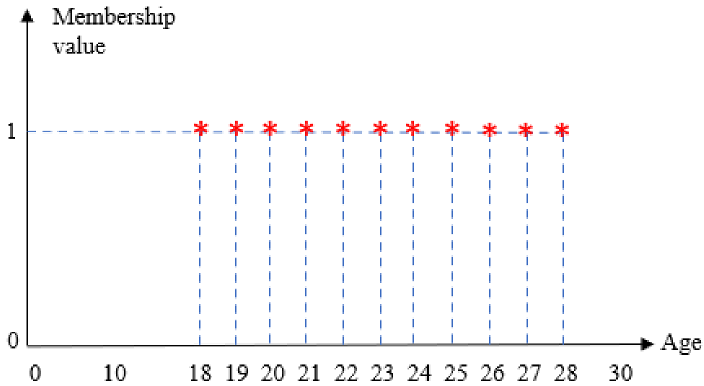


Figure 3.1 Crisp set for "Youth" (Y) concept

Another example is the concept of expensive. In daily life, prices of the products are often classified as cheap or expensive. The classical set, whose elements are nonnegative real numbers, and which considers prices greater than or equal to 100 Turkish liras and less than or equal to 200 Turkish liras as expensive can be defined as $E = \{x| \ 100 \leq x \leq 200\}$, where x is any member of universal set. The definition with characteristic function of this cluster is shown graphically in Figure 3.2.

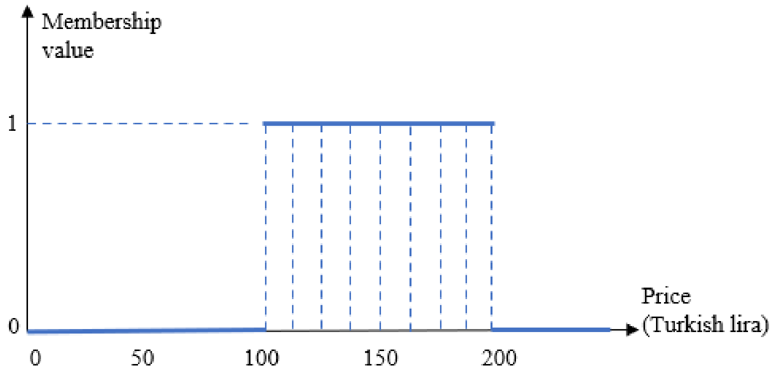


Figure 3.2 Crisp set for “Expensive” (*E*) concept

As seen in Figure 3.2, all nonnegative real numbers greater than or equal to 100 and less than or equal to 200 are members of the set *E* with equal degree and their membership values are 1. According to this set, there is no difference between 100.5 and 199.9. However, in real life, there is a big difference in monetary terms between these two values. Again, the same set considers the value 100 as expensive while the value 99.999 as “not expensive” since it is not an element of this set. However, in daily life, 0.001 has no monetary value. Such situations indicate that classical sets are not often a suitable method for describing real life and linguistic variables.

Fuzzy sets, unlike classical sets, do not have sharp and exact boundaries. There are smooth transitions between fuzzy sets. These transitions are related to the degree to which an element belongs to the set. In fuzzy set theory, an object may be a member of the set, may not be a member of the set, or may be an element with a certain degree of the set. In other words, the degree of membership is not limited to only 0 and 1 values. Instead, the membership value can be any real number in the closed unit interval [0,1]. Any element belonging a certain degree to a fuzzy set can belong with another degree to another fuzzy set. The point to be noted is that the sum of membership values of an element must be equal to 1 (Jang, Sun, & Mizutani, 1997).

Just like classical sets, fuzzy sets are also defined by a function. If X is an universal set and for any x is an element of X, then a fuzzy set A in X is defined by a function μ_A which maps for all x to a real number in the interval [0,1]. The function μ_A that defined a fuzzy set is called *membership funtion*, the value of $\mu_A(x)$ represents the grade of membership or membership value of x in A (Zadeh, 1965). According to this definition, the notation of the fuzzy set A is

$$\mu_A : X \to [0,1]. \tag{3.4}$$

Since every fuzzy set is defined by a specific and unique membership function, A, which is called the name, identifier, or label of the set, can be used instead of μ_A in the notation in Equation 3.4 (Klir & Yuan, 1995).

Another way to describe a fuzzy set with a membership function is to use ordered pairs. According this method, fuzzy set A is defined as a set of ordered pairs such that

$$A = \{(x, \mu_A(x)) \mid x \in X\}. \tag{3.5}$$

The fuzzy set example of the young classical set in Figure 3.1 is given in Figure 3.3. The difference between these two graphs is the membership values of the set elements. While the membership value of all the elements belonging to the set is 1 in Figure 3.1, it is clear in Figure 3.3 that the elements belong to the set with different membership degrees. The membership degrees given are subjective for this example. Also, the fuzzy set Y in Figure 3.3 is defined using Equation 3.5 as Y = {(18, 0.1), (19, 0.2), (20, 0.4), (21, 0.6), (22, 0.8), (23, 1) (24, 0.8), (25, 0.6), (26, 0.4) (27, 0.2), (28, 0.1)}.

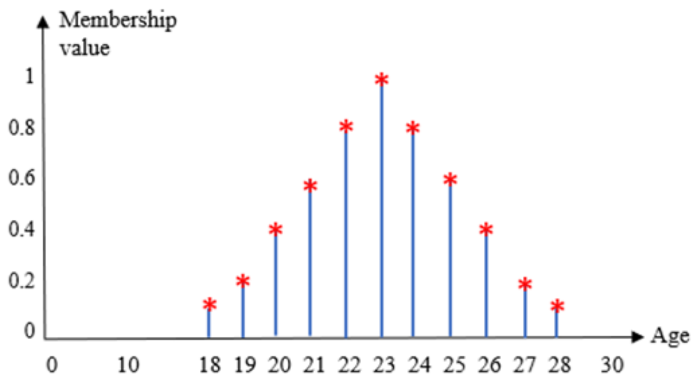


Figure 3.3 Fuzzy set for “Young” (Y) concept

The concept of expensive, which is shown in Figure 3.2 with the classical set approach, is shown as a fuzzy set in Figure 3.4. Just like in Figure 3.2, the interval of E set is [100, 200] and its universal set is nonnegative real numbers ($\mathbb{R}^+$) in Figure 3.4. However, the membership values of the elements in this set are different. The only member with the membership value of 1 is 150. Membership values of other elements are calculated by using the membership function specified in the definition of the set using Equation 3.5. The fuzzy set E in Figure 3.4 is defined in Equation 3.6, using Equation 3.5.

$$E = \{(x, \mu_E(x)) \mid x \in \mathbb{R}^+\}, \tag{3.6}$$

where

$$\mu_E(x) = \frac{1}{1 + \left(\frac{x - 150}{10}\right)^4}.$$

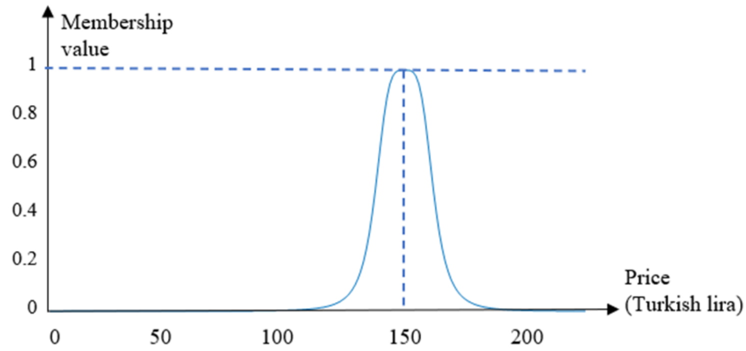


Figure 3.4 Fuzzy set for “Expensive” (E) concept

Fuzzy sets have two different notation alternatives depending on whether the universal set is discrete or continuous.

- If X is an discrete universal set collection of discrete object $\{x_1, x_2, \ldots\}$, then the fuzzy set A is denoted as

$$A = \sum_{x_i \in X} \frac{\mu_A(x_i)}{x_i} = \frac{\mu_A(x_1)}{x_1} + \frac{\mu_A(x_2)}{x_2} + \cdots . \tag{3.7}$$

- If X is a continous universal set, then the fuzzy set A is denoted as

$$A = \int_{X} \frac{\mu_A(x)}{x}. \tag{3.8}$$

The summation and integration signs used in the alternative definitions given in Equation 3.7 and Equation 3.8 are not used for addition or integration. They stand for the union of pairs of the elements and their membership values. Similarly, fraction bar is only marker and does not imply division. Also, slash (/) can be used instead of fraction bar to write the notation in Equation 3.7.

The fuzzy set Y in Figure 3.3 has a discrete universal set. So, Equation 3.7 is used to rewrite the set Y with alternative notation. The fuzzy set E in Figure 3.4 has a continuous universal set. Therefore, Equation 3.8 is used to rewrite the set E with alternative notation. Y is written with alternative notation such that Y = 0.1/18+ 0.2/19+ 0.4/20+ 0.6/21+ 0.8/22+ 1/23+ 0.8/24+ 0.6/25+ 0.4/26+ 0.2/27+ 0.1/28, and E is written with alternative notation in Equation 3.9.

$$E = \int_{\mathbb{R}^+} \frac{\dfrac{1}{1+\left(\dfrac{x-150}{10}\right)^4}}{x} \tag{3.9}$$

3.1.2 Membership Functions

Functions that define fuzzy sets are called *membership functions*. Membership functions also give the membership values of the set elements. In order for a function to be a membership function, it must have certain properties. The parts of the membership functions that provide certain conditions are specially named (Şen, 2004). These parts are shown on the trapezoidal membership function in Figure 3.5.

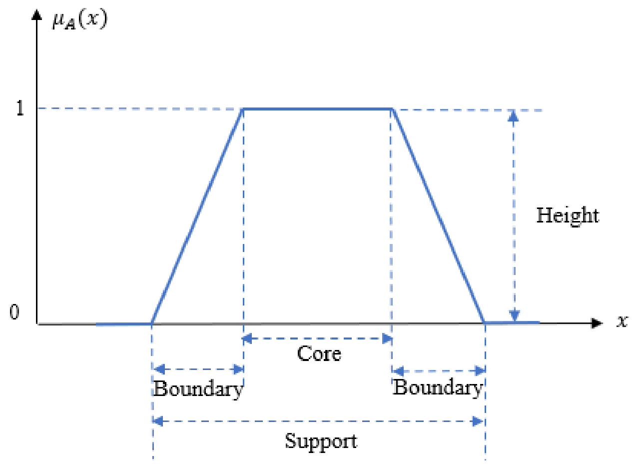


Figure 3.5 The parts of membership function

The core, support, boundary, height parts of a fuzzy set A with universal set X, x is an element of X and membership function μ_A are defined from Equation 3.10 to Equation 3.13 (Jang et al., 1997; Klir & Yuan, 1995).

The set containing all the elements with membership degrees equal to 1 in the fuzzy set is called *core*. The core is defined such that

$$\text{core}(A) = \{x|\ \mu_A(x) = 1\}. \tag{3.10}$$

The set containing all the elements with membership degrees greater than 0 in the fuzzy set is called *support*. The support is defined such that

$$\text{support}(A) = \{x|\ \mu_A(x) > 0\}. \tag{3.11}$$

The *boundary* of a fuzzy set is the set that includes all the elements with membership degrees are different from 0 and 1 of the fuzzy set. The boundary is defined such that

$$\text{boundary}(A) = \{x|\ 0 < \mu_A(x) < 1\}. \tag{3.12}$$

The largest membership value obtained by any element in the fuzzy set is called *height*. The height is defined such that

$$\text{height}(A) = sup\ \mu_A(x), \tag{3.13}$$

where *sup* is a function that gives maximum value. The height of a fuzzy set can be at most 1.

The height of a fuzzy set is 1 is called normality. In other words, if fuzzy set A is *normal*, there exists at least an element x such that $\mu_A(x) = 1$. The normality is associated with the core, and if a fuzzy set is normal, its core is a non-empty set. Figure 3.6(a) and in Figure 3.6(b) shows examples of normal and non-normal fuzzy sets, respectively.

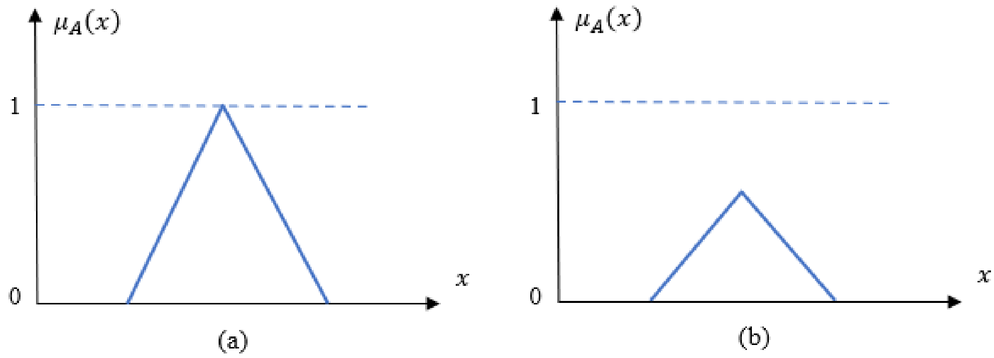


Figure 3.6 Normal and non-normal fuzzy sets

A fuzzy set has the property of convexity in the result of satisfying a condition defined using the membership function. A fuzzy set A is *convex* if and only if

$$\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \ min[\mu_A(x_1),\ \mu_A(x_2)] \tag{3.14}$$

for all $x_1, x_2 \in X$ and $\lambda \in [0,1]$, where *min* gives the minimum value. The convex fuzzy set shown in Figure 3.7(a) contains the illustrated version of Equation 3.14. Figure 3.7(b) is a non-convex fuzzy set.

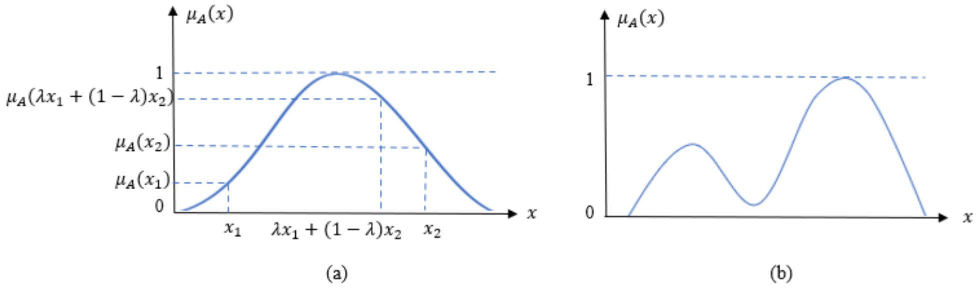


Figure 3.7 Convex and non-convex fuzzy sets

There are different kinds of membership functions that describe fuzzy sets. In the literature, membership functions with different properties such as triangular, trapezoidal, gaussian, generalized bell, sigmoidal, left-right, S, Z and π have been defined (Jang et al., 1997). In fuzzy logic applications, considering the properties of the set being studied, the type of function that best describes the set is used. Triangular, trapezoidal, gaussian, generalized bell are the most commonly used membership functions to define fuzzy sets.

A triangular membership function is defined using three parameters $\{a, b, c\}$ such that

$$\text{triangle}(x; a, b, c) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ \dfrac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x, \end{cases} \tag{3.15}$$

where a, b, c are elements of universal set such that $a < b < c$. The parameters $\{a, b, c\}$ in Equation 3.15 also give the x coordinates of the vertices of the triangular membership function.

A trapezoidal membership function is defined using four parameters $\{a, b, c, d\}$ such that

$$\text{trapezoid}(x; a, b, c, d) = \begin{cases} 0, & x \leq a \text{ or } d \leq x \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d, \end{cases} \quad (3.16)$$

where *a*, *b*, *c*, *d* are elements of universal set such that *a*< *b*< *c*< *d*. The parameters {*a*, *b*, *c*, *d*} in Equation 3.16 also give the x coordinates of the vertices of the trapezoidal membership function. If the *b* and *c* parameters are equal, the trapezoidal membership function is reduced to the triangular membership function. Figure 3.8(a) and Figure 3.8(b) illustrate the triangular and trapezoidal membership functions, respectively.

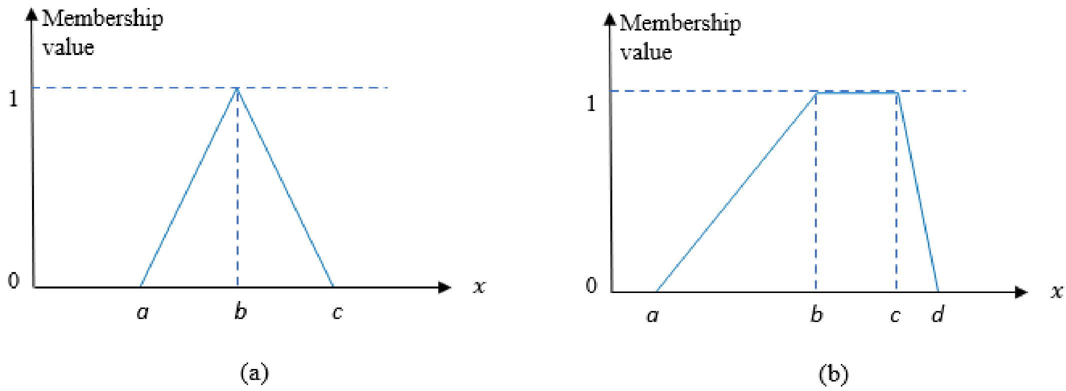


Figure 3.8 Triangular and trapezoidal membership functions

A gaussian membership function is defined using two parameters $\{\sigma, c\}$ such that

$$\text{gaussian } (x; \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}}. \quad (3.17)$$

Parameters σ, c in Equation 3.17 represent the width and center of the membership function, respectively. Since the σ parameter is the width of the function, it directly affects the shape of the function. As this value increases, the shape of the function expands.

A generalized bell membership function is defined using three parameters {*a*, *b*, *c*} such that

$$\text{bell}\ (x; a, b, c) = \frac{1}{1 + \left|\frac{x - c}{a}\right|^{2b}}. \tag{3.18}$$

Parameters a, c in Equation 3.18 represent the width and center of the membership function, respectively. The parameter b is used to control the slope of the curve. Figure 3.9(a) and Figure 3.9(b) illustrate the gaussian and generalized bell membership functions, respectively.

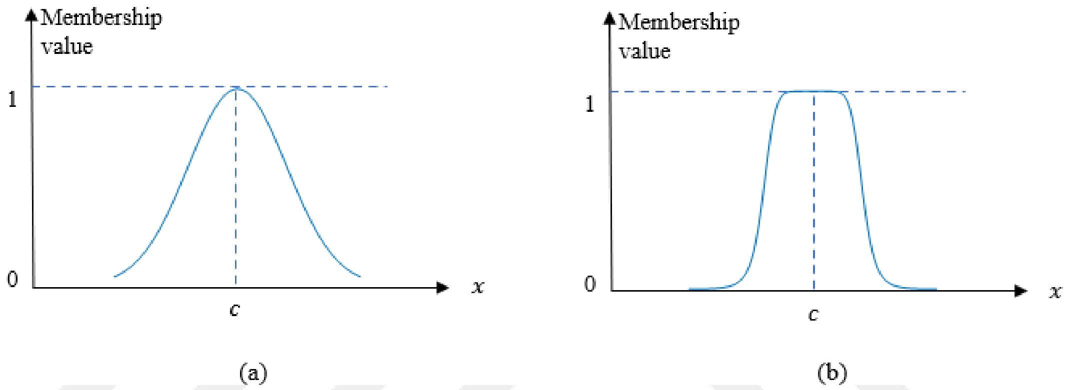


Figure 3.9 Gaussian and generalized bell membership functions

3.2 Fuzzy Inference System

Real-life systems are often not fully explained by the classical logic approach. According to Zadeh, there are two main reasons why classical logical systems cannot solve problems with multi-valued and ambiguous statements. First, they do not provide a system for representing ambiguous expressions in natural language. Second, it cannot be inferred from the system in case the ambiguous meaning can be expressed symbolically in various ways (Zadeh, 1988). In other words, a mathematical expression (model) suitable for the system is needed in order to model with the classical logic approach. However, this is not always possible. Mathematical modeling of some systems may be difficult or even impossible. In case it is possible, the model obtained may not be used due to reasons such as cost, changing environmental conditions, and time (Klir & Yuan, 1995).

Fuzzy logic describes real-life systems as closely as to reality possible. Extending the divalent approach to polyvalent, it imitates the operation of human logic. Considering the variability of conditions, it adopts an approach of belonging with degree rather than certainty for objects. It is very suitable for solving ambiguous problems, thanks to its ability to represent expressions whose meaning is uncertain with flexible limits. Contrary to classical logic, fuzzy logic, which makes it easier to define real life thanks to its multi-valued structure, is used in modeling systems, allowing the model to make inferences and make decisions just like human logic in this process. The method that interprets the input values of the system based on fuzzy rules and obtains an output value is called a fuzzy inference system (Kalogirou, 2009).

Fuzzy inference system is a well-known and efficient fuzzy logic implementation as well as being a popular framework based on fuzzy set, fuzzy rule, and fuzzy reasoning. It is known by different names in the literature such as fuzzy rule based system, fuzzy model, fuzzy associative memory and fuzzy system since it is used in various fields such as automatic control, data classification, decision analysis, expert systems, time series prediction, robotics and pattern recognition. Since the most important and at the same time the first application that enables fuzzy logic to become widespread, aims to control a system using FIS, fuzzy logic controller or fuzzy controller names are often used instead of FIS in the literatüre (Caroprese, Comito, Talia, & Zumpano, 2022; Jang et al., 1997). Due to its use of linguistic variables instead of mathematical models and its rule-based structure, it can be defined as the process of controlling using sentences instead of equations in its simplest form (Jantzen, 1998).

FIS basically consists of four steps; fuzzification, fuzzy rule base, fuzzy inference engine and defuzzification. In order to start the process, first the problem to be modeled is determined. Input values are defined for the variables suitable for the problem. The degree to which the input values belong to fuzzy sets is determined and this is called fuzzification. In the fuzzy inference engine step, using the rules created on the fuzzy rule base, the output is obtained for each fuzzy input. FIS is completed by converting the fuzzy outputs to a single number in the defuzzification step. Figure 3.10 shows the interconnections among these steps.

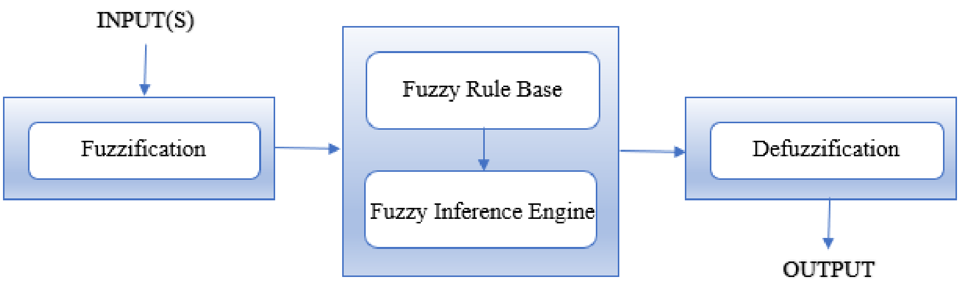


Figure 3.10 A general scheme of a fuzzy inference system

3.2.1 Fuzzification

The first step of FIS is fuzzification. In this step, the goal is converting the input values to fuzzy values and get fuzzy inputs. The fuzzy form of an input is the membership values in the fuzzy set. So, the degree of belonging of the crisp input values to the fuzzy sets is defined by using membership functions. In Figure 3.11, the fuzzification of the crisp input value x_0 on the membership function A is illustrated (Caroprese et al., 2022; Jantzen, 1998).

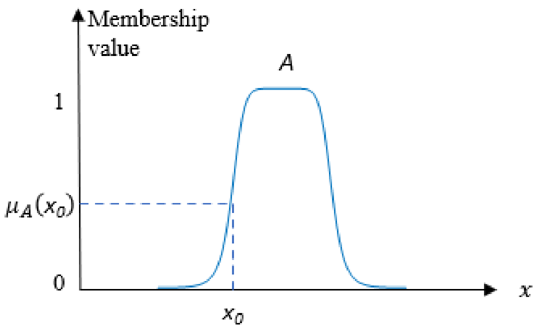


Figure 3.11 Fuzzification

3.2.2 Fuzzy Rule Base

FIS is the process of mapping an input to an output using fuzzy logic (Kalogirou, 2009). This mapping is not random. How the system should behave in any situation, the output value of a given input, in other words, the inference that the system will make is based on some conditions. While these conditions are expressed through equations in mathematical models, they are expressed through sentences containing linguistic variables representing fuzzy sets and fuzzy logic operators representing operations in fuzzy inference system. These conditional statements are called fuzzy rules (Altaş,1999).

Fuzzy rules are if-then statements that express the relationship between variables in linguistic terms. The “if” part of a fuzzy rule is related to the input and is called antecedent or premise. The “then” part of the fuzzy rule is associated with output and is called consequent (Kalogirou, 2009). The form of a single fuzzy if-then rule is such that “If x is A then, y is B”, where A and B are linguistic values defined by fuzzy sets on the universes of discourse X and Y, respectively. When the system contains more than one input, the antecedent of a fuzzy rule can have multiple parts. In this case, the relationship between the inputs is described with “and, or, not” fuzzy logic operators. The form of a fuzzy rule whose antecedent contains two parts is “If x is A and/or/not y is B then, z is C”, where A, B and C are linguistic values defined by fuzzy sets on the universes of discourse X, Y and Z, respectively. The operators “and”, “or”, and “not” are defined respectively as the minimum, maximum, and complement functions (Jang et al., 1997).

The fuzzy rule, which provides the relationship between input and output, directly affects the results of the system. So, the number, quality and obtaining method of fuzzy rules forming the fuzzy rule base are very important. The FIS process aims to control and make inferences just like a real-life expert. Thus, the knowledge of an experienced human expert is used while creating the rule base. Information containing linguistic terms given by the expert is converted into if-then form. In cases where expert knowledge is not available, mathematical model, fuzzy model of the process or learning algorithms that find the rules theirselves are used (Jantzen, 1998; Şaka,1999).

3.2.3 Fuzzy Inference Engine

The fuzzy inference engine is the step that involves combining the fuzzy input values in fuzzy rules using fuzzy operators and aggregate the outputs obtained from each rule with the selected method.

In the fuzzy inference engine, firstly, the antecedent parts of the fuzzy rules are handled. The degree to which each part in the antecedent satisfies the rule is known by converting inputs to fuzzy form in the fuzzification step. If the antecedent part has multiple parts, operations are performed between the values according to the fuzzy logic operator used and a single value is obtained. Differences in the rest of the fuzzy inference engine have created different types of fuzzy inference engines (systems). Some of these inference methods are Mamdani, Sugeno, Tsukamoto, Max-Prod, Zadeh, Gödel, Kleene-Dienes, and Sharp (Jang et al., 1997; Ödük, 2019). The most common of these are Mamdani and Sugeno methods.

The Mamdani inference system was first used in 1974 by Mamdani and Assillan, in the first application of fuzzy logic, to control a steam engine with rules created using the experience of human operators (Mamdani, 1977). Both antecedent and consequent parts of fuzzy rules used in Mamdani inference system consist of linguistic variables. Therefore, it is easy to create rules by utilizing human operator experiences. It allows the rule base to be interpreted intuitively. It has widespread acceptance (Caroprese et al., 2022).

The inputs of the Mamdani inference system are fuzzy values that are obtained from the fuzzification step, and the output is a fuzzy set. The fuzzy set, which is the output of the consequent part, is shaped by using the value obtained from the antecedent part of the fuzzy rule. One of the minimum and product implication methods is used to shape the output fuzzy set. After this process is applied to all rules, the output fuzzy sets from each rule are aggregated. Thus, a single fuzzy set that will be the input of the defuzzification step is obtained (Jantzen, 1998; Kalogirou, 2009). In Figure 3.12, the Mamdani inference system with two rules and two inputs is illustrated together with the fuzzification step. The rules included by the rule base of the illustrated system are in Equation 3.19.

$$\begin{aligned}&\text{If x is } A_1 \text{ and y is } B_1 \text{ then z is } C_1,\\ &\text{If x is } A_2 \text{ and y is } B_2 \text{ then z is } C_2,\end{aligned} \tag{3.19}$$

where A_1, A_2, B_1, B_2, C_1 and C_2 are linguistic values defined by fuzzy sets on the universes of discourse X, Y and Z.

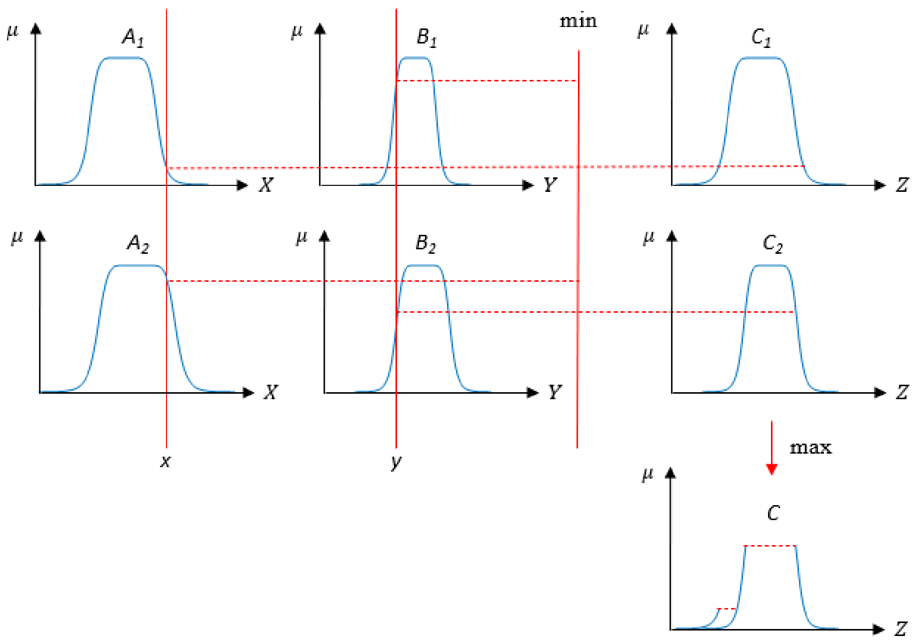


Figure 3.12 Mamdani fuzzy inference system

Another fuzzy inference system is the Sugeno fuzzy inference system proposed in 1985, also known as Takagi-Sugeno and Takagi-Sugeno-Kang. In the study in which the system is proposed, the authors mentioned that the other inference system contains a large number of linguistic variables, causing difficulties. Therefore, they proposed a mathematical tool to construct a fuzzy model (Takagi & Sugeno, 1985).

Just like the Mamdani inference system, the antecedent parts of the fuzzy rules used in the Sugeno inference system also contain linguistic variables. So, the processes of fuzzified the inputs, applying the fuzzy operators and obtaining a single value from the antecedent part are the same. The main difference of the Sugeno fuzzy inference system is that the output membership function in the consequent part is either a constant or a linear function. Accordingly, the form of the fuzzy rule used in a two input Sugeno inference system is generally in Equation 3.20.

$$\text{If x is A and y is B then } z = px + qy + r, \tag{3.20}$$

where A and B are linguistic values defined by fuzzy sets on the universes of discourse X, Y; z is variable of the consequence whose value is implication inferred; p, q and r are all constant (Takagi & Sugeno, 1985). The value z is calculated using the equation in the consequent part of the fuzzy rule. This process is applied to each rule. Unlike the Mamdani method, the output of the rule is a crisp value, not a fuzzy set. Therefore, the final output of the system is obtained without the need for defuzzification step (Caroprese et al., 2022).

The value obtained from the antecedent part of each rule and the value obtained from the consequent part are multiplied to find the final output. The sum of the results found is divided by the sum of the values obtained from the antecedent part of each rule. Figure 3.13 shows the process of a Sugeno fuzzy inference system. The rules included by the rule base of the illustrated system are as in Equation 3.21.

$$\begin{aligned} &\text{If x is } A_1 \text{ and y is } B_1 \text{ then } z_1 = p_1x + q_1y + r_1, \\ &\text{If x is } A_2 \text{ and y is } B_2 \text{ then } z_2 = p_2x + q_2y + r_2, \end{aligned} \tag{3.21}$$

where A_1, A_2, B_1 and B_2 are linguistic values defined by fuzzy sets on the universes of discourse X, Y; z_1, z_2 are variables of the consequence whose value is implication inferred; p_1, p_2, q_1, q_2 r_1, and r_2 are all constant. Moreover, w_1 and w_2 in Figure 3.13 represent the crisp values obtained from the antecedent part of the rule.

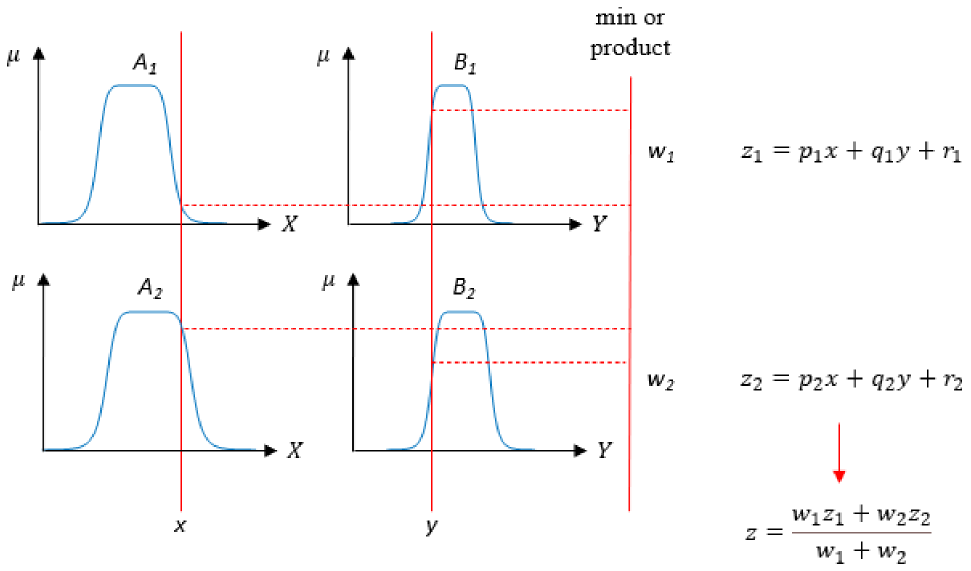


Figure 3.13 Sugeno fuzzy inference system

3.2.4 Defuzzification

The last step of the FIS is defuzzification. The operations performed in this step can be considered as the opposite of the fuzzification step in terms of quality. The input of the defuzzification process is a fuzzy set and the output is a crisp value. The aim of defuzzification is to convert the fuzzy set, which is the output of the fuzzy inference engine, to a single real number (Klir & Yuan, 1995).

Defuzzification can be done using a variety of methods. Some of these methods are centroid of area, bisector of area, mean of maximum, smallest of maximum and largest of maximum. Centroid of area method is based on finding the center of gravity of the fuzzy set. In accordance with this purpose, the elements of the fuzzy set are multiplied by their membership degrees. The obtained results are aggregated and divided by the sum of all membership degrees. If the fuzzy set is continuous, the summation is replaced by the integral. The formulization of defuzzification of the continuous fuzzy set C defined in the Z universal set using the centroid of area method is

$$z^* = \frac{\int_Z \mu(z) z \, dz}{\int_Z \mu(z) \, dz}. \tag{3.22}$$

In Equation 3.22, z* is the crisp output that is the centroid of the cluster, z is any element of Z, μ(z) is the membership degree.

The bisector of area method finds the vertical line that divides the area under the function representing the fuzzy set into two equal parts. For finding this line, a value is found where the sum of the membership values of the elements between it and the smallest element in the range, and the sum of the membership values of the elements between it and the largest element is equal. This value satisfies the following condition

$$\int_{\alpha}^{z*} \mu(z)dz = \int_{z*}^{\beta} \mu(z)dz, \tag{3.23}$$

where z^* crisp output, α is the minimum element of Z and β is the maximum element of Z. Equation 3.23 is used for continuous cases while defuzzification using the bisector of area method.

The mean of maximum method calculates the average of the values have the largest membership degrees. The mean z* is crisp value and is defined as

$$z^* = \frac{\int_M z\,dz}{\int_M dz} \tag{3.24}$$

where z is an any element of Z and M={z | $\mu(z) = \max(\mu(z))$}. When Equation 3.24 is rearranged for the discrete case, the mean is equivalent to the sum of all elements in M divided by the number of elements in M.

Smallest of maximum finds the smallest value among the values with the largest membership degree. This value is

$$z^* = \min\{z \mid \mu(z) = \max(\mu(z))\}. \tag{3.25}$$

Largest of maximum finds the largest value among the values with the largest membership degree. In symbols,

$$z^* = \max\{z \mid \mu(z) = \max(\mu(z))\}. \tag{3.26}$$

If there is only one value with the largest membership degree in a fuzzy set, the z* values obtained from Equation 3.24, Equation 3.25 and Equation 3.26 are equal.

3.3 Adaptive Neuro-Fuzzy Inference System

The fact that the fuzzy inference system has been used in many studies, has achieved successful results and become widespread in a short time has revealed that it is a very suitable method for defining uncertain systems. Fuzzy rules, which are part of the system, enable the fuzzy inference system, which is used in applications such as prediction, control or inference, to benefit from human experience and reasoning. In 1993, Jyh-Shing Roger Jang approached the system with its improvable aspects in addition to these important advantages provided by the method. Jang mentioned in his study that there is no standard method used to transform human knowledge into fuzzy rules to be used in the FIS, and there is a need for effective methods to be used to increase the performans of the system. So, he proposed the Adaptive-Network-based Fuzzy Inference System architecture, semantically equivalent Adaptive-Neuro Fuzzy Inference System or simply ANFIS, which models a fuzzy inference system by creating fuzzy rules used in the system together with appropriate membership functions in the same study (Jang, 1993).

Basically, ANFIS is a fuzzy inference system implemented within the framework of adaptive networks. An adaptive network is a network structure that includes nodes, directional connections between nodes, and whose output depends on parameters related to these nodes thanks to its adaptability. The relationship between input and output depends on the modifiable parameter values of the nodes. The learning rule specifies the variation of the parameters so that the system has the lowest error measure, in other words, it gives the most accurate output. ANFIS models a fuzzy inference system based on both human knowledge and input-output pairs given to the system thanks to all these features of the adaptive network structure.

ANFIS is a class of adaptive networks that is functionally equivalent to fuzzy inference system (Jang, 1993). Unlike FIS, it creates all the fuzzy rules that the system needs itself. Its main purpose is to determine the optimal values for the functionally equivalent fuzzy inference system parameters by using input and output data and applying a learning algorithm. Optimization of parameters is based on minimizing the difference between the actual value obtained by the system and the known objective value (Haznedar & Kalınlı, 2016). Changing the parameters means that the general behavior of the adaptive network changes, in other words, the system learns by using the environmental information (Walia, Singh, & Sharma, 2015). In this manner, the system adapts itself according to the data it will model.

ANFIS is consturacted as an adaptive network that is functionally, usually, equivalent to the Sugeno-type inference system. Figure 3.14 shows the ANFIS architecture, which is equivalent to the Sugeno type inference system with two inputs and two rules. The rules of the system are in Equation 3.27.

$$\begin{aligned} &\text{If x is } A_1 \text{ and y is } B_1 \text{ then } f_1 = p_1x + q_1y + r_1, \\ &\text{If x is } A_2 \text{ and y is } B_2 \text{ then } f_2 = p_2x + q_2y + r_2, \end{aligned} \tag{3.27}$$

where A_1, A_2, B_1 and B_2 are linguistic values defined by fuzzy sets on the universes of discourse X, Y; x and y are inputs; f_1 and f_2 are outputs; p_1, p_2, q_1, q_2, r_1, and r_2 are all constant. The Sugeno inference system is illustrated in Figure 3.13 and the corresponding equivalent ANFIS architecture is shown in Figure 3.14. The value “z” in Figure 3.13 is expressed as “f” in Figure 3.14.

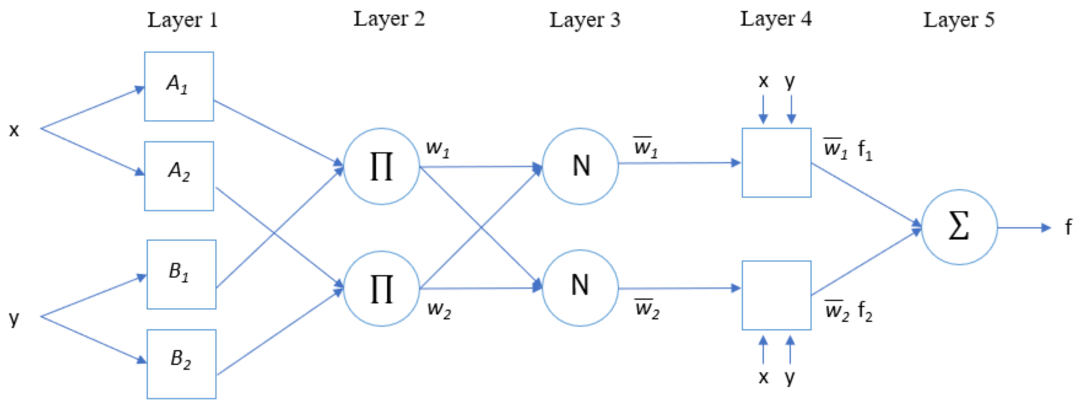


Figure 3.14 ANFIS structure with two inputs and two rules

ANFIS consists of five layers. Each layer contains nodes, which are indicated by squares or circles according to their properties (Walia et al., 2015). The nodes in the same layer have similar functions. The node function or the output of the *i*th node in layer l denoted by O_i^l (Jang et al., 1997). These node functions and the operation of the layers are detailed as follows (Jang, 1993);

- **Layer 1:** The first layer of the ANFIS architecture is the layer where the inputs are fuzzified. Each node in this layer is an adaptive node represented by a square with a node function

$$\begin{aligned} O_i^1 &= \mu_{A_i}(x) && \text{or} \\ O_{i+2}^1 &= \mu_{B_i}(y), && \text{for i= 1, 2} \end{aligned} \qquad (3.28)$$

where x (or y) is the input to node i, A_i (or B_i) is the linguistic value and μ_{A_i} (or μ_{B_i}) is the membership function. Output values of the node represented by O_i^1 (or O_{i+2}^1) in Equation 3.28 are membership degrees that depend on input values and membership functions. In other words, it equals the degree to which the given x (or y) satisfies the quantifier A_i. The membership functions described in Section 3.1.2 can be used in this layer. Generally, the generalized bell function is preferred as the membership function and $\mu_{A_i}(x)$ (or $\mu_{B_i}(y)$) is equal to Equation 3.18.

- **Layer 2:** Each node in this layer is a circle node that represents the rules created by the system. The number of nodes is equal to the number of rules in the system. Each node in this layer is fixed nodes labeled with Π and its output is the product of all the incoming signals from Layer 1 such that

$$O_i^2 = w_i = \mu_{A_i}(x)\mu_{B_i}(y), \qquad \text{i= 1, 2.} \tag{3.29}$$

Each node output in this layer is also equal to the firing strength of the relevant rule and is shown as w_i in Equation 3.29.

- **Layer 3:** Layer 3 is the layer where the firing strengths from Layer 2 are normalized. Each node in this layer is a circular fixed node labeled with N. The *i*th node in this layer calculates the normalized firing strength of the *i*th rule by dividing the firing strength of the *i*th rule by the sum of the firing strengths of all the rules. The output of this layer is

$$O_i^3 = \overline{w}_i = \frac{w_i}{w_1 + w_2}, \tag{3.30}$$

for i=1,2. The $\overline{w_i}$ given in Equation 3.30 represents the normalized firing strength of the ith rule.

- **Layer 4:** This layer contains adaptive nodes, represented by the square. The main purpose of this layer is to calculate the weighted outputs of the given rules at each node. Therefore, the system uses the normalized firing strength values calculated in the previous layer and the output values in the consequent part of the fuzzy rules, shown as f_i in Equation 3.31. Every node *i* in this layer has a node function such that

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i(p_i x + q_i y + r_i), \qquad \text{i= 1, 2} \tag{3.31}$$

where $\overline{w}_i$ is the output of Layer 3, p_i, q_i, r_i are the parameters in consequance part of fuzzy rules. In addition, O_i^4 is the output of Layer 4.

- **Layer 5:** The last layer of the ANFIS structure is Layer 5, where the overall output is calculated. There is only one node in this layer. This node is a fixed circle node labeled with Σ. It sums all incoming signals and calculates the overall output. The output of this layer and also the output of the system is

$$O_1^5 = \overline{w}_i f_i = \sum_i \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}, \tag{3.32}$$

  for i=1,2. The system output, denoted by O_1^5 in Equation 3.32, is equivalent to the "f" in Figure 3.14.

ANFIS updates the parameters by applying a learning algorithm to give the desired input-output mapping. Although the basic learning algorithm of adaptive networks is based on the gradient method, Jang has mentioned four learning algorithms for ANFIS architecture, namely "Gradient Descent Only", "Gradient Descent and One Pass of Least Squares Estimates", "Gradient descent and Least Squares Estimates", and "Sequential (Approximate) Least Squares Estimates Only". However, the proposed learning algorithm is gradient descent and least squares estimates, which is a hybrid learning algorithm (Jang, 1993).

The learning of ANFIS, which has a hybrid learning algorithm, consists of two phases: forward pass and backward pass. These phases require some mathematical calculations. In summary, the antecedent parameters are fixed in the forward pass of the hybrid learning algorithm and the optimum consequence parameters are identified by the least squares estimate. In the second phase, backward pass, the consequence parameters are fixed and the antecedent parameters are updated using gradient descent method. (Walia et al., 2015).

3.4 Fuzzy C-Means Clustering

Clustering is the process of dividing a set or data collection into groups such that the similar elements belong to the same cluster (Hung & Yang, 2001). In classical clustering methods, the boundaries of clusters are clearly defined. In addition, an object either belongs to a set or it does not. However, fuzzy clustering methods allow objects to belong to more than one cluster with values varying within the range of [0,1].

One of the widely used fuzzy clustering methods is Fuzzy C-Means clustering. First introduced by Ruspini, the FCM algorithm was developed by Dunn in 1973 and explained for a single-valued special case. The algorithm was defined for a larger range by Bezdek in the same year and generalized (Hathaway & Bezdek, 1988; Hung & Yang, 2001).

The purpose of FCM clustering is to divide the set or data collection on which it is applied into c fuzzy groups. At first view, it may seem that there is no difference between classical clustering methods and fuzzy clustering methods since they have the same purpose as the classical clustering method. However, the biggest difference between classical c-means (k-means) clustering is the smooth transitions FCM clustering provides. FCM does not cluster objects on a strictly member and strictly non-member perceptive. Instead, it gives the objects the freedom to belong to more than one cluster at the same time with some conditions. These conditions are defined for the membership matrix *U* of the elements of the finite set *X*, which consists of *n* elements defined in a d-dimensional space, intended to be divided into *c* clusters such that

$$u_{ij} \in \ [0,1] \ for \ all \ i = 1, 2, \ldots, c \ and \ for \ all \ j = 1, 2, \ldots, n \tag{3.33}$$

$$\sum_{i=1}^{c} u_{ij} = 1 \ for \ all \ j = 1, 2, \ldots, n \tag{3.34}$$

$$0 < \sum_{j=1}^{n} u_{ij} < n \ for \ all \ i = 1, 2, \ldots, c, \tag{3.35}$$

where $X \subset \mathbb{R}^d$, $2 \leq c < n$ and $u_{ij} \in U$ (Hathaway & Bezdek, 1988; Klir & Yuan, 1995).

Equation 3.33 is a result of the main feature of the fuzzy logic approach. In other words, objects can belong to clusters, with membership values ranging from 0 to 1. According to Equation 3.34, the sum of the membership values of an object must be equal to 1. The third and last condition that the membership values to be used in this algorithm must provide is given in Equation 3.35. According to this condition, the sum of membership values of all elements belonging to any cluster must be greater than 0 and less than n, which is the number of elements. If the sum of these values is 0, it means that there is no element belonging to the cluster, and the sum is 1 means that all elements belong to that cluster with a membership value of 1. Equation 3.35 does not contain equality, as both cases make the purpose of clustering meaningless.

The FCM algorithm is based on minimizing the value of an objective function. The objective function using membership values providing the conditions in Equations 3.27, 3.28 and 3.29 is defined by

$$J_m(U,V) = \sum_{j=1}^{n}\sum_{i=1}^{c}(u_{ij})^m \parallel x_j - v_i \parallel^2, \tag{3.36}$$

where X is a finite set containing n distinct element such that $X=\{x_1, x_2, \ldots, x_n\} \subset \mathbb{R}^d$, c is the number of clusters, u_{ij} is the membership value of jth object belonging to the ith cluster, U is the membership matrix consists of u_{ij}, v_i is the cluster center (prototype) of ith cluster, V is the cluster center vector consists of v_i, $\parallel x_j - v_i \parallel$ is the Euclidian distance between x_j and v_i, and m is the parameter which defines the fuzziness of the clusters such that $1< m < \infty$ (Hathaway & Bezdek, 1988).

The objective function given in Equation 3.36 measures the quality of partitioning using the distance between objects and cluster centers and membership values (Hung & Yang, 2001). For this purpose, the value of Equation 3.36 is calculated repeatedly until it is less than a certain threshold value or for a certain number of iterations. First of all, cluster centers and membership values should be calculated for this calculation. Cluster centers and membership values are defined such that

$$v_i = \frac{\sum_{j=1}^{n} (u_{ij})^m x_j}{\sum_{j=1}^{n} (u_{ij})^m} \tag{3.37}$$

and

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\| x_j - v_i \|}{\| x_j - v_k \|} \right)^{\frac{2}{m-1}}} \tag{3.38}$$

respectively.

The first step of the FCM clustering process is to determine the initial values. Firstly, a cluster number c that satisfies the condition of $2 \leq c < n$ is selected for the system. Another value required by the system is the parameter m. An m value is decided in the range $(1, \infty)$. The algorithm is started after an randomly initial guess for the membership matrix U that satisfies Equations 3.33, 3.34 and 3.35.

In the second step, cluster centers are calculated using Equation 3.37.

In the third step, the membership matrix U is recalculated using Equation 3.38 according to the obtained cluster centers.

In the fourth step, the old membership values (U^{old}) and the new membership values (U^{new}) calculated in the third step are compared. If $\| U^{new} - U^{old} \| < \varepsilon$, then the algorithm is completed, otherwise it returns to the second step, where ε is a small positive constant.

Another way to start the FCM algorithm is to use an initial guess for the cluster center vectors V (Hathaway & Bezdek, 1988). This way is not different from the previous process. It can be defined as the rearrangement of the steps in the previous process according to the cluster center vector. Since the initial value for cluster center vectors V is determined in the first step, membership values are calculated using Equation 3.38 in the second step. In the third step, using Equation 3.37, cluster centers are recalculated according to the membership values found. In the fourth step, the old cluster centers and the new cluster centers calculated in the third step are compared. Just like in the stop condition defined for membership values, the algorithm continues until the difference between cluster centers is less than ε (Nayak, Naik, & Behera, 2015).

The FCM algorithm is simply an iterated procedure. As a third way, it determines the cluster centers and membership values using the following steps (Jang et al., 1997);

Step 1: A membership matrix U is randomly determined that satisfies Equations 3.33, 3.34, and 3.35.

Step 2: Cluster centers are calculated using Equation 3.37.

Step 3: Membership values are updated using Equation 3.38.

Step 4: The value of the objective function is calculated using Equation 3.36.

Step 5: If the value of the objective function is below a certain threshold or the difference between it and the value of the objective function calculated in the previous step is below a certain threshold, then the algorithm is completed, otherwise is retruned to the second step.

Irrespective of the FCM clustering process defining, the main purpose is to minimize the objective function. After the clustering is completed, it is decided to which cluster the object belongs to, according to the values contained in the obtained membership matrix U. The largest membership value of the object is determined and the object becomes a member of that cluster.

The point to be considered in the FCM algorithm, which has applications in areas such as pattern recognition, classification, data mining, image segmentation, medical image segmentation, qualitative modeling, neural network, image analysis, is the selection of the number of clusters before the algorithm starts (Hung & Yang, 2001; Jang et al., 1997; Nayak et al., 2015). The ideal number of clusters for the set on which FCM will be applied may vary according to the structure of the set.

CHAPTER FOUR
APPLICATION

Stress is an inevitable reality for the individual. It is also a problem that most people try to get rid of. The reason for this is that people are most affected by the distress state of stress and fight it. Thus, stress is a situation that individuals both can never get rid of completely and they want to get rid of. The best way to get rid of something that cannot be completely eliminated is to get rid of its negative effects and benefit from it. The first step in avoiding the negative effects of stress and managing it is to determine the level of stress.

Stress is very important not only for the health of the individual but also for the safety of the individual. In particular, instant stress is a situation that is observed in individuals who are prone to commit crimes. In places where security is also important for both the individual and the society, such as bank and passport transactions, many crimes that can be committed can be prevented by instant stress detection. This thesis, which was prepared with this motivation, generally proposes an application for assessment the stress level of the individual using photographs.

In this chapter, the dataset selected for the application and its properties are explained. In addition to the FIS model that form the basis of the application, techniques such as image processing, fuzzy c-means, and ANFIS were also examined. At the same time, the explanation was supported by the given codes, tables, figures and outputs. All stages of the application and more are detailed step by step under different sections.

4.1 Overview of the Framework

This thesis has a multi-stage structure as shown in Figure 4.1. All these stages are structured on the basis of comparing two photographs of the individual, one of which is known to belong to her neutral state. For this purpose, the facial region of the individual was determined and cropped using some photographs in the dataset described in detail in Subsection 4.2.1. By using these photographs, the eyebrow, eye, forehead and mouth regions that are frequently used in stress determination have determined.

In the next step, photographs containing the facial parts of the individual were converted into matrix form. As a result of various operations on the matrix forms of the photographs, the difference between the matrices was found. This difference is the difference between the first picture, which is the neutral state of the individual (considered as stress-free), and the photograph intended to determine the stress level. This difference was used to determine the parameters for the membership functions of the input variables in the FIS model.

In the previous step before creating the ANFIS model, the FCM algorithm was used on the dataset and clustering was performed. As a result, the stress levels of individuals were divided into four clusters. In this way, the required output variable for the ANFIS model has been reached.

The ANFIS model was established by using the input and output values obtained as a result of the previous processes. The dataset was divided into three groups as training, testing and checking, and the model was trained. The output values of each of the data were calculated using the obtained model and the cluster they belonged to was found.

After the training of the ANFIS model, an FIS model was created based on the rules that are automatically created in the rule editor. The output values of the same dataset were recalculated using the created model. Then, the clusters that the outputs belong to were determined. The rules used while creating the model were examined and a relationship was established between clusters and stress levels.

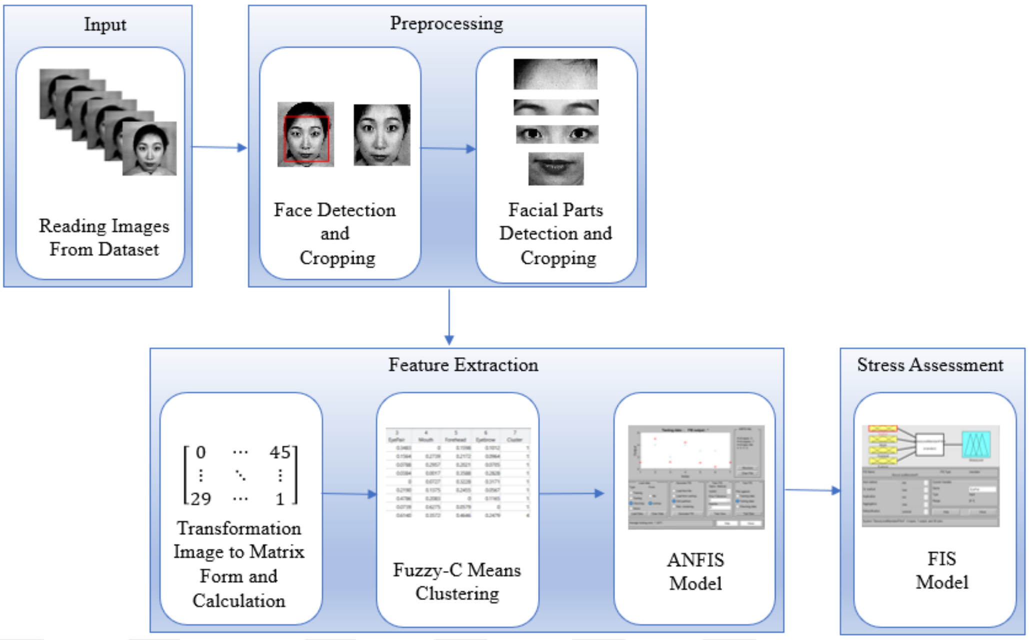


Figure 4.1 Stages of the proposed framework for stress assessment

All operations shown in Figure 4.1 were performed using the R2018b version of the MATLAB program. The fact that the MATLAB program is a matrix-based program has been beneficial during the development of the model. In addition, the hardware used in this thesis is a Lenovo IdeaPad 3 15IML05 (Intel Core i5-10th generation processor, 8 GB RAM) model computer.

4.2 Datasets

Two different datasets were used, namely The Japanese Female Facial Expression (JAFFE) Database and Animal Faces-HQ (AFHQ) for the model developed within the scope of this thesis. The specifications of the datasets, the methods of obtaining them and the sample images are important for recognizing the datasets. Besides, the uses and purposes in the model of the datasets are explained in detail in Section 4.3 and Subsection 4.5.3.

4.2.1 The Japanese Female Facial Expression Database

The first step of the application is to determine the dataset for the targeted model. Therefore, first of all datasets containing facial expressions of individuals were examined for this application which aims to detect stress by making use of facial expressions. During this review, the characteristics, purpose of use, number, size and reliability of the photographs in the datasets were taken into consideration. As a result, many datasets containing facial expressions of individuals have been reached.

Among the analyzed datasets, JAFFE database was found suitable for the model due to reasons such that

- Each image is the same size,
- The eyebrow, forehead, eye and mouth areas to be used for the model are obvious and clear,
- Not using any accessories (hats, glasses, etc.) and make-up,
- Composing of the photographs facial expressions containing six basic emotions and neutral states,
- Labeling of photos according to the emotional state they reflect.

At the same time, the fact that it has been used in many studies aiming to determine stress has increased the reliability that the dataset is suitable for the model.

The preferred JAFFE dataset for this thesis was developed by Michael J. Lyons, Miyuki Kamachi, and Jiro Gyoba in 1998 (Lyons, Kamachi, & Gyoba, 2020). The entire dataset consists of images containing seven different facial expressions of Japanese female subjects. The hair of subjects was tied so that their facial expressions could be clearly seen while the images were taken. Subjects have sat in front of a semi-reflective sheet and captured their own images using a remote control. Photographs of 10 female subjects for each facial expression were recorded at least three times, at most four times (Lyons, Akamatsu, Kamachi, & Gyoba, 1998).

Images taken at the Psychology Department in Kyushu University are in ".tiff" format and are not compressed. Each of the photos in the dataset has the same size and 256x256 pixel resolution. The JAFFE dataset, which originally contained 219 photos, includes 213 photos in publicly available form of it, because six photos were overlooked (Lyons, 2021). The photos have been tagged based on the statements of the expressor. While labeling, happiness, sadness, surprise, anger, disgust, fear and neutral are abbreviated as “HA”, “SA”, “SU”, “AN”, “DI”, “FE”, “NE” respectively. Participants were identified with the initials of their names (KA, KL, KM, KR, MK, NA, NM, TM, UY, YM). In Figure 4.2, samples containing a photograph of each facial expression of the same participant are given with their labels. The number next to the abbreviations of facial expressions on the labels indicates the number of poses in the relevant facial expression of the participant, and the last number indicates the order number in dataset of the image.

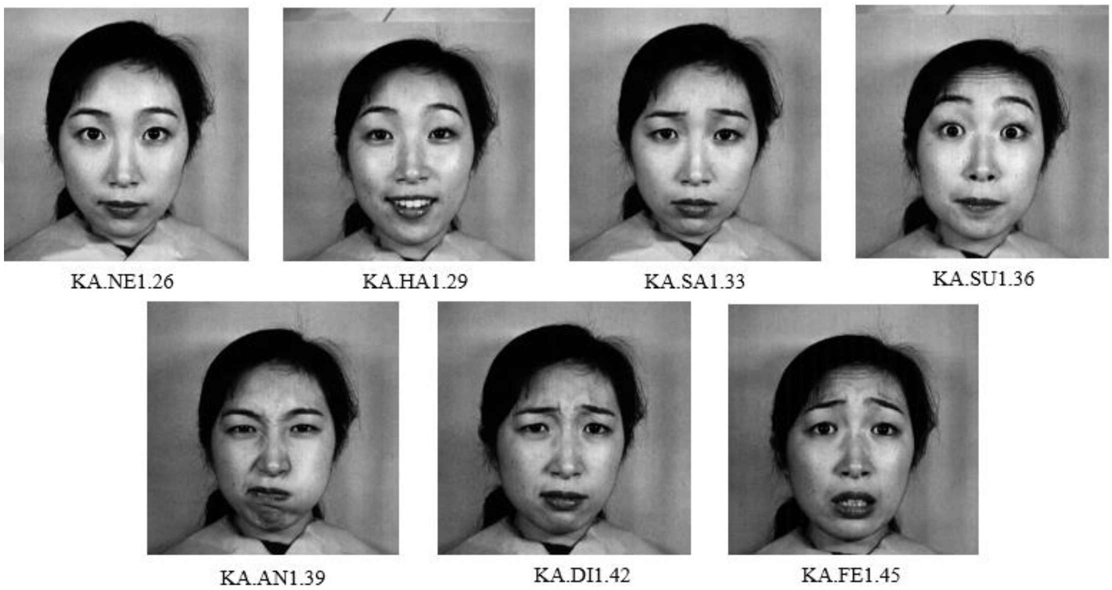


Figure 4.2 Sample images of seven facial expressions in the JAFFE dataset

JAFFE, which is widely used in areas such as emotion detection and stress determination, is an accessible dataset for non-commercial studies under some conditions. If deemed appropriate, the dataset requested via an e-mail containing the requested information is opened to access with a personal link. The JAFFE dataset was obtained from the Zenodo repository for use in this thesis as a result of the mentioned processes.

4.2.2 Animal Faces-HQ Database

Another dataset used in the application is Animal Faces-HQ. AFHQ was created in 2020 by Yunjey Choi, Youngjung Uh, Jaejun Yoo, and Jung-Woo Ha (Choi, Uh, Yoo,

& Ha, 2020). The dataset which consists of three parts as cat, dog and wildlife, includes facial images of cats, dogs and wild animals (lion, tiger, fox, leopard, etc.). Each section contains approximately 5000 photos, and the dataset consists of 15000 images in total. Each image in the AFHQ dataset, examples of which is given in Figure 4.3, is the same size. High quality pictures have 512x512 resolution. The photos in the dataset were collected from Flickr and Pixabay sites, and the low resolution ones were extracted by human power.

As can be clearly seen from the pictures given in Figure 4.3, the photographs are focused on the facial region of the animals. Pictures, which are a kind of animal portrait, are different from many datasets consisting of animal pictures in this respect. In accordance with the intended use in the model,

- Being each picture the same size,
- The large number of pictures in the dataset,
- Being facial areas of animals obvious and clear

played an important role in choosing the AFHQ dataset for this thesis.

Figure 4.3 Sample animal images of the AFHQ database

Although AFHQ is a new dataset, it has found its place in the literature and has been used in many studies (Han, Gao, Wang, & Zou, 2021; Kim, Park, Jeon, Kim, &

Kim, 2022). It is easy to reach as it is available to everyone. In their article where the producers also explained the formation of AFHQ, they shared a website address where the researchers stated that they could access the dataset (Choi et al., 2020). The AFHQ dataset was downloaded from Kaggle for use in this thesis.

4.3 Reading Images

The main purpose of the model proposed in this thesis is to assess the stress level using facial expressions of individuals. For this reason, it was inevitable to use a dataset containing facial expressions of individuals to obtain the input data of the model. The most appropriate dataset for the system was determined as JAFFE.

Although the JAFFE dataset includes seven different emotions, the images labeled SA, AN and FE in the dataset were used in this model because of the relationship between negative emotions and stress, which was explained in detail in Subsection 2.2.2 and Section 2.4. In addition, since the model made an inference by comparing two images of the individual, images containing the neutral state of the individual were also needed.

During the development of the model, images that were not suitable for the detection of the face and facial region were determined. For this reason, no pictures labeled KM are included in the application. The images of the remaining nine participants labeled as SA1, AN1, FE1, NE1 and NE2 were used. The model was created using a total of 45 images.

Before starting to write the code of the model, a folder for each emotions was created on the computer so that the determined photos can be loaded to the MATLAB environment and used in the code. Reading the dataset in the program was carried out through these five folders.

While reading images in MATLAB can be achieved with a single function, these elements are assigned to a variable as a list in order to read images in folders containing multiple elements. Then the names of the listed images are concatenated horizontally in a loop and assigned to another variable. The images were read using the variable and *imread()* function without closing the loop. Examples of outputs that the model displays after reading the inputs are given in Figure 4.4.

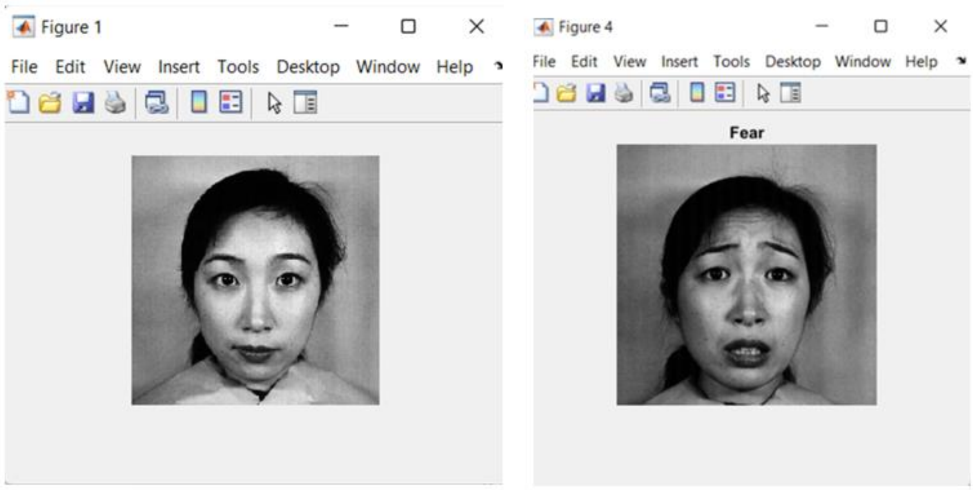


Figure 4.4 Sample images shown after reading the dataset

In Figure 4.4, neutral (KA.NE1.26) and fear (KA.FE1.45) images of the same participant (KA) are given as an example. These images have been chosen to facilitate the explanation of the application and they represent other images in the dataset. However, it should be underlined that every step described in the application is valid for all images used by the model.

4.4 Face Detection and Cropping

The images in the dataset include the background, hair and neck of the person besides the face. Even so, the part that the application needs is the face part of the person. Therefore, at this stage of the model, the facial part in the images was detected.

In this study, a detector using the Viola-Jones algorithm was used for face detection. The Viola-Jones algorithm was developed by Paul Viola and Michael Jones in 2001. Another motivation for this algorithm, which is used by its developers in a machine learning approach that detects objects in an image, is face detection. In their work where they describe their algorithms, they also have explained their systems they developed to detect faces from images with examples (Viola & Jones, 2001).

Viola-Jones object detection framework basically includes three phases. The first step is to extract the facial features using the detection window containing black and white regions given in Figure 4.5. The features are calculated by using the difference between the sum of the pixels in the white part of the rectangles and the sum of the pixels in the black region. Features common to human faces, such as the eye area being darker than the cheeks, or the nose being brighter than the eyes, reveal this measurable difference (Viola & Jones, 2001).

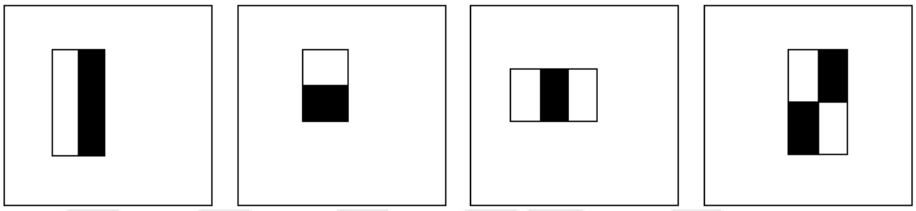


Figure 4.5 Rectangle features used in Viola-Jones algorithm

The second step is to select the features called weak and strong classifiers to be used while classifying. While making this selection, another algorithm with complex calculations is used.

The operations performed in the third and final stage can be called classification in summary. The general form of the detection process that includes this classification is called “cascade” (Viola & Jones, 2001). This classification, which is multi-layered, is made according to a discarding system based on whether the sub-images obtained from the image can contain the face region. Face is detected in the image passing all layers (Alionte & Lazar, 2015).

The programming language used in the thesis, MATLAB, has an object detector using the Viola-Jones algorithm. In the face detection phase of the study, a detector was first created using the *vision.CascadeObjectDetector()* system object. Using this detector, the facial regions in the images, whose reading in the model was elaborated in Section 4.3, were detected. In order to follow the operation of the system step by step, it has been deemed appropriate to display these regions on the screen. In these outputs, the facial regions are surrounded by a red bounding box rectangle as seen in Figure 4.6. In addition, the emotional state that image belongs to is stated in the given title.

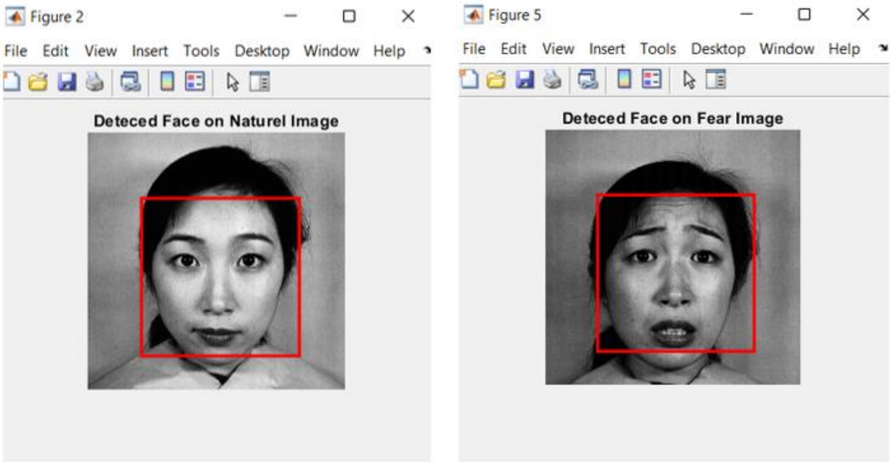


Figure 4.6 Examples of detected face regions

The next step after the detection of the face is the cropping of the framed face region. In Figure 4.7, the images given in Figure 4.6 are cropped by the model. In the next steps, the model uses cropped form of images detected face region. In this way, while detecting the facial parts described in Section 4.5, the system has reached the most accurate result more easily and quickly by using the cropped photo.

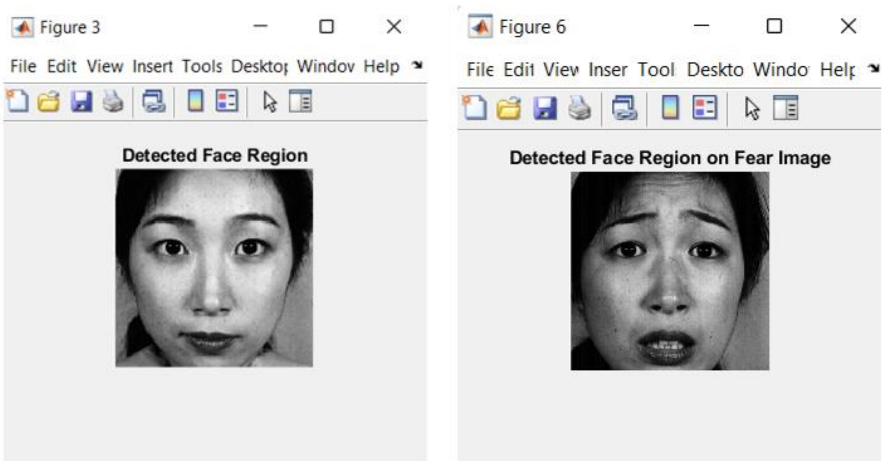


Figure 4.7 Cropped face regions

4.5 Facial Parts Detection and Cropping

While choosing the facial parts to be used in the model, the parts of the individual that undergo the most changes during stress were preferred. The facial parts extracted from the images are the eye area, mouth area, forehead and eyebrows. The frequent use of these parts of the human face in studies aiming to determine the stress level corroborated reliability for the model.

Just like in face detection, facial parts other than the eyebrow were basically obtained using the detector. However, different methods were used in addition while detect the mouth and forehead area. The process of detecting and cropping the facial parts has been detailed under different headings.

4.5.1 Eye Pair Detection and Cropping

The eyes are of great importance for determining the stress level for reasons based on Subsection 2.2.1. Accordingly, the first part of the face detected after face detection from the images is the eye region. The *vision.CascadeObjectDetector()* used in face detection also allows to detect some facial parts. Among these facial parts are the eyes. This detector creator, which offers multiple options when determining the eye area, has been found suitable to be used in the proposed model thanks to its successful results.

The classification models that the detector provides for the eye area are of three types according to the regions it detects: right eye detection, left eye detection and a pair of eye detection. While developing the algorithm, firstly, classification models that find the eyes as right and left separate were used. However, it has been observed that the result images do not cover the wrinkles around the eyes caused by stress. Furthermore, the regions determined using these models cover all or a part of the eyebrows of the person. Seeing that the eyebrow area is another parameter of the model, these results are not acceptable. Besides, in a study comparing success between these classification models, eye pair detection was found to be the most successful among these three options with a rate of 90% (Shen, 2016). All these reasons have shown that the most suitable classification model for the system developed within the scope of the thesis is “EyePairBig”. The examples of the images in which the pair of eyes are detected, given in Figure 4.8, prove this.

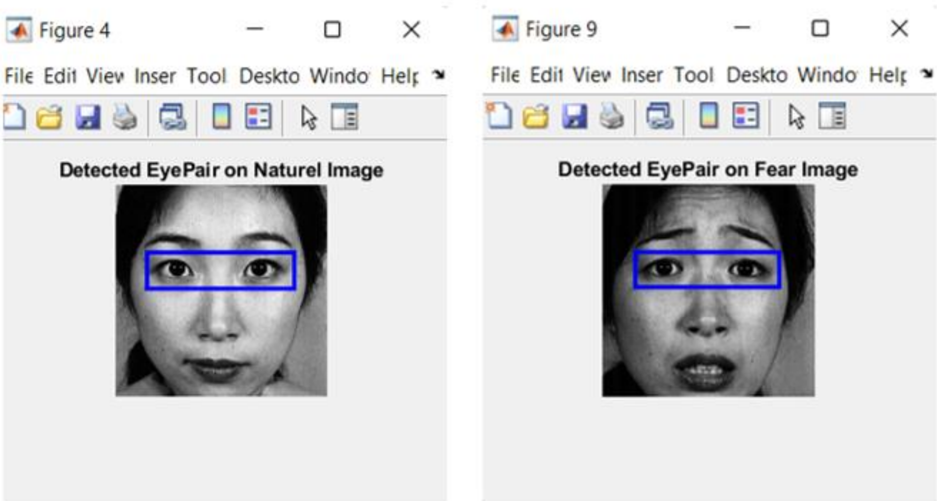


Figure 4.8 Examples of detected eye pair

After the eye pair was detected, codes were added to ensure that this region was surrounded by a blue rectangle, thus enriching the model visually. In the next step, the bounded region is cropped using the *imcrop()* function. Thus, images that give the input values of the first parameter of the model were obtained. The images given in Figure 4.9 are examples of 45 images obtained at this stage.

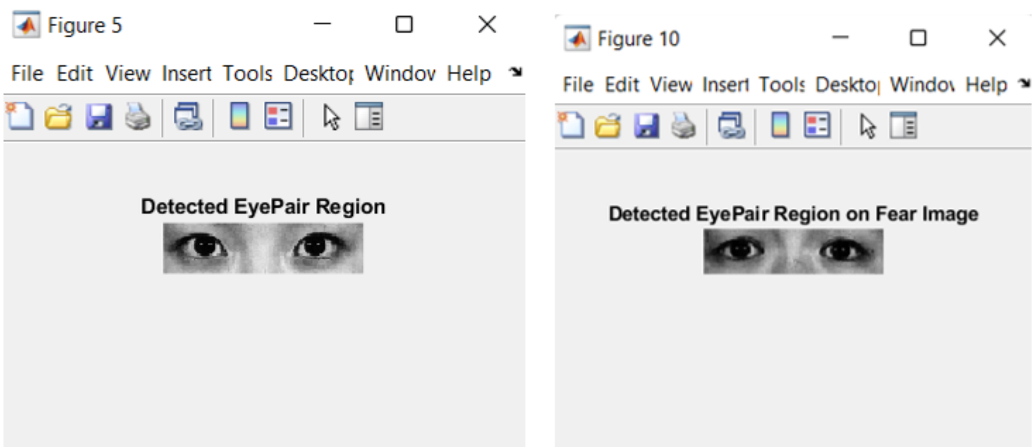


Figure 4.9 Cropped eye pair regions

4.5.2 Mouth Detection and Cropping

The second step in facial part detection is mouth detection. The mouth area was basically detected using the same detector. However, “Mouth” classification model of the detector was insufficient to detect the mouth region in the images. For this reason, improvement studies have been carried out so that the model can give clear and proper results.

While developing the model, the mouth area was first tried to be determined using only the detector. In the results obtained, it was observed that the system could not make any determination in some photographs in the dataset, and determined more than one region as the mouth region in some photographs. In order to solve the problem, the image is cropped based on the idea that the system should scan the mouth at the bottom of the image. Since every photo in the database has the same size, a rectangle that is known to involve the mouth region was determined and given to the model. The sizes of the rectangle used to crop the images in the dataset are given in vector form in Equation 4.1, taking into account the sizes of the images studied.

Let x_{min} , y_{min} ,w, and h are positive integers, the rectangle has the following form

$$[x_{min}\ y_{min}\ w\ h] \tag{4.1}$$

where x_{min} , y_{min} are the smallest values in spatial coordinate system along x-axis and y-axis respectively, w is the weight and h is the high. In order to understand the cropping of the image using the rectangle form given in Equation 4.1, it is important to mention the representation of the image in the spatial coordinate system, which is explained in detail in Subsection 4.6.1. When we display the image in the spatial coordinate system, the upper left corner is considered the point (0,0) (see Figure 4.19). In simpler terms, after cropping the image using this vector, the coordinates of the upper left corner of the new image correspond to the point (x_{min}, y_{min}) in the original image. The original image is cropped from this point to the w-value width and the h-value height. In other words, the coordinate of the lower right corner of the cropped image is (x_{min}+w, y_{min}+h). Examples of the images obtained are given in Figure 4.10.

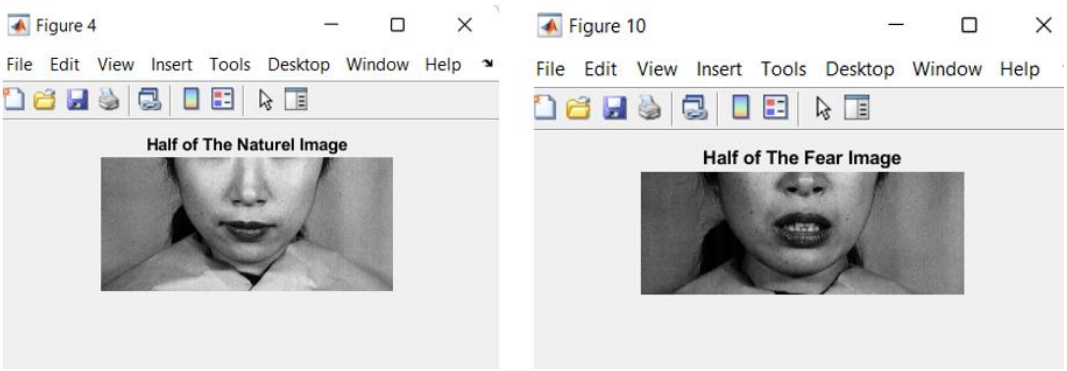


Figure 4.10 Examples of cropped images using vector

In the next step, the detector created in the first step of mouth detection was used again on the cropped images obtained. The regions found by the system that correctly detects the mouth on the new images are enclosed by a green rectangle as seen in Figure 4.11.

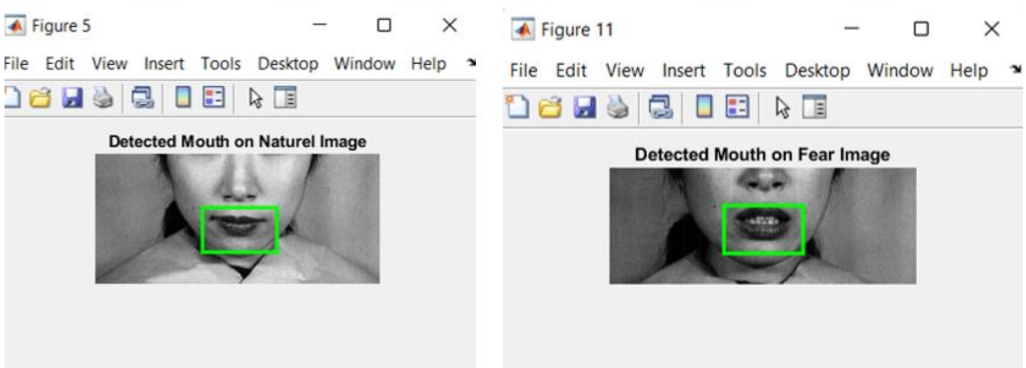


Figure 4.11 Examples of detected mouth regions

The mouth regions detected in the last stage of mouth detection are cropped. The system has been developed to display the cropped parts on the screen. The output examples of the system are given in Figure 4.12.

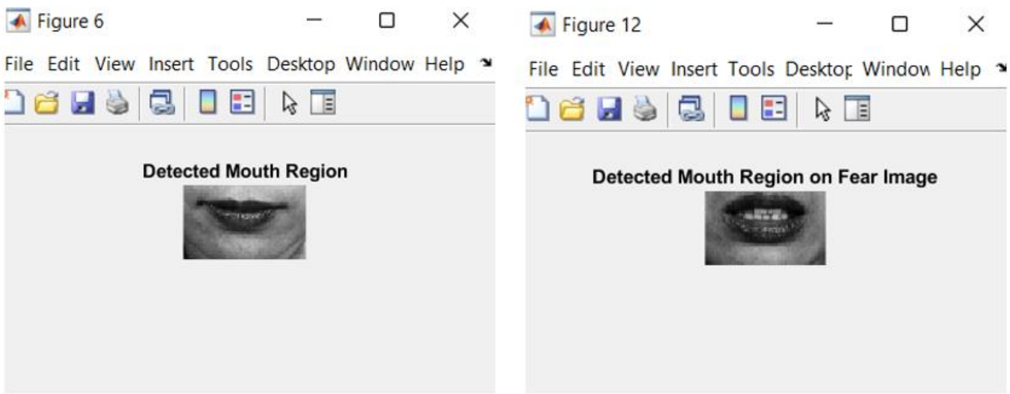


Figure 4.12 Cropped mouth regions

4.5.3 Forehead Detection and Cropping

In cases where the individual has neutral state and other facial expressions, the long and short lines that occur especially in the forehead area reveal a great change between the two states. Therefore, the third facial region chosen for the model proposed in this study is the forehead. In the forehead detection, *vision.CascadeObjectDetector()*, which is also used while eye pair and mouth are found, is used. However, this detector does not have a classification model developed to detect the forehead region from the image. However, MATLAB Computer Vision Toolbox allows the user to train a custom classifier.

The *trainCascadeObjectDetector()* function given in Figure 4.13 is used to train the cascade classifier needed for forehead detection. Thus, a classification model that is not contained by the system object is obtained as a result of the training. However, positive and negative image samples are needed for this cascade classifier training.

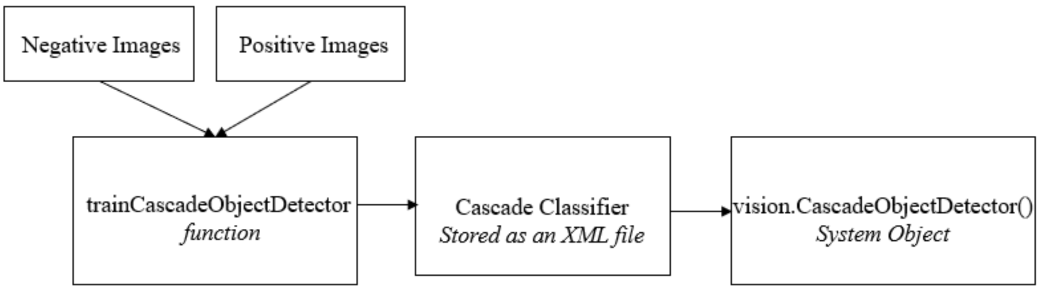


Figure 4.13 Detector training stages

Examples of positive images should include the objects the model was trained to detect (the forehead region for this study). In order to label these objects with bounding boxes, the “Image Labeler” application in Computer Vision Toolbox is used. For cascade classifier training, the already is studied on JAFFE dataset was used. However, since a large amount of data is needed for training, all 213 images in the dataset were used. Image Labeler creates a table for positive samples identified after labeling is complete.

While selecting the dataset for the negative images, the object that the model is expected to detect is not ignored. Negative images should be similar to positive images but should not contain the searched region. The most suitable examples for these features are considered to be images containing animal faces. For this reason, the AFHQ dataset, the examples of which are given in Figure 4.3, as detailed in Subsection 4.2.2, was preferred as a negative sample.

After the necessary samples were provided, the training of the detector named “Foreheadregion.xml” was started. While the detector was being trained, the “FalseAlarmRate” and “NumCascadeStages” options provided by the function were selected as 0.1 and 5, respectively.

The last step of Forehead detection is to create the detector using the newly trained “Foreheadregion.xml” classifier. The newly created detector detected all forehead regions in the dataset. The detected forehead regions are enclosed by a yellow bounding box rectangle as seen in Figure 4.14.

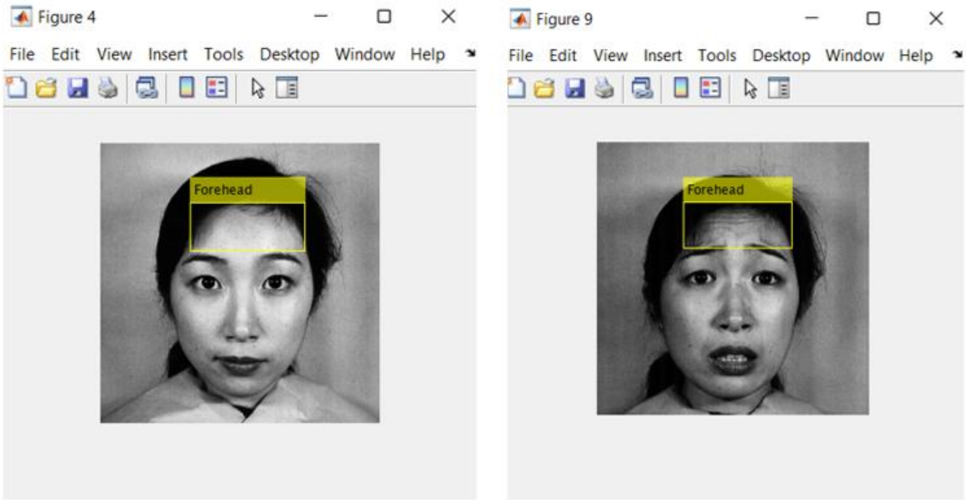


Figure 4.14 Examples of detected forehead regions

The framed forehead area was cropped and new images were obtained examples of which are given in Figure 4.15. Thus, the process of obtaining the images giving the numerical values of the third parameter of the model has been completed.

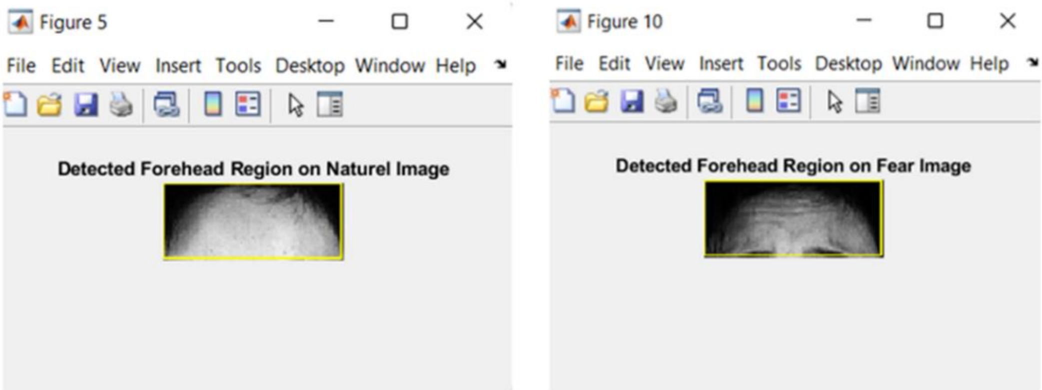


Figure 4.15 Cropped forehead regions

4.5.4 Eyebrow Detection and Cropping

The last facial region that gives the input values for the model is the eyebrows. Eyebrows are most related with the eye region among the facial regions selected as parameters in this study. For this reason, it was deemed appropriate for the model that the eyebrows should not be separated as right and left, just like the eyes. Unlike other facial regions, a detector was not used in the detection of eyebrows.

In the first stage of eyebrow detection, the “Image Labeler” application, which was also used in forehead detection, was used. After labeling the rectangle containing the eyebrows, the labeled regions were saved with the name “Eyebrow Region” and the extension “.mat” and exported to MATLAB workspace. Eyebrowregion table is a table consisting of the information of the rectangle containing the labeled eyebrow areas and the names of the images in the dataset.

Table 4.1 Some rows of the “Eyebrowregion” table

Image File Name	**Eyebrows**
‘C:\Users\jaffedbase\KA.NE1.26.tiff’	[77,94,105,22]
‘C:\Users\jaffedbase\KA.FE1.45.tiff’	[74,97,116,20]

In Table 4.1, only the rows containing the information of the images in Figure 4.7 of the “Eyebrowregion” table are given. The size of the table used in the model is 45x2 in parallel with the number of images in the dataset.

The next step after eyebrow detection is the cropping of the determined regions. The cropping step was performed using the algorithm whose pseudo-code is given in Figure 4.16. This algorithm not only crops the images, but also writes them to an externally created folder. Written versions of the obtained images to the folder are given in Figure 4.17. In addition, Figure 4.17 includes the cropped eyebrow images obtained from the images in Figure 4.7 in enlargement for the continuity of the explanation.

INPUTS: Jaffedbase (Dataset)

Foldername (The file that the images in the dataset are listed)

Eyebrowregion (Eyebrowregion table)

Find the lenght of Foldername

L= The lenght of Foldername

for k=1:L

filename= Concatenate Jaffedbase and the name of Foldername (k)

Image=Read filename

bboxeyebrow=k th row and 2 column of Eyebrowregion

bboxeyebrow_2= Convert bboxeyebrow table to cell

Eyebrowimage=Crop Image according to bboxeyebrow_2

Write Eyebrowimage with the name of Foldername(k) in externally created folder

end

Figure 4.16 Eyebrow regions cropping pseudo-code algorithm

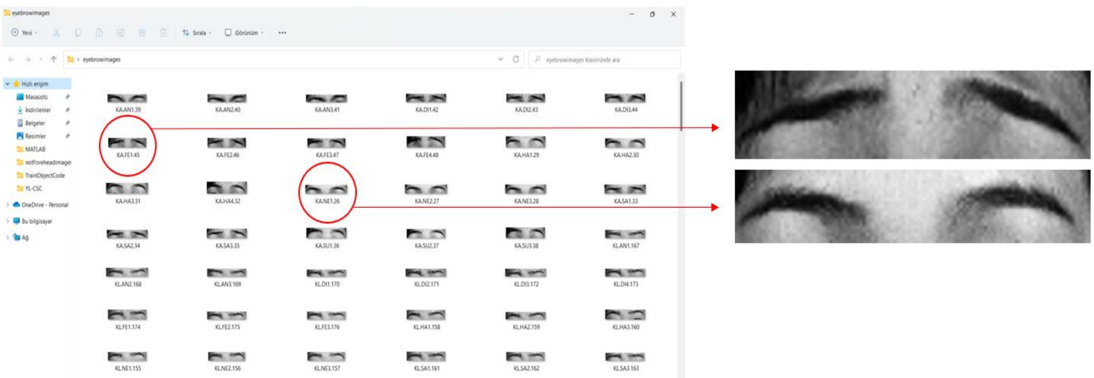


Figure 4.17 Images of cropped eyebrow regions

By detecting the eyebrow regions, the facial parts that need to be determined from the images are completed. As a result, a total of four new images, eye pair, mouth, forehead and eyebrow, were obtained from each image in the dataset. Thus, the number of images that need to be studied on has been updated to 180.

4.6 Images Matrices of Facial Parts

The model proposed in this thesis used as input the numerical values by comparing the photographs taken in the neutral, neutral (pose 2), fear, anger, and sadness state of the individual. Therefore, in this part of the study, the operations performed to matrix representations of images obtained in Section 4.5 are explained. However, in order to perform these operations, it is important to first understand how it is possible to transform an image into a matrix.

4.6.1 Image Matrix

The (digital) image is a whole that contains a lots of numerical information. The basic structure of the image is a matrix, each element of which is positive integers, as shown in Figure 4.18. A matrix with M rows and N columns consists of MxN elements. Each element in the matrix representing the image is called image element, picture element, pel or, most commonly, pixel (Gonzalez & Woods, 2008).

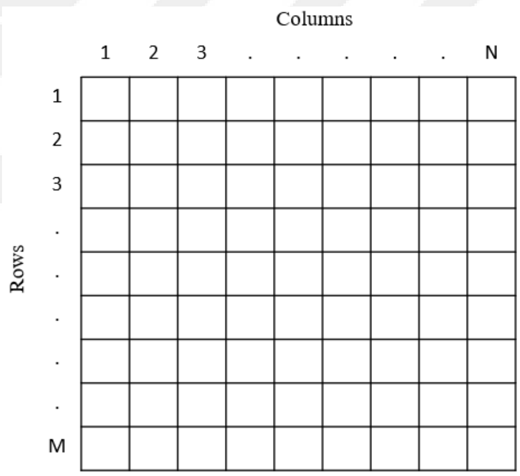


Figure 4.18 The fundamental structure of an image

Pixel is the smallest element of the image (Aydın, 2021; Grande, 2012). Each value of the pixel represents the brightness or intensity at its location, in other words, the color (Kumar & Verma, 2010). In other words, the pixel contains the color or intensity information of its location numerically (Phillips, 2000).

There are three types of images: binary image, grayscale (intensity) image and true color (RGB) image according to the numerical value of the pixel and matrix dimension

(Kumar & Verma, 2010). Since the JAFFE dataset used in this thesis consists of grayscale images, the explanation was carried out on this type.

If necessary to give more details, when the image is placed in a 2-dimentional (2D) spatial coordinate system, as shown in Figure 4.19, each point on the image has an x and y value corresponding to it.

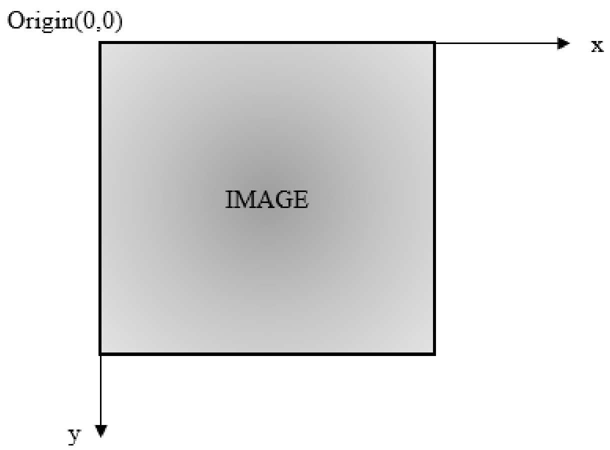


Figure 4.19 Representation of the image in the 2D spatial coordinate system

The values that x and y values can have on the spatial coordinate system are continuous. However, when obtaining the image matrix, these values are taken as discrete. To illustrate, an image has *MxN* size takes *M* values as *x=0, 1, 2, 3…, M-1* along the x-axis and *N* values as *y=0, 1, 2, 3…, N-1* along the y-axis. Let *f* be a two-dimentional continuous function. The value of *f* at *(x, y)* coordinates, denoted *f (x, y)*, gives intensity or gray level at that point. At the same time, *f (x, y)* is the value of pixel. Thus, the image is transformed into a matrix as in Equation 4.2, which consists of the values in the *f* function of each *(x, y)* point (Gonzalez & Woods, 2008).

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix} \tag{4.2}$$

The value of each pixel is called the gray level value (Haralick & Shapiro, 1991). Gray level boundaries are two colors, black and white. Gray level values, on the other hand, can take 256 different values, including 0 representing black and 1 representing white, with gray tones between these two colors. Accordingly, the pixel can take f(x,y) values in the range of [0, 255], where f(x,y) is an integer. The image in which each pixel has a value 0 to 255 is called grayscale, intensity or gray level image (Haralick & Shapiro, 1991).

4.6.2 Equalization of The Image Matrices

MATLAB stores the images in its workspace as a matrix. Therefore, the matrix representations of all new images obtained in Section 4.5 are in the developed system. However, the sizes of the images obtained differ from each other, as the facial parts in each photo are bounded by rectangles of different sizes. Accordingly, the shapes of the matrices representing the images are also not the same. In order to subtraction operation between the matrices, their shapes must be the same. Therefore, before calculating on the matrices, an algorithm has been developed to equalize their shapes.

The proposed model is ready to equalize the shape of the matrices by using the algorithm developed. It should be noted that the purpose of the system is not that the 180 existing matrices have the same size as a result of this operation. While determining the stress level, the comparison of neutral state-neutral state (pose 2), neutral state-fear, neutral state-anger, neutral state-sadness images is based. In parallel with this, the matrices whose size must be equalized belong to the neutral and other facial expression (neutral (pose 2), fear, anger, sadness) of the same individual. Considering that four different images were obtained from each image, the system made 16 times matrix equalization for each individual.

When the matrices of the images in Figure 4.9 are examined, it has been determined that the matrix size of the image of the neutral state of the individual is 28x111, the matrix size of the image of the fearful state is 27x108. In accordance with the developed algorithm, the model assigns 0 value to the relevant elements in the matrix of the fear image and equalizes the sizes of the matrices as 28x111. Similarly, size equalization was performed between the relevant matrices and the step of finding the difference between the matrices was started.

4.7 Difference of Matrices

At this stage of the application, calculations were made on the matrices obtained in Section 4.6 using mathematical operations. Firstly, subtraction was performed between the matrices of the relevant images to calculate the change between the two facial expressions of the individual. Thus, a difference matrix was obtained. In view of the fact that the numerical values in the pixels may differ from each other, it is possible to subtract some pixel values from a smaller value when finding the difference matrix. Thus, the difference matrix also includes negative integers. But negative integers are meaningless in terms of gray level. Therefore, by taking the absolute value of the difference matrix, a difference matrix that all elements are positive is obtained. In addition, the system has been developed to display the calculated difference matrix as an image. In Figure 4.20, the image form of the difference matrix obtained from the images in Figure 4.9 is given.

Figure 4.20 The image representation of difference matrix

The next operation on the matrices is to find the mean of the difference matrices consisting of the elements taken their absolute value. Finding the mean of the matrices is important both to find the mean change in two different images of the individual and to convert the matrix to a single real number. For this purpose, the means of the matrices were found by using the *mean()* function, which is among the basic statistical functions of MATLAB. This function uses the equation in Equation 4.3 to calculate the mean of any N-element vector V$=[V_1, V_2, \dots, V_N]$.

$$\frac{1}{N}\left(\sum_{i=1}^{N} \mathrm{V_i}\right) \tag{4.3}$$

In the next step, the means of the matrices giving the difference between the two images were transferred to a table containing the names of the images compared in the first two columns, and the eyepair, mouth, forehead and eyebrow variables in the other columns. This table is a sketch of expressing the changes in images with numerical data. The operations in the next steps were performed using the data in this table.

4.8 Normalization

At this stage, normalization was performed on the data in order to scale the data in a common range. There are many types of normalization. As a normalization method for this study, it was preferred min-max normalization. Thus, the range of the data is rescaled to the interval $[0,1]$.

The normalized version x' of data x in $[X_{min}, X_{max}]$ that rescaled to the interval $[0,1]$ is defined such that

$$x' = \frac{x - X_{min}}{X_{max-} X_{min}}. \tag{4.4}$$

The values in the table mentioned in Section 4.7 are normalized using Equation 4.4. Each column containing numerical values in the table is an input of the proposed model. Therefore, each column is normalized within itself, separately. The normalized version of the data is given in Table 4.2.

Table 4.2 Normalized version of the data

NeutralImage	SampleImage	EyePair	Mouth	Forehead	Eyebrow
“KA.NE1.26.tiff”	“KA.NE2.27.tiff”	0.3483	0	0.1598	0.1012
“KL.NE1.155.tiff”	“KL.NE2.156.tiff”	0.1564	0.2739	0.2172	0.0964
“KR.NE1.71.tiff”	“KR.NE2.72.tiff”	0.0788	0.2957	0.2021	0.0705

Table 4.2 Continues

“MK.NE1.113.tiff”	“MK.NE2.114.tiff”	0.0384	0.0017	0.3588	0.2828
“NA.NE1.199.tiff”	“NA.NE2.200.tiff”	0	0.0727	0.3228	0.3171
“NM.NE1.92.tiff”	“NM.NE2.93.tiff”	0.2190	0.1375	0.2455	0.0567
“TM.NE1.177.tiff”	“TM.NE2.178.tiff”	0.4786	0.2083	0	0.1165
“UY.NE1.134.tiff”	“UY.NE2.135.tiff”	0.0739	0.6275	0.0579	0
“YM.NE1.49.tiff”	“YM.NE2.50.tiff”	0.6140	0.3572	0.4646	0.2479
“KA.NE1.26.tiff”	“KA.FE1.45.tiff”	0.6236	0.4146	1	0.8547
“KL.NE1.155.tiff”	“KL.FE1.174.tiff”	0.3800	0.3575	0.2571	0.5339
“KR.NE1.71.tiff”	“KR.FE1.89.tiff”	0.2973	0.9484	0.3340	0.7739
“MK.NE1.113.tiff”	“MK.FE1.131.tiff”	0.8635	0.1968	0.5836	0.5554
“NA.NE1.199.tiff”	“NA.FE1.217.tiff”	0.5051	0.2975	0.3681	0.1928
“NM.NE1.92.tiff”	“NM.FE1.110.tiff”	0.4667	0.7527	0.4218	0.3042
“TM.NE1.177.tiff”	“TM.FE1.196.tiff”	0.4679	0.4498	0.2850	0.3855
“UY.NE1.134.tiff”	“UY.FE1.152.tiff”	0.3801	0.2518	0.5761	0.1759
“YM.NE1.49.tiff”	“YM.FE1.67.tiff”	0.9081	0.8145	0.3150	0.6609
“KA.NE1.26.tiff”	“KA.SA1.33.tiff”	0.2854	0.1446	0.4193	0.3417
“KL.NE1.155.tiff”	“KL.SA1.161.tiff”	0.6295	0.3094	0.2599	0.3069
“KR.NE1.71.tiff”	“KR.SA1.77.tiff”	0.0613	0.2571	0.2448	0.3376
“MK.NE1.113.tiff”	“MK.SA1.119.tiff”	0.5585	0.3425	0.1586	0.1066
“NA.NE1.199.tiff”	“NA.SA1.205.tiff”	0.5611	0.3299	0.8044	0.6126
“NM.NE1.92.tiff”	“NM.SA1.98.tiff”	0.4781	0.0592	0.3399	0.6279
“TM.NE1.177.tiff”	“TM.SA1.184.tiff”	0.4758	0.1619	0.3555	0.3232
“UY.NE1.134.tiff”	“UY.SA1.140.tiff”	0.4446	0.4311	0.6208	0.5445
“YM.NE1.49.tiff”	“YM.SA1.55.tiff”	0.7690	0.6708	0.2567	0.6386
“KA.NE1.26.tiff”	“KA.AN1.39.tiff”	1	0.8578	0.6997	0.8151
“KL.NE1.155.tiff”	“KL.AN1.167.tiff”	0.2655	0.9143	0.0897	0.3829
“KR.NE1.71.tiff”	“KR.AN1.83.tiff”	0.3556	0.8457	0.4309	0.5282
“MK.NE1.113.tiff”	“MK.AN1.125.tiff”	0.8553	1	0.4964	0.3620
“NA.NE1.199.tiff”	“NA.AN1.211.tiff”	0.3655	0.5587	0.3790	0.3967
“NM.NE1.92.tiff”	“NM.AN1.104.tiff”	0.1288	0.8658	0.6547	0.2036
“TM.NE1.177.tiff”	“TM.AN1.190.tiff”	0.4757	0.2833	0.5553	0.5753
“UY.NE1.134.tiff”	“UY.AN1.146.tiff”	0.1944	0.7201	0.4999	0.5464
“YM.NE1.49.tiff”	“YM.AN1.61.tiff”	0.7610	0.9294	0.5621	1

4.9 Dataset Clustering

The first fuzzy technique used in application is FCM clustering. The dataset used in the application does not contain information about the stress levels of individuals. In other words, the output values of the systems developed in this thesis are not yet known. By contrast, the system needs both input and output values for the training of the ANFIS model. Therefore, before the system was built, using the values in Table 4.2, it was deemed appropriate to divide the dataset into four clusters, which will also represent the stress levels in the future, using the FCM cluster method.

When performing the FCM clustering on the dataset, first of all, the data must be normalized. However, this step was already provided as the data was normalized in Section 4.8. In the next step, the centers of the clusters from which the data will be classified are determined. Found clusters centers are given in Table 4.3.

Table 4.3 The centers of clusters

Cluster Name	**Variables**			
	EyePair	Mouth	Forehead	Eyebrow
Cluster 1	0.1838	0.2069	0.2527	0.1835
Cluster 2	0.8145	0.7907	0.5095	0.7214
Cluster 3	0.3496	0.7287	0.4273	0.4608
Cluster 4	0.4981	0.3039	0.3892	0.3568

Each row in Table 4.2 is actually an element of the dataset on which is tried to be clustered using the FCM algorithm. In other words, each row is a data. After the centers of the clusters were found, the membership values of each element expressing the degree of belonging to the clusters were calculated.

Calculating the membership values is very important in inferring which cluster the data belongs to. Which cluster the data belongs to is decided according to the maximum value of the membership degree. For example, when the first row in Table 4.4 is examined, it can be clearly observed that 0.6468, 0.0409, 0.0754 and 0.2369 are the degrees of membership in Cluster 1, Cluster 2, Cluster 3, Cluster 4, respectively. Since the maximum of the values is 0.6468, the data belongs to Cluster 1. Data were assigned to one of four groups, each representing a stress level, using the same method. The last column of Table 4.4 contains the cluster result to which each data belongs.

Table 4.4 Membership values and FCM clustering results

Images		**Membership Values**				**Results**
Neutral Image	**Sample Image**	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**FCM cluster**
“KA.NE1.26.tiff”	“KA.NE2.27.tiff”	0.6468	0.0409	0.0754	0.2369	1
“KL.NE1.155.tiff”	“KL.NE2.156.tiff”	0.9002	0.0108	0.0301	0.0589	1
“KR.NE1.71.tiff”	“KR.NE2.72.tiff”	0.8217	0.0216	0.0607	0.0961	1
“MK.NE1.113.tiff”	“MK.NE2.114.tiff”	0.6854	0.0401	0.0874	0.1871	1
“NA.NE1.199.tiff”	“NA.NE2.200.tiff”	0.7021	0.0380	0.0896	0.1702	1
“NM.NE1.92.tiff”	“NM.NE2.93.tiff”	0.8628	0.0148	0.0340	0.0885	1
“TM.NE1.177.tiff”	“TM.NE2.178.tiff”	0.4723	0.0680	0.1246	0.3351	1
“UY.NE1.134.tiff”	“UY.NE2.135.tiff”	0.4350	0.0872	0.2605	0.2173	1
“YM.NE1.49.tiff”	“YM.NE2.50.tiff”	0.0984	0.0556	0.0992	0.7469	4
“KA.NE1.26.tiff”	“KA.FE1.45.tiff”	0.1304	0.3722	0.2472	0.2502	2
“KL.NE1.155.tiff”	“KL.FE1.174.tiff”	0.1904	0.0737	0.2024	0.5335	4
“KR.NE1.71.tiff”	“KR.FE1.89.tiff”	0.0902	0.2540	0.5250	0.1308	3
“MK.NE1.113.tiff”	“MK.FE1.131.tiff”	0.1380	0.2524	0.1688	0.4409	4
“NA.NE1.199.tiff”	“NA.FE1.217.tiff”	0.1617	0.0316	0.0707	0.7359	4
“NM.NE1.92.tiff”	“NM.FE1.110.tiff”	0.0655	0.0907	0.7101	0.1337	3
“TM.NE1.177.tiff”	“TM.FE1.196.tiff”	0.1197	0.0544	0.1847	0.6411	4
“UY.NE1.134.tiff”	“UY.FE1.152.tiff”	0.2988	0.0555	0.1308	0.5149	4
“YM.NE1.49.tiff”	“YM.FE1.67.tiff”	0.0353	0.7824	0.1068	0.0754	2
“KA.NE1.26.tiff”	“KA.SA1.33.tiff”	0.4546	0.0359	0.0847	0.4248	1
“KL.NE1.155.tiff”	“KL.SA1.161.tiff”	0.1201	0.0539	0.0881	0.7380	4
“KR.NE1.71.tiff”	“KR.SA1.77.tiff”	0.7416	0.0287	0.0866	0.1431	1
“MK.NE1.113.tiff”	“MK.SA1.119.tiff”	0.3219	0.0728	0.1431	0.4621	4
“NA.NE1.199.tiff”	“NA.SA1.205.tiff”	0.1401	0.2411	0.2453	0.3734	4

Table 4.4 Continues

“NM.NE1.92.tiff”	“NM.SA1.98.tiff”	0.2281	0.1042	0.1429	0.5248	4
“TM.NE1.177.tiff”	“TM.SA1.184.tiff”	0.1511	0.0256	0.0491	0.7741	4
“UY.NE1.134.tiff”	“UY.SA1.140.tiff”	0.1176	0.1458	0.3180	0.4186	4
“YM.NE1.49.tiff”	“YM.SA1.55.tiff”	0.0647	0.5670	0.2061	0.1622	2
“KA.NE1.26.tiff”	“KA.AN1.39.tiff”	0.0389	0.7826	0.1027	0.0759	2
“KL.NE1.155.tiff”	“KL.AN1.167.tiff”	0.1515	0.1430	0.5376	0.1680	3
“KR.NE1.71.tiff”	“KR.AN1.83.tiff”	0.0269	0.0615	0.8657	0.0459	3
“MK.NE1.113.tiff”	“MK.AN1.125.tiff”	0.0770	0.5160	0.2624	0.1446	2
“NA.NE1.199.tiff”	“NA.AN1.211.tiff”	0.0971	0.0561	0.5953	0.2515	3
“NM.NE1.92.tiff”	“NM.AN1.104.tiff”	0.1636	0.1282	0.5287	0.1795	3
“TM.NE1.177.tiff”	“TM.AN1.190.tiff”	0.1309	0.112	0.1805	0.5773	4
“UY.NE1.134.tiff”	“UY.AN1.146.tiff”	0.0627	0.0681	0.7780	0.0912	3
“YM.NE1.49.tiff”	“YM.AN1.61.tiff”	0.0461	0.7276	0.1438	0.0825	2

4.10 ANFIS Model

At this stage of the application, the stages of the ANFIS model developed to provide information to the FIS model developed to assess the stress level within the scope of this thesis are explained. All operations carried out up to this stage provided the system with the data needed for the establishment of ANFIS and FIS models. However, the rules that produces in ANFIS model are needed to generate FIS model. Therefore, the ANFIS model was first built.

For this thesis, the application of MATLAB called “Neuro-Fuzzy Designer”, which is used to develop the ANFIS model, was preferred. The user can access this application either from the application section in MATLAB Toolstrip or by using the *neuroFuzzyDesigner* command. The window that opens regardless of which method is used is given in Figure 4.21.

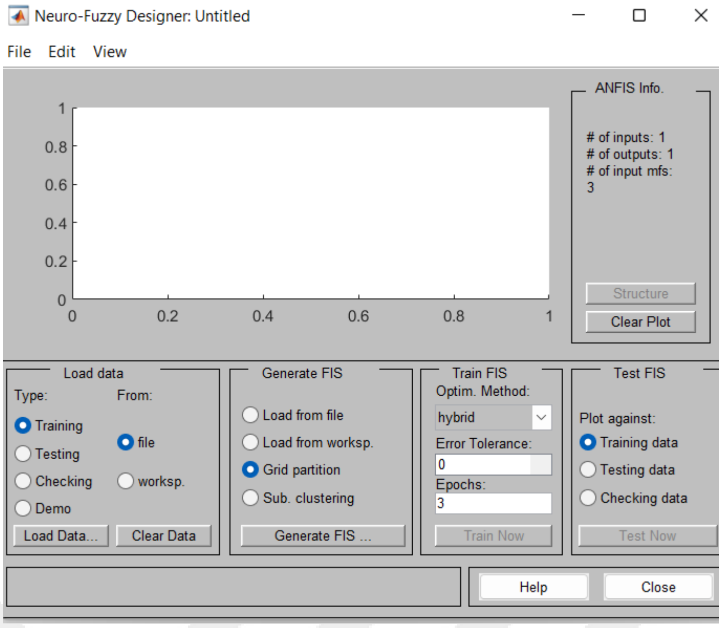


Figure 4.21 Neuro- Fuzzy Designer Application

The first step in training the ANFIS model is to divide the dataset into three groups: testing, training and checking. All input and output information required by the ANFIS model is given in Table 4.4. Therefore, the data required by the model were obtained by editing this table. First of all, since the system works with numerical data, all the data between the third and seventh columns of the table are transferred to an other table. Then, the percentages deemed appropriate for the separation of values were determined as 80% for training, 20% for testing, and 10% for checking. After separating the 36 data used for the model according to the determined percentages, they were converted from the table to the matrix. Then, the data was loaded into the system using the "Load Data" section in Figure 4.21.

In the second step, the number of input, output and membership functions of the model were determined. ANFIS model needs both input and output values due to its structure. The values obtained by comparing the images of the individual are inputs for the model. As detailed in Section 4.5, 4 main regions were selected for comparison of the images. Since the model uses the values from these regions, the input number of the model has been determined as four in parallel with this.

The ANFIS model is trained using the relationship between the known outputs of the data used. Therefore, the user has to give the outputs to the system before the training starts.

Another thing whose number needs to be determined is the membership function. In this thesis, it was deemed appropriate to divide the amount of change obtained from the images of individuals into four groups as “None”, “Low”, “Moderate”, and “High”. This group number also means that each input value has four membership functions.

As a result, the model consists of four inputs consisting of “Eyepair”, “Mouth”, “Forehead”, “Eyebrow”, and one output. In addition, each input has four membership functions.

The model automatically detects the input and output numbers from the training dataset loaded into the system. Therefore, numbers are not specified for input and output. However, the number of membership functions is determined by the user. The “Generate FIS” section in Figure 4.21 is used for the addition of these numbers. In addition, the type of membership functions is determined from this section. In the developed model, the type of membership functions are selected as “trimf” for inputs and “constant” for output.

The third step is to train the model. The number of epochs is decided before the model is trained. The epoch number for this model is determined as 100.

After the training is complete, the system is ready to test the data. Before testing the data, it is important to examine the fuzzy rules and ranges determined by the model during training, to understand the structure of the model. The ANFIS model determines itself the ranges needed by the system and the fuzzy rules used in finding the outputs. Some of the rules used by the model are given in Figure 4.22.

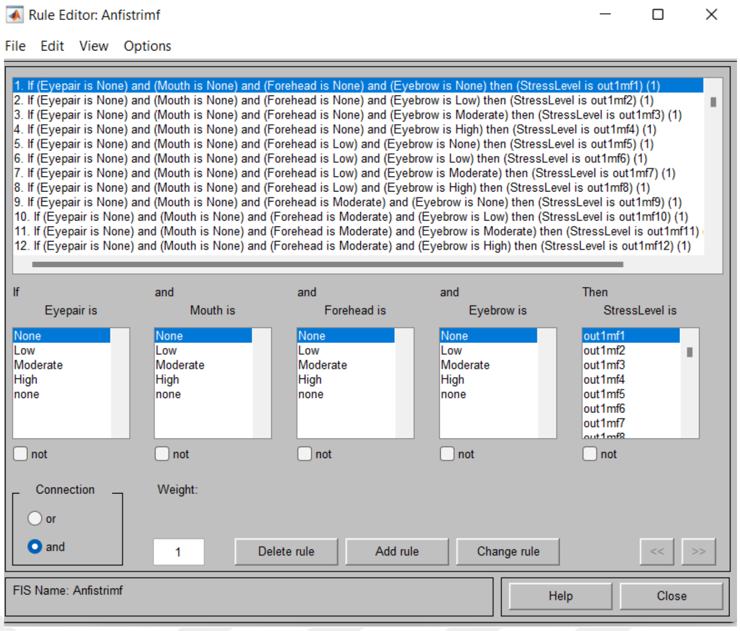


Figure 4.22 ANFIS rule editor

Although 12 of them are given in Figure 4.22, a total of 256 rules were generated during the training of the model. In addition the “Rule editor” allows the user to delete the rule, add a new rule or change the existing rule. In Figure 4.23, the structure of the system consisting of 4 inputs, 1 output and 256 rules is given.

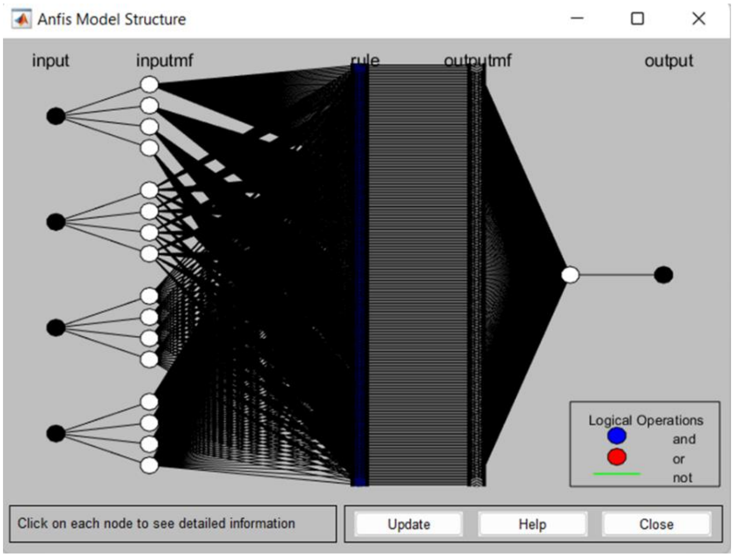


Figure 4.23 The structure of ANFIS model

After the structure of the generated model was examined in detail, the data was tested. Neuro-Fuzzy Designer displays the training, testing, and checking data and outputs of the system in the plot. Figure 4.24 contains plots of training, testing, checking data, and outputs.

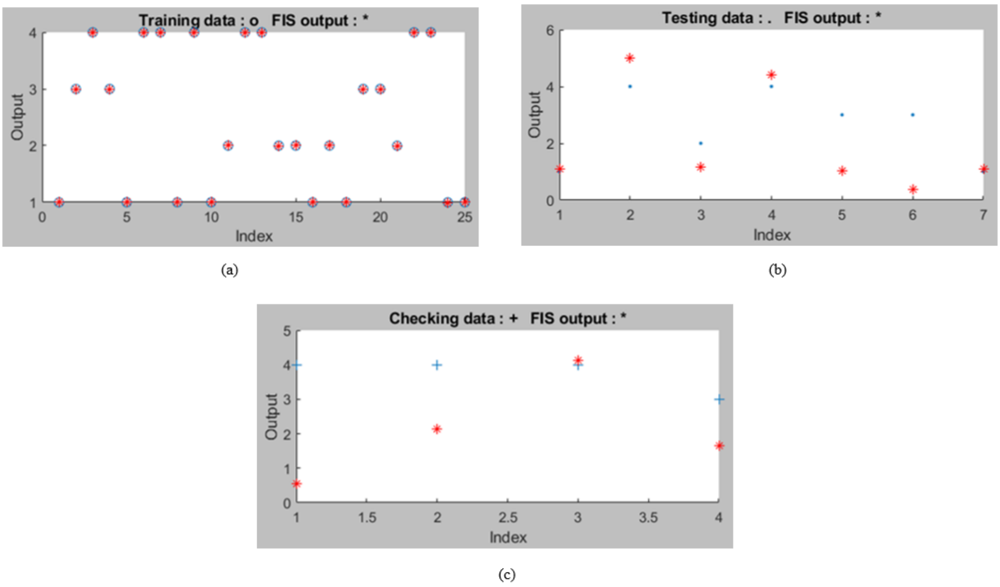


Figure 4.24 The output plots of inputs

Figure 4.24 shows the data and output values used in the training of the model in the graph (a), the testing data and output values in the graph (b), and the checking data and output values in the graph (c). The blue icons represent the loading data, and the red colored icons represent the output value found by the model.

Although the approximate values of the outputs are estimated from the graphics, their exact values can be evaluated with the command line. The outputs of 36 inputs were calculated at once, and the results are given in Table 4.5.

Table 4.5 The output results of ANFIS model

Neutral Image	Sample Image	The output results of ANFIS model
“KA.NE1.26.tiff”	“KA.NE2.27.tiff”	1.0000
“KL.NE1.155.tiff”	“KL.NE2.156.tiff”	1.0000
“KR.NE1.71.tiff”	“KR.NE2.72.tiff”	1.0000
“MK.NE1.113.tiff”	“MK.NE2.114.tiff”	1.0000
“NA.NE1.199.tiff”	“NA.NE2.200.tiff”	1.0858

Table 4.5 Continues

“NM.NE1.92.tiff”	“NM.NE2.93.tiff”	1.0856
“TM.NE1.177.tiff”	“TM.NE2.178.tiff”	1.0000
“UY.NE1.134.tiff”	“UY.NE2.135.tiff”	1.0000
“YM.NE1.49.tiff”	“YM.NE2.50.tiff”	4.0000
“KA.NE1.26.tiff”	“KA.FE1.45.tiff”	2.0000
“KL.NE1.155.tiff”	“KL.FE1.174.tiff”	0.5439
“KR.NE1.71.tiff”	“KR.FE1.89.tiff”	3.0000
“MK.NE1.113.tiff”	“MK.FE1.131.tiff”	4.0000
“NA.NE1.199.tiff”	“NA.FE1.217.tiff”	4.0000
“NM.NE1.92.tiff”	“NM.FE1.110.tiff”	1.0250
“TM.NE1.177.tiff”	“TM.FE1.196.tiff”	2.1260
“UY.NE1.134.tiff”	“UY.FE1.152.tiff”	4.0000
“YM.NE1.49.tiff”	“YM.FE1.67.tiff”	2.0000
“KA.NE1.26.tiff”	“KA.SA1.33.tiff”	1.0000
“KL.NE1.155.tiff”	“KL.SA1.161.tiff”	5.0140
“KR.NE1.71.tiff”	“KR.SA1.77.tiff”	1.0000
“MK.NE1.113.tiff”	“MK.SA1.119.tiff”	4.0000
“NA.NE1.199.tiff”	“NA.SA1.205.tiff”	4.1236
“NM.NE1.92.tiff”	“NM.SA1.98.tiff”	4.0000
“TM.NE1.177.tiff”	“TM.SA1.184.tiff”	4.0000
“UY.NE1.134.tiff”	“UY.SA1.140.tiff”	4.0000
“YM.NE1.49.tiff”	“YM.SA1.55.tiff”	1.1663
“KA.NE1.26.tiff”	“KA.AN1.39.tiff”	2.0000
“KL.NE1.155.tiff”	“KL.AN1.167.tiff”	0.3734
“KR.NE1.71.tiff”	“KR.AN1.83.tiff”	3.0000
“MK.NE1.113.tiff”	“MK.AN1.125.tiff”	2.0000
“NA.NE1.199.tiff”	“NA.AN1.211.tiff”	1.6661
“NM.NE1.92.tiff”	“NM.AN1.104.tiff”	3.0000
“TM.NE1.177.tiff”	“TM.AN1.190.tiff”	4.4059
“UY.NE1.134.tiff”	“UY.AN1.146.tiff”	3.0000
“YM.NE1.49.tiff”	“YM.AN1.61.tiff”	2.0000

When the output values in Table 4.5 are examined, it is observed that the majority of the results are integers. However, the outputs contain decimals as well as integers. The purpose of the model is to examine the stress level under four groups and since it is known that the output values used in the model consist of four values determined by the FCM cluster, the output range is divided into four groups.

While determining the intervals of the groups, the threshold value determination method, which was used in the literature before, was used (Tuna, 2015). The ranges specified for the outputs of this model are assumed as [1, 1.1] representing Cluster 1, (1.1, 2.1] representing Cluster 2, (2.1, 3.1] representing Cluster 3, and (3.1, 4] representing Cluster 4. The output values in Table 4.5 have been examined considering these ranges. When Table 4.5 is examined, it is clear that the ANFIS output value of the images in Figure 4.4 is 2.0000. According to the assumed range values, this data belongs to Cluster 2. This result is the same as the result found by the FCM algorithm in Table 4.4. As a result, it can be said that the ANFIS model makes a correct inference for this data. Using the same method, the output values of all inputs in the dataset were interpreted and the cluster they belonged to was determined.

4.11 Determination of The Range

Determining the range is the last step before generating the proposed FIS model for determining the stress level. The model developed in this thesis aims to divide the stress level of individuals into four different levels, as explained in Section 4.1. Likewise, the membership function number of the inputs in the FIS model used to determine these levels was determined as four.

The ranges determined in this step represent both the amount of change in the eyepair, mouth, forehead and eyebrow variables, and the required ranges for the membership functions described in detail in Section 4.12. The ranges of membership functions of the inputs used in the FIS model are based on the amount of change that occurs in the variables. Therefore, the meanings that the intervals represent are not different from each other, in fact. It was deemed appropriate to scale the amount of change in eyepair, mouth, forehead and eyebrow variables as “None”, “Low”, “Moderate” and “High” to be used as ranges of membership functions.

While determining the ranges, the quantiles of the data given in Table 4.2 were found. The quantiles finding process was carried out in two stages. Firstly, the data were divided into two groups, the data obtained using neutral-neutral (pose 2) images (first nine lines), and the others (lines 10-36). While making this distinction, it is assumed that individuals are stress-free in their neutral state, based on the labeling in the dataset. Therefore, the neutral-neutral (pose 2) data in the first nine rows of Table 4.2 gave the range of the level at which the change was “None”. The smallest value and the largest value of the neutral-neutral (pose 2) data represent the minimum and maximum values for the range, respectively, to be found separately for each variable.

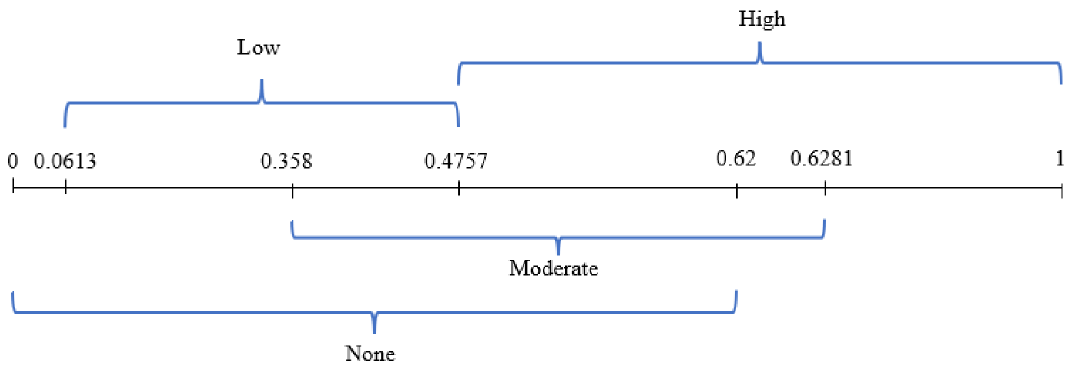


Figure 4.25 The ranges of eyepair

In the next step, the minimum, lower quartile, median and upper quartile values of the array containing all the data obtained from the images of fear, anger and sadness were found. In Figure 4.25, the division scheme of the eyepair variable into ranges is given. In this scheme, 0 represents the minimum value of the neutral-neutral (pose 2) data, and 0.62 the maximum value. Thus, the range of the “None” class was found to be [0, 0.62]. The minimum, lower quartile, median and upper quartile values of other data were found to be 0.0613, 0.358, 0.4757, and 0.6281, respectively. Using these values, the range is divided into three classes as “Low”, “Moderate” and “High”. The ranges of other variables were determined by the same method. Thus, the required ranges for the FIS model were obtained.

4.12 FIS Model

The last fuzzy technique used for stress assessment is FIS. Although FIS is similar to the ANFIS model developed in Section 4.10, they differ from each other in basic points such as the application used, ranges and rules entry. At this section, the development stages of the FIS model are explained in detail.

"Fuzzy Logic Designer" application of MATLAB was used while building the FIS model. The application, which is located in the "Control System Design and Analysis" section of the applications section on Toolstrip, can also be accessed using the *fuzzy* and *fuzzyLogicDesigner* commands.

Fuzzy Logic Toolbox supports two types of fuzzy inference systems. Mamdani type of the fuzzy inference system is chosen for this study. After the application is displayed, every information needed for the generation of the model must be entered by the user. First, input and output variables must be added into the system. Just like in the ANFIS model, the difference between the images of the individual is used for the input values of Mamdani FIS. This difference was obtained using the four facial regions: "Eyepair", "Mouth", "Forehead", "Eyebrow" described in Section 4.5. For this reason, the system contains four inputs with the same name. The system aims to find the stress level of the individual using these inputs. Therefore, the system has only one output named "Stress Level".

The second step needed to create the model is the ranges of the input and output variables. The difference values calculated from the images are normalized in Section 4.8. In this way, it is known that all the values of the inputs are included in the range of [0,1]. Therefore, the range of each input is added as [0,1]. Output range is entered as [1,4]. Because stress levels of individuals consist of four levels. All values determined so far have been added to the Fuzzy Logic Designer application and are given in Figure 4.26.

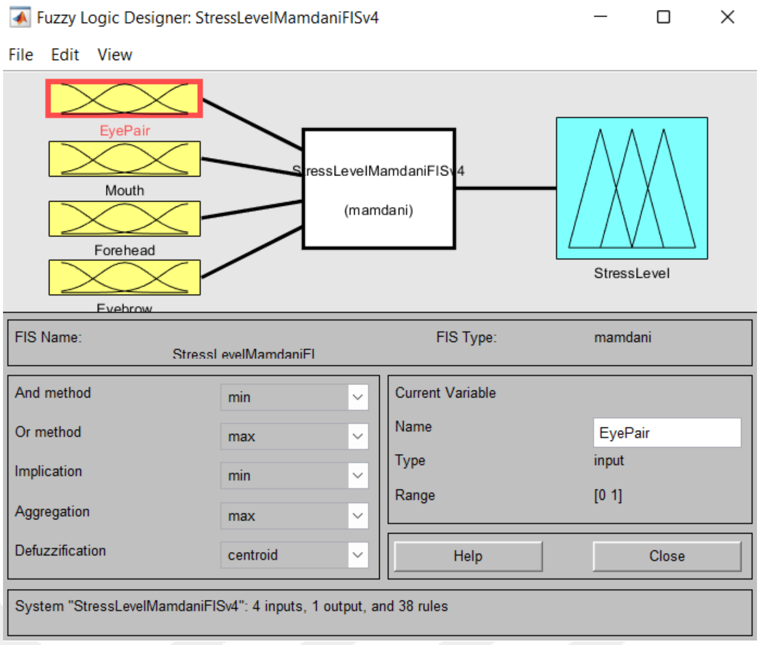
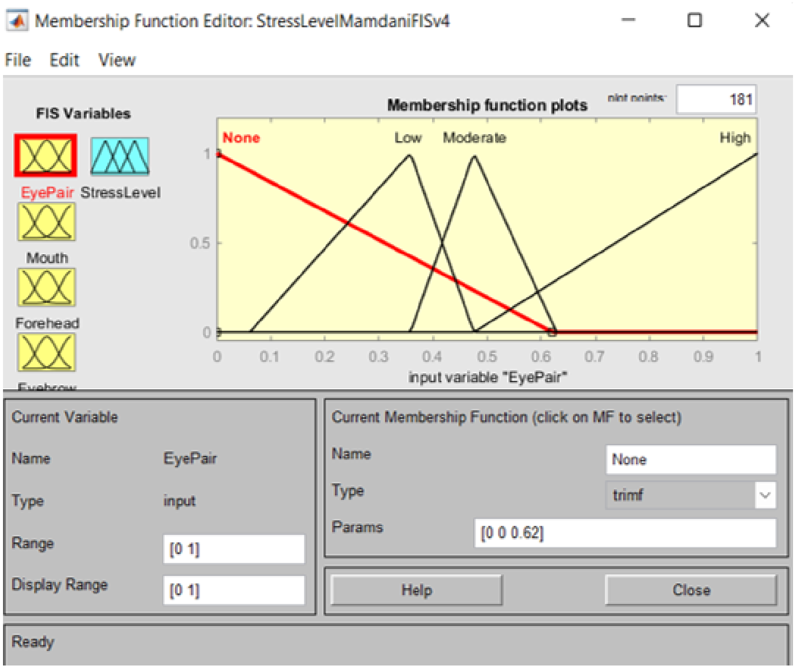


Figure 4.26 Fuzzy Logic Designer application

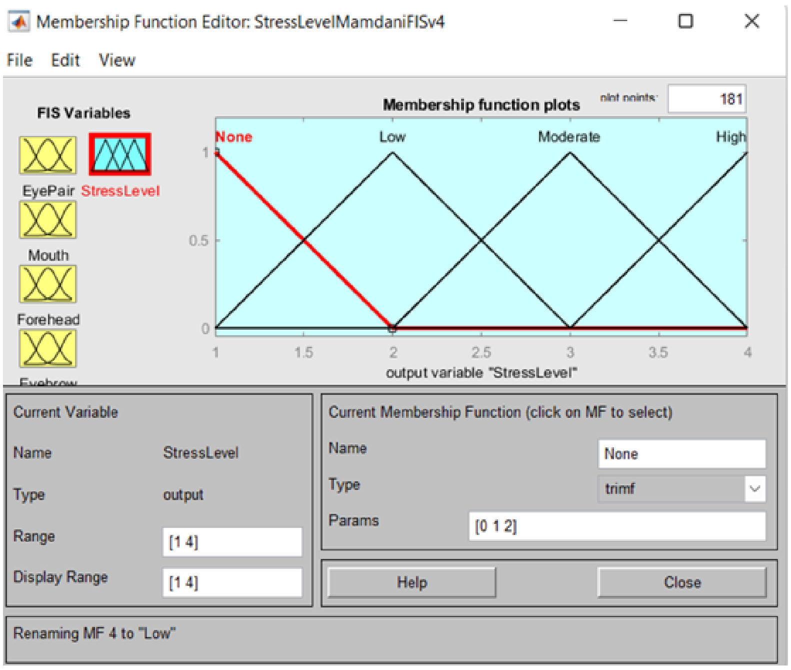
The next step is to determine the number and numerical parameters of membership functions of the inputs and outputs. The Membership Function Editor is the tool that display and edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system. The all number, names and numerical parameters of membership functions add using Membership Function Editor.

In this model, four membership functions of each input are used. The numerical parameters of the membership functions actually refer to the ranges detected in Section 4.11. Therefore, the method used to find the numerical parameters of membership functions is detailed in Section 4.11. The determination of the intervals depends on the magnitude of the difference between the two images, as explained earlier. Moreover, the names and numerical parameters values of the membership functions of the Eyepair input are also given. The graph (a) in Figure 4.27 includes the membership functions and their parameters of this input.

The FIS model does not need to know the output information of the inputs beforehand. Instead, the numbers of membership functions and numerical parameters must be entered into the system. Since the stress level of the images was desired to be divided into four levels, four membership functions were determined for the output, bearing the names of these levels ("None", "Low", "Moderate", "High"). The graph (b) in Figure 4.27 includes the membership functions and parameters of the output.



(a)



(b)

Figure 4.27 The Membership Function Editor

The most important tool that defines the behavior of the system is the list of rules added to the system. While creating the rule for the FIS model, the results of the FCM algorithm in Table 4.4 and the rules obtained as a result of the training of the ANFIS model were taken as reference. Unlike the ANFIS model, no maximum number of rules has been added to the system. The maximum number of rules that can be added to an FIS model with N inputs and M number of membership functions for each input is defined as

$$N^M. \tag{4.5}$$

The maximum number of rules that can be added to the FIS model developed within the scope of this thesis was found to be 256 using Equation 4.5. However, the most important criterion when adding a rule is not the excess of the number of rules, but the quality of the rules. In other words, considering the inputs, rules should be added to the system as needed. Therefore, the number of rules added when construct this FIS model is 38. Some of these rules are

- If (Eyebrow is Low) and (Mouth is None) and (Forehead is None) and (Eyebrow is None) then (Stress Level is None),
- If (Eyebrow is Low) and (Mouth is Low) and (Forehead is High) and (Eyebrow is None) then (Stress Level is Moderate),
- If (Eyebrow is High) and (Mouth is High) and (Forehead is Low) and (Eyebrow is High) then (Stress Level is High).

The model is ready for use with the enter of the rules into the system. The constructed FIS model was saved in the MATLAB workspace with the name “StressLevelMamdaniFISv4”. The results of the model for the inputs are given in Table 4.6.

Table 4.6 The output values of FIS model

Neutral Image	Sample Image	FIS Model Output Values	Stress Level
“KA.NE1.26.tiff”	“KA.NE2.27.tiff”	1.3541	None
“KL.NE1.155.tiff”	“KL.NE2.156.tiff”	1.3589	None
“KR.NE1.71.tiff”	“KR.NE2.72.tiff”	1.3686	None
“MK.NE1.113.tiff”	“MK.NE2.114.tiff”	1.3855	None
“NA.NE1.199.tiff”	“NA.NE2.200.tiff”	1.3404	None
“NM.NE1.92.tiff”	“NM.NE2.93.tiff”	1.3561	None
“TM.NE1.177.tiff”	“TM.NE2.178.tiff”	1.8494	Low
“UY.NE1.134.tiff”	“UY.NE2.135.tiff”	1.3780	None
“YM.NE1.49.tiff”	“YM.NE2.50.tiff”	1.9995	Low
“KA.NE1.26.tiff”	“KA.FE1.45.tiff”	3.5741	High
“KL.NE1.155.tiff”	“KL.FE1.174.tiff”	2.0231	Low
“KR.NE1.71.tiff”	“KR.FE1.89.tiff”	3.6226	High
“MK.NE1.113.tiff”	“MK.FE1.131.tiff”	3.5743	High
“NA.NE1.199.tiff”	“NA.FE1.217.tiff”	1.9622	Low
“NM.NE1.92.tiff”	“NM.FE1.110.tiff”	2.9134	Moderate
“TM.NE1.177.tiff”	“TM.FE1.196.tiff”	2.0179	Low
“UY.NE1.134.tiff”	“UY.FE1.152.tiff”	2.0001	Low
“YM.NE1.49.tiff”	“YM.FE1.67.tiff”	3.3755	Moderate
“KA.NE1.26.tiff”	“KA.SA1.33.tiff”	1.3410	None
“KL.NE1.155.tiff”	“KL.SA1.161.tiff”	2.0002	Low
“KR.NE1.71.tiff”	“KR.SA1.77.tiff”	1.3399	None
“MK.NE1.113.tiff”	“MK.SA1.119.tiff”	1.8833	Low
“NA.NE1.199.tiff”	“NA.SA1.205.tiff”	3.5468	High
“NM.NE1.92.tiff”	“NM.SA1.98.tiff”	2.9999	Moderate
“TM.NE1.177.tiff”	“TM.SA1.184.tiff”	1.9637	Low
“UY.NE1.134.tiff”	“UY.SA1.140.tiff”	3.5882	High
“YM.NE1.49.tiff”	“YM.SA1.55.tiff”	3.0647	Moderate
“KA.NE1.26.tiff”	“KA.AN1.39.tiff”	3.6156	High

Table 4.6 Continues

"KL.NE1.155.tiff"	"KL.AN1.167.tiff"	2.9999	Moderate
"KR.NE1.71.tiff"	"KR.AN1.83.tiff"	3.0825	Moderate
"MK.NE1.113.tiff"	"MK.AN1.125.tiff"	2.9998	Moderate
"NA.NE1.199.tiff"	"NA.AN1.211.tiff"	2.8591	Moderate
"NM.NE1.92.tiff"	"NM.AN1.104.tiff"	3.6003	High
"TM.NE1.177.tiff"	"TM.AN1.190.tiff"	3.5634	High
"UY.NE1.134.tiff"	"UY.AN1.146.tiff"	3.1257	Moderate
"YM.NE1.49.tiff"	"YM.AN1.61.tiff"	3.5660	High

The graph (b) in Figure 4.27 was used when the output values given in Table 4.6 are interpreted according to the stress level. While the horizontal axis in this graph gives the numerical parameters of the membership functions, the vertical axis gives the membership degrees of the data. Accordingly, since the membership degree of an output to the "None" class in the range of [0 1.5) is higher than the other classes, the stress level such an output is determined as "None". By the same method, values between (1.5, 2.5) are "Low", values between (2.5, 3.5) are "Moderate" and values between (3.5, 4] are "High".

As an example, the Mamdani FIS model results of the images given in Figure 4.4 are given in row 10 of Table 4.6. It is clear that the output value (3.5741) of the images is in the range of (3.5, 4). Therefore, the stress level of the individual in the sample image ("KA.FE1.45.tiff") was assessed as "High". Using the same method, all output values of the images in the dataset were examined and their stress levels were assessed. The stress levels of individuals, that assessed using the FIS model proposed in this study, are given in Table 4.6.

In the last stage of the application, the results of FIS model were evaluated based on the FCM cluster results. In fact, the techniques used in application are a link in the chain. If examined elaborately, the output values of the inputs must be known beforehand in order to generate the ANFIS model. In this application, these values were obtained through the FCM cluster. Rules to be added for the FIS model should have a reference. For this, the rules created by the ANFIS model as a result of a training were taken as a basis. Briefly, the FCM cluster supports the ANFIS model, and the ANFIS model supports the FIS model.

Although the ANFIS model provides information to the FIS model, it also provides output values that determine the stress levels of the data. The rules of the FIS model and the outputs it gives were carefully examined and a match was made between the clusters which outputs of the ANFIS model belong. As a result of this examination, it has been observed that the output classes of the ANFIS model, Cluster 1, Cluster 2, Cluster 3 and Cluster 4, correspond to the stress levels of “None”, “High”, “Moderate” and “Low” in the FIS model, respectively. Since the ANFIS model is based on the FCM cluster, the same match applies to the FCM cluster.

When the FCM cluster results in Table 4.4 and the FIS outputs in Table 4.6 were examined, it was determined that the FIS model assessed the stress level of 11 data incorrectly. The FIS model, which correctly predicted the stress level of 25 out of 36 data, made a correct assessed for approximately 70% of the dataset.

CHAPTER FIVE
CONCLUSION AND FUTURE WORKS

Stress is a universal concept that concerns people of all ages, from young to old, and even all living things. Stress, which contains many emotions and is covered by many emotions, exists in every moment of human life. It is thought as the cause of many diseases and many problems in daily life. Stress can be considered as sometimes the cause and sometimes the result of situations that negatively affect human life as work inefficiency, exhaustion, headache, argue with a loved one, as well as situations that make people feel good as wedding, having a baby, graduation.

It is important to detect it in order to protect itself from the negative effects of stress, which is intertwined with human life, or to benefit from its existence. Many different methods such as biomedical methods, scales, facial expression have been used while determining the stress level. However, in this thesis, the most appropriate method has been determined as facial expression due to reasons such as time, instant observation, accessibility of the equipment used, and applicable to human life. Therefore, in this thesis, a model using images containing facial expressions has been proposed to assess the stress levels of individuals.

Literature review is very important in terms of structuring the application generated in the thesis on solid foundations. Therefore, firstly, many articles, books, master’s and doctoral theses on the concept of stress were examined. It has been observed that stress is the subject of technology fields such as artificial intelligence, machine learning, image processing, and neural network, as well as medical fields such as physiology and psychology.

For this study, which aims to assess the level of stress in the individual, it is inevitable to investigate many aspects of stress, from the first definition to its relationship with emotions. Because stress is at the center of study. In order to determine the stress level, it is necessary to know what stress is first. Thus, the etymology of the concept of stress, its definitions, the leading scientists who played a role in its development, its symptoms, sources and its relationship between emotions were examined and explained. As a result of these studies, the parts that stress is most associated with face were determined. Eyebrows, eyes, mouth and forehead were chosen as the variables of the application.

Different techniques used to determine the stress level were encountered while examining the literature. However, the characteristics of the target were also taken into account when choosing the techniques of the application. Although stress level can be measured with scales that are confirmed their reliabilities and validities, it actually depends on variables such as the individual's perception and age, time, and culture. An event that some people consider insignificant can be a cause of great distress for some people. Stress does not have a clear distinction like black and white. In other words, stress is actually a fuzzy concept. For this reason, the most suitable technique for assessment the stress level can be fuzzy technique.

Fuzzy technique is another concept at the center of the study. Since fuzzy techniques are used especially during the development process of the application, it is very important to know their structures, features and algorithms. Therefore, the concept of fuzzy logic, which is the basis of fuzzy techniques, is included in the thesis. FCM, ANFIS and FIS models used in the application were explained in detail.

In the light of all the information obtained, an application was generated that assess the stress levels of individuals by using their images. In the application, based on the relationships between stress and emotions, the difference between the neutral state of the individual, which is considered stress-free, and the photos of fear, angry and sad, where the presence of stress is sure, was used. In order to find the difference values, the associated facial regions were obtained using image processing.

The dataset is divided into four clusters with FCM clustering because of the photos in the dataset are not labeled according to the stress levels of the individuals and reach the outputs required for ANFIS, which is one of the techniques of the application. A list of rules to be used in FIS was generated using ANFIS model. Then the model was established and the stress level was determined for each individual. Based on the clustering results, it was concluded that the generated FIS model was 70% successful.

Some results were obtained when the relationship between the stress levels determined by the FIS model and emotions of individuals was examined. In the neutral state images, the stress level of seven individuals was “None” and the stress level of two individuals was “Low”. Since it is known that the individual is stress-free, this result proves that the model successfully detects stress-free individuals. In the fear images, the stress level of four individuals was determined as “Low”, the stress level of two individuals as “Moderate”, and the stress level of three individuals as “High”. Stress level distribution in sad images of individuals is two “None”, three “Low”, two “Moderate” and two “High”. The stress level of five individuals was determined as “Modetare” and the stress level of four individuals as “High” from the images labeled as anger. According to these results, it was concluded that the stress of the individuals when they are angry is more than other emotions.

Some determinations have been made in order to contribute to the future studies of the application developed in this thesis study. The dataset used in the application of this thesis does not provide information about the stress levels of individuals. Using a dataset containing the stress levels of individuals can add a new dimension to the application. In addition, all of the images in the dataset belong to female participants. Developing the model using images of both male and female individuals may provide better results for all individuals regardless of gender. Another determination is related to the number of participants. More images can be obtained for the dataset by increasing the number of participants. The common purpose of all these determinations about the dataset is to optimize the proposed model in this thesis. Therefore, in future studies, it is aimed to develop a more comprehensive dataset containing many photographs belong both male and female participants labeled according to their stress levels.

Another determination made is aimed at supporting the stress level of individuals with a second method. In further studies, a scale to determine stress levels can be applied to individuals in the dataset, or preliminary information can be obtained according to the experiencing of individuals life events that are known to cause stress. In this way, the results obtained using self-reporting questionnaire methods can be used as a new input in the model.

It is foreseen that the model developed in this thesis will provide significant benefits in security problems such as bank robbery, passport control and fraud. Especially passport control at airports is a very important and stressful process in terms of security. Using the photo in the passport of the individual as a neutral pose and taking photos at certain intervals during the passport control process can provide all the necessary data for the model. Stress level can be determined without disturbing the passenger and without cause potential criminals to suspect thanks to the developed model. Thus, this thesis can contribute that the prevention of many possible crimes.

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