ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEFENSIVE SYSTEMS AGAINST UNMANNED VEHICLES

M. Sc. Thesis by
Alperen Ziya SÖKMEN

Department of Defense Technology

December, 2023

ANKARA

DEFENSIVE SYSTEMS AGAINST UNMANNED VEHICLES

A Thesis Submitted to

The Graduate School of Natural and Applied Sciences of

Ankara Yıldırım Beyazıt University

In Partial Fulfillment of the Requirements for the Degree of

Master of Department of Defense Technology

by

Alperen Ziya SÖKMEN

December, 2023

ANKARA

M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DEFENSIVE SYSTEMS AGAINST UNMANNED VEHICLES"** completed by **ALPEREN ZİYA SÖKMEN** under the supervision of **Prof. Dr. HÜSEYİN CANBOLAT** 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. Hüseyin CANBOLAT

Supervisor

Prof.Dr. Remzi YILDIRIM	Prof.Dr. Hasan Şakir BİLGE
Jury Member	Jury Member

Prof.Dr. Sadettin ORHAN

Director

Graduate School of Natural and Applied Sciences

ETHICAL DECLARATION

I hereby declare that, in this thesis which has been prepared in accordance with the Thesis Writing Manual of Graduate School of Natural and Applied Sciences,

- All data, information and documents are obtained in the framework of academic and ethical rules,
- All information, documents and assessments are presented in accordance with scientific ethics and morals,
- All the materials that have been utilized are fully cited and referenced,
- No change has been made on the utilized materials,
- All the works presented are original,

and in any contrary case of above statements, I accept to renounce all my legal rights.

Date: **Signature: …………………………………………..**

Name & Surname: Alperen Ziya SÖKMEN

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my advisor, Prof. Dr. Hüseyin CANBOLAT, for his invaluable support and encouragement during the course of my thesis. His guidance and expertise have been instrumental throughout my research and the process of composing this thesis. Additionally, I extend my heartfelt thanks to my beloved wife, Eda ÇETİN SÖKMEN, as well as my sisters Aybüke SÖKMEN, Sevinç ÇETİN, and Feyza İNAK for their unwavering assistance throughout this study.

2023, 08 December **Alperen Ziya SÖKMEN**

DEFENSIVE SYSTEMS AGAINST UNMANNED VEHICLES

ABSTRACT

Unmanned Aerial Vehicles are aerial vehicles that can be remotely controlled or act autonomously and that can be fitted with payloads. Today, UAVs are used in many different areas such as reconnaissance, surveillance, scientific research, firefighting, agriculture and forestry, communication, trade, bomb or missile air attacks and border protection-control. The fact that UAVs are preferred over airplanes are cost effective, have a low level of human factor in flight and can be used in areas with chemical, biological, radiological and nuclear contamination. Due to these advantages, it has been observed that the use of UAVs has increased. However, this increase has begun to be seen as a threat to countries; threfore, many countries have sought a defense system against UAVs. For this reason, in my thesis, general information about the UAVs used for military purposes, which is the subject of the study, was given, the methods of neutralizing the UAVs used for offensive purposes and the defense systems used against them were examined.

In the conclusion of all the analyses, in addition to Defense Mechanisms against existing UAVs, the use of Kamikaze Drones has been recommended. The reasons for proposing the use of Kamikaze Drones have been elucidated. Their advantages, such as enabling focused and proportional use of force, providing a more precise and customizable approach, and the ability to be deployed more swiftly, contribute to the recommendation for the use of Kamikaze Drones. It is emphasized that both Air Defense Systems and the use of Kamikaze Drones should not be considered in isolation, but rather approached as a conceptual whole. The operational principle of the system has been explained through the formulation of an algorithm. In light of all this information, the utilization of Drones against threatening UAVs is considered to be a significant force multiplier. Looking at the conclusion, it is assessed that the threat posed by evolving UAV systems being used against nations will increase, underscoring the necessity to enhance defense systems against UAVs in this context.

Keywords: UAV, unmanned aerial vehicle, drone, classification, uav attacks, detecting, neutralizing, anti-drone system, anti-uav system, counter uav system

İNSANSIZ ARAÇLARINA KARŞI SAVUNMA SİSTEMLERİ

ÖZET

İnsansız Hava Aracı (İHA), uzaktan kontrol edilebilen veya otonom hareket eden, üzerine faydalı yükler takılabilen hava araçlarıdır. Günümüzde İHA; keşif, gözetleme, bilimsel araştırma, yangınla mücadele, ziraat ve ormancılık, haberleşme, ticaret, bomba veya füzeli hava atakları ve sınırların korunması-kontrolü gibi birçok farklı alanda kullanılmaktadır. İHA'ların uçaklara tercih edilmesinde uygun maliyetli olması, uçuştaki insan faktörünün az seviyede olması ve kimyasal, biyolojik, radyolojik ve nükleer kirlenme olan bölgelerde kullanılabilmesi etkin olmuştur. Bu avantajlarından dolayı İHA'ların kullanımının arttığı gözlemlenmiştir. Ancak bu artış ülkeler için tehdit olarak görülmeye başlamış ve bu nedenle de birçok ülke İHA'lara karşı savunma sistemi arayışına girmiştir. Bu sebeple tezimde çalışmaya konu olan askeri amaçlı kullanılan İHA'larla ilgili genel bilgilendirme yapılmış, saldırı amaçlı kullanılan İHA'ları etkisiz hale getirme yöntemleri ve onlara karşı kullanılan savunma sistemleri incelenmiştir.

Tüm incelemelerin sonucunda mevcut İHA'lara karşı Savunma Yöntemlerine ek olarak Kamikaze Dronların kullanımı önerilmiştir. Kamikaze Dronların kullanımı, önerme sebepleri açıklanmıştır. Hedefe odaklanmış ve ölçülü güç kullanımını mümkün kılması, daha hassas ve özelleştirilebilir yaklaşım sunması, daha hızlı bir şekilde kullanılabilme yeteneği gibi avantajlardan dolayı Kamikaze Dronların kullanımı önerilmiştir. Hava Savunma Sistemlerinin tek olarak ele alınamayacağı gibi Kamikaze Dron kullanımıda tek olarak ele alınmamış ve konsept olarak yaklaşılmıştır. Sistemin çalışma prensibi bir algoritma yazılarak anlatılmıştır. Tüm bu bilgiler ışığında tehdit olan İHA'lara karşı Kamikaze Dronların kullanımının büyük bir güç çarpanı olabileceği değerlendirilmektedir. Sonuca bakılacak olursa gelişen İHA sistemlerinin ülkelere karşı tehdit olarak kullanılmasının artacağı, bu kapsamda İHA'lara karşı kullanılan savunma sistemlerinin geliştirilmesinin gerekli olduğu değerlendirilmektedir.

Anahtar Kelimeler: İHA, insansız hava aracı, drone, sınıflandırma, iha saldırıları, tespit, etkisiz hale getirme, anti-drone sistemi, anti-iha sistemi, karşı iha sistemi

CONTENTS

NOMENCLATURE

Greek Letter Symbols

μ	Mikro

Subscripts

cm	Centimeter
ft	Feet
g	Gramme
gHz	Gigahertz
h	Hour
kg	Kilogramme
km	Kilometer
kt	Knots
m	Meter
max	Maximum
mHz	Megahertz
mi	Mile
min	Minimum
min	Minute
mm	Milimeter
mph	Miles per hour
nm	Nautical mile

Acronyms

AGL	Above Ground Level
APV	Automatically Piloted Vehicle
AWACS	Airborne Warning and Control System
BBC	British Broadcasting Corporation
BLOS	Beyond-Line-Of-Sight
COMINT	Communications Intelligence
DOD	Department of Defense
ELINT	Electronic Intelligence
EO	Electro-Optic
GCS	Ground Control Station

GMTI	Ground Moving Target Indicator
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HALE	High Altitude Long Endurance
IAI	Israel Aerospace Industries
IFF	Identification Friend Or Foe
IN	INC
IR	Infra-Red
ISAR	Inverse Synthetic Aperture Radar
ISR	Intelligence Surveillance And Reconnaissance
LM	Loitering Missile
LOS	Line-Of-Sight
MALE	Medium Altitute Long Endurance
MSL	Mean Sea Level
NATO	North Atlantic Treaty Organization
PVC	Remotely Piloted Vehicle
RATO	Rocket-Assisted Take-Off
RCAT	Radio Controlled Serial Target
RF	Radio Frequency
ROA	Remotely Operated Aircraft
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communication
SAU	Special Air Unit One
SIGINT	Signal Intelligence
SPA	Special Purpose Aircraft
STANAG	Standardization Agreement
TAF	Turkish Armed Forces
TAI	Turkish Aerospace Industries
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Air Vehicle
UHF	Ultra High Frequency
UMA	Unmanned Aircraft

USA	United States of America
USAR	UAV SYSTEM Airworthiness Requirements
USSR	Union of Soviet Socialist Republics
UTA	Unmanned Tactical Aircraft
VLUAV	Vertical Landing Unmanned Aerial Vehicle
VTOL	Vertical Take-off and Landing
Wi-Fi	Wireless Fidelity

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

With the advancement of technology, numerous innovations have begun to affect human life. Among these innovations, the aviation sector has also taken its share, giving rise to Unmanned Aerial Vehicles (UAVs). Nowadays, UAVs can be preferred in various fields and for different purposes. Due to advantages such as cost-effectiveness, minimal human involvement during flight, and the ability to be used in areas with chemical, biological, radiological, and nuclear contamination, Unmanned Aerial Vehicles have become increasingly prevalent. Different definitions regarding UAVs are made by institutions, countries, and organizations. Generally, UAVs can be described as remotely controlled or autonomously operated aerial vehicles capable of carrying useful payloads. In this study, rather than focusing on a single definition, it is considered effective to examine various definitions to better comprehend the concept of UAV.

Parallel to the development of technology, UAV technology has evolved. The adventure that began with approximately 200 unmanned-piloted hot air balloons in the war between the Austro-Hungarian Empire and Venice in 1849, considered the world's first UAVs, continued with radio-controlled UAVs. It has gained capabilities such as automatic takeoff and landing, autonomous flight, and payload transportation, continuously acquiring new functionalities. Countries have actively followed these developments, using a variety of UAVs in their inventories. In our country, various UAVs have been utilized, and the first use of UAVs was observed with Banshee. Currently, TB2, Akıncı, and Aksungur UAVs, especially in the military field, continue to be employed.

As the number of UAVs increases, the need for classification has emerged. Just as UAVs do not have a single definition, different classifications have been made by institutions and countries according to specific needs, leading to diversity in the classification of UAVs. Generally, UAVs are classified based on features such as weight, altitude, and wing type.

In today's world, UAVs are used in various fields such as intelligence, surveillance, reconnaissance, air attacks, firefighting, and border protection. However, due to their advantages, terrorist organizations have also started to use UAVs, posing a threat to the security of countries. There is an observed increase in the use of UAVs by terrorist groups against our country. These attacks are on the rise. UAVs have actively been used in recent and ongoing wars, especially in the Russia-Ukraine and Nagorno-Karabakh conflicts. It is evident that UAVs now play a significant role in the military domain.

With the increasing threat of UAVs, countries have sought defense systems against UAVs, and various systems incorporating different methods have been produced. In this context, systems work in two steps: detection and neutralization, rendering UAVs ineffective. The first step is to detect the threatening UAV, which can be achieved through various methods such as radars, RF analysis, acoustic analysis, EO/IR cameras, and the human eye. Once detected, UAVs can be neutralized using methods such as lasers, weapons, manipulation, GPS jamming, RF jamming, nets, and birds.

In the study, due to occasional inadequacy of existing systems, a search for a new method has been initiated, and in this context, the use of Kamikaze Drones is proposed. The advantages of Kamikaze Drones, such as focusing on the target, enabling proportional use of force, offering a more precise and customizable approach, and the ability to be deployed more rapidly, have led to their preference. The use of Kamikaze Drones is not considered in isolation, just as air defense systems cannot be treated as a single entity. Therefore, for a better understanding of the detection sensors that can be used in the system, examples are provided. Following the examination of sensors, the working principle of the system is explained by writing an algorithm, supported by flowcharts. The pseudocode is analyzed step by step, covering all stages from detecting a UAV to rendering it ineffective. In light of this information, it is aimed to contribute to the literature by suggesting that the use of Kamikaze Drones against threatening UAVs could be a significant force multiplier and providing pseudo-code.

1.1 Aim of Thesis

Throughout history, countries have fought each other, and many tools and methods have been used to become the winner of the war. With the development of technology, UAVs have been added to these vehicles and as a result of their advantages, UAVs are now used for military purposes in the world. In this case, it brought with it the increasing threat of UAVs and made it necessary to provide general information about UAVs used for military purposes. At this point, it is aimed to research on the methods of neutralizing UAVs used for offensive purposes and the defense systems used against UAVs. In the literature, there are no studies and comprehensively published sources in this field. For this reason, in this thesis, it is aimed to collect UAV types, UAV attacks and defense systems in a single source. The overarching aim of this thesis is to explore new methods that could be employed against threatening UAVs. The use of Kamikaze Drones is proposed as a suitable new approach. The use of Kamikaze Drone has been considered as a concept throughout the approach. This capability has been investigated using sample sensors used in the Kamikaze Drone System. In addition to all these, in this thesis, a kamikaze drone counter-attack algorithm is developed and a pseudo code is written for this purpose. It is aimed to contribute to the literature by considering that the Kamikaze Drone can be integrated into Defense Systems with the pseudo-code written.

1.2 Hypothesis

In the study, researches were conducted on the defense systems used against UAVs used for military purposes and how to fight effectively. In this context, an answer has been sought to the question of how countries can effectively fight against UAVs. It has also been suggested to use Kamikaze Drones against threatened UAVs.

1.3 Thesis Overview

The thesis is categorized as follows:

Chapter 2, the definition, examples and classification of unmanned aerial vehicles are examined.

Chapter 3, UAV attacks are presented.

Chapter 4 examined UAV detection methods.

Chapter 5 suggested the use of kamikaze drone, developed an algorithm and written a pseudo code.

Chapter 6 concludes the thesis and gives insight about future work.

CHAPTER 2

UNMANNED AERIAL VEHICLES

In general, UAVs are aircraft that can be remotely controlled without any pilot/operator, can be fitted with useful loads such as sensors and cameras according to the task to be used, and can land automatically/manually at the end of the mission. There is no single definition of UAVs. Various definitions have been made by countries, groups, institutions, etc.

According to the definition made by the International Civil Aviation Organization (ICAO), unmanned aerial vehicles are autonomous, fully / remotely controlled vehicles that can fly without a pilot [1]. According to the definition made by Encyclopedia Britannica, a UAV is a military aircraft carrying sensors, target designators, offensive munitions or electronic transmitters designed to intercept or destroy enemy targets that can be controlled autonomously/remotely or using both [2].

According to the definition made by the Presidency of the Republic of Türkiye Presidency of Defence Industries, which was established to strengthen Türkiye's national defense industry and manage the procurement processes of military systems and technologies, UAVs A non-human powered aircraft that uses aerodynamic forces to generate lift, can fly by itself or can be remotely controlled, is expendable or reusable, and capable of carrying a lethal or non-lethal payload [3].

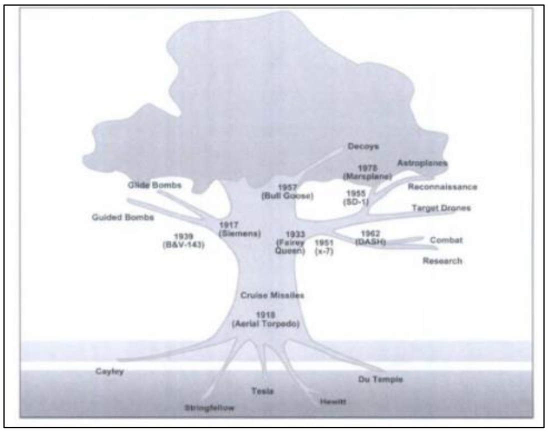


Figure 2.1 A family tree of unmanned aircraft [4].

It has been named with different names since it started to be used. The names he received from the day he was released to this day are listed chronologically in the Figure 2.2.

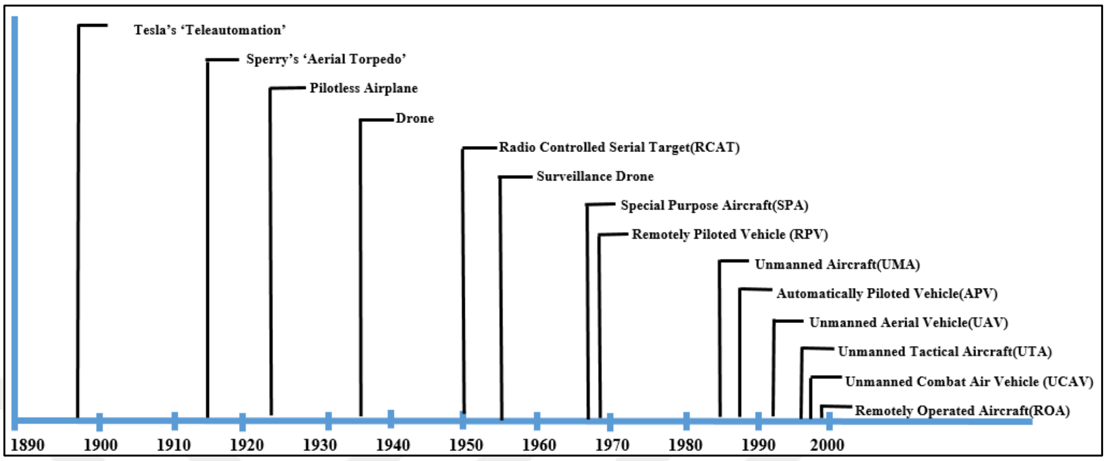


Figure 2.2 Chronology of names applied to robotic aircraft [4].

Considering the use of UAVs, it should not be considered as just a vehicle. In order to be able to use UAVs, they can be actively used together with systems such as aircraft, mission system and ground system. According to Karaağaç, the term "UAV systems" has recently been used for unmanned aerial platforms, which for a long time were only called "UAV". The reason is that the expression UAV only refers to the flying platform and does not cover the entire system [5].

2.1 Historical Development of UAVs

Considered to be the first UAV, it was developed by Charles Perley of New York in February 1863, two years after the Civil War began. The hot air balloon designed by Perley had a structure that could carry a basket of explosives connected to the timing mechanism. Thanks to the designed structure, wick ignition would be provided [6]. The biggest disadvantage of this vehicle, which brought a great change to its period after its use, was that it could not be controlled remotely.

After the uncontrollable balloon, the first radio-controlled airplane was produced in 1917. The system developed by Peter Cooper and Elmer A. Sperry of the USA carried a 300-pound bomb loaded on the plane for 80 km instead of the pilots of the Curtiss

N-9 trainer aircraft belonging to the US Navy. It has not been used much due to the difficulties in production and programming. In the same years, an UAV named Aerial Torpedo was developed by General Motors in 1910. It was going to the programmed point before the flight, leaving its wings and destroying it by diving into the target. This vehicle, which costs $400, was ordered by the USA, but was discontinued due to the end of the World War I [7]. In this vehicle, it was planned to be destroyed only by going to the target, and no return was planned.

After World War I, it was evaluated that UAVs could be effective in wars. In this context, the use of low-cost unmanned aircraft and fake targets was considered in order to distract the enemy anti-aircraft guns and to use their ammunition unnecessarily in the war.

The first reusable drone, Queen Bee, was used for training missions. The radio-controlled Queen Bee was able to ascend to an altitude of 17,000 feet and cover a maximum distance of 300 miles. It was actively used as a target aircraft until 1947 [8].

After the idea of using drones as decoys was generally accepted, the Radioplane Company (now known as Northrop Grumman) developed radio-controlled decoy planes called "Radioplanes" in the USA. The planes, which cost only $600, were able to land with a parachute. The aircraft, which were used to train anti-aircraft personnel rather than engage the enemy anti-aircraft guns in war, was also the first example of the use of target aircraft for training purposes [7].

During World War II, the Germans started producing flying bombs called V-1s, and the V-1s with their 900 kg bombs caused thousands of deaths. Thus, the V-1s became the first truly unmanned bombers. The USA produced SAU-1 (Special Air Unit One) UAVs as a precaution against V-1s. These UAVs went down in history as the first countermeasure UAVs [9].

In the 1960s, when jet technology developed, the sound barrier was overcome and the cold war intensified, the USA began serious studies to develop an invisible UAV. The jet-propelled Q-2C Firebee is the first semi-invisible UAV, and with its ability to land with a parachute, it became the ancestor of today's UAVs in this respect. But a more important feature of the Q-2C is that it was the first reconnaissance/observation fixed-wing conventional aircraft. Firebees have performed 34000 missions both day and night in Japan, Vietnam and Thailand, not only for observation and reconnaissance, but also for successful missions such as distribution of letters/advertisements for propaganda purposes, detection of Surface-to-Air Missiles(SAM), and helped to understand the operational importance of UAVs made a great contribution [10].

The U-2 observation plane belonging to the USA, which provides important information for an intelligence, was shot down in the USSR in 1960 and the pilot was captured [11]. After this unfortunate event for the USA, the work of unmanned aerial vehicles gained momentum. As a result, D-21 aircraft were produced by Lockheed Martin. This drone, which can reach the first high altitude and four times the speed of sound, is considered as an alternative to the U-2 aircraft [12].

In 1973, Israel entered this field. Israel, which bought 12 Firebees with a secret agreement from the USA, modified them and revealed Firebee 1241. Firebee 1241s, which played important roles in the Yom Kippur War, both served as reconnaissance and observation aircraft and were used as "Target Aircraft" to distract the Egyptian Air Defense systems. When all the 43 air defense missiles owned by Egypt were spent to shoot down these planes, the points turned to their side in Israel's war in Egypt, and this aspect positively affected Israel's success in the Yom Kippur War [10].

Israel used UAV which was effective by emitting dummy signals after Firebee 1241. In 1982, during the Galilee Peace Operation, Israeli warplanes flew over the Bekaa Valley to destroy SAM batteries. Before the flight, the UAVs collected the records of the Syrian radars by collecting their electronic frequencies. They then programmed the collected frequencies into anti-radiation missiles. When the attack with the planes started, as the drones emitting false signals were roaming the battlefield, the Syrian operators thought that the Israeli planes were attacking and launched the SAMs. As soon as the SAMs were exhausted, Israeli warplanes easily struck the area [13].

In the 1980s, he created the Scout, an Israeli Mini-UAV. The Scout, produced by IAI(Israel Aerospace Industries), could not be hit, thanks to its 3.96-meter wingspan and fiberglass fuselage, both to avoid being caught by the radar and its small size [14].

The Scout UAV, which proved its competence during the Lebanon War in 1982, contributed greatly to the success by destroying the SAM batteries at the very beginning of the war [15].

In the 1991 Gulf War, it was seen that drones could be used more effectively. Although there were very few UAVs on the battlefield, they took an active role in identifying many targets that could be hit. In 1998, UAVs in Kosovo determined targets for warplanes by flying low, taking the risk of being shot down. Targets marked by UAVs were destroyed by warplanes. With this application, in which the laser marking system is attached, it has begun to be considered to integrate the missile system into the UAVs [16].

The Predator B and Reaper UAVs were used for offensive purposes, and the Predator A UAV was given weapon capability. In the 2000s, it started to be used in roles such as mine detection and environmental protection, in addition to the purpose of attack. Figure 2.3 shows the ratio of UAVs to manned aircraft. With the increase in UAVs, this rate is increasing [17].

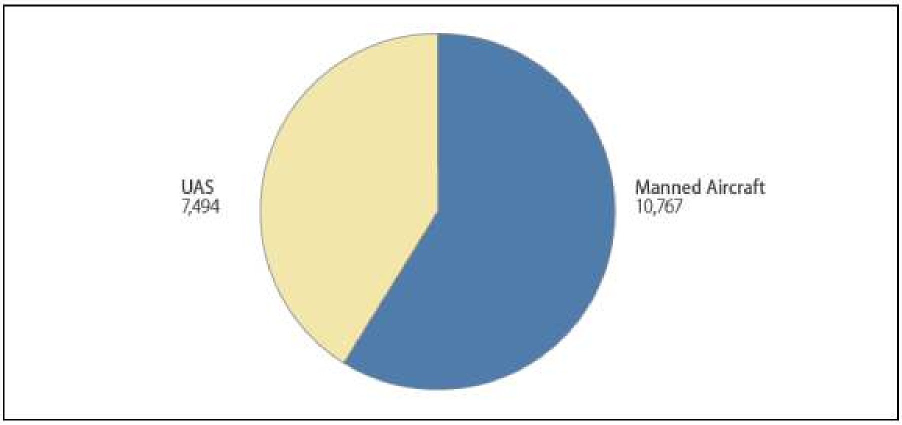


Figure 2.3 Manned Aircraft Inventory versus UAS Inventory [17].

In November 2002, thanks to the inclusion of the UAV in the operations, the killing of an al-Qaeda terrorist in Yemen took 5 minutes, once it was detected [18]. This attack was the first attack by a drone with a missile system. The development continued in this way and the production of advanced armed and unarmed UAVs of countries gained momentum.

The MQ-5B, MQ-1C, MQ-9 and Predator C UAVs have been developed by the USA and continue to be used in major operations. In addition, CAIG Wing Loong II and CH-5 by China, Yabhon United 40 by United Arab Emirates, MQ-9B SkyGuardian by England and Heron TP by Israel. In this context, UAVs such as Bayraktar TB2 and Anka, which were produced by Türkiye and changed the fate of many wars such as Ukraine and Karabag, and which were great power multipliers, will be examined in the next section.

2.2 UAV use in the world and in Türkiye

In this sub-title, the UAV samples used in the world were specified and the UAVs used by Türkiye were examined in order from past to present.

2.2.1 Major UAVs used in the world

In this sub-title, eight main UAV samples used in the world were examined.

2.2.1.1 Global Hawk

Figure 2.4 Global Hawk [19].

With a project that started in 1995, Global Hawk took its place in the world as a UAV with military use, Intelligence, Surveillance and Reconnaissance(ISR) capability and capable of flying at high altitudes.The Global Hawk has been used in overseas operations since 2001 [19]. Global Hawk, which has officially served in the Iraq and Afghanistan wars until now, also served in the disaster area after the earthquake in

Tohoku, Japan in 2011 and the typhoon in the Philippines in 2013. It was stated by a news source that Global Hawk carried out observation flights on the battle line during the Second Nagorno-Karabakh War in 2020. In addition, the US Air Force uses the Global Hawk UAVs stationed in Italy intensively in the Eastern Mediterranean, Black Sea and regions close to Ukraine. It is stated that Ukraine effectively uses the intelligence provided by Global Hawk and E-3 Sentry AWACS(Airborne Warning and Control System) aircraft against the Russian Army [20]. Its specifications are shown in Table 2.1.

Table 2.1 Specifications of Global Hawk [19].

Producing Company	Northrop Grumman
Country of Origin	United States
First Flight Year	1998
Wing Span	39,8 m
Length	14,5 m
Height	4,7 m
Speed Range	575 km/h
Service Ceiling	18.288 m
Endurance	Up to 34 h
Max Loaded Weight	14.628 kg

2.2.1.2 MQ-9 Reaper

Figure 2.5 MQ-9 Repear [21].

The MQ-9 Repear is used in important tasks such as ISR, combat search and rescue and close air support. Primarily used for intelligence gathering purposes, the MQ-9 is effectively used due to its significant navigation time, multi-mode communication package, wide range sensors and precision weapon features [21]. This UAV is actively used in the field by the USA. It is actively used in the fight against DAESH, especially in Syria and Iraq [22]. Its specifications are shown in Table 2.2.

Table 2.2 Specifications of MQ-9 Repear [21].

Producing Company	General Atomics Aeronautical Systems, Inc.
Country of Origin	United States
First Flight Year	2001
Wing Span	20,1 m
Length	11 m
Height	3,8 m
Speed Range	444 km/h
Service Ceiling	Up to 15.240 m
Endurance	Up to 14 h
Max Loaded Weight	4.760 kg

2.2.1.3 RQ-11B Raven

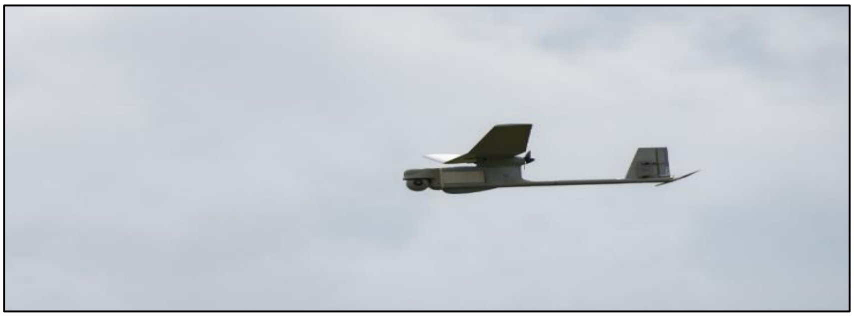


Figure 2.6 RQ-11B Raven [23].

Manufactured by AeroVironment, the RQ-11B is a man-packaged UAV that supplies real-time ISR and target information. It can move autonomously and non-autonomously in the air. This hand-launched UAV weighs less than 5 kg and has an endurance of 90 min. It was especially actively used in operations in Afghanistan [23]. Its specifications are shown in Table 2.3.

Table 2.3 Specifications of RQ-11B- Raven [23].

Producing Company	AeroVironment
Country of Origin	United States
First Flight Year	2001
Wing Span	1,37 m
Length	1 m
Operation Flight Altitude	150-1.000 ft (AGL)
Cruise Speed	41,84 km/h
Endurance	60-90 min
Operational Range	10 km
Power Plant	Direct Drive Electric Motor

2.2.1.4 Hermes 900

Figure 2.7 Hermes 900 [25].

Elbit Hermes 900 is a MALE(Medium Altitute Long Endurance) class UAV manufactured by Elbit Systems. Developed over Hermes 450. It has an endurance of over 30 hours with primarily reconnaissance, surveillance and communications roles. Currently, it has been exported to countries such as Brazil, Colombia, Chile [24]. Its specifications are shown in Table 2.4.

Table 2.4 Specifications of Hermes 900 [24].

Producing Company	Elbit Systems
Country of Origin	Israel
First Flight Year	2009
Wing Span	15,3 m
Max Payload	350 kg
Operation Flight Altitude	Up to 30.000 ft (AGL)
Takeoff Weight	1.180 kg
Endurance	36 h
Operational Range	2.500 km
Power Plant	Rotaz 914

2.2.1.5 HESA SHAHED-136

Figure 2.8 HESA SHAHED-136 [26].

SHADED-136 manufactured by HESA company; It is used in missions such as close air support, ISR and attack. While launching the rocket, Rocket-Assisted Take-Off is used and then it starts to move with the engine it owns. HESA is currently used by two countries [26]. These countries are Iran and Russia. It is claimed to have been used in the ongoing Russia-Ukraine War [27]. Its specifications are shown in Table 2.5.

Table 2.5 Specifications of HESA SHAHED 136 [28].

Producing Company	Iran Aircraft Manufacturing Company(HESA)
Country of Origin	Iran
First Flight Year	2021
Wing Span	2.5 m
Length	3.5 m
Takeoff Weight	200 kg
Speed	185 km/h
Operational Range	1.800-2.000 km
Engine	Md550 or 3W motors

2.2.1.6 Lancet Kamikaze Drones

Figure 2.9 Lancet loitering munitions [29].

The Lancet consists of reconnaissance, communication, navigation and attack components. Loitering munitions drone ARMY-2019 developed by ZALA Aero was exhibited at the military expo in Moscow. The Lancet can be controlled until the last moment of the flight, thanks to the TV orientation. The ammunition, which has an optical-electronic guidance unit, can be pre-programmed before flight [29]. It is claimed that it was actively used in the Russia-Ukraine War [30]. Its specifications are shown in Table 2.6.

Table 2.6 Specifications of Lancet Kamikaze [30].

<table>
<tr><td>Producing Company</td><td colspan="2">ZALA Aero</td></tr>
<tr><td>Country of Origin</td><td colspan="2">Russian</td></tr>
<tr><td rowspan="2">Lancet-1</td><td>Payload</td><td>1 kg</td></tr>
<tr><td>Endurance</td><td>30 min</td></tr>
<tr><td rowspan="3">Lancet-3</td><td>Payload</td><td>3 kg</td></tr>
<tr><td>Endurance</td><td>40 min</td></tr>
<tr><td>Speed</td><td>110 km/h</td></tr>
</table>

2.2.1.7 ZALA KYB-UAV

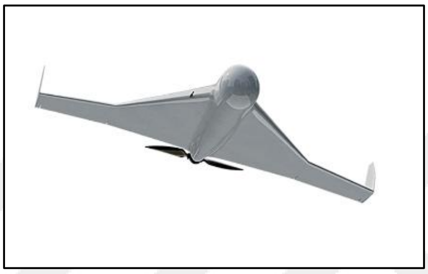


Figure 2.10 ZALA KYB-UAV loitering munitions [31].

ZALA KYB-UAV is a loitering munitions manufactured by Aero Group and used by Russia. The product has the features of ease of use, high sensitivity and silent operation. After the UAV takes off, it searches for the target and after finding it, it is destroyed by diving on it. This UAV is alleged to have been used in Ukraine by Russia in February 2022 [31]. Its specifications are shown in Table 2.7.

Table 2.7 Specifications of ZALA KYB-UAV [31].

Producing Company	ZALA Aero Group
Country of Origin	Russia
First Flight Year	2020
Wing Span	0,95 m
Length	3,5 m
MTOW	6 kg
Max Speed	81 mph
Cruise Speed	62 mph
Operational Range	40 mi
Ceiling	984 ft

2.2.1.8 IAI Harop

Figure 2.11 IAI Harop [32].

Manufactured by IAI, Harop is a munitions used as an EO(Electro-Optic) guided assault weapon to detect and precisely attack targets. It is used by launching from the ramp and is controlled over a two-way data link. It is used to attack high-value targets [32]. This UAV is known to be used by Azerbaijan, Israel and India. It is claimed that it was first used by Azerbaijan in 2016 in Nagorno-Karabakh [33]. It is also claimed that it was used by Azerbaijan in the Second Nagorno-Karabakh War that took place in 2020 [34]. Its specifications are shown in Table 2.8.

Table 2.8 Specifications of IAI Harop [32].

Producing Company	IAI
Country of Origin	Israel
First Flight Year	2020
Endurance	Up to 9 h
RCS	Less than 0.5 m^2
Max Altitute	15.000 ft
Communication Range	200 km

2.2.2 Unmanned Aerial Vehicle Projects in Türkiye

Thanks to the benefits provided by UAV systems, their use is increasing worldwide. Working on UAV systems in Türkiye, thanks to the tasks it has undertaken and especially its cost and usage advantages, it has come to an important position, especially with TB2 Bayraktar. In this context, there are many types of UAVs developed.

2.2.2.1 Meggitt Banshee

The first target aircraft that the Turkish Armed Forces started to use is the Banshee produced by the Meggitt Company. Developed by the British Target Technology company, Banshee began to be developed in 1980. The development activities of the system were completed in 1983 and subsequently put into use. The Banshee is designed to be used both at sea and on land. It can be equipped with active/passive radar cross-sectional area extender, IR(Infra-Red) tracer, acoustic tracer, KEC launcher and many payloads. S-400 components of the Turkish Air Force were subjected to a series of fire tests in Sinop between 5 to 16 October 2020. Banshee was used as the target aircraft in these tests [18]. Its specifications are shown in Table 2.9.

Table 2.9 Specifications of Meggitt Banshee [35].

Wing Span	2,49 m
Length	2,84 m
Height	0,86 m
Wing Area	2,42 m^2
Speed Range	Option 1 103 - 200 mph Option 2 103 - 225 mph
Launch Speed	Catapult Minimum 68 mph
Range	Optical tracking 10 km GPS tracking> 100 km
Endurance	75 min at WOT > 90 minutes at typical, mixed throttle settings
Operational Envelope	Max. altitude 6.000 m Min. altitude 5 m Max. dive angle 70^o
Recovery	Parachute or skid landing

2.2.2.2 TAI UAV-X1 Şahit

Figure 2.12 UAV-X1 Şahit [36].

Studies for the first UAV of Türkiye, TAI(Turkish Aerospace Industries) UAV-X1 Şahit, started in 1990. In April 1992, two prototypes of the First Domestic UAV TAI UAV-X1 Şahit were produced, but mass production activities did not take place. However, in the literature, the drone produced by Türkiye is the UAV-X1 [36].

2.2.2.3 GNAT 750

Figure 2.13 Ground-based GNAT-750 [38].

The GNAT 750, produced by General Atomics in 1989, is designed as a UAV with a long-lasting tactical surveillance and support system to meet the required needs. The UAV can fly to a target 2,000 km away and can fly over the target for approximately 12 h [37]. Its specifications are shown in Table 2.10.

Table 2.10 Specifications of GNAT 750 [37].

Wing Span	10,75 m
Length	5 m
Height	0,5 m
Speed Range	59 m/s
Service Ceiling	7.620 m
Endurance	48 h
Max Loaded Weight	254 kg

This UAV, which was added to the inventory by Türkiye in 1993 by placing an order for 6 units, has served for many years. The first UAVs to enter the inventory of the TAF were the GNAT 750s. After ANKAs produced by TAI started to enter the inventory, the GNAT adventure came to an end [38].

2.2.2.4 CL-89 UAVs

Figure 2.14 CL89 UAV [39].

CL-89 is a surveillance drone. It produced by West Germany, United Kingtom and Canada in the 1960s. Flights started in 1994 with five Canadair CL-89 UAVs, which were donated by Germany in 1993. However, the UAV was removed from the inventory due to accidents and logistical problems [40]. Its specifications are shown in Table 2.11.

Table 2.11 Specifications of GNAT 89 [41].

Wing Span	0,94 m
Length	2,6 m
Max Speed	460 mph
Service Ceiling	3.000 m
Range	60 km
Max Loaded Weight	156 kg

2.2.2.5 Turna and Keklik UAVs

Figure 2.15 Turna UAVs [43].

In parallel with the import of UAVs needed by the TAF, steps have been taken to produce domestic UAVs. As a result of these, by TAI, respectively; Crane and Partridge were produced in 1996, Pelikan and Martı in 2003, Öncü in 2008, Şimşek in 2012 and ANKA in 2010 [42]. According to the news of the Hürriyet, TAI delivered two Keklik and twelve Turna, which it produced within the scope of the Remote Controlled Target Aircraft System project, to the Turkish Armed Forces(TAF). In the written statement made by TAI, it was noted that Keklik, with its compact structure, is an inexpensive training option that can be prepared for action quickly and is used as a transition aircraft in Turna adaptation trainings. It was stated that Turna was used in firing or non-fire tracking trainings with heat, radar, optical guided missiles and barreled weapon [44]. Its specifications are shown in Table 2.12.

Table 2.12 Specifications of Turna UAVs [43].

Endurance	90 min
Max Speed	335 km/h
Service Ceiling	3.658 m
Range	50 km
Max Loaded Weight	70 kg

2.2.2.6 Martı and Pelikan UAVs

Figure 2.16 Martı UAVs [45].

The first prototype of Martı UAV was produced by TAI in 2003. Typically, used for educational purposes, Martı UAV is used in aerial image acquisition and digital image analysis studies [45]. In 2004, the Martı UAV, developed for coastal erosion investigations, was started to be used. This unmanned aerial vehicle had the ability to take off from the launcher and autonomous flight capability [46].

Figure 2.17 Pelikan UAVs [45].

In the same year as Martı UAV, Pelikan UAV-X2 studies started. Pelikan is a scaled UAV half the size of the air platform of the Martı UAV [45]. Its specifications are shown in Table 2.13.

Table 2.13 Specifications of Pelikan UAVs [47].

Wing Span	3,60 m
Length	3,0 m
Max Speed	120 km/h
Service Ceiling	1.525 m
Endurance	6 h
Max Loaded Weight	35 kg

2.2.2.7 Harpy

Figure 2.18 Harpy [50].

In 1998, a project related to Harpy-1 was signed in Türkiye. This drone is more commonly called Loitering Munition. Israeli-developed passive radar seeker and high-explosive warhead. By providing electromagnetic and E/O sensor and datalink capability to the UAV, it is directed to a specific emitter [48]. Within the scope of the project initiated by the Turkish Air Force IAI company, two Harpy I batteries (108 Harpy I UAVs) were procured at a cost of approximately $80 million. Türkiye has tried and used Harpy especially in Anatolian Eagle Exercises [49]. Its specifications are shown in Table 2.14.

Table 2.14 Specifications of Harpy UAVs [50].

Max Speed	416 km/h
Service Ceiling	4.512 m
Endurance	9 h
Communication Range	200 km

Another drone used in the same years is the Gözcü. Developed for short range ISR purposes; Thanks to its catapult launch and parachute landing features, it can land and take off on any terrain without the need for an airport [46].

2.2.2.8 ANKA and ANKA/S

Figure 2.19 ANKA [51]

2004 was the year that Türkiye made significant progress in the field of UAV systems. TAI was also asked to produce a MALE UAV. For this purpose, ANKA UAV has been developed. The production of ANKA, a Turkish UAV, was completed and taken out of the hangar with a ceremony on July 16, 2010.It has important features such as redundant high data speed digital data connection, redundant/autonomous flight control system, redundant/automatic landing and take-off system, landing capability in emergency areas and autonomous return and landing capability to the base from which the link is broken [51].

The works continued rapidly. It has been used effectively especially in the fight against terrorists. ANKA Blok-B, which also functions as an Armed-UAV with SAR(Synthhetic Aperture Radar)/ISAR(Inverse Synthhetic Aperture Radar)/GMTI(Ground Moving Target Indicator) radar integration and Roketsan products MAM-L and MAM-C, made its first flight in 2015. It is equipped with Electronic Warfare and Intelligence (ELINT AND COMINT) Systems. Thus, for the first time in Türkiye, the UAV capable of collecting electronic intelligence from the air was developed. Then, the ANKA-S project was started by gaining control capability via satellite and integrating various features. ANKA-S, which reaches a height of 10 km, can stay in the air for 24 hours. It can carry 200+ kg as a duty load. In the same way, the duration of stay in the air can be increased to 30 hours depending on the duty load [52]. Its specifications are shown in Table 2.15.

Table 2.15 Specifications of ANKA [51].

Wing Span	17,5 m
Length	8,6 m
Max Altitude	9.144 m
Service Ceiling	5.486-7.010 m
Endurance	Up to 30 h
Max Loaded Weight	350 kh
Communication Range	Up to 250 km

2.2.2.9 Bayraktar Mini UAV

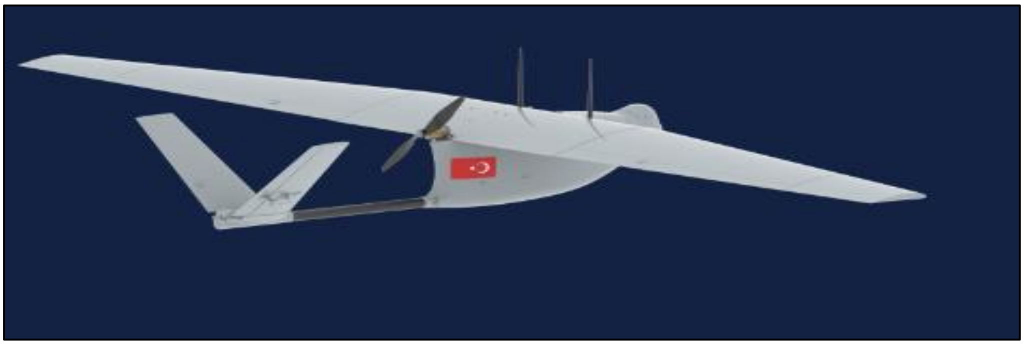


Figure 2.20 Bayraktar Mini UAV [53].

As of 2006, Mini-UAV projects have increased in Türkiye. Bayraktar and Malazgirt by Kale and Baykar, Efe and Arı by Vestel Defense, Güventürk by METU and Globiha by Global Teknik. KaleKalıp/Baykar Makina Joint Venture won the tender opened by the Republic of Türkiye Ministry of National Defense Land Forces Command. It has been used since 2010 [7].

Bayraktar Mini-UAV attracted particular attention in its period due to its national and original design, autopilot guidance control systems, ground control station and command control electronic hardware and software system. It has been used extensively, especially by the units fighting against terrorism. It is a system that allows the Turkish soldier to observe the surrounding area without risking his own life, can be carried on the back, and can be easily mounted and flown when needed. It can perform reconnaissance, surveillance, target detection, identification and recognition functions. Basically, the aircraft consists of Ground Control Station(GCS), ground data terminal (automatically oriented antenna system), daytime camera system, night (thermal) camera system and support equipment [54]. Its specifications are shown in Table 2.16.

Table 2.16 Specifications of Bayraktar Mini UAV [53].

Wing Span	2 m
Length	1,2 m
Max Speed	74 km/h
Service Ceiling	610 m
Endurance	60-80 min
Communication Range	15 km

2.2.2.10 Heron

Figure 2.21 Heron [55].

With the increase in the developments in the world and the need for foreign resources, the demands for UAVs continued. In order to meet the urgent need for UAVs, Heron and Searcher UAVs from IAI Company between 2007-2010; On the other hand, Dominator UAV was leased from Aeronautics Company and used by the Land Forces. ten Heron UAVs supplied from IUP Company, created by the partnership of IAI and

Elbit companies, were included in the Air Force inventory in 2010. Heron took its place as the first UAV system to enter the inventory of the Turkish Air Force [56]. It was developed in Heron as time went on. It has 3 models: Heron TP, Heron and Heron MK II. Its specifications are shown in Table 2.17.

Table 2.17 Specifications of Heron [55].

Wing Span	16,6 m
Length	8,5 m
Max Speed	259 km/h
Service Ceiling	Up to 11.000 m
Max. Takeoff Weight	1.270 kg
Endurance	Up to 45 h
Communication Range	Up to 350 km (LOS) Up to 1.000 km (BLOS)

2.2.2.11 Karayel

Figure 2.22 Karayel [57].

In the same years, the Karayel UAV, a product of Vestel Defense, made its first flight in 2009. Flight tests were carried out in 2009. It is exported to many countries. NATO(North Atlantic Treaty Organization)'s STANAG(Standardization Agreement) 4671 "UAV SYSTEM Airworthiness Requirements (USAR)" is applied at all stages from design to production, development and testing. It is the first UAV feature where these standards are applied [7]. Its specifications are shown in Table 2.18.

Table 2.18 Specifications of Karayel [57].

Wing Span	10,5 m
Length	6,5 m
Max Speed	150 km/h
Service Ceiling	6.900 m
Max. Takeoff Weight	550 kg
Endurance	20 h
Communication Range	Up to 150 km (LOS)

2.2.2.12 Bayraktar TB2

Bayraktar TB2 is another UAV produced by Baykar, which has made a name for itself in many campaigns and wars. Bayraktar TB2 UAVs, which have been used since 2015, are used to detect, identify and neutralize terrorists. It has also been used effectively in Operation Olive Branch and Operation Euphrates Shield [58]. There are features such as auto taxi, automatic take-off feature, automatic landing feature, automatic navigation system etc. in Bayraktar. It is used in Azerbaijan, Ukraine and Qatar [52]. According to the BBC's report, military experts and defense analysts believe that the effective use of armed and UAVs played a significant role in the outcome of the 44-day conflict in Nagorno-Karabakh in favor of Azerbaijan and in gaining superiority over Armenia on the battlefield. In this context, TB2 played a critical role in achieving victory in the 2020 Nagorno-Karabakh War [59].

Figure 2.23 Bayraktar TB2 [60].

Bayraktar is actively used in Ukraine. It destroyed critical defense vehicles such as howitzer, military convoy and air defense systems belonging to Russia. Ukraine gained significant advantages in its war with Russia. Images of destruction destroyed by TB2, but unconfirmed, have been published on many websites [61]. Its specifications are shown in Table 2.19.

Table 2.19 Specifications of Bayraktar TB2 [60].

Wing Span	12 m
Length	6.5 m
Max Speed	222 km/h
Service Ceiling	5.486-7.620 m
Max. Takeoff Weight	700 kg
Endurance	27 h
Communication Range	Up to 300 km

2.2.2.13 Aksungur

Figure 2.24 Aksungur [62].

TAI has further increased its efforts and produced the Aksungur Armed-UAV, which can carry more airborne and more payloads. Aksungur, which can detect enemy submarines in underwater defense warfare with Sonobuoy, can be able to carry general purpose bombs used in F-16s. In order to ensure communication in emergencies and disasters, base station integration will also be carried out [63]. Aksungur carries out target detection, identification and surveillance activities in firefighting. According to the statement made by TAI, Aksungur UAV, developed by the company with domestic and national resources, has given the General Directorate of Forestry a breather in the fight against fire since 1 June, when it took office [64]. In this way, it plays an important role in monitoring the places where fire crews have difficulty in reaching, and in the early detection of fires with its patrol duties. President of Presidency Defense Industry İsmail Demir stated on his social media account that the tests of the domestic and national Aksungur Armed-UAV were successfully completed and delivered to the TAF on October 20, 2021. The prominent features of the version used are 50 hours of flight time, 40000 ft service altitude and 750 kg payload [65]. Its specifications are shown in Table 2.20.

Table 2.20 Specifications of Aksungur [62].

Wing Span	24 m
Length	11,6 m
Service Ceiling	12.192 m
Max. Takeoff Weight	3.300 kg
Endurance	50 h
Communication Range	Up to 250 km

2.2.2.14 ALPAGU

Figure 2.25 Alpagu [66].

ALPAGU Fixed Wing Attack UAV was produced by STM to hit targets out of sight. Besides having a light weight, it can be easily carried by only one person and is capable of fully autonomous navigation [66]. It can be called a kamikaze drone. It is also planned to be used with national ammunition produced by MKE [67]. Being easy to set up and being portable is a particularly big power factor.

In addition, within the scope of the GPS(Global Positioning System) Independent Autonomous Navigation System Development (KERKES) project developed by STM, fixed-wing and rotary-wing (multi-rotor) UAVs such as Alpagu are planned to perform missions in non-GPS environments [68]. Its specifications are shown in Table 2.21.

Table 2.21 Specifications of Alpagu [66].

Launch Method	Self-contained gas generator
Engine	Electrical
Warhead	400 g
Endurance	Up to 15 min
Operational Range	Up to 10 km

2.2.2.15 KARGU

Figure 2.26 KARGU [66].

KARGU produced by STM is a loitering munition system designed for ISR and precision hitting. In addition to being able to destroy fixed and moving targets with high precision in daytime conditions, the UAV can also hit with the same precision at night [66]. It is planned to use KARGU in an integrated way with other platforms, and work continues in this context. Currently used by the TAF and Gendarmerie General Command, the UAV is planned to be used on different platforms as well [69]. Its specifications are shown in Table 2.22.

Table 2.22 Specifications of KARGU [66].

Wing Span	60 cm
Length	60 cm
Battery Charging Time	60 min
Max. Flight Altitude	3.000 m
Cruise Speed	72 km/h
Endurance	30 min
Operational Range	10 m (with external antenna) 6,5 km with onboard GCS antenna

2.2.2.16 TOGAN

Figure 2.27 TOGAN [66].

TOGAN is a multi-rotor UAS designed to carry on tactical surveillance and reconnaissance missions. It incorporates a payload using a 30x zoom lens, enabling imaging of distant targets and threats. It employs advanced image processing capabilities, enabling the detection and classification of threats that are difficult to spot with human eye. TOGAN is able to estimate the coordinates of visible targets, which can then be forwarded to a nearby. A secondary TOGAN platform can be commanded to take over the mission being executed by the primary one, enabling uninterrupted surveillance [66]. Its specifications are shown in Table 2.23.

Table 2.23 Specifications of TOGAN [66].

Producing Company	STM
Country of Origin	Türkiye
Preparation Time	Less than 1 minute
Wing Span	60 cm
Length	60 cm
Battery Charging Time	80 min
Max. Flight Altitude	3.300 m (MSL(Mean Sea Level))
Max Cruise Speed	72 km/s
Endurance	45 min
Operational Range	10 m (with external antenna) 6,5 km with onboard GCS antenna

2.2.2.17 ALPAGUT

Figure 2.28 ALPAGUT [71].

With STM, Roketsan will change the balance in the war environment and develop the Intelligent Roaming Ammunition System ALPAGUT. It is more advantageous than cruise missiles with its cost-effectiveness and operational use. The use and importance of Intelligent Loitering Munitions in wars and conflicts has been increasing in recent years. ALPAGUT will be able to detect and identify the target without being noticed with its dual-mode seeker head. At the same time, the position will not be affected by the jamming systems, and it will be able to point to the target with the precision guidance-control drive system. In addition to all these features, the system will also offer important advantages to its users with the throw-forget feature [70].

ALPAGUT can be used on various platforms, including air, land and sea. It can be used on platforms such as Akıncı, Aksungur, Hurkus, Atak-2, Gokbey and MILGEM [71]. Its specifications are shown in Table 2.24.

Table 2.24 Specifications of ALPAGUT [71].

Producing Company	STM and ROKETSAN
Country of Origin	Türkiye
Manufacturing Date	2022
Wing Span	2,5 m
Length	2,3 m
Weight	45 kg
Operational Range	Up to 60 km
Cruise/Diving Speed	35 m/min , 100 m/min
Endurance	Up to 60 min
Warhead Type	11 kg Particle Effect Armor Piercing and Thermobaric Options

2.2.2.18 Boyga

Figure 2.29 Baygu [66].

The Boyga is a UAV designed to fire an 81mm mortar at a target. The mortar can be thrown manually as well as by determining the coordinate. With the ballistic prediction algorithm, the user can see where the air will fall [66]. Its specifications are shown in Table 2.25.

Table 2.25 Specifications of Baygu [66].

Producing Company	STM and MKE
Country of Origin	Türkiye
Manufacturing Date	2022
Detachable arms Dimensions	900x900×510 mm
Dimensions	550×500×510 mm
Battery Charging Time	80 min
Weight	16,2 kg
Operational Range	10 km (with external antenna) 6,5 km with onboard GCS antenna
Cruise Speed	54 km/h
Endurance	Up to 35 minutes
Max. Flight Altitude	2.000 m MSL

2.2.2.19 Bayraktar Akıncı

Figure 2.30 Bayraktar Akıncı [72].

Another drone built by Bayraktar, which is of great importance for Türkiye, is Akıncı. Akıncı, which has larger dimensions compared to Bayraktar TB2, has an automatic take-off and landing feature on the runway. Akıncı UAV, which is longer and wider than the Bayraktar TB2, has an automatic take-off and landing feature on the runway. Besides Line of Sight(BLOS) communication with Akıncı, the biggest advantage is Beyond Line of Sight(LOS) communication. Akıncı is capable of carrying out operations carried out by warplanes. SAR has air-to-air radar and collision avoidance radars. Used in air-to-ground and air-to-air attack missions.

Akıncı UAV can carry locally produced ammunition such as Bozdoğan, Gökdoğan and Cirit [72]. According to the news of Anadolu Agency on 7 December 2019, Akıncı UAV stayed in the air for 16 minutes after automatically taxiing and completing its take-off. Afterwards, it made its first automatic landing at Çorlu Air Base Command [73]. Akıncı broke the altitude record of Turkish aviation history on 09 July 2021 by staying in the air for 25 hours and 46 minutes at an altitude of 38,039 feet [74]. Akıncı UAV made a close arm flight with SoloTürk at TEKNOFEST held at Atatürk Airport between April 27 and May 1, 2023. Its specifications are shown in Table 2.26.

Table 2.26 Specifications of Bayraktar Akıncı [72].

Wing Span	20 m
Length	12,2 m
Service Ceiling	9.144-12.192 m
Max. Takeoff Weight	6.000 kg
Max Speed	360 km/h
Endurance	24 h

2.2.2.20 Bayraktar DİHA

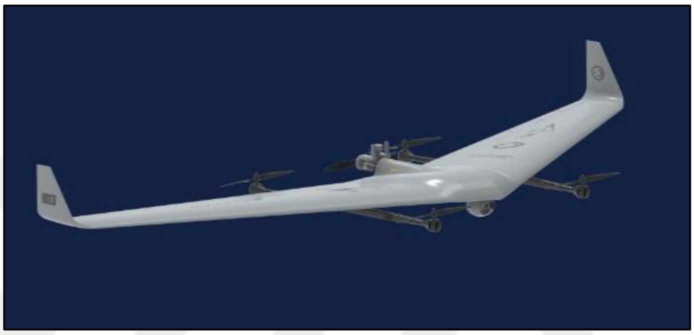


Figure 2.31 Bayraktar VLUAV [75].

Bayraktar Vertical Landing UAV (VLUAV) belongs to the Mini Tactical UAV class. It is planned to be used in ISR activities. It is in prototype stage by Baykar. The UAV can perform autonomous cruise takeoff and landing, as well as semi-autonomous cruise flight. It has three types of landing patterns: vertical, fuselage and parachute landing [75]. It is planned to have features such as extremely fast maneuvering ability and flight without a runway. It is planned to be deployed on ships such as TCG Anadolu [76]. Its specifications are shown in Table 2.27.

Table 2.27 Planned Specifications of Bayraktar VLUAV [75].

Wing Span	5 m
Length	1.5 m
Service Ceiling	2.743-4.572 m
Max. Takeoff Weight	50 kg
Max Speed	148 km/h
Endurance	12 h
Communication Range	150 km

2.2.2.21 Bayraktar TB3

Figure 2.32 Bayraktar TB3 [77].

TB3 is an Armed-UAV developed by Baykar that can take off and land on aircraft -carriers with short runways such as TCG Anadolu. The UAV is planned to be used in offensive missions as well as ISR missions. The UAV, which will have foldable wings, can be controlled as LOS and BLOS [77]. Its specifications are shown in Table 2.28.

Table 2.28 Planned Specifications of Bayraktar TB3 [77].

Wing Span	14 m
Length	8,35 m
Max. Takeoff Weight	1.450 kg
Max Speed	296 km/h
Endurance	Up to 24 h

2.2.2.22 Bayraktar Kızılelma

Figure 2.33 Bayraktar Kızılema [78].

Ongoing UAV studies in Türkiye continue unabated. Finally, Kızılelma, which is planned to be used as an alternative to warplanes and is considered to be a great power multiplier, is being developed by Bayraktar.

Kızılelma will be able to land and take off on aircraft carriers with short runways, such as TCG Anadolu, in addition to its maneuverability and stealth feature [78]. Kızılelma's pre-flight and flight tests are carried out at the Flight Training and Test Center. Completed the first autonomous taxi and takeoff roll test without any problems on November 20, 2022 [79].

The Bayraktar Kızılelma has completed its first flight on December 14, 2022. The drone is expected to be carrier-capable and has thus been designed to land and take off on short runways. It is planned to land and take off from the TCG Anadolu amphibious assault ship [80].

Its specifications are shown in Table 2.29.

Table 2.29 Planned Specifications of Bayraktar Kızılelma [78].

Combat Radius	500 nm
Service Ceiling	10.668 m
Max. Takeoff Weight	6.000 kg
Cruise Speed	733 km/h
Endurance	5 h

2.3 The Classification of UAVs

The Directorate General of Civil Aviation, which is affiliated to the Ministry of Transport and Infrastructure, carries out the regulations regarding UAVs in Türkiye. The working conditions of the UAVs, the technical requirements of the pilots and crews to use the UAVs, the use of UAV airspaces are shaped according to the last updated SHT-UAV 2020 instructions [81].

As there is no single definition of UAVs, different classifications have been made in various sources regarding their classification. It can be classified in various categories such as intended use, wing type, size, weight, flight range and altitude.

These categories are;

1. According to the usage area of the aircraft;
2. According to the type of control system used;
3. According to flight rules;
4. According to the condition of the area used in the air;
5. According to the type of aircraft;
6. According to the wing type;
7. According to the direction of the lift force at take-off and landing;
8. According to the take-off – landing type;
9. According to the engine type of the aircraft;
10. According to the fuel system;
11. According to the fuel tank type;
12. According to the number of uses from the fuel system;
13. General category (UAV maximum take-off weight, range, airtime, maximum altitude values);
14. According to the distance radius that can be realized;
15. According to flight altitude;
16. According to the function and application areas [82].

However, it is the classification of NATO and the USA that is widely accepted. In this context, the classification of NATO, the USA and Türkiye will be examined in the following sections.

2.3.1 UAV Classification of NATO

According to NATO classification, UAVs are divided into three classes according to their weight.

These classes, on the other hand, are classified into six different groups according to other basic features such as altitude and communication range.

Table 2.30 NATO's UAVS Classification [83].

Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Primary Supported Commender	Example Platform
CLASS I (less than 150 kg)	Small Up to 20 kg	Tactical Unit (employs launch system)	Up to 5K ft AGL	50 km (LOS)	BN/Regt, BG	Hermes 90 Luna
	MINI 2-20 kg	Tactical Sub-unit (manual launch)	Up to 3K ft AGL	25 km (LOS)	Coy/Sqn	Aladin DH3 DRAC Eagle Raven Scan Skylark Strix T-Hawk
	MICRO	Tactical PI, Sect, Individual (single operator)	Up to 200 ft AGL	5 km (LOS)	PI, Sect	Black Widow
CLASS II (150 kg to 600 kg)	TACTICAL	Tactical Formation	Up to 10.000 ft AGL	200 km (LOS)	Bde Comd	Aerostar Hermes 450 iView 250 Ranger Sperwer
CLASS III (more than 600 kg)	Strike/ Combat	Strategic/National	Up to 65.000 ft	Unlimited (BLOS)	Theater COM	
	High Altitude, Long Endurance (HALE)	Strategic/National	Up to 65.000 ft	Unlimited (BLOS)	Theater COM	Global Hawk
	MALE	Operational/theater	Up to 45.000 ft MSL	Unlimited (BLOS)	JTF COM	Predator B Predator A Harfang Heron Heron TP Hermes 900

2.3.2 UAV Classification of UK

In the UAV classification of the British Ministry of Defense, civil drones are included in the classification alongside military UAVs. The reason for this is the increase in the use of drones and their widespread use.

Table 2.31 UK's UAVS Classification [84].

Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Civil Category (UK CAA)	Example Platform
Class I <150 kg	MICRO Up to 2 kg	Tactical Platoon, Section, Individual (single operator)	Up to 200ft AGL	5 km (LOS)	Weight Classification Group (WCG) 1 Small Unmanned Aircraft (Up to 20kg)	Black Widow
	MINI 2-20 kg	Tactical Sub-Unit (manual launch)	Up to 3.000ft AGL	25 km (LOS)		Scan Eagle, Skylark, Raven, DH3
	SMALL Bigger than 20 kg	Tactical Unit (employs launch system)	Up to 5.000ft AGL	50 km (LOS)	WCG 2 Light Unmanned Aircraft (20><150 kg)	Luna, Hermes 90
Class II **150–600kg**	TACTICAL	Tactical Formation	Up to 10000ft AGL	200 km (LOS)	WCG 3 UAV (Bigger than 150 kg)	Sperwer, Iview 250, Aerostar, Watchkeeper
Class III **>600 kg**	MALE	Operational/ Theatre	Up to 45.000ft AGL	Unlimited (BLOS)		Reaper, Heron, Hermes 900
	HALE	Strategic/ National	Up to 65.000ft AGL	Unlimited (BLOS)		Global Hawk
	Strike/ Combat	Strategic/ National	Up to 65,000ft AGL	Unlimited (BLOS)		

2.3.3 UAV Classification of US

According to the US Army, UAVs are divided into five different groups according to their max takeoff weight, operating altitute and airspeed characteristics. There are common values in this classification and they are generally classified as group.

Table 2.32 US's UAVS Classification [85].

UAS Category	Max Gross Takeoff Weight	Normal Operating Altitude (FT)	Airspeed	Current Army UAS in Operation
Group 1	Up to 20 pounds	Up to 1200 (AGL(Above Ground Level))	Up to 100 kt	RQ-11B Raven
Group2	21-55 pounds	<3.500 AGL	<250 kt	No current system
Group3	<1320 pounds	<18.000 mean sea level (MSL)		RQ-7B Shadow
Group 4	>1320 pounds		Any Airspeed	MQ-5B, MQ-1C
Group 5		>18.000 (MSL)		No current system

2.3.4 UAV Classification of the European Civil UAV Roadmap

The classification based on weight and flight altitude used in the European Civil UAV Roadmap is given in the table below.

Table 2.33 UAV Classification of the European Civil UAV Roadmap [86].

UAS Category	Takeoff Weight	Normal Operating Altitude (FT)
Mikro	Up to 7	Up to 300 ft
Mini	8-400	300 - 4.000 ft
Rotary Wing	-	-
MALE	400-4.000	15.000 - 45.000 ft
HALE	-	Bigger than 45.000 ft

2.3.5 UAV Classification of the European UAS Community

According to the European UAS Community, UAVs are divided into three main categories: Tactical, Special and Strategic and Purpose. These categories are divided into parts according to the range, altitute, endurance and maximum takeoff weight properties.

Table 2.34 UK's UAVS Classification [83].

UAS Categories	Acronym	Range (km)	Flight Altitute (m)	Endurance (hours)	MTOW (kg)
Tactical					
Nano	η	< 1	100	< 1	< 0,025
Mini	μ (Micro)	< 10	250	1	< 5
Close Range	Mini	< 10	150 [b] to 300 [a]	< 2	< 30 (150 [b])
Short Range	SR	30 to 70	3.000	3 to 6	200
Medium Range	MR	70 to 200	5.000	6 to 10	1.250
Medium Range Endurance	MRE	> 500	8.000	10 to 18	1.250
Low Altitute Deep Penetration	LADP	> 250	50 to 9.000	0,5 to 1	350
Low Altitute Long Endurance	LALE	> 500	3.000	> 24	< 30
Medium Altitute Long Endurance	MALE	> 500	14.000	24 to 48	1.500
Strategic					
High Altitude Long Endurance	HALE	> 2000	20.000	24 to 48	(4.500[c])12.000
Special Purpose					
Unmanned Combat Aerial Vehicle	UCAV	approx. 1500	10.000	approx. 2	10.000
Lethal	LETH	300	4.000	3 to 4	250
Decoy	DEC	0 to 500	5.000	< 4	250
Stratospheric	STRATO	> 2000	>20.000 & <30.000	> 48	TBD
Exo-stratospheric	EXO	TBD	> 30.000	TBD	TBD
Space	SPACE	TBD	TBD	TBD	TBD

TBD = To Be Defined [a] = according to national legislation [b] = in Japan [c] = Predator B

2.3.6 UAV Classification of Türkiye Directorate General of Civil Aviation

The General Directorate of Civil Aviation makes the necessary regulations regarding the UAV in Türkiye. Necessary instructions are included in the SHT-UAV 2020 instructions published by the General Directorate. Within these instructions, there is a classification of UAVs. In this context, classification is generally made according to weights [87].

Table 2.35 Directorate General of Civil Aviation's UAV Classification [87].

Class	MTOW
UAV0	Between 500 g and 4 kg
UAV1	Between 4 kg and 25 kg
UAV2	Between 25 kg and 150 kg
UAV3	Bigger than 150 kg

CHAPTER 3

UAV ATTACKS

In the last few years, within the scope of the lessons learned by many terrorist organizations, especially from the Syrian Civil War, critical developments in the drone use of the PKK Terrorist Organization have been observed. The first of these trends is the acceleration in the using of UAVs in terrorist attacks. The UAV and Armed-UAV capabilities that Türkiye has gained with its successful defense modernization, the strengthening of the outposts, the increase in the quantity and quality of close air support platforms (eg T-129 attack helicopter), the developments in the air-ground munitions used, the strengthening of special operations units such as special operations and commandos, gaining significant combat experience and similar factors limit the terrorist organization's ability to make sensational acts at home. The second trend is the changes in unmanned platforms used in attacks. While rotary-wing drones called quadcopter/multicopter were used in terrorist acts in 2016, it has been observed that fixed-wing, glider-type hull platforms have been used recently. The use of drones without remote control has also increased in order to get rid of the effect of jammers used for defense purposes. In this type of drone used, it is stated that GPS-based systems, in which navigation coordinates are entered beforehand, dispatch the drones [88].

3.1 UAV attacks against Türkiye

In this sub-title, UAV attacks in Türkiye were examined. In general, it has been seen that UAV attacks are made to military base areas and critical areas.

3.1.1 Hakkari, Attack on military unit with drone

In 2016, a drone used by PKK terrorists and trapped with grenades in Hakkari center was shot down while trying to land it in order to attack the military unit [200]. As can be seen in the picture attached below, ammunition and various parts were added to the Quadcopter type drone by the terrorists. With the grenade carrying mechanism attached to it, the grenade was carried, and an engine was added to detonate the grenade. In addition, electronic circuit and external power supply have been added to control the parts. With this mechanism added to the drone, it is seen that they want to attack and aim to attack places they cannot approach from afar [89].

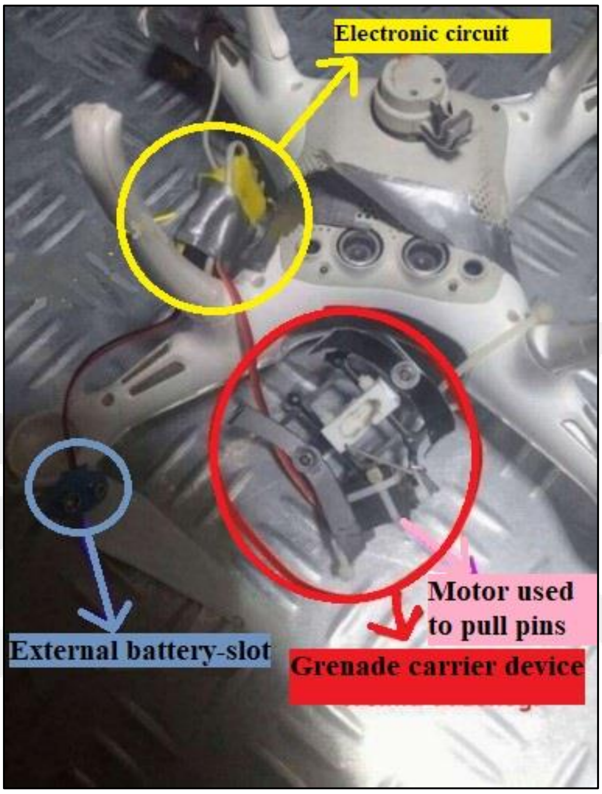


Figure 3.1 Drone Attack Assembly [89].

3.1.2 November 10, 2018 Drone Attacks

With Türkiye playing a more active role in the operations against the PKK, the movement area of PKK terrorists has been restricted. The terrorists, who cannot implement their treacherous plans against Türkiye, cannot get out of the rocks where they hide and cannot take action comfortably. While they used to be able to carry out the actions they wanted comfortably in the past, they are now in great trouble with the development of the defense industry and the spread of vehicles such as UAVs. That's why they are trying to survive by attacking Türkiye with drones.

It is claimed that the PKK established a secret drone base in the Mahmur camp in Northern Iraq in order to carry out drone attacks professionally. The organization secretly provides drone training to terrorists in Mahmur, a terror hotspot. According to the Security report obtained by the Special Intelligence Department of the Sabah Newspaper, the drones that crashed in Şırnak on November 10, 2018 were GPS assisted and equipped with bombs. In total, there were 8 unsuccessful attack attempts. At 9:15 AM, plastic explosive with electric detonator device, weighing about 450 g, was found on the drone that crashed into the governor's garden. It is evaluated that the plane may have been directed by PKK terrorist organization members from the Şırnak rural area (Cudi Mountain) or Northern Iraq region. Various barracks and military areas were attacked at the same time, but all were unsuccessful [90].

Figure 3.2 Drone crashing into Şırnak Governorate [90].

One of the victims of this type of drone attack, called a suicide drone, was Venezuelan President Nicolas Madura. Communications Minister Jorge Rodriguez announced that two explosive-laden UAVs detonated next to the protocol lines. Nicolas Madura survived the attack at the last moment. seven soldiers were injured in the attack [91].

3.1.3 12 November 2017 UAV Attack

On November 12, 2017, the tactical bomb 'drone' of the terrorist organization PKK was shot down in the operation that continues in the rural area of Tendürek Mountain in Doğubayazıt district of Ağrı. A Chinese-made PKK drone with a camera that can be controlled 300 meters away, capable of carrying rifle bombs, mortar shells and grenades, was seized. It was seen that there was a separate engine to pull the pin of the grenade placed in the assembly on the drone, which was neutralized by the commandos [92].

Figure 3.3 Drone seized in Ağrı Tendürek [92].

3.1.4 19 May 2021 UAV Attack on 8th Main Jet Base Command

On May 19, 2021, the PKK attempted to attack the 8th Main Jet Base Command in Diyarbakır with two model planes. It was prevented thanks to the attention of the Turkish Army. It is estimated that the deactivated model planes and the brain cards that make the drones used by the PKK ghosts were taken from Canada. According to the news written by Ergan, it was understood that the organization's drones and model planes had multiple frequency brain cards with a very different and complex system. These drones, which are difficult to catch by anti-drones and jammers due to their Multi-frequency, were shot down with machine guns [93].

3.1.5 11 May 2021 UAV Attack to Turkish Military Base in Syria

The TAF prevented an attack attempt by the terrorist organization YPG/PKK in northern Syria and neutralized a terrorist, the Ministry of National Defense said in a statement in 11 May 2021. This attack was carried out with an UAV. However, the attack was unsuccessful thanks to the attention of the TAF. The UAV was dropped and the departure point was determined using the flight control card. The terrorists in the designated area have been destroyed [94].

3.1.6 Attempt to Attack Turkish Military in Iraq with UAV in May 2021

The Turkish Ministry of National Defense reported that an UAV that the terrorist organization PKK tried to use to organize an attack in Northern Iraq was shot down by Turkish forces in 05 May 2021. The UAV was destroyed by Turkish commandos in the Metina region. While the Turkish commandos continue to destroy the terrorist organization's shelters, the terrorists are trying to organize an attack with model planes because they are afraid to leave their shelters. However, thanks to the attention of the Turkish military, these attacks fail [95].

Figure 3.4 UAV used for attack in Iraq [95].

3.2 Drone attacks in the world

3.2.1 The First Drone Attack

In 1849, the Austrians launched about 200 balloons equipped with bombs at Venice. Some of the balloons, controlled by timed fuses, burst as planned. When the literature is examined, it is stated that this attack is the first UAV attack in history [96]. These balloons, which are considered the basis of drones in history, can be considered as the first drone attack in history.

3.2.2 Drone Attacks on Hmymim and Tartus Bases

Russia has two military bases in Syria, namely Bassel Al-Asad (Hmeymim) airbase in Latakia and Tartus Naval Base [97]. According to CNB's news dated January 11, 2018, ten UAVs loaded with explosives targeted Hmeymim base and three UAV s targeted Tartus base on January 05-06, 2018 [98]. Seven UAVs were destroyed by Pantsyr-S and six UAVs were neutralized by Electronic-Warfare. The Russian Ministry of Defense stated that there were no casualties or damage thanks to the anti-aircraft missiles [99].

Figure 3.5 Model Drone Used in Drone Attacks on Hmymim and Tartus Bases [99].

3.2.3 Two Major Saudi Oil Installations Hit by Drone Strike

Energy and oil are among the most important regions for countries. For this reason, attacks are also carried out on these critical regions for countries. UAVs seem to be preferred more easily now that they infiltrate regions more easily and their cost is cheaper. The recent drone attack on Aramco Company in 2019 can be cited as an example of attacks on energy fields. The Houthis attacked Saudi Arabia with ten UAVs. Because of these attacks, oil giant Saudi Aramco said production of 5.7 million barrels per day - more than half of the country's overall daily output - was suspended [100]. In 2022, attacks were made again in the same region. At the end of this attack, the price of oil per barrel reached 120 dollars and affected the whole world [101].

3.2.4 Drone attack in Abu Dhabi

The attack occurred on January 18, 2022, in Abu Dhabi, the capital of the United Arab Emirates. An explosion occurred in three oil-laden tankers in the industrial zone. As a result of the attack, which also targeted the construction area at Abu Dhabi Airport, a fire broke out in the region and three people lost their lives [102].

3.2.5 Russia-Ukraine War 2022

In the Russia-Ukraine War, fighter interceptors, armored vehicles, UAVs and missiles are actively used as well as manpower. It is considered that both countries actively use UAVs. It is claimed that on November 4, 2022, a boat belonging to the Ukrainian Navy was shot down by a Lancet kamikaze drone. In the video recordings published by the Russian Ministry of Defense, it is evaluated that the same type of Lancet Kamikaze UAVs are used to destroy sea and land targets of the Ukrainian Armed Forces [30]. It is also claimed that the ZALA KYB-UAV was used by Russia over Ukraine in February 2022 [31].

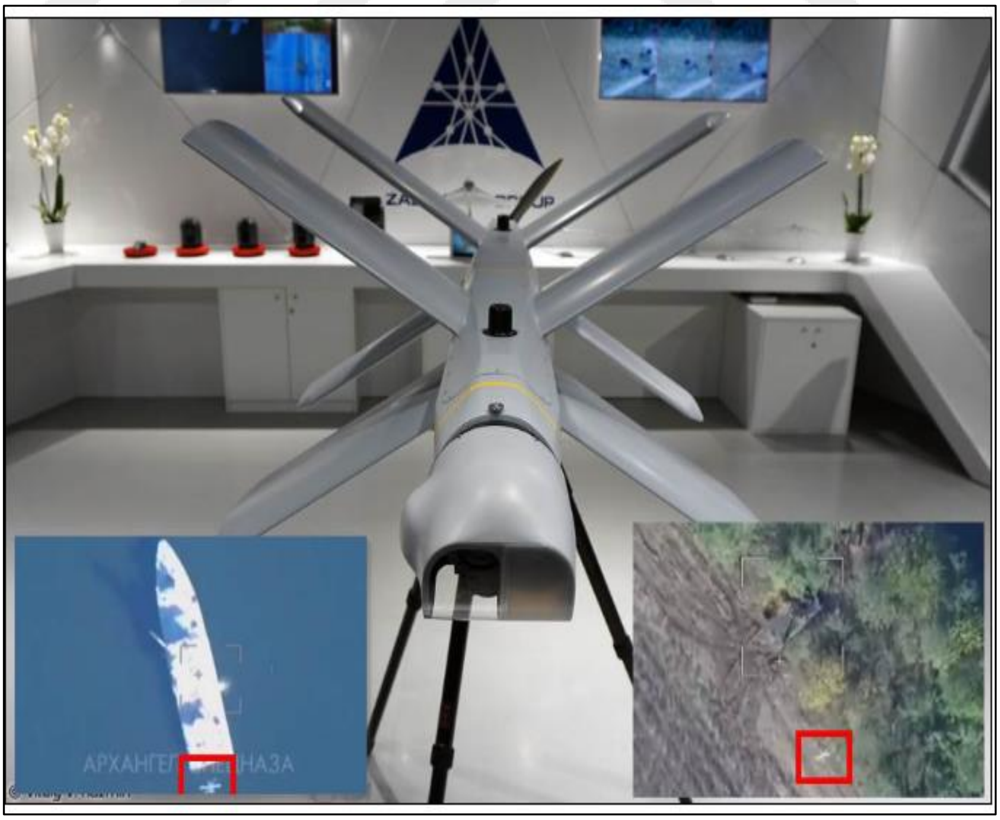


Figure 3.6 Lancet Drone [30].

3.2.6 Second Nagorno-Karabakh War

Azerbaijan lands had been occupied by Armenia for about 30 years. In the early 1990s, Armenia attacked Karabakh and occupied seven provinces around it. After the occupation, approximately 1 million Azerbaijani Turks had to leave their homeland. In addition to provocative statements, Armenia continued its attacks against Azerbaijan on the line of contact. On September 27, 2020, the Armenian Army made extensive provocations along the front line and opened fire on the positions of the Azerbaijani Army and civilian settlements with large-scale weapons, artillery and mortars. As a result of the intense bombardment of Armenia, civilian and military casualties occurred, and infrastructure was severely damaged in some areas. Thereupon, the Second Nagorno-Karabakh War, which was called the "Homeland War" by the Azerbaijani Turks and lasted for 44 days, ended on November 10, 2020 [103]. During this war, heavy weapons and rockets were used, especially Bayraktar TB2 and IAI Harop. The impact of these UAVs used in achieving victory is enormous.

Figure 3.7 S300 spying with TB2 [34].

Bayraktar TB2 Armed- UAVs belonging to the Azerbaijan Armed Forces were especially effective in the suppression and destruction of the Armenian Air Defense (SEAD / DEAD).

It destroyed a large number of S-300 Air Defense System components belonging to the Armenian Army. As a result of the operation carried out against three S-300 Air Defense Systems and one S-125 battery belonging to Armenia on the Azerbaijan border, heavy losses were inflicted on the Armenian Air Defense Elements. It was a huge power multiplier against Armenia in the war.

In addition to Bayraktar TB2, IAI Harop and IAI Skystriker loitering munitions were also used in the operation [34].

Figure 3.8 Bayraktar TB2 of Azerbaijan [104].

CHAPTER 4

DEFENSE AGAINST UAVS

There are three main parts to neutralize the threatened UAVs.

1. Detect
2. Classify
3. Neutralization

In this context, it is first detected by methods such as aircraft, radar, EO/IR sensors. Classification and identification of the detected aircraft is done. This stage is done by evaluating the technical characteristics of the aircraft such as speed and altitude. Afterwards, it is neutralized by Soft-Kill or Hard-Kill methods. Figure 4 shows the Counter Drone System Architecture determined by METEKSAN.

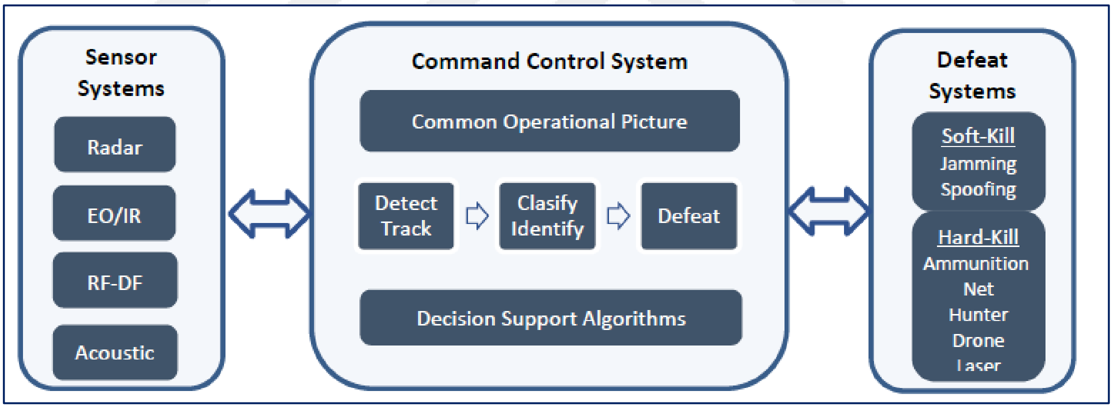


Figure 4.1 Counter Drone System Architecture [105].

4.1 Detection Methods of UAVs

In this study, the detection methods of UAVs are examined under five sub-headings. The examined headings are as indicated in Figure 4.2.

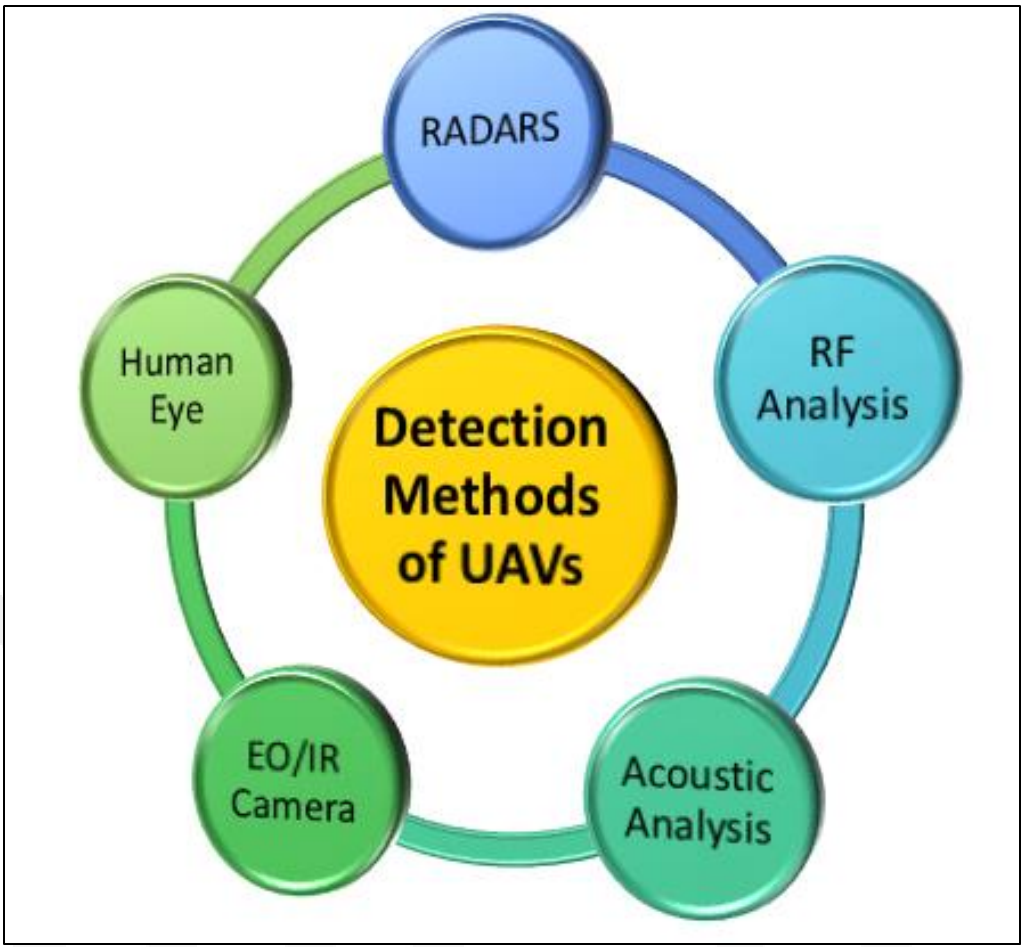


Figure 4.2 Detection Methods of UAVs.

4.1.1 Detecting with Radars

The first of the methods for detecting UAVs is radars. When the working principle of radars is examined; If the transmitted electromagnetic waves collide with an obstacle, they are reflected back from this obstacle and if these reflected electromagnetic waves are received by the source again, it is determined that there is an object in the relevant region. It is classified as active due to the presence of electromagnetic wave flow. Figure 4.3 shows the working principle of radar.

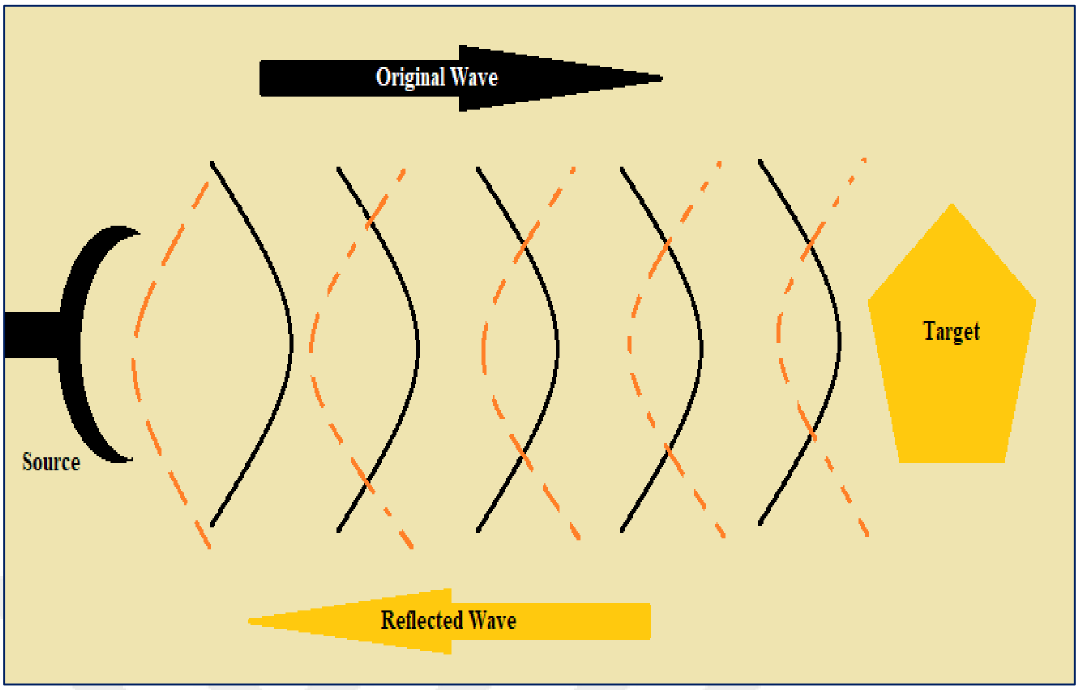


Figure 4.3 Working Principle of Radar [104].

Electromagnetic energy travels at a constant speed through the air at the speed of light, 300,000 km per second. This constant velocity allows the distance between reflected objects to be determined [106]. After these measured values, the object whose location is determined is evaluated. This evaluation is made by the radars' own algorithms. Radars are classified according to the application area. For example, the algorithms of the Meteorological Radar and the Air Defense Radar are different. Thanks to these algorithms, detection can be made according to the desired features.

4.1.1.1 Basic Types of Radar

There are fundamentally two kind of Radar, Primary and Secondary.

4.1.1.1.1 Primary Radar

In Primary Radar, the transmitter spreads the signal around and if there is a target, the signal comes back from the target to the receiver. In this radar, the signal distortion rate is high because the reflected signal from the receiver is minimal. Also, the size and location of the target cannot provide precise information [107]. Table 4.1 shows the standard radar frequency nomenclature.

Table 4.1 Standard Radar frequency nomenclature [107].

Band Designation	Frequency Range	Usage
HF	3-30 MHz	OTH surveillance
VHF	30-300 MHz	Very-long-range surveillance
UHF	300-1,0000 MHz	Very-long-range surveillance
L	1-2 GHz	Long-range surveillance En route traffi c control
S	2-4 GHz	Moderate-range surveillance Terminal traffi c control Long-range weather
C	4-8 GHz	Long-range Tracking Airborne weather detection
X	8-12 GHz	Short Range tracking Missile guidance Mapping, marine RADAR Airborne Intercept
K_a	12-18 GHz	High Resolution Mapping Satellite altimetry
K	18-24 GHz	Little use (water Vapour)
K_a	27-40 GHz	Very-High-Resolution Mapping Airport surveillance
Milimeter	40-100 GHz	Experimental

ALPER Marine LPI Radar produced by Aselsan and operating in X Band is shown in Figure 4.4.

Figure 4.4 ALPER Marine LPI Radar Operating in X Band [108].

4.1.1.1.2 Secondary Radar

In order for this radar to work in accordance with its purpose, it must have a device called Transponder on its target. If the target does not have this device and the IFF system is turned off, the target cannot be detected on the secondary radar. Its working principle is generally based on question and answer. The interrogation signal from the radar is answered by the aircraft in the transponder device. The sent response contains the target's location, altitude, status, and more useful information [107]. Figure 4.5 shows the general struction of IFF.

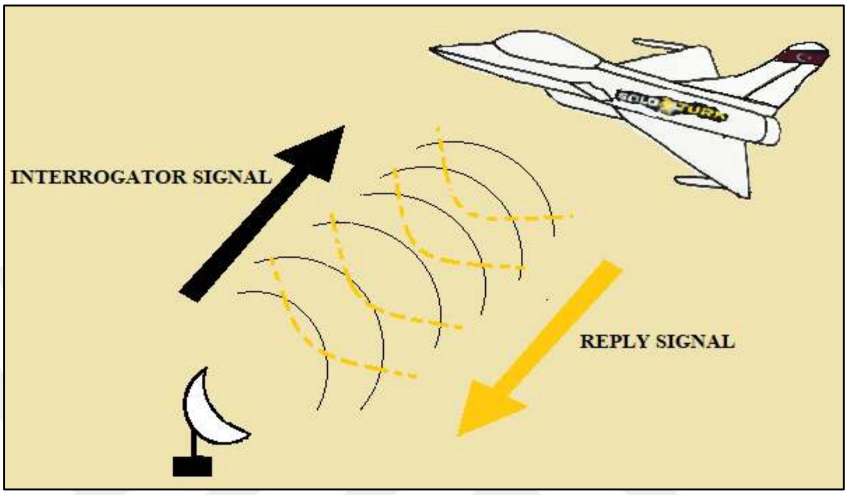


Figure 4.5 The General Struction of IFF.

4.1.2 Detecting with Radio Frequency (RF) Analysis

With the Radio Frequency (RF) based detection method, the UAV is detected by using the communication signal between the UAV and the ground station.The frequency bands of 2.400 – 2.483 GHz and 5.725 – 5.825 GHz are used in drone communication protocols [109].

The main aim of this method is to scan and detect the frequency bands used between the UAV and the GCS. Unlike the Radar method, this method can be considered passive. Because in this method, no RF broadcast is made. However, there are UAVs that cannot be detected using this method. If the UAV is flying autonomously and programmed prior to takeoff without receiving any commands from anywhere, no RF signal flow will occur between the UAV and the GCS. This method is unsuccessful for autonomous unmanned aerial vehicles because RF detection cannot be made.

4.1.3 Detecting with Acoustic Analysis

With the Acoustic Analysis method, it is possible to collect the sound signal from the rotor/motor of the UAV through the sound sensor and extract the sound characteristic parameters for identification/detection. In addition, this method has the advantages of detection and positioning [109]. UAVs are classified based on previously generated acoustic information. According to the created library, both the location of the UAVs and themselves are determined. It is adversely affected by weather conditions and environmental noise [110].

4.1.4 Detecting with Electro-Optical or Infrared/Thermal Camera

One of the methods used to detect UAVs is the use of EO/IR/Thermal Camera. This can be considered as a passive method due to the use of electromagnetic waves coming from outside. This method also uses EO radiation emitted or reflected by a target to detect UAVs [111].

The other camera that is included in this method and enables unmanned aerial vehicles to be detected with a camera is the IR/Thermal Camera. UAV detection is made by using infrared energy emitted from objects and cannot be detected by the human eye. The temperatures of the target appear in different color tones. It is not affected by bad weather conditions and can distinguish even very small temperature differences [110].

4.1.5 Detect With the Human Eye

Apart from other methods, if the altitude of the UAV is low, it can be detected with the human eye. In the evening and when it gets dark, the lamps on them provide great convenience, especially in their detection. Measures are taken against UAVs detected by their lamps and they are dropped.

4.2 Neutralizing Methods of UAVs

After the detection of UAVs, if it is a threat, it is necessary to neutralize it. In this context, there are many methods used in the world. The methods used are presented in the Figure 4.6.

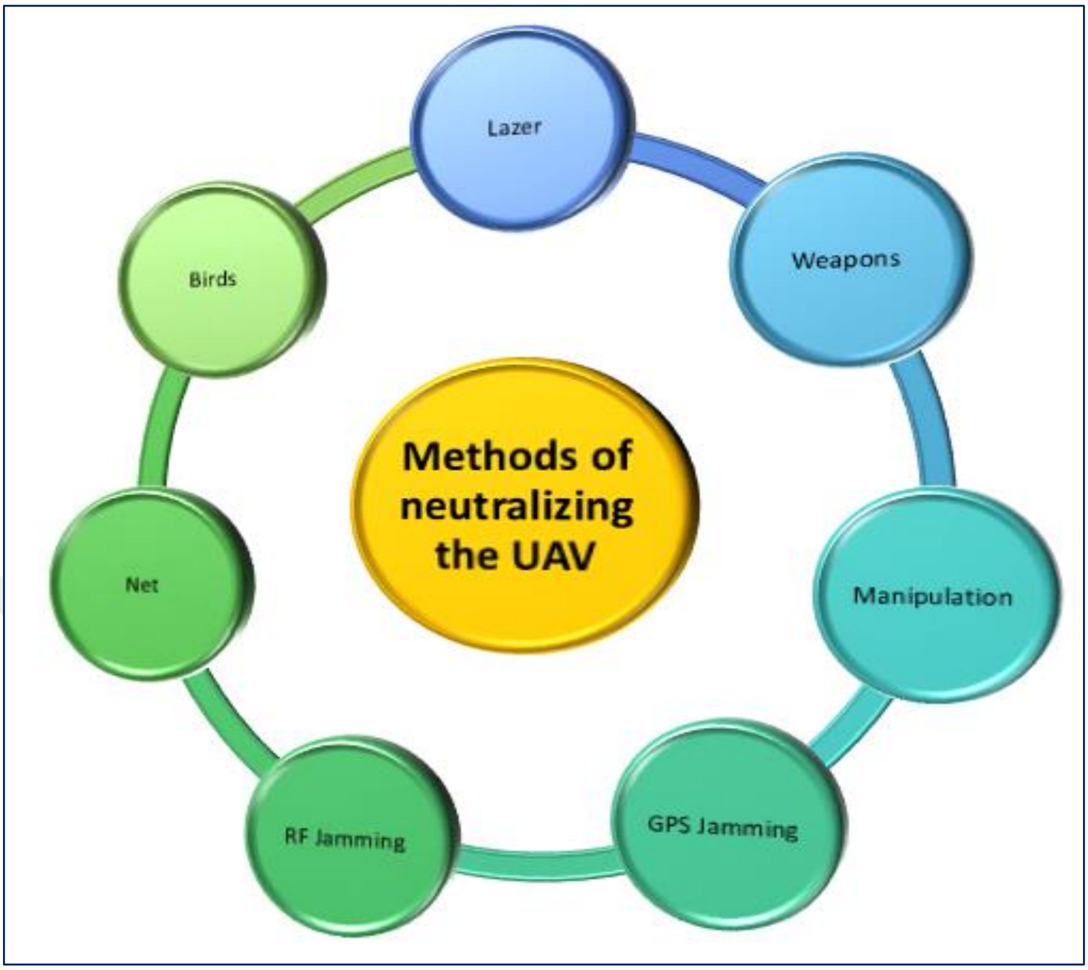


Figure 4.6 Methods of neutralizing the UAV.

4.2.1 GPS Jamming

The GPS is a satellite-based radio navigation system owned by the United States government [112]. In this system, generally 4 or more satellites with an unobstructed LOS are used. In this way, it provides more precise geographical location and time information to a GPS receiver anywhere on or near the world. Most of the UAVs report their location using GPS. Jamming is possible in these systems. In the GPS Jammer method, the GPS system of the UAV is jammed. In this way, the UAV thinks that it is in another place [113]. The jammed UAV can be neutralized by directing it to the desired area with this method. However, this method is ineffective against autonomously moving UAVs like the RF Jamming.

As an example of the use of GPS Jamming, in 2018, the 10th anniversary of the annual Hong Kong Wine & Dine Festival, the drones started to drop during the light choreographic show with 100 drones. By unknown person or persons during the show with the GPS jammer used, 46 of the drones were dropped to the ground. There are many more such GPS Jammer use cases [114].

4.2.2 RF Jamming

RF Jamming is to prevent a wireless device from communicating with other devices/wireless network. Equipment called RF Jammer is used to prevent communication [115]. In this way, the UAVs that are a threat can be removed from being a threat by disconnecting the control center. UAVs with jammed RF connection may be in the following situations according to the design or out of the design;

a. UAV makes a controlled landing in its current position
b. UAV returns to user-set home location (which could be set to a target position instead of home)
c. UAV falls uncontrolled to the ground
d. UAV flies off in a random uncontrolled direction [113].

Due to the use of RF Jammers against RF signals, they may adversely affect other systems operating with RF signals. For example cell phone etc.

4.2.3 Nets

This method is generally used for small UAVs. Currently, two network methods are used. The first method; An UAVs carrying a net can neutralize or capture the threatened UAV by throwing a net.

The first example of this method was seen in Japan. Net-carrying drones were used to shoot down an UAV that was detected on the prime minister's office in 2015 and found to be carrying radioactive material [116]. An example image of this method is shown in Figure 4.7.

Figure 4.7 A UAV carrying a net [116].

Another network method is to disable it by throwing a net with the help of any device. An example of this method is to neutralize harmful UAVs by throwing a net with a shoulder-fired weapon called Skywall 100 developed by Openwork Engineering Company [117]. An example image of this method is shown in Figure 4.8.

Figure 4.8 Skywall 100 [117].

In addition, an anti-drone projectile, which does not throw a net directly and can be used as a projectile, becomes a net after it is thrown. SkyNet Mi-5 shells are anti-drone shells. After the bullets are fired, the five interconnected pieces rotate and move towards the threat drone, enveloping the frame. It then creates the net to neutralize it and bring it down [118]. An example image of SkyNet Mi-5 is shown in Figure 4.9.

Figure 4.9 SkyNet Mi-5 [118].

4.2.4 Manipulation

In this method, the UAV's communication line is tapped and the drone is taken under control. It is possible to hijack this line as some UAVs are controlled by methods such as RF. Cyber Security Weekend was organized by Kaspersky Lab in 2019 in Cape Town, South Africa. 13-year-old student named Reuben Paul, also known as Cyber Ninja in the organization, managed to hack the drone within minutes [119].This situation once again showed the world how easy it is to hack to UAV.

4.2.5 Birds

Birds of prey such as eagles and hawks have been used for hunting for many years and are still being used. Today, with the development of technology, it has also been used to catch drones. Birds have been trained using these hunting instincts, and significant success has been achieved in neutralizing threatened small UAVs. Following the Paris terrorist attacks in 2015 and drone incidents flying in critical areas, the French Air Force trained eagles to intercept and destroy threat aircraft. Eagles, which are still actively used, continue to improve their skills [120]. A picture of using an eagle to neutralize drones is shown in the Figure 4.10.

Figure 4.10 Using Winged Warriors To Hunt Down Drones [120].

4.2.6 Laser

Another method to neutralize the detected Aircraft/UAV is Laser. The laser beam device is directed to the relevant aerial vehicle and disabled. However, the disadvantage of this method is its high cost. For example, the High-Energy Laser Weapon System under development by Raytheon Technology continues to be tested. It is planned to be used against targets such as mortars and UAVs [121].

4.2.7 Weapons

Although this method is more primitive than other methods, it is a method of neutralizing the UAV by direct intervention by a person using a weapon. After detecting the threatened UAV, it is neutralized by the person standing on the ground by throwing ammunition at the UAV. This method is used for UAVs with lower altitudes and visibly threatening UAVs. However, care must be taken when aiming and shooting. If the ammunition misses, it can pose a danger to the area.

4.3 Use of UAV Defense Systems in the World and in Türkiye

In this sub-title, the drone defense systems produced and used in Türkiye and in the world are examined.

4.3.1 Anti-UAV systems used in Türkiye

Türkiye is surrounded by seas on three sides, rich in underground resources, geopolitically and strategically located in a very important place. For this reason, from the past to the present, it has dealt with the enemies that are a threat to the country and continues to do so. The adventure that started with a horse and a sword has left its place to technology today. With the development of technology, UAVs were added to the threatening mortar shells, guns and planes. It has started to work on neutralizing UAVs, which are a threat to domestic companies, and has given them to Türkiye's use. The UAV Defense Systems used by Türkiye will be explained in the following parts.

4.3.1.1 İHTAR Anti-Drone System

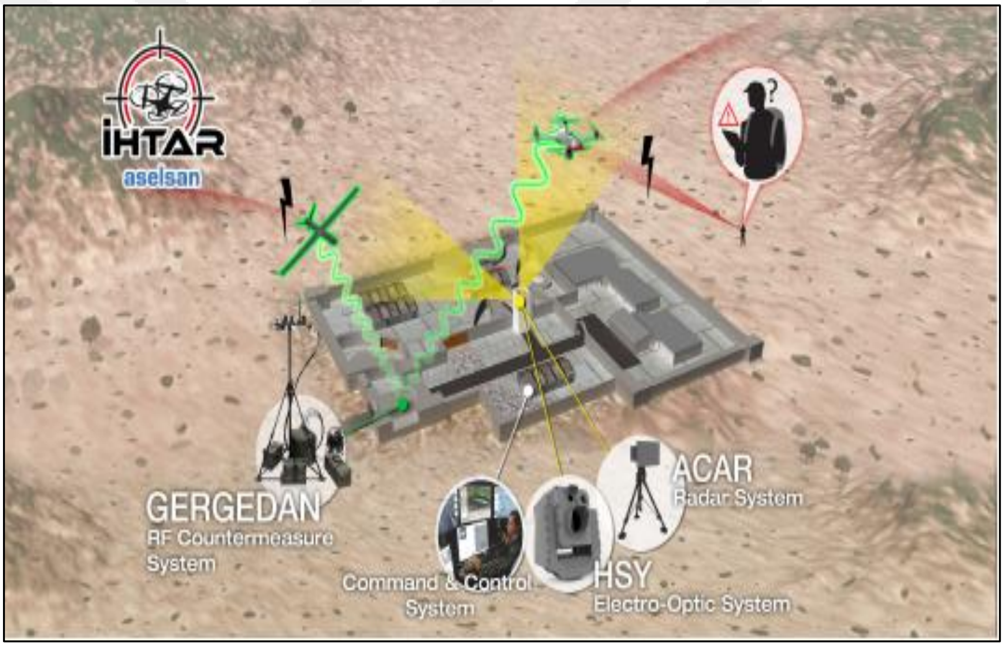


Figure 4.11 İHTAR Anti-Drone System [122].

The Anti-Drone System produced by Aselsan aims to neutralize mini/micro UAV threats in urban/rural environments. In general, İHTAR can be stated that it has two subsystems. These;

- ACAR Radar
- GERGEDAN RF Jamming System.

First of all, mini and micro UAVs use ACAR Radar for detection and tracking in all weather conditions day and night. It uses the GERGEDAN Jammer System to neutralize the threatening UAVs. The GERGEDAN RF Jamming System covers the entire frequency band. This system can be used against UAVs that are more than one threat, not just a single target, due to RF jamming. The system can be used as a fixed as well as portable. The system can scan 360 degrees as well as scan the desired sector. It has a Mini-UAV detection distance of 5 km [122].

4.3.1.2 Kapan Counter Drone System

KAPAN Counter Drone System, produced by Meteksan, ensures the neutralization of UAVs with its radar system, thermal/daytime cameras, RF Jammer and laser system (optional).

KAPAN's subsystems;

a. Retinar FAR-AD Drone Detection Radar,
b. Passive RF-DF sensors
c. Laser System (optional)
d. RF Jammer System

Retinar FAR-AD Drone Detection Radar is 3D radar with special libraries for detecting, tracking and classifying drones. After detecting the object that is considered to be a threat by radar, passive evaluation is made with the help of existing passive RF-DF sensors. RF sensors also support identification and classification, thanks to the UAV communication frequencies library. Afterwards, the finalized threat assessment is provided by the EO/IR systems. If the UAV is considered to be a threat, it is neutralized with the RF Jammer System or laser available in the system [123]. The picture of KAPAN Counter Drone System is shown in Figure 4.12.

Figure 4.12 KAPAN Counter Drone System [124].

The radar detection range in the system is 1,5 km for small drones and 2,5 km for large drones for large drones. The cameras used are high resolution and long range. It has the possibility of neutralization by RF jamming or laser destruction at a distance of 500 m [125].

4.3.1.3 ES-60 MB Electromagnetic Anti Drone Gun

The ES-60 Electromagnetic Anti-Dron Gun, produced by Harp Engineering Art Company, neutralizes the threat UAV using electromagnetic methods. Uninterrupted jamming is applied to drone command and GPS/Glonass frequencies with fast scanning. Using the Anti-Drone weapon for 3 seconds is enough to blunt and take over the drone systems. The weapon, which is very light in weight, has a range of 3000 m and provides mobile use. It is stated on the company's website that it is used for the protection of many heads of state, important energy facilities and for the purpose of ensuring the security of government buildings [126]. The picture of ES-60 MB is shown in Figure 4.3.1.3.

Figure 4.13 ES-60 MB Electromanyetic Anti Drone Gun [126].

According to the news of Anadolu Agency, the efficiency of the antennas developed by the company was confirmed as a result of the tests carried out [127].

4.3.1.4 UAV CAGE

The UAV CAGE, which has a 360 degree coating produced by the National Defense Company, can provide protection up to a radius of 3,000 meters depending on geographical conditions. The system provides protection against UAV, which is a threat, by suppressing the frequencies in the desired frequency range. The system is especially preferred for the protection of critical places such as military bases and airports.Working with 220–240V mains voltage, the system works 7 days and 24 hours. In addition to its simple installation and fast use, it can be easily tested before operation. UAV CAGE is actively used in the TAF [128]. The picture of UAV CAGE is shown in Figure 4.14.

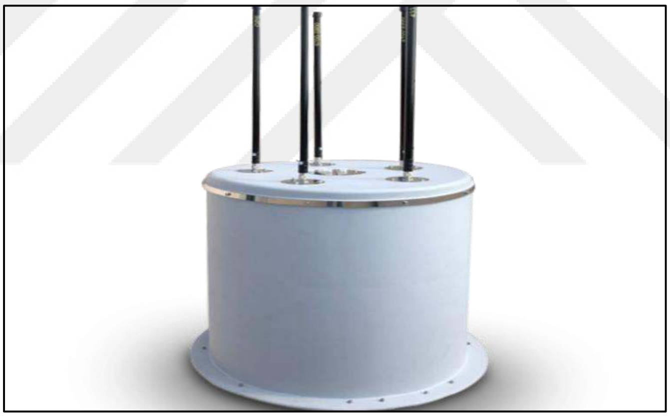


Figure 4.14 UAV CAGE [128].

4.3.1.5 İLTER Drone/UAV Detection and Neutralization System

Another UAV detection and blocking system is the İLTER Drone/UAV Detection and Neutralization System produced by Boğaziçi Defense Company. It can be considered that the system consists of three subsystems. These systems are Detection System, Blocking System and Spoofing. In addition to detecting mini/micro UAVs with the Detection System, it detects the wireless communication of the UAV and its remote control between the UHF, S and C frequency bands. With the Blocking System, it blocks the communication frequencies detected between the UAV and the control controller. If the flight feels autonomous, global positioning systems such as GNSS(Global Navigation Satellite System), GLONASS, GALILEO, BEIDOU block the frequency bands. The last subsystem, the Spoofing System, emits fake GNSS signals to prevent threats flying autonomously. It ensures that the threatened UAVs are removed to the desired coordinates [129]. The picture of İlter System is shown in Figure 4.15.

Figure 4.15 İLTER [129].

4.3.2Anti-UAV systems used in the World

In order to neutralize threatening UAVs, UAV Defense Systems are used in the world as well as in Türkiye. Defense Systems used in the world are examined in this section.

4.3.2.1 Falcon Shield Counter Unmanned Air System(C-UAS)

Falcon Shield produced by Leonardo Electronics is designed against low, slow and small air systems which are threats. Due to its technical features, it makes precise detection, tracking, identification, geo-location and mitigations of the drones. It is evaluated that with its 360-degree coverage radar, EO sensors and RF sensors, it allows for easy detection of threatened drones. It can be used effectively thanks to its options to be used as fixed, relocatable or deployable configurations [130]. The picture of Falcon Shield is shown in Figure 4.16.

Figure 4.16 FALCON Shield [130].

4.3.2.2 Repellent-Patrol

The Repellent-Patrol system, produced by the Russian Company Rosoboronexport, is considered to be an electronic warfare system used against small UAVs. The system enables the detection and orientation of the transmission and control systems of UAVs as well as the monitoring of signal parameters. By processing the signal parameters, type determination of UAVs is provided. It is evaluated that by suppressing the detected signals, it ensures that the communication between the controller and the UAV is interrupted. The system processes frequencies in the 200-600 mHz range and has electronic suppression capability up to 30 km range. It is considered to have 360 degree coverage, which is an important feature for the system [131]. The picture of Repellent-Patrol is shown in Figure 4.17.

Figure 4.17 Repellent-Patrol [131].

4.3.2.3 ELI-4030 Drone Guard

Another UAV Defense System used in the world is the ELI-4030 Drone Guard produced by IAI. It can be considered that the system consists of 4 subsystems: Drone Detection, Identification, Classification and Defeat. The detection methods of the system have multiple sensors, just like the systems described in other sections. The system has 360 degree coverage while detecting and tracking up to 50 km. The system has Verification, Identification and Classification possibilities up to 20 km. It has a range of 10 km to neutralize the threatened UAV. To neutralize, the system offers two options. The first of these options is to capture the communication line or navigation between the controller and the UAV, and the other option is to neutralize using a weapon system [132].

CHAPTER 5

USING KAMIKAZE DRONES AGAINST UAVS

In my thesis, the Defense Systems used against UAVs in the previous chapters were explained. It has been observed that the deactivation of the threatened UAVs consists of three stages, which can be divided into Detect, Classify, and Neutralizing. In this context, neutralizing phase comes after detect and classify phase.

In this study, the neutralization of UAV has been examined in seven stages, and if we review it again;

- GPS Jamming,
- RF Jamming,
- Nets,
- Manipulation,
- Birds,
- Laser,
- Weapons are seen to consist of methods.

However, these methods are sometimes insufficient in neutralizing UAVs. For this reason, a new method has been sought and it is considered that the use of Kamikaze drones against UAVs can be effective in combating UAVs.

If Kamikaze Drones are to be defined first, they are UAVs with fixed/rotary wings, capable of flying autonomously/non-autonomously, hitting the target with the warhead it carries, and destroying the target along with its destruction.

Advantages of Kamikaze Drones;

- They are difficult to detect due to the fact that they generally fly from low altitudes,
- Its costs are cheap,
- The drone is ready to be launched,

- Being easily portable,
- They can be thrown from platforms such as catapults and launchers and do not need a runway.

However, Kamikaze Drones have disadvantages as well as these advantages. Disadvantages of Kamikaze Drones;

- They cannot be reused,
- In case of wrong configuration, it can harm friendly troops.

5.1 Kamikaze Drone Use in the World

When their use in the world is examined, there are many kamikaze drones that are claimed to be used by countries. In Chapter 2, Kamikaze Drones samples used in the world were examined. It has been claimed that HESA SHADED-136, produced by Iran Aircraft Manufacturing Company, was used in the Russia-Ukraine War [27]. It has been claimed that the Lancet Kamikaze Drone and KYB-UAV produced by ZALA Aero, like SHADED-136, were used in the Russia-Ukraine War [30]. It was stated that Harop, produced by IAI, was actively used by Azerbaijan against high-value targets in the Nagorno-Karabakh Wars [34].

In addition, it has been observed that UAVs used for hobby purposes have been revised by different terrorist groups and used for offensive purposes such as kamikaze drones. In these attacks, the Kamikaze Drone has been found to be a great power multiplier and inflicts great damage to targets. In parallel with the usage in the world, studies on many Kamikaze Drones such as ALPAGU by STM Company and AZAB by Robit Company are carried out in Türkiye.

When Attacks and Kamikaze Drones are examined, it is seen that the purpose of use is to attack ground targets such as high value targets, critical places, radars, tanks, and air defense systems.

There is no example in the literature that these UAVs are used against any UAV. Thanks to the advantages it has, it is thought that the Kamikaze Drone will be of great benefit to be used against UAVs that are a threat.

The features that the Kamikaze Drone to be used against UAVs should have are examined under the following headings.

a. Fuses

Fuses are systems that are generally used in missile and rocket systems, and that allow the warhead to be detonated at any time after launch, and also provide safe storage of ammunition. It is examined in five sections: Time, Proximity, Percussion, Auxillary and Combination [133].

As stated in the definition, these systems are generally used in missile and rocket systems. With the integration of these systems into the Kamikaze drone, it is thought that ensuring the destruction of the threatened drone at the desired time will have a great impact. Depending on the size of the threatened UAV and the fuse type to be used, it is considered appropriate to ensure that it detonates when it approaches or hits the target.

b. Control

It is thought that the drone's ability to fly both autonomously and non-autonomously may be more effective in combating UAV. The drone, which can work in integration with sensors such as radar, E/O and I/R, can be programmed in advance and it was thought that it would be appropriate to use the sensors to track targets with the Tracker feature. However, in case of unexpected malfunctions that may occur in sensors and systems providing autonomous flight, it is thought that non-autonomous control will be taken over and controlled by the operator to move it more effectively.

It is also thought that it may be appropriate that it may also have I/R guidance feature. When the definition of infrared guidance is examined, it is the movement towards the hottest point according to the sensor with the I/R sensor it has. However, the biggest disadvantage of I/R guidance is that it may be insufficient due to daylight if used during the day. For this reason, it is considered that using this guidance system when there is no daylight can be more effective in combating UAV.

c. Platform

It is considered that Kamikaze Drones can be launched from ground-based launchers and do not need a runway, which may be good in terms of ease of use. Thanks to this advantage, it is thought that the UAV, which is a threat, can be quickly neutralized with the Kamikaze Drone, which is kept ready in the launchers.

In addition to the features considered above, more features can be added. Since the study was carried out theoretically, the features that are considered to be good for Kamizake Drone to be used effectively against UAV, which is a threat, are stated.

5.2 Available Sensors for Use in the System

The most crucial step in neutralizing a threatening UAV is the detection of its presence. In this context, the proposed system should employ not only a single type but also multiple types of sensors to ensure comprehensive monitoring of the designated area. The following sections examine sensors commonly used in the market and defense systems, as well as those that can be utilized in the system.

5.2.1 Radars

In the recommended UAV defense system utilizing Kamikaze Drones, the first set of sensors are radars. These radars should be strategically placed at the center of the area to be protected or in an area without geographical obstacles. After installation, it is crucial for the radar to have maximum coverage to enhance detection capabilities. For the system's Identification Friend or Foe (IFF) query, the UAV must possess an IFF antenna and transponder device. Additionally, to detect unmanned aerial vehicles lacking an IFF response capability, the system should incorporate a Search Radar

5.2.1.1 Search Radars

One of the primary radar types, the Search Radar, can provide information about the position, altitude, and speed of an object detected in the air. However, it does not enable Friend or Foe identification. Some of the radars used in air defense systems are examined in the following sections.

5.2.1.1.1 Doruk

Figure 5.1 The Doruk UAV Detection Radar [134].

The Doruk UAV Detection Radar, produced by RST Technology, is employed for the detection of low-altitude targets over land/sea. In addition to facilitating the acquisition of various target-related information such as direction and altitude, it plays a significant role in detecting targets with a low radar cross-section. Moreover, it boasts easily portable and operable features. It is claimed to operate effectively in all weather conditions [134]. Its specifications are shown in Table 5.1.

Table 5.1 Specifications of Doruk 3D [134].

Detection	UAV: > 6 km Helicopter: > 25 km
Accuracy	Range: <11 m Scanning Rate: Adjustable up to 180°/sec
Operational Readiness	≤10 min
Operating Temperature	Between -40 to +60 °C

5.2.1.1.2 Ground Observer 12

Figure 5.2 The GO 12 [135].

The Ground Observer 12, a Ground Surveillance Radar manufactured by Thales, is a preferred radar due to its small size and lightweight (16 kg). The system is claimed to be deployable within 5 minutes and capable of fully autonomous operation. In addition to its target tracking capability, it offers a coverage range spanning from 50 m to 27 km [135]. Its specifications are shown in Table 5.2.

Table 5.2 GO 12 [135].

Detection	UAV: > 7 km Helicopter: > 19 km
Coverage	Between 50m to 27km
Azimuth	<360°

5.2.1.1.3 TV-904 3D ANTI-UAV RADAR

Figure 5.3 TV/904 [136].

The TV-904, manufactured by Transvaro, is utilized for observing close targets in low-altitude operations. As a low-altitude security radar system, it has the capability to detect, locate, and classify moving ground and sea objects, including helicopters and drones. In addition to its ease of portability and installation, it is a cost-effective system. It can detect both moving and stationary targets in all weather conditions and particularly in low-light levels.

After identifying targets within its coverage area, the TV-904 sends the directions, altitudes, and routes of suspicious targets to the system for further analysis [136]. Its specifications are shown in Table 5.3.

Table 5.3 TV-904 [136].

Detection	Mini-UAV: ≥ 5 km Tactical-UAV: ≥ 10km Tactical-UAV: ≥ 15 km
Weight	35 kg
Scanning Angle	Between 0° to 360°
Min. Detection Height	≤ 10m

5.2.1.2 IFF Radars

IFF radars, which generally work simultaneously with primary radars, are among the radars that enable friend and foe identification. It consists of an interrogator and a transponder device.

5.2.1.2.1 IFF Mk XIIA(S)

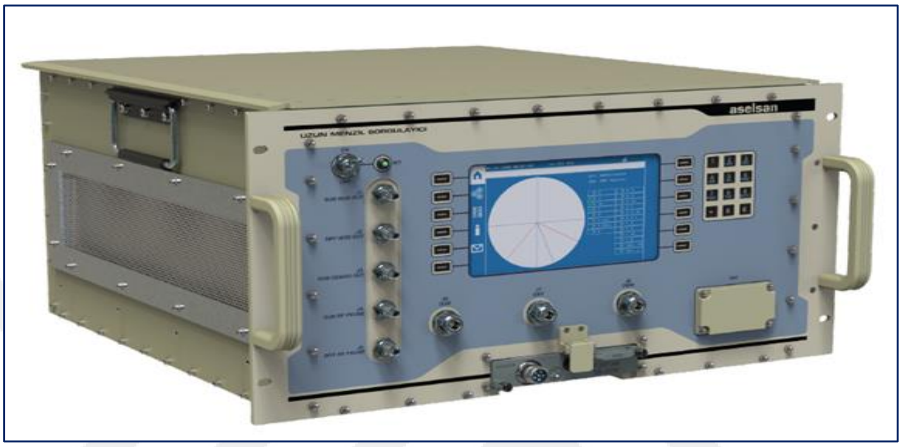


Figure 5.4 IFF Mk XIIA(S) [137].

The Mod 5/S Long-Range IFF Interrogator, manufactured by Aselsan, is compliant with STANAG 4193 Version 3, supporting Mod 1, Mod 2, Mod 3/A, Mod C, Mod S, and encrypted Mod 5 modes. The Long-Range IFF Interrogator can interrogate targets in coordination with the primary sensor or operate independently of the primary sensor. The transmission frequency is 1030 MHz, and the reception frequency is 1090 MHz. It has a specified range of 250 nautical miles [137]. Its specifications are shown in Table 5.4.

Table 5.4 IFF Mk XIIA(S) [137].

Mode	Mod 1, 2, 3/A, C, 5 Level 1 and Level 2 and Mod S
Transmit Frequency	1030 MHz
Receive Frequency	1090 MHz
Range	250 NM
Power	115/ 220 VAC, 47-63 MHz

5.2.1.2.2 ASR-9

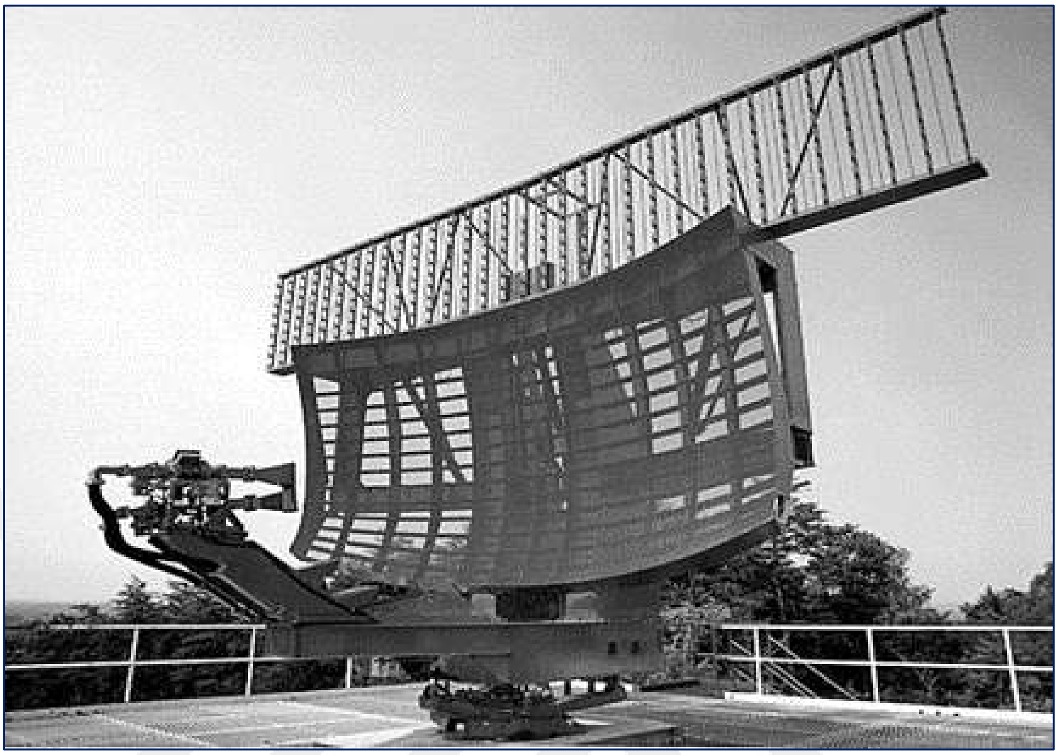


Figure 5.5 ASR-9 [138].

The Northrop Grumman ASR 9 stands as a highly utilized advanced radar system, notably recognized as the first airport surveillance radar to concurrently depict both weather patterns and aircraft. Distinguishing itself, the ASR 9 integrates circular polarization with moving target detection, resulting in significantly enhanced aircraft detection capabilities during adverse weather conditions. Positioned atop the radar antenna is the IFF antenna, instrumental in discriminating between friendly and hostile entities. With an operational range extending up to 60 nautical miles, the ASR 9 establishes itself as a versatile and reliable radar system in aviation surveillance [138]. Its specifications are shown in Table 5.5.

Table 5.5 ASR-9 [138].

Peak Power	1.3 Mwgawatt
Instrument Range	Up to 60 NM
Range Resolution	450 ft

5.2.2 IR/EO/Daylight Cameras

In various applications such as air defense systems and border security, a variety of IR/EO/Daylight cameras are available. In this section, these cameras and their features are examined under a few examples.

5.2.2.1 SPYNEL-X

Figure 5.6 SPYNEL-X [139].

SPYNEL-X, employed for purposes such as airport/airfield surveillance, military base protection, and maritime wide area surveillance, is a high-resolution Infrared Search and Track sensor providing 360-degree viewing capability. It conducts night and day imaging in all weather conditions [139]. SPYNEL-X encompasses various models, with the features of two models examined in Table 5.6.

Table 5.6 Specification of SPYNEL-X's [139].

	SPYNEL-X 3500	SPYNEL-X 8000
Horizontal FOV	360°	360°
Vertical FOV	20°	5°
Vertical motorized tilt	± 45°	± 45°
IFOV	0.3 x 0.3 mrad x mrad	0.08 x 0.08 mrad x mrad

Table 5.6(continued) Specification of SPYNEL-X's [139].

	SPYNEL-X 3500	SPYNEL-X 8000
Scanning speed	2 rps (360°/0.5sec)	0.5 rps (360°/2sec)
Detector type	MWIR megapixel FPA	MWIR megapixel FPA
Cooling	Stirling microcooler	Stirling microcooler
Image resolution	23 000 (H) x 1280 (V)	92 000 (H) x 1280 (V)
Video output and control	IP	IP
Dimensions (Dia x H)	385 mm x 580 mm	385 mm x 580 mm
Weight	< 40 kg	< 40 kg
Operating temperature	-40°C to +71°C	-40°C to +71°C
Protection standard	IP 66	IP 66
Power supply	24V DC / 10 Amps	24V DC / 10 Amps
Detection range for Human: Vehicle: RHIB:	 Up to 2.5 km Up to 5 km Up to 5 km	 Up to 9 km Up to 12.5 km Up to 12.5 km

5.2.2.2 TV/GUARD

Figure 5.7 TV/GUARD [140].

Manufactured by the Turkish company Transvaro, the TV/GUARD is a multi-sensor camera designed for tracking moving targets. It is equipped with a Short-Wave Infrared (SWIR) camera, a Mid-Wave Infrared (MWIR) cooled thermal camera, a low-light daytime camera, a laser rangefinder, a laser designator, GPS, and an electronic compass [140]. The integration of these multiple sensors enables effective detection. Its specifications are shown in Table 5.7.

Table 5.7 TV/GUARD [140].

	For Human(1.8m x 0.5m);	For NATO(2.3m x 2.3m);
Detection Range	≥ 12 km / 17 km	≥ 26 km / 32 km
Identification Range	≥ 3 km / 4.3 km	≥ 6.5 km / 9.4 km
Recognition Range	≥ 1.5 km / 2.1 km	≥ 3.2 km / 4.7 km
Camera	Resolution: 2 megapiksel 1920x1080 Electronical Zoom: 8x Optical Zoom: 35x Visual Angle: 2.3°~ 56°	
Weight	20 kg	

5.2.3 Accoustic Sensors

Acoustic sensors are devices that analyze the sounds produced by the rotors/motors providing power to UAV propellers, allowing for the identification of UAVs. Microphones placed in different locations capture these sounds and feed them into the system. However, this method is ineffective for fixed-wing UAVs and UAVs in free fall. Additionally, the system can be deceived by attaching a different motor or propeller to an existing UAV. Its most effective range is 500m. Another disadvantage is its susceptibility to ambient noise [141]. The picture of Acoustic Sensor produced by DroneShield is shown in Figure 5.8.

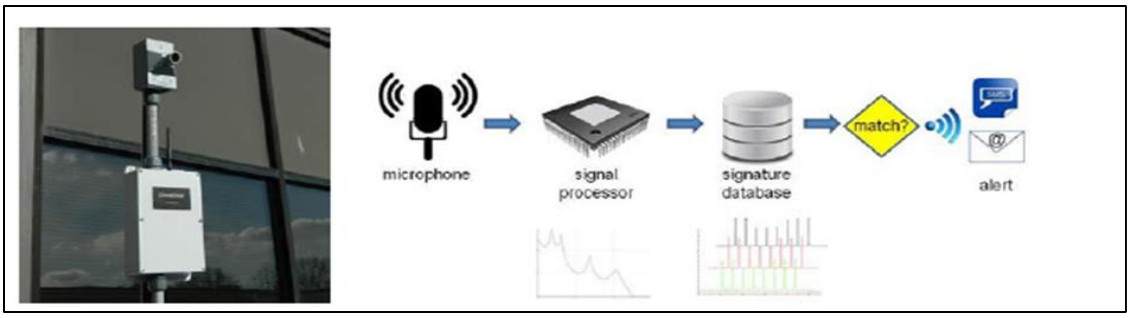


Figure 5.8 Accoustic Sensor [141].

Even if threatening UAVs cannot be detected due to factors such as low altitude or a low radar cross-section, these sensors have the capability to identify them. Since each UAV carries a unique sound signature, this method allows for UAV detection by evaluating the sound signature. In this context, the operational principle of Acoustic Sensors produced by DroneShield is examined below. Numerous microphones in the system continuously listen to the surrounding sounds in real-time. These listened sounds are digitized with the help of signal processors. The acquired data is compared with sound data in the database, and if a match is found, an alert is triggered. Alerts can be conveyed to users through email, SMS, video systems, or visual interfaces [141].

5.3 Proposed Algorithm Review

In contemporary airspace monitoring systems, the need to rapidly and accurately identify, classify, and neutralize aerial threats, especially UAVs, has become crucial. This thesis delves into this subject and proposes the use of Kamikaze Drones as a novel method for rendering threatening UAVs ineffective. Although the proposed method has not been experimentally tested, a flowchart and pseudocode have been developed as an approach. It is essential to note that the use of Kamikaze Drones has been evaluated not in isolation but as an integrated part of a defense system. In the subsequent sections, an algorithm is outlined and systematically examined to ensure the effective detection and subsequent classification of UAVs.

In accordance with the illustrated Figure 5.9 the process encompassing the detection of a threatening UAV and rendering it ineffective involves an underlying algorithm and sequential steps. Within this scope, the necessary steps for the system's operation have been meticulously examined below, and pseudo-code pertaining to the algorithm has been generated.

In light of the provided information, the following steps have been formulated:

1. System Initialization,
2. Sensor Scanning,
3. Data Verification,

4. Object Verification,
5. Friend/Enemy Verification,
6. Threat Verification,
7. Kamikaze-Drone Direction,
8. Mission Completion.

These steps outline the systematic process for the effective utilization of the proposed algorithm, ensuring the readiness and functionality of the system for the identification and neutralization of threatening UAVs.

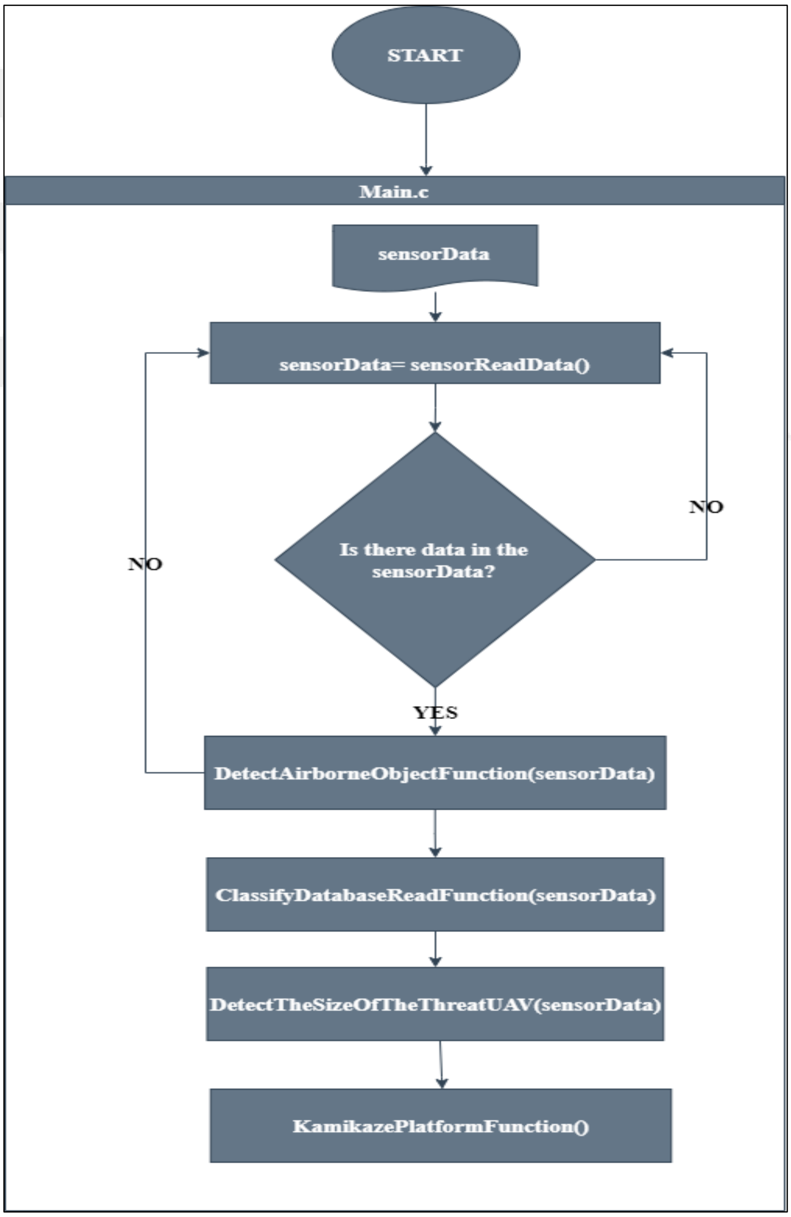


Figure 5.9 Proposed main flow chart of kamikaze drone usage in defense system.

5.3.1 System Initialization

Initially, the system installation is carried out, followed by the initiation of the system. Upon system initialization, the first action mandates a reset of the data acquisition sensor to its default state. This ensures the system commences data acquisition from a neutral standpoint, eliminating any potential data remnants from prior scans. The sensor reset process is a necessary process for the detection of the aircraft to be healthy. The proposed pseudo-code is presented below.

START

RESET_SENSOR()

5.3.2 Sensor Scanning

Once the sensor resets, the system engages in an active scanning mode. Active scanning is carried out by Radar, E/O,I/R,Daylight cameras, accoustic sensors in the system. Active scanning is performed using Search Radar and IFF Radar. E/O and I/R cameras enable UAV detection, with E/O and I/R cameras utilized during the night and daylight cameras during the day. The Accoustic sensor can also contribute to identifying the type of UAV based on its motor sound. In this step, it is crucial to ensure that the cameras are strategically positioned to cover each other's blind spots. The deployment of multiple sensors at various locations is essential for enhancing the probability of detecting threats. In the proposed defense system, operators should be present to enable the accurate evaluation of data from the sensors. While the radar continues its 360-degree scanning, cameras can provide support to the system through both artificial intelligence and operator assistance.

This step is critical in neutralizing threatened UAVs, and the proposed pseudo-code is presented below.

data = READ_SENSOR_DATA()

After reading the data from the sensors, the acquired information is stored in a variable named 'data.' Additionally, the flowchart designed for this step resembles Figure 5.10.

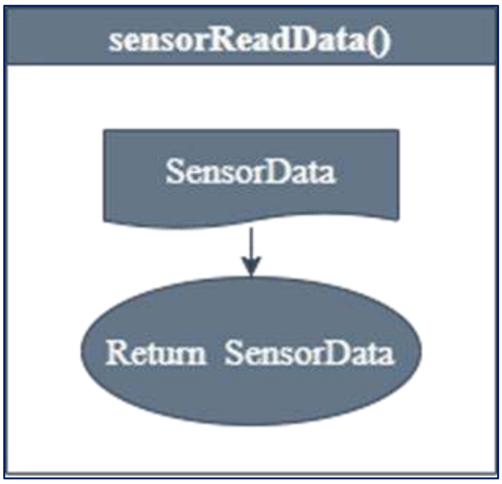


Figure 5.10 Proposed flowchart of sensorReadData function.

5.3.3 Data Verification

If an object is detected in the air, a warning is received in Command Control Center. However, in the absence of detected data, the system intuitively reverts to its reset state, emphasizing the importance of continuous monitoring. The crucial aspect here is not to rely solely on one sensor for decision-making in detection. For instance, a radar might not detect an aircraft due to its altitude, but the same aircraft could be identified using a daylight camera. In this context, any detection from even a single sensor is considered for evaluation. The Figure 5.11 depicts an example scan. It can be inferred that there is a detection at the location indicated by the black dot.

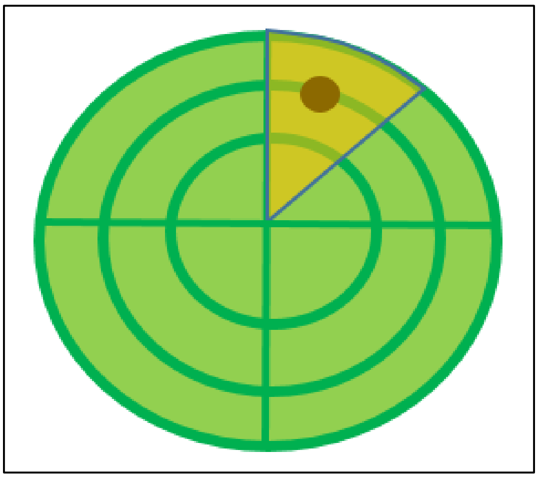


Figure 5.11 Example of Radar Detection Proposed flowchart of sensorReadData function.

When the radar detects an object, as exemplified in the figure, the detection is indicated in the system by a black dot. The green circled areas represent the radar's coverage, and the yellow-shaded circle denotes the momentarily scanned area.

The other types of sensors, namely I/R and daylight cameras, can be utilized for detection through artificial intelligence, aided by operators overseeing the system 24/7. It is recommended to employ the Acoustic sensor, another recommended sensor, in conjunction with Radar/I/R/Daylight sensors to gather additional information about the detected object.

The proposed pseudo-code is presented below.

```
IF data is detected THEN
        PRINT("Detection in the air")
        ...
        ...
ELSE
        PRINT("No detection in the air")
```

The 'data' variable in the provided pseudo-code represents the information obtained by the sensors used in the defense system. If the sensors detect an object in the air, the system is expected to proceed to the next stage, displaying the 'Detection in the air' alert. If no object is detected, it should output 'No detection in the air' and return to the stage of reading data from the sensors.

5.3.4 Object Verification

The essence of this algorithm lies in its ability to discern the type of detected objects in the air. During detection, the system intelligently determines whether the object is an aircraft. Situations such as wind, birds, and meteorological factors are filtered within the system during detection, aiding in the determination of whether the detection pertains to an aircraft.

To ascertain whether the detected object in the air is an aircraft, additional information from the IFF antenna is utilized in this stage, complementing the Search Radar. If a response signal is received at 1090 MHz in response to the query signal sent at 1030 MHz, it can be evaluated that the detection is associated with an aircraft.

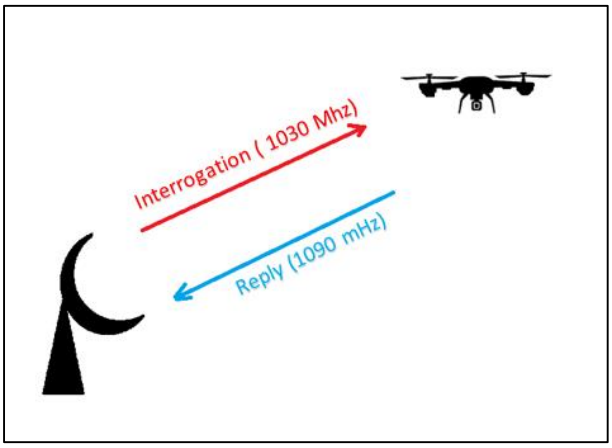


Figure 5.12 IFF Interrogation and Reply.

Similar to the preceding stage, Data Verification, if the detected object can be identified using I/R and daylight cameras, a decision can be made regarding whether it is an aircraft. The parameters of the detected object, including its motion pattern and velocity, are processed through the integrated artificial intelligence system. In this context, the proposed flowchart is illustrated in Figure 5.13.

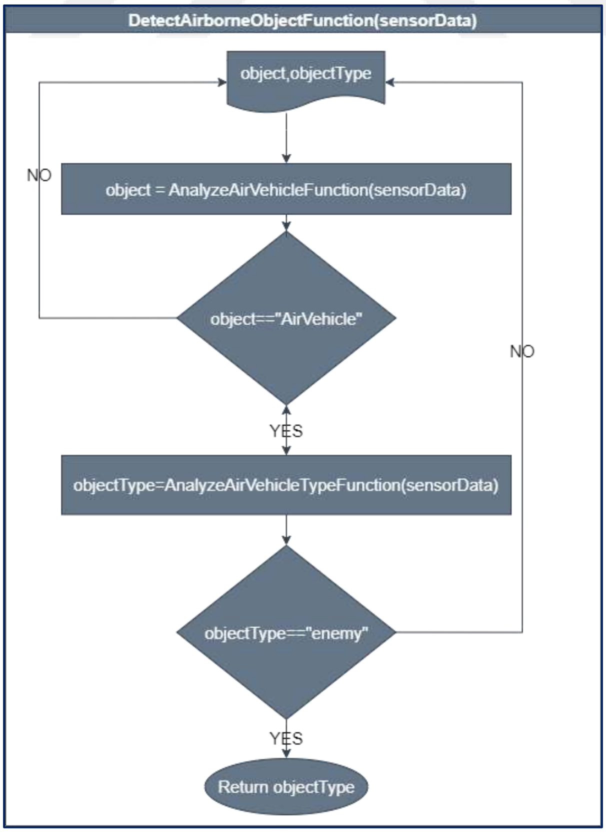


Figure 5.13 Proposed Flowchart of DetectAirborneObject Function.

The flowchart specified in Figure 5.14 illustrates several steps within the algorithm. Subsequent sections examine these steps individually in the form of separate flowcharts.

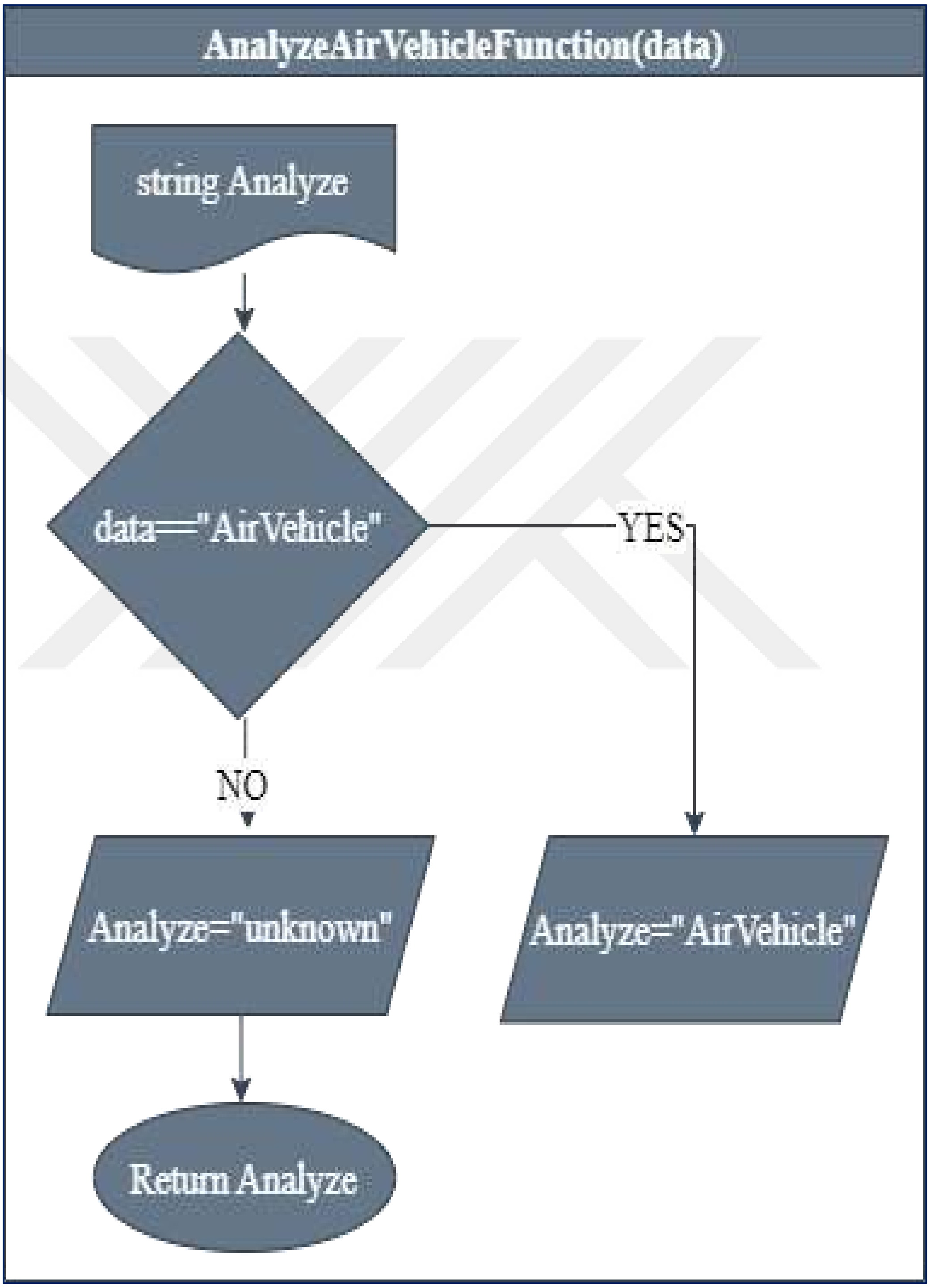


Figure 5.14 Proposed flowchart of AnalyzeAirVehicleFunction.

The proposed pseudo-code is presented below.

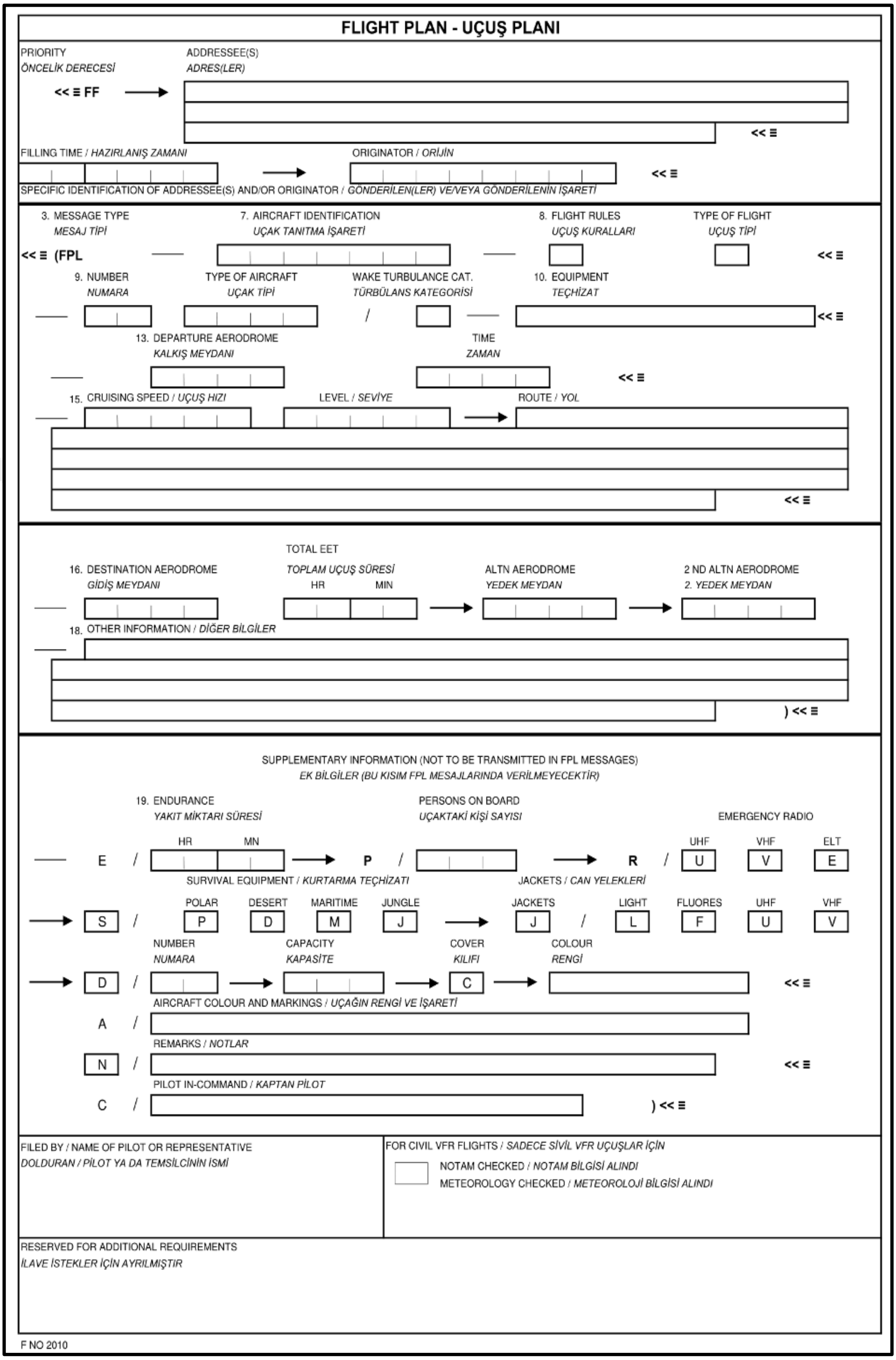
```
IF data is aircraft THEN
        PRINT("Detected object is an aircraft")
         .....
         .....
ELSE
        PRINT("Detected object is not an aircraft")
END IF
```

The data, which is compared and filtered with the database, is labeled as either 'Air Vehicle' or 'Unknown,' and then assigned to the 'Analyze' variable. If an aircraft is detected, the 'AnalyzeAirVehicle' function is entered, triggering a notification of "*Detected object is an aircraft.*" Subsequently, the algorithm proceeds to the next phase, which is the Friend/Enemy Verification stage. However, if it is not an aircraft, the algorithm reverts to the scanning stage, accompanied by a notification stating "*Detected object is not an aircraft*.

5.3.5 Friend/Foe Verification

The system then proceeds to consult a database to determine if the detected aircraft is categorized as friend or foe. In this context, flight notifications and plans play a significant role in the identification of friendly entities. The daily maintenance of flight plans and flight requests in a database is considered crucial for determining whether the detected aircraft is of friendly or foe origin.

According to AIP ENR-1.10 – 1 document, to expedite the issuance of ATC clearance, flight plans should be submitted at least 30 minutes before departure and no more than 5 days (120 hours) in advance [142]. In this context, the filled Flight Plan is illustrated Figure 5.15 Information such as aircraft type, flight level, cruising speed, route and IFF code are obtained from the Flight Plan.



FLIGHT PLAN - UÇUŞ PLANI

PRIORITY
ÖNCELİK DERECESİ

ADDRESSEE(S)
ADRES(LER)

<< ≡ FF

<< ≡

FILLING TIME / HAZIRLANIŞ ZAMANI

ORIGINATOR / ORİJİN

<< ≡

SPECIFIC IDENTIFICATION OF ADDRESSEE(S) AND/OR ORIGINATOR / GÖNDERİLEN(LER) VE/VEYA GÖNDERİLENİN İŞARETİ

3. MESSAGE TYPE
MESAJ TİPİ

7. AIRCRAFT IDENTIFICATION
UÇAK TANITMA İŞARETİ

8. FLIGHT RULES
UÇUŞ KURALLARI

TYPE OF FLIGHT
UÇUŞ TİPİ

<< ≡ (FPL

<< ≡

9. NUMBER
NUMARA

TYPE OF AIRCRAFT
UÇAK TİPİ

WAKE TURBULANCE CAT.
TÜRBÜLANS KATEGORİSİ

10. EQUIPMENT
TEÇHİZAT

/

<< ≡

13. DEPARTURE AERODROME
KALKIŞ MEYDANI

TIME
ZAMAN

<< ≡

15. CRUISING SPEED / UÇUŞ HIZI

LEVEL / SEVİYE

ROUTE / YOL

<< ≡

16. DESTINATION AERODROME
GİDİŞ MEYDANI

TOTAL EET
TOPLAM UÇUŞ SÜRESİ
HR MIN

ALTN AERODROME
YEDEK MEYDAN

2 ND ALTN AERODROME
2. YEDEK MEYDAN

18. OTHER INFORMATION / DİĞER BİLGİLER

) << ≡

SUPPLEMENTARY INFORMATION (NOT TO BE TRANSMITTED IN FPL MESSAGES)
EK BİLGİLER (BU KISIM FPL MESAJLARINDA VERİLMEYECEKTİR)

19. ENDURANCE
YAKIT MİKTARI SÜRESİ

PERSONS ON BOARD
UÇAKTAKİ KİŞİ SAYISI

EMERGENCY RADIO

HR MN

UHF VHF ELT

E / P / R / U V E

SURVIVAL EQUIPMENT / KURTARMA TEÇHİZATI

JACKETS / CAN YELEKLERİ

POLAR DESERT MARITIME JUNGLE

JACKETS LIGHT FLUORES UHF VHF

S / P D M J

J / L F U V

NUMBER
NUMARA

CAPACITY
KAPASİTE

COVER
KILIFI

COLOUR
RENGİ

D / C

<< ≡

AIRCRAFT COLOUR AND MARKINGS / UÇAĞIN RENGİ VE İŞARETİ

A /

REMARKS / NOTLAR

N /

<< ≡

PILOT IN-COMMAND / KAPTAN PİLOT

C /

) << ≡

FILED BY / NAME OF PILOT OR REPRESENTATIVE
DOLDURAN / PİLOT YA DA TEMSİLCİNİN İSMİ

FOR CIVIL VFR FLIGHTS / SADECE SİVİL VFR UÇUŞLAR İÇİN

NOTAM CHECKED / NOTAM BİLGİSİ ALINDI
METEOROLOGY CHECKED / METEOROLOJİ BİLGİSİ ALINDI

RESERVED FOR ADDITIONAL REQUIREMENTS
İLAVE İSTEKLER İÇİN AYRILMIŞTIR

F NO 2010

Figure 5.15 Flight Plan [142].

In this context, it is deemed appropriate for military and civilian flights to reach the Command and Control Center through methods such as flight plans and notification tools like phones. The integration of data from the General Directorate of State Airports Authority and other sources into the system's established database is planned. In this regard, the Flight Plan database is recommended to be structured as Table 5.8.

Table 5.8 Flight Plan Table.

Call Sign	Aircraft Type	IFF	Departure Airbase	Landing Airbase	Departure Time	Landing Time	Flight Level
THY3AA	A330	1453	ISPARTA	ANKARA	1400	1515C	FL320

Through this created table, it is possible to determine whether the detected aircraft in the air is friendly or hostile. The first and crucial stage in making the friend/foe distinction is the use of the IFF system.

In this context, if it is determined that the detected track belongs to an aircraft, an IFF query is sent to the relevant aircraft.

a. If the aircraft has responded to the IFF query;

- If the vehicle to which the IFF query is sent has a transponder device, it sends a 4-digit number (like 1071) to the querying IFF antenna.
- The received 4-digit number is compared with the information in the flight plan in the existing database.
- Simultaneously, information such as altitude/speed/course from the Search Radar is also compared with the database.
- Whether the relevant aircraft is in contact with any control station is determined by establishing contact with the relevant stations.
- Based on this information, if the data from the radars matches the database and the aircraft is in contact with a control station, the detected aircraft is classified as "Friendly." Subsequently, the sensors continue scanning the airspace.

b. If the aircraft has not responded to the IFF query;

- The information received from the Search Radar (altitude/speed, etc.) is compared with the data in the database. If these pieces of information do not match and it is confirmed that the aircraft is not in contact with any control station, the system classifies the respective track as 'Hostile'.

However, if the information received from the Search Radar (altitude/speed, etc.) does not match the data in the database and the aircraft is in contact with a control station, it may still be considered friendly.

If identified as a threat or hostile UAV, an alert signal is issued to the system. If it's not a threat, the system resets the sensor. The proposed flowchart, developed based on all this information, is presented in Figure 5.16.

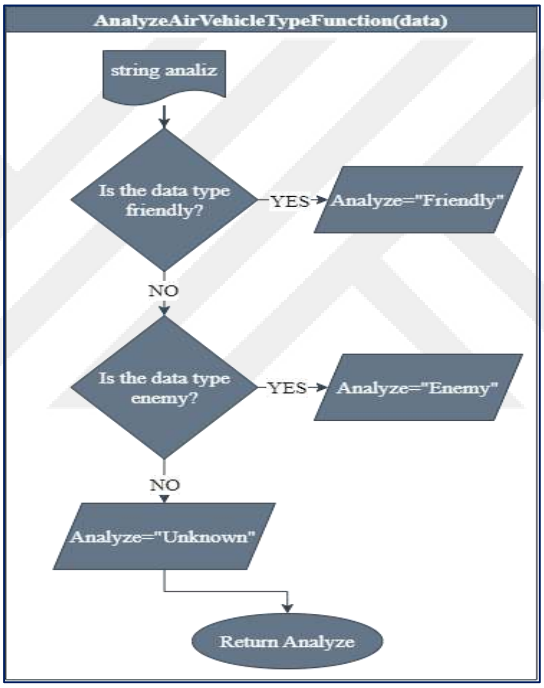


Figure 5.16 Proposed flowchart of AnalyzeAirVehicleTypeFunction.

The proposed pseudo-code is provided below.

```
status = CHECK_DATABASE_FOR_FRIEND_OR_FOE()
IF status is foe THEN
        PRINT("Threat UAV detected")
          SEND_ALERT_SIGNAL()
      ………
ELSE
        PRINT("Detected entity is friendly")
END IF
```

As indicated in both the flowchart and pseudo-code, if the identified UAV is determined to be an enemy, a "*Threat UAV detected*" alert is displayed on the screen, and the system sends a warning to users through the SEND_ALERT_SIGNAL() function to stay vigilant. If the UAV/aircraft is friendly, a "*Detected entity is friendly*" message is presented on the screen.

5.3.6 Threat Verification

Subsequently, the system checks whether the detected UAV's specifications are predefined in the database.

At this stage, the determination of the UAV type involves comparing the images captured by I/R and daylight cameras with the database. Simultaneously, the type of the UAV detected by radar is determined by comparing information such as speed, altitude, and radar cross-section with the database's UAV information, addressing potential threats. Additionally, the type of the detected aircraft can be established by utilizing acoustic signatures from various microphones forming acoustic sensors in the protected area. However, the use of acoustic sensors faces significant limitations, including a short range, susceptibility to environmental noise, and the inability to detect UAVs without engines.

Within this context, it is considered beneficial to determine which Kamikaze Drone will be employed against the detected UAVs through the relevant sensors. Determining the Kamikaze Drone to be used against previously detected UAVs can facilitate faster and more effective intervention. Detected UAVs can be categorized based on weight, relying on the Directorate General of Civil Aviation's UAV Classification for classification standards. In this thesis, UAVs labeled as İHA0 and İHA1 are examined within the same class.

In summary, at this stage, the system makes decisions about the type of the detected UAV by comparing images captured by I/R and daylight cameras with the database, determining the threat level of the UAV detected by radar, and utilizing acoustic sensors to further confirm the type of the detected aircraft.

The categorization of UAVs based on weight is considered for an efficient response, following the classification standards provided by relevant aviation authorities.

Table 5.9 Classification of UAVs.

Class	MTOW
UAV0	Between 500 g and 25 kg
UAV1	Between 25 kg and 150 kg
UAV2	Bigger than 150 kg

After the stage of determining the UAV type through the system's sensors, the appropriate Kamikaze Drone specified in the database is selected. In this context, for UAV Class 0, a Small Payload Kamikaze Drone is chosen, for UAV Class 1, a Medium Payload Kamikaze Drone is selected, and for UAV Class 2, a High Payload Kamikaze Drone is chosen. Here, Kamikaze Drones are classified based on the explosives they carry.

If the sensors cannot identify the UAV type, the system defaults to selecting the Medium Payload Kamikaze Drone. In this section, for the system to operate more effectively and make clearer detections, sensor data is recorded in the database for later use. Following the fall of the UAV, ground personnel determine the UAV's type.

After identifying the UAV type, the sensor data is matched with the UAV type and recorded in the database, facilitating easier detection by the system in the event of the UAV being used as a threat.

Once the selection of the Kamikaze Drone is determined, personnel perform final checks on the Kamikaze Drone ready on the catapult and prepare it for launch. The Kamikaze Drone can be launched from the catapult, as exemplified Figure 5.17. The catapult, being not fixed to the ground and lightweight, possesses the capability to be transported to the desired location.

Figure 5.17 Scorpion UAV Catapult Launcher [143].

In this context, the flowchart designed for selecting the appropriate Kamikaze Drone against the detected threat UAV is depicted in Figure 5.18.

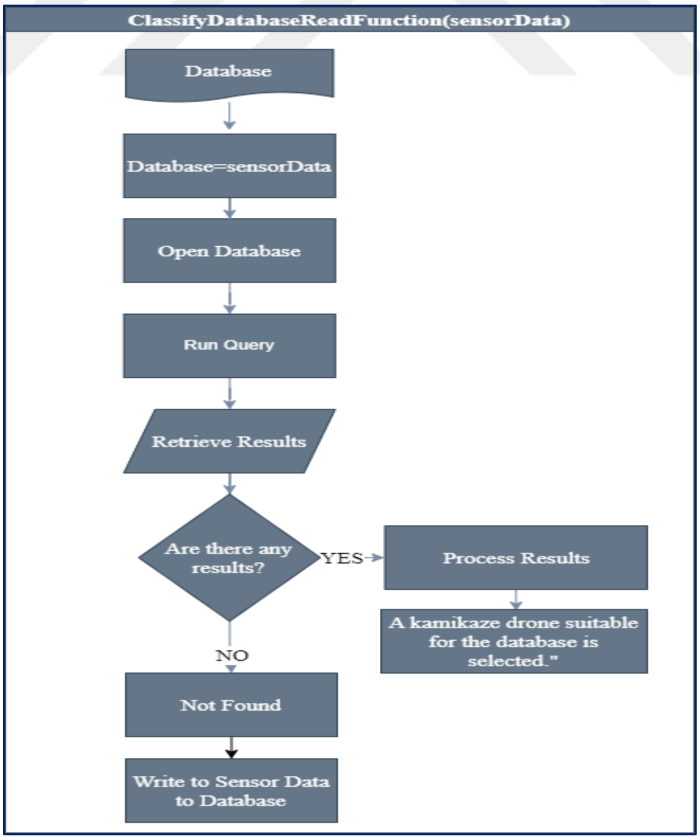


Figure 5.18 Proposed Flowchart of ClassifyDataReadFunction.

The proposed pseudo-code is provided below.

```
known = CHECK_IF_UAV_IS_KNOWN_IN_DATABASE()

IF unknown THEN
        size = DETERMINE_UAV_SIZE()

IF size is small THEN
        SELECT_KAMIKAZE_DRONE_WITH_LOW_PAYLOAD()
        PRINT("Low payload kamikaze drone selected")
        SAVE_SENSOR_DATA_TO_DATABASE()

ELSE IF size is medium THEN

        SELECT_KAMIKAZE_DRONE_WITH_MEDIUM_PAYLOAD()
        PRINT("Medium payload kamikaze drone selected")
        SAVE_SENSOR_DATA_TO_DATABASE()

ELSE IF size is large THEN
           SELECT_KAMIKAZE_DRONE_WITH_HIGH_PAYLOAD()
           PRINT("High payload kamikaze drone selected")
           SAVE_SENSOR_DATA_TO_DATABASE()
END IF
ELSE
          SELECT_DATABASE_DEFINED_KAMIKAZE_DRONE()
          PRINT("Appropriate kamikaze drone ready")
          END IF

          SAVE_UAV_SIGNAL_DATA_TO_DATABASE()
          PRINT("UAV saved to database")
```

The flowchart devised for this stage is provided Figure 5.19.

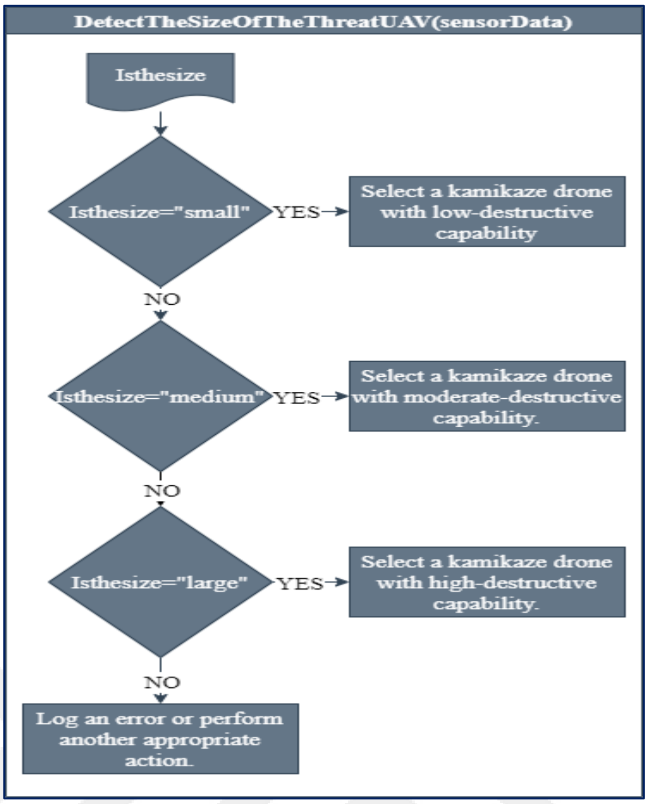


Figure 5.19 Proposed flowchart of DetecttheSizeOfTheThreatUAV.

5.3.7 Kamikaze-Drone Direction

The system determines the position, altitude, speed, and direction parameters of the detected UAV through sensors. An analysis is conducted on these parameters. Based on the analysis performed by the system, it is determined whether the detected threat UAV's movement is variable or stable.

- If the UAV is stable, meaning its parameters such as direction, speed, and altitude show minimal variability, the autonomous guidance of the Kamikaze Drone to be launched is planned as a priority.
- If UAV parameters exhibit significant variability, for example, if there is a situation where the detected altitude changes from 400 ft to 300 ft and then back to 500 ft, the semi-autonomous use of the Kamikaze Drone is considered important for the system's effectiveness.

In this context, the Katapult automatically rotates in the desired direction for the prompt neutralization of the threat UAV by the ready-to-launch Kamikaze Drone. Subsequently, the Kamikaze Drone is launched towards the threat UAV. After being launched, the Kamikaze Drone directed towards the UAV is tracked in real-time by the ground control center.

- If the threatening UAV has been neutralized, the mission is considered successful.
- If the UAV cannot be neutralized but can be re-engaged, it is redirected towards the threatening UAV by the ground station.
- If the UAV cannot be neutralized and is in a condition where the Kamikaze Drone cannot be used again, an alert is sent to the system, and a plan is made to launch another Kamikaze Drone. The flowchart devised for this stage is provided Figure 5.20.
- If the Kamikaze Drone fails to hit the threatened UAV for any reason and remains reusable, it can safely land with its built-in parachute.

The proposed pseudo-code is provided below.

```
uav_parameters = GET_UAV_POSITION_SPEED_DIRECTION()

LAUNCH_KAMIKAZE_DRONE_TOWARDS_TARGET()
PRINT("Kamikaze drone directed towards target")

IF uav_parameters are not stable THEN
        USE_NON_AUTONOMOUS_CONTROL_FROM_GCS()
ELSE
        DRONE_PROCEEDS_AUTONOMOUSLY()
END IF

IF Target_Not_Destroyed And Drone_Is_Reusable THEN
CONTINUE

IF Target_Not_Destroyed And Drone_Is_Not_Reusable THEN
        NEW_KAMİKAZE_DRONE_LAUNCH()
END IF
```

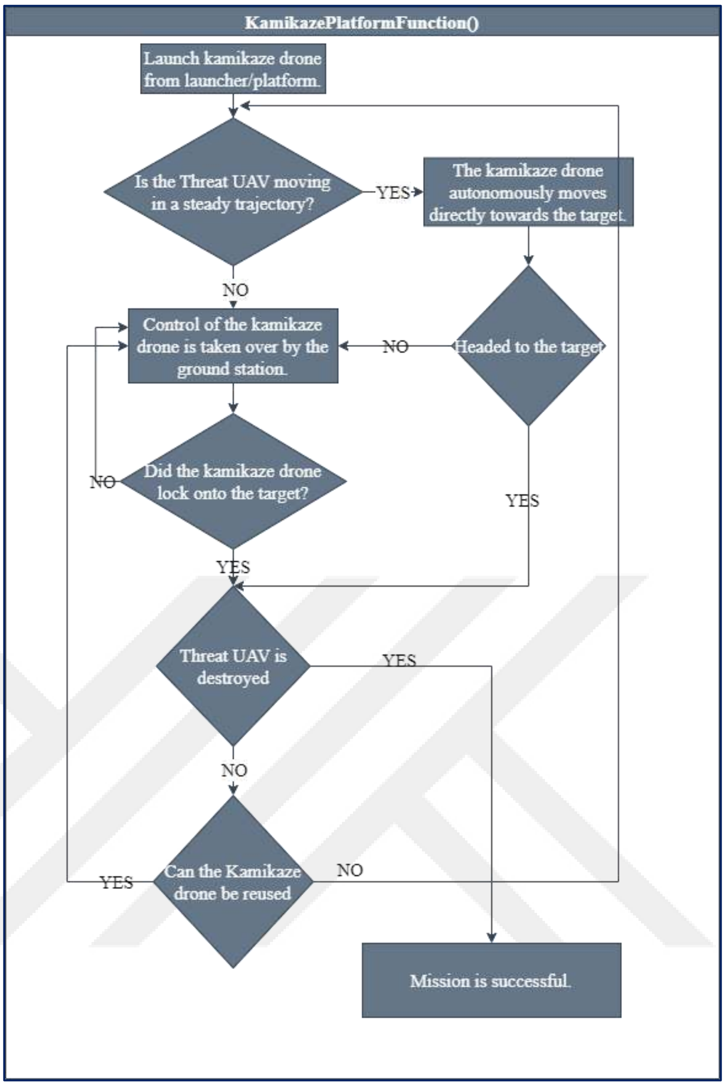


Figure 5.20 Proposed flowchart of Kamikaze Platform Function

5.3.8 Mission Completion

If the hostile target is successfully neutralized, the system confirms "Mission successful, target destroyed", logs the event, and resets to ensure continuous monitoring. The proposed pseudo-code is provided below.

```
ELSE
        PRINT("Mission successful, target destroyed")
        LOG_THE_MISSION()
END IF

UNTIL SYSTEM_SHUT_DOWN
```

If the threatening UAV is successfully neutralized, the LOG_THE_MISSION() function is employed to maintain a record of the mission. Subsequently, the system receives a notification of "*Mission successful, target destroyed*." Following this, the system continues its operation until it is shut down using SYSTEM_SHUT_DOWN. The sensors revert to the scanning step.

For a more comprehensive and coherent examination, the complete proposed pseudo-code, previously delineated in fragmented segments within the thesis, has been provided Appendix A.

CHAPTER 6

CONCLUSION

In this study, which examines the defense systems used against UAVs; In the first part, the definition, historical development and classification of UAVs are discussed. First of all, it has been seen that there is no fixed and single definition of UAVs and it varies from person to person and country to country. It has been understood that the definition of aircraft that can be remotely controlled or acted autonomously, on which payloads can be mounted, is emphasized. In the historical development part of UAVs, which is another subject examined, the history of UAVs in the world and the history of UAVs used in Türkiye were examined in general terms. It has been seen that the adventure that started with a hot air balloon started the development process of UAVs, opening a great age by producing radio-controlled aircraft. In this context, it has also been noticed that its use for surveillance and attack purposes has increased. It has been determined that it is a great power multiplier especially in the wars that affected history such as the Yom Kippur War, the Gulf War and Kosovo in the Middle East. It has been observed that their numbers are gradually increasing and they are an indispensable element especially in wars and operations. In the chapter, the main UAVs used in the world for many purposes such as surveillance, attack and intelligence are examined.

In this context, it has been observed in Global Hawk, MQ-9 Reaper, RQ-11B, Hermes 900, HESA Shaded-136, Lancet Kamikaze Drones, Zala KYB-UAV Drones and IAI Harop. It has been examined that they were used for many purposes such as surveillance in the Tokyo earthquake and Philippines typhoon, fighting against DAESH, ISR and attack in Iraq, Afghanistan, Russia-Ukraine, Nagorno-Karabakh Wars. After the main UAVs used in the world, UAV projects in Türkiye and the UAVs used are also discussed. It has been seen that Türkiye's unmanned aerial vehicle adventure started with Meggitt Banshee and continued with the first domestic work, TAI UHA-X1 Witness. In this context, GNAT 750, CL-89, Turna and Keklik, Martı and Pelikan, Harpy, Anka and Anka/S, Bayraktar Mini, Heron, Karayel, Bayraktar TB2, Aksungur, Alpagu, Kargu, Togan, Alpagut, Boyga, Akıncı, Bayraktar DIHA, Bayraktar TB3 and Kızılelma UAVs are classified according to their technical features and uses.

It has been seen that UAVs are used for many purposes such as testing, ISR, aerial image acquisition and digital image analysis studies, coastal erosion investigations, as well as for many purposes such as target in exercises such as Anatolian Eagle Exercises. Especially in areas that cannot be entered due to geographical conditions, the UAVs produced and used by Türkiye have been very effective against terrorists. When examined in terms of usage in the world, it was seen that Bayraktar TB-2 was used in Azerbaijan and Ukraine and changed the course of the war in the wars that took place there. In the Nagorno-Karabakh war, it was considered to be the most effective UAV in winning the war.

In the first chapter, the classification of UAVs was continued and it was seen that they were classified according to many categories such as usage area, wing type, flight altitute. In this context, classifications according to Türkiye Directorate General of Civil Aviation, NATO, UK, US, European Civil UAV Roadmap and European UAS Community were examined.

In the second part, the UAV attacks against Türkiye and the examples of UAV attacks in the world are discussed in two parts. UAV attacks against Türkiye by terrorists were generally aimed at military base areas and military areas, by integrating cameras into small UAVs in general, and by placing surveillance and bombs to attack. The section continued with the UAV attacks in the world. In general, attacks on hard-to-reach places using UAVs are explained. Threatened unmanned aerial vehicles must first be detected, their purpose must be learned (assessed whether they are a threat), and they must be neutralized.

In the third part, the situations mentioned in the previous sentence are examined. The methods of detecting UAVs are generally examined under the headings of radars, RF Analysis, Acoustic Analysis, EO/IR Camera and Human Eye. Then, the neutralizing methods of UAVs used in the world were examined and listed under the titles of Laser, Weapons, Manipulation, GPS Jamming, RF Jamming, Net and Birds. Some examples of usage of related methods are stated in the research. In the last section, the main Anti-

UAV Systems used in Türkiye and in the world are explained. In the last section, the main Anti-UAV systems used in Türkiye and in the world are explained. In the light of this information, the biggest step in neutralizing UAVs is detection. As examined in the study, there are a wide variety of UAV detection methods. However, as technology develops, UAV technology also develops.

In the study, it was noticed that one of the detection methods is radar and there are generally 2 types of radar. In this context, it is known that if an unmanned aerial vehicle does not have an IFF system, it can only be detected with the search radar, but the search radar is also very sensitive to environmental conditions and does not see low altitudes due to geographical conditions. In addition, nano and stealth technology are also becoming widespread. It is considered that with these technologies, it will be difficult to detect UAVs. In this context, radars used in Defense Systems must have a layered radar coating that can meet all altitude values. Thanks to the Low-Medium-High altitude coating, it will be easier to detect. It is evaluated that it will be easy to detect using multisensors such as EO/IR camera, RF Analysis, Acoustic Analysis. It has been determined that it would be appropriate to use multi-methods to neutralize UAVs, which are considered as a threat. For example, it is known that the GPS Jamming method can affect civil air traffic, as well as the devices operating in the environment in RF Jamming.

In the light of all this information, the use of Kamikaze Drones has been suggested in addition to the Defense Systems that can be used against UAVs. It is considered that Kamikaze Drones can be used against threatening UAVs and play an active role in the fight, due to the advantages of being able to be launched from any location, being inexpensive and being ready for use quickly. The utilization of Kamikaze Drones has been conceptualized and developed in conjunction with the defense system as a whole. Examples of sensors that could be employed in the system have been provided, and all stages, from system initialization to rendering the UAV ineffective, have been systematically examined step by step.

In this context, the use of Kamikaze Drones against threatening UAVs has been determined within the thesis, and an algorithm has been developed. The relevant algorithm has been meticulously examined step by step. However, it is assessed that further enhancement of the said algorithm for practical implementation within systems would be beneficial.

As a result, it is considered that it is of great importance for the Air Defense System to use a layered Defense System Against Unmanned Aerial Vehicles and aircraft that may pose a threat, as well as to reinforce the system with Kamikaze Drone and to fight more effectively.

REFERENCES

[1] ICAO. Global Air Traffic Management Operational Concept. Retrieved January 18, 2022, from https://www.icao.int/Meetings/anconf12/Document%20Archive/9854_cons_en%5B1%5D.pdf. 2005

[2] Guilmartin, J.F. *Unmanned Aerial Vehicle*, Retrived January 19, 2022, from https://www.britannica.com/technology/unmanned-aerial-vehicle. July 15, 2020

[3] Presidency of the Republic of Türkiye Presidency of Defence Industries. Türkiye Unmanned Aerial Vehicle Systems Roadmap (2011-2030). Retrieved January 22, 2022, from http://ercancinar.com/wp-content/uploads/2017/10/SSM_%C4%B0HA_Sistemleri_Yol_Haritas%C4%B1_2012.pdf. December 2011

[4] Newcome, L.R. *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles*. American Institute of Aeronautics and Astronautics, ISBN 1-56347-644-4, 173 pages, Reston 2004.

[5] Karaağaç, C. Geleceğin Harekât Ortamında İHA Sistemleri: Askeri Uygulamalar & Teknoloji Gereksinimleri. Retrieved January 20, 2022, from https://www.academia.edu/7911351/Gelece%C4%9Fin_Harek%C3%A2t_Ortam%C4%B1nda_%C4%B0HA_Sistemleri_Askeri_Uygulamalar_and_Teknoloji_Gereksinimleri. 2014

[6] Pre-aviation UAVs Perley's Aerial Bomber (USA). (n.d.). Retrieved January 22, 2022, from https://www.pbs.org/wgbh/nova/spiesfly/uavs_01.html

[7] Akyürek, S., Yılmaz, M. A., Taşkıran, M. İnsansız Hava Araçları Muharebe Alanında ve Terörle Mücadelede Devrimsel Dönüşüm. Retrieved January 25, 2022, from https://www.academia.edu/9199556/%C4%B0nsans%C4%B1z_Hava_Ara%C3%A7lar%C4%B1_Muharebe_Alan%C4%B1nda_ve_Ter%C3%B6rle_M%C3%BCcadelede_Devrimsel_D%C3%B6n%C3%BC%C5%9F%C3%BCm_. December, 2012.

[8] 1930s DH.82B Queen Bee (UK). (n.d.). Retrieved January 20, 2022, from https://www.pbs.org/wgbh/nova/spiesfly/uavs_05.html

[9] Gülbahar, Ö., KARAYEL İnsansız Hava Aracının Statik Ve Dinamik Analizleri. Unpublished masters. İstanbul Teknik University Institute of Science. 2015

[10] Uyar, T. *ANKA Başarısı ve İnsansız Hava Araçları*, Retrieved January 20, 2022, from http://www.tevfikuyar.com/2010/blog/mesleki-yazilar/anka-basarisi-ve-insansiz-hava-araclari.html. 18 July 18, 2010

[11] U-2 Overflights and the Capture of Francis Gary Powers, 1960. (n.d). Retrived January 21, 2022, from https://history.state.gov/milestones/1953-1960/u2-incident.

[12] Ehrhard, T. P., Air Force UAVs: The Secret History. Retrieved January 26, 2022, from https://apps.dtic.mil/sti/pdfs/ADA526045.pdf. July 06, 2010

[13] Sanders, R., An Israeli Military Innovation UAVs. JFQ Winter 2002-2003, p.114-118. Retrieved January 29, 2022, from https://www.semanticscholar.org/paper/An-Israeli-Military-Innovation%3A-UAVs-Sanders/a105ab54318b91d6c4f3363d0b3f7ee856ca2407. 2002

[14] Özyurt, M. E., Okutan, H.E., Unpublished masters, Karadeniz Teknik Üniversitesi. 2021

[15] Tsach, S., Chemla, J., Penn, D., Budianu D. History Of UAV Development In IAI & Road Ahead. ICAS 2004, Retrieved January 29, 2022, from https://www.icas.org/ICAS_ARCHIVE/ICAS2004/PAPERS/519.PDF. 2004

[16] Mahadevan, P. The Military Utility Of Drones. CSS Analysis in Security Policy, *(78)*,2. Retrieved February 06, 2022, from Semantic Scholar. 2010

[17] Gertler, J., “U.S. Unmanned Aerial System”,Congressional Research Service (CRS) Report for Congres, (9). Retrieved January 30, 2022, from https://sgp.fas.org/crs/natsec/R42136.pdf. January 3, 2012

[18] Ayyıldız, M. *Türk S-400'lerinin Hedefi: Banshee*. Retrieved February 5, 2022, from https://www.savunmasanayist.com/s-400-banshee-hedef-ucak/. October 6, 2020

[19] Global Hawk. (n.d.). Retrieved February 5, 2022, from https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104516/rq-4-global-hawk/.

[20] Bozoklu, B. *RQ-4 Global Hawk Ve MQ-4C Triton İnsansız Hava Araçları.* Retrieved Jun 26,2023, from https://mavivatan.net/rq-4-global-hawk-ve-mq-4c-triton-insansiz-hava-araclari/. Jun 24, 2023

[21] MQ-9 Reaper. (n.d.). Retrieved February 6, 2022, from https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/.

[22] Ünal,B, Avcı, E. ABD'nin DAEŞ'e karşı en etkin silahı. Anadolu Agency. Retrieved July 10, 2022, from https://www.aa.com.tr/tr/dunya/abdnin-daese-karsi-en-etkin-silahi/18012. 10 August 10, 2015

[23] RQ-11B Raven. (n.d.). Retrieved Jun 5, 2022, from https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104533/rq-11b-raven/.

[24] Elbit Hermes 900 (Kochav). Retrieved 15 November 15, 2022, from https://www.militaryfactory.com/aircraft/detail.php?aircraft_id=1236. May 07, 2022

[25] Hermes 900. (n.d.). Retrieved November 15, 2022, from https://elbitsystems.com/product/hermes-900/.

[26] HESA Shahed-136. Retrieved November 01, 2022, from https://www.military factory.com/aircraft/detail.php?aircraft_id=2520#images. October 13, 2022

[27] Iran Says It Shipped Drones To Russia Before Ukraine War. Reuters. Retrieved November 05, 2022, from https://www.reuters.com/world/iran-acknowledges-drone-shipments-russia-before-ukraine-war-2022-11-05/#:~:text=Iranian%20Foreign%20Minister%20Hossein%20Amirabdollahian,unmanned%20aerial%20vehicles%20every%20day. November 5, 2022

[28] Shahed-136 Loitering Munition. Retrieved November 06, 2022, from https://english.iswnews.com/22339/military-knowledge-shahed-136-loitering-munition/. January 12, 2022

[29] Army 2019: ZALA Aero unveils new loitering munitions. Retrieved November 18, 2022, from https://www.armyrecognition.com/army-2019_news_russia_online_show_daily_media_partner/army_2019_zala_aero_unveils_new_loitering_munitions.html. July 01, 2019

[30] Discover Russian Lancet Suicide Drones Used To Strike Ukrainian Land And Naval Targets. Retrieved November 18, 2022, from https://www.armyrecognition.com/ukraine_-russia_conflict_war_ 2022/ discover_russian_lancet_suicide_drones_used_to_strike_ukrainian_land_and_naval_targets.html. November 04, 2022

[31] ZALA KYB-UAV. Retrieved 18 November 18, 2022, from https://www.militaryfactory.com/aircraft/detail.php?aircraft_id=2460. March 23, 2022

[32] HAROP. (n.d.). Retrieved November 18, 2022, from https://www.iai.co.il/p/harop.

[33] Sanchez, R. 'Suicide drone' used for first time in fighting between Azerbaijan and Armenia. Telegraph. Retrieved November 19, 2022, from http://www.telegraph.co.uk/news/2016/04/08/suicide-drone-used-for-first-time-in-fighting-between-azerbaijan/. 08 April 08, 2016

[34] Karakuş, O. *Azerbaycan Bayraktar TB2'lerinin İmha Ettiği S - 300'ler*. Retrieved November 19, 2022, from https://www.savunmasanayist.com/azerbaycan-bayraktar-tb2lerinin-imha-ettigi-s-300ler/. 15 September 15, 2020

[35] Meggitt Defence Systems Ltd. BANSHEE Aerial Target System. [Brochure]. Ashford, UK

[36] İlk Yerli İnsansız Hava Aracı İlk İHA. (n.d.). Retrieved November 20, 2022, from https://www.sanalsavunma.com/ilk-yerli-insansiz-hava-araci-ilk-iha/.

[37] Goebel, G. *Early US Target Drones*. Retrieved February 12, 2022, from http://www.vectorsite.net/twuav_01.html. February 1, 2012

[38] Kahraman, A. Türkiye'nin Kullandığı İlk İHA: GNAT-750. Retrieved February 05, 2022, from https://www.kokpitteyiz.com/turkiyenin-kullandigi-ilk-iha-gnat-750/. March 24, 2021

[39] Arnaud. CANADAİR CL-89 / CL-289. Retrieved January 01, 2022, from https://www.avionslegendaires.net/avion-militaire/canadair-cl-89-cl-289/. Jun 09, 2018

[40] Aksan, S. Türkiye'nin gökyüzündeki başarı imzası: Yerli İHA ve SİHA'lar. TRTHaber. Retrieved February 05, 2022, from https://www.trthaber.com/haber/gundem/turkiyenin-gokyuzundeki-basari-imzasi-yerli-iha-ve-sihalar-464449.html. March 03,2020

[41] Goebel, G. *Early US Target Drones*. Retrieved February 12, 2022, from http://www.vectorsite.net/twuav_10.html. February 1 2012

[42] Ateş, E. Türkiye'nin İnsansız Hava Aracı (İHA) İhracat Rekabet Gücünün Analizi. Turkish Journal of Unmanned Aerial Vehicles-2021, 3, 07-16. Retrieved February 05, 2022, from ResearchGate database. 2021

[43] ŞİMŞEK ve TURNA Hedef Uçak Sistemleri. (n.d.). Retrieved February 13, 2022, from https://www.millisavunma.com/simsek-ve-turna-hedef-ucak-sistemleri/.

[44] Keklik ve Turna TSK'ya teslim edildi. Hürriyet, Retrieved March 05, 2022, from https://www.hurriyet.com.tr/gundem/keklik-ve-turna-tskya-teslim-edildi-36232. November 10, 2001

[45] Yurdakul, F. *Türkiye'nin İHA Serüveni*. Retrieved October 19, 2022, from https://www.trmilitarynews.com/turkiyenin-iha-seruveni/. March 08, 2020

[46] Altunok, T., Türkiye'nin İHA Serüveni. Bilim ve Teknik Dergisi, 517, 38-41. Retrieved February 11, 2022, from TUBITAK E-DERGI database. 2010.

[47] Fuzuli. A., An overview of Turkish UAV R&D and production. TRDefence. Retrieved February 13, 2022, from http://www.trdefence.com/forum/viewtopic.php?f=17&t=375. 2010

[48] O'Gorman, R., Abbott, C. Remote control war Unmanned combat air vehicles in China, India, Israel, Iran, Russia and Türkiye. Open Briefing, 64. Retrieved February 08, 2022, from https://www.openbriefing.org/publications/report-and-articles/remote-control-war/. September 20, 2013

[49] Ayyıldız, M., Harpy İHA. Retrieved February 10, 2022, from https://aveonj.com/iai-harpy/. 2021.

[50] HARPY. (n.d.). Retrieved February 11, 2022, from https://www.iai.co.il/p/harpy.

[51] Turkish Aerospace. (2021). ANKA Information Brochure[Brochure]. Kahramankazan, Ankara

[52] Küçük, T. *İHA Serüveni 2: Türk Endüstrisinin Yükselişi*. Retrieved October 31, 2020, from https://www.tdefenceagency.com/iha-seruveni-2-turk-endustrisinin-yukselisi/. February 14, 2022

[53] Bayraktar Mini İHA. (n.d.). Retrieved October 31, 2022, from https://www.baykartech.com/tr/uav/bayraktar-mini-iha/.

[54] Bayraktar, H., Bayraktar, S., Teknolojileriyle Dünyadaki Rakipleriyle Yarışan Özgün ve Milli İnsansız Hava Araçları Bayraktar, Malazgirt ve Çaldıran. Bilim ve Teknik Dergisi, 517, 42-47. Retrieved February 12, 2022, from TUBITAK E-DERGI database. 2010.

[55] Heron. (n.d.). Retrieved November 02, 2022, from https://www.iai.co.il/p/heron

[56] Karaağaç, C., İHA Sistemleri Yol Haritası-Geleceğin Hava Kuvvetleri 2016-2050. Retrieved February 13, 2022, from https://thinktech.stm.com.tr/uploads/docs/1608914423_satm-bb-17-0200-sektor-raporlari-iha-260417.pdf. February, 2016

[57] Vestel. (2016). KARAYELTactical UAV [Brochure]. Vestel Defence Industry

[58] Yıldırım, G. Bayraktar TB2 Zeytin Dalı Harekatı'nda 4 bin saat uçtu. Anadolu Agency. Retrieved February 05, 2022, from https://www.aa.com.tr/tr/turkiye/bayraktar-tb2-zeytin-dali-harekatinda-4-bin-saat-uctu/1097076. March 23, 2018

[59] Köker, İ. Dağlık Karabağ: İHA ve SİHA'ların rolü ne oldu, Azerbaycan'a nasıl avantaj sağladı?. BBC. Retrieved February 16, 2022, from https://www.bbc.com/turkce/haberler-dunya-54917938. November 12, 2020

[60] Bayraktar TB2. (n.d). Retrieved February 16, 2022, from https://baykartech.com/tr/uav/bayraktar-tb2/.

[61] Kılıç, G. Ukrayna Ordusu Rus Konvoyunu İmha Etti. TGRT Haber. Retrieved March 01, 2022, from https://www.tgrthaber.com.tr/dunya/ukrayna-ordusu-rus-konvoyunu-imha-etti-goruntuler-bayraktar-tb2yi-akillara-getirdi-2815252. February 23, 2022

[62] Aksungur. (n.d.). Retrieved March 02, 2022, from https://www.tusas.com/urunler/iha/yuksek-faydali-yuk-kapasitesi/aksungur.

[63] Aksoy, D. TRT Haber, AKSUNGUR'un üretim tesisine girdi. TRT Haber. Retrieved February 17, 2022, from https://www.trthaber.com/haber/dunya/trt-haber-aksungurun-uretim-tesisine-girdi-588767.html. 16 Jun 2021

[64] Aksungur'un kameraları orman yangınlarına odaklandı. TRTHaber, Retrieved July 05, 2022, from https://www.trthaber.com/haber/bilim-teknoloji/aksungurun-kameralari-orman-yanginlarina-odaklandi-593345.html. July 05, 2021

[65] SON DAKİKA: Yeni Müjde Geldi! İlk AKSUNGUR Envantere Girdi: Bu 8 Özellik Çok Konuşulur. Sabah, Retrieved October 21, 2022, from https://m.sabah.com.tr/ekonomi/2021/10/20/son-dakika-yeni-bir-mujde-olarak-duyuruldu-ilk-aksungur-teslim-edildi/amp?paging=9&utm_source=haberindevami&utm_medium=haberindevami&utm_campaign=haberindevami, October 21, 2021

[66] STM Defence. Tactical Mini UAV Systems [Brochure]. Çankaya, Ankara

[67] STM Alpagu Kamikaze İHA (Dolanan Mühimmatı). (n.d.). Retrieved October 21, 2022, from https://www.millisavunma.com/stm-alpagu-kamikaze-iha-dolanan-muhimmati/.

[68] KERKES Project. (n.d.) Retrieved October 22, 2022, from https://www.stm.com.tr/en/our-solutions/autonomous-systems/kerkes-project.

[69] Yıldırım, G. Anadolu Agency tours state-of-the-art Turkish UAV maker. Anadolu Agency. Retrieved Jun 15, 2022, from https://www.aa.com.tr/en/economy/anadolu-agency-tours-state-of-the-art-turkish-uav-maker/1877808. December 03, 2022

[70] A New Game-Changing System from STM and ROKETSAN : ALPAGUT. STM Defence, Retrieved October 29, 2022, from https://www.stm.com.tr/en/media/news/new-game-changing-system-stm-and-roketsan-alpagut. 27 October 27, 2022

[71] Anatolian Agency. (2022) Türkiye's new loitering munition system Alpagut [Brochure]. 01 Çankaya, Ankara

[72] Bayraktar Akıncı. (n.d.). Retrieved July 22, 2022, from https://baykartech.com/tr/uav/bayraktar-akinci/.

[73] Kar, N. Turkey successfully tests locally-made armed drone. Anadolu Agency. Retrieved February 23, 2022, from https://www.aa.com.tr/en/science-technology/Türkiye-successfully-tests-locally-made-armed-drone/1666399. December 07, 2019

[74] Bayraktar AKINCI TIHA broke the altitude record in Turkish aviation history. DHA. Retrieved April 4, 2022, from https://www.dha.com.tr/english/bayraktar-akinci-tiha-broke-the-altitude-record-in-turkish-aviation-history-1836626. February 23, 2021.

[75] Bayraktar DİHA. (n.d.). Retrieved April 22, 2022, from https://baykartech.com/en/uav/bayraktar-diha/.

[76] Bayraktar DİHA nedir, özellikleri nelerdir?. Yenişafak, Retrieved April 04 2021, from https://www.yenisafak.com/bayraktar-diha-nedir-teknik-ozellikleri-neler-bayraktar-dihanin-kullanim-yerleri-h-3806228. April 21, 2022

[77] Bayraktar TB3. (n.d.). Retrieved April 04, 2022, from https://baykartech.com/tr/bayraktar-tb3/.

[78] Bayraktar Kızılelma. (n.d.). Retrived April 05, 2022, from https://baykartech.com/tr/muharip-insansiz-ucak-sistemi/.

[79] Charpentreau, C. *Bayraktar Kizilelma combat drone conducts ground tests ahead of first flight*. Retrieved December 16, 2022, from https://www.aerotime.aero/articles/32734-bayraktar-kizilelma-combat-drone-ground-test. November 23, 2022

[80] Charpentreau, C. *Türkiye Bayraktar Kızılelma Combat Drone Completes First Flight*. Retrieved December 16, 2022, from https://www.aerotime.aero/articles/Türkiyes-bayraktar-kizilelma-combat-drone-completes-first-flight. 14 December 14, 2022

[81] Cetin, Sokmen, E. İHA İle Olay Yeri İnceleme Ve Dokümantasyon. Unpublished masters, POLİS AKADEMİSİ. 2022

[82] Korchenko A.G., Illyash O.S. The Generalized Classification of Unmanned Air Vehicles, Retrieved February 15, 2022, from https://ieeexplore.ieee.org/document/6705275. October, 2013

[83] Ehredt, D. Contributing Stakeholders. P. Blyenburgh,(Ed.) 2010-2011 UAS Yearbook - UAS: The Global Perspective. Retrieved February 15, 2022, from https://www.dcabr.org.br/download/cursos-eventos/eventos/eventos-realizados/2010/seminario-vant-27-10-2010/cd-uvs-yearbook/pdf/P078b_pub_Skive.pdf. June, 2010

[84] UK Ministry of Defence. Joint Doctrine Note 2/11 The Uk Approach To Unmanned Aircraft Systems. Swindon: The Development, Concepts and Doctrine Centre Ministry of Defence. Retrieved February 15, 2022, from https://assets.publishing.service.gov.uk/media/5a81d239ed915d74e34003bc/20110505-JDN_2-11_UAS_archived-U.pdf. August, 2017

[85] U.S. Army UAS Center of Excellence. Eyes of the Army U.S. Army Roadmap for Unmanned Aircraft Systems 2010-2035. Retrieved February 16, 2022, from https://irp.fas.org/program/collect/uas-army.pdf. 2010

[86] SSM. Türkiye İnsansız Hava Aracı Sistemleri Yol Haritası (2011 - 2030). Retrieved February 16, 2022, from http://ercancinar.com/wp-

content/uploads/2017/10/SSM_%C4%B0HA_Sistemleri_Yol_Haritas%C4%B1_2012.pdf. 2011

[87] Directorate General of Civil Aviation. İnsansız Hava Aracı Sistemleri Talimatı (SHT-İHA). Retrieved December 10, 2021, from https://web.shgm.gov.tr/documents/sivilhavacilik/files/mevzuat/sektorel/talimatlar/2020/SHT-IHA_Rev-04.pdf. July 12, 2020

[88] Kasapoğlu, C., Kırdemir, B. Terör Tehdidinde Yeni Boyut: Drone Saldırıları ve Türkiye'nin Milli Güvenliğine İlişkin Gelişmeler Dış Politika & Güvenlik, EDAM, (1), 2-13. 2019

[89] PKK'dan Hakkari'de bombalı drone saldırısı!. Internet Haber. Retrieved December 10, 2021, from https://www.internethaber.com/pkkdan-hakkaride-bombali-drone-saldirisi-1722395h.htm. November 12, 2016

[90] Şimşek, A., Karaman, N. PKK'nın Drone Üssü Mahmur'da. Sabah. Retrieved December 12, 2021, from https://www.sabah.com.tr/gundem/2018/11/15/pkknin-drone-ussu-mahmurda. October 15, 2018

[91] Gokkus, B., Citak, İ. Venezuela Devlet Başkanı Maduro'ya Saldırı Anı Kamerada. Euronews. Retrieved December 13, 2021, from https://tr.euronews.com/2018/08/05/venezuela-devlet-baskani-maduro-ya-saldiri-ani-kamerada. August 07, 2018

[92] Akbuğa, A. PKK'nın Bomba Yüklü 'Drone'u Düşürüldü. İHA. Retrived December 18, 2021, from https://www.iha.com.tr/haber-pkknin-bomba-yuklu-droneu-dusuruldu-687246. November 12, 2017

[93] Ergan, U. Hain Saldırıda Kanada Izi!.. PKK'nın Dronları Kanada'dan mı?. Hürriyet. Retrieved December 20, 2021, from https://www.hurriyet.com.tr/gundem/pkknin-dronlari-kanadadan-mi-41814380. May 20, 2021

[94] Gencturk, A. Turkish Forces foil ypg pkk model plane attack in the northern Syria. TimeTurk. Retrieved November 18, 2022, from https://www.timeturk.com/en/turkish-forces-foil-ypg-pkk-model-plane-attack-in-northern-syria/news-37106. May 25, 2021

[95] Turkish forces shoot down PKK model plane in northern Iraq. Daily Sabah, Retrieved May 11, 2021. from https://www.dailysabah.com/politics/war-on-terror/turkish-forces-shoot-down-pkk-model-plane-in-northern-iraq. November 18, 2022

[96] Drushnin, J. Remote Piloted Aerial Vehicles : An Anthology. Retrieved November 18, 2022, from http://www.ctie.monash.edu/hargrave/rpav_home.html#Beginnings. February 2, 2003

[97] Polat, S. Rusya'nın Akdeniz'deki tek askeri üssü Suriye'de. Anadolu Agency. Retrieved November 17, 2022, from https://www.aa.com.tr/tr/dunya/rusyanin-akdenizdeki-tek-askeri-ussu-suriyede/396367. October 02, 2015

[98] Reid, D. A swarm of armed drones attacked a Russian military base in Syria. CNBC. Retrieved November 17, 2022, from https://www.cnbc.com/2018/01/11/swarm-of-armed-diy-drones-attacks-russian-military-base-in-syria.html. January 11, 2018

[99] Head of the Russian General Staff's Office for UAV Development Major General Alexander Novikov holds briefing for domestic and foreign reporters. Retrieved November 17, 2022, from https://eng.mil.ru/en/news_page/country/more.htm?id=12157872@egNews. January 11, 2018

[100] Hamad, M. İ. Venezuela Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran. The New York Times. Retrieved November 17, 2022, from https://www.nytimes.com/2019/09/14/world/middleeast/saudi-arabia-refineries-drone-attack.html. September 14, 2019

[101] Yaakoubi, A., Dahan M. Saudi Aramco petroleum storage site hit by Houthi attack, fire erupts. Reuters, Retrieved November 18, 2022, from https://www.reuters.com/world/middle-east/saudi-air-defences-destroy-houthi-drones-state-tv-2022-03-25/#:~:text=RIYADH%2C%20March%2026%20(Reuters),storage%20tanks%20but%20no%20casualties. March 26, 2022

[102] Abu Dabi'de drone saldırısı! Dışişleri Bakanlığı kınadı. Superhaber. Retrieved January 18, 2022, from https://www.superhaber.tv/abu-dabide-drone-saldirisi-disisleri-bakanligi-kinadi-video-376633. January 18, 2022

[103] Rehimov, R. Azerbaycan'ın zafer kazandığı 2. Karabağ Savaşı'nın üzerinden 2 yıl geçti. Anatolian Agency. Retrieved November 19, 2022, https://www.aa.com.tr/tr/dunya/azerbaycanin-zafer-kazandigi-2-karabag-savasinin-uzerinden-2-yil-gecti/2695589. September 27, 2022

[104] Lake, J. Azerbaijan Exercises with Turkish Drones. Retrieved November 19, 2022, from https://www.timesaerospace.aero/news/training/azerbaijan-exercises-with-turkish-drones. January 04, 2022

[105] Counter Drone Systems. (n.d.). Retrieved February 01, 2022. from https://www.meteksan.com/en/yayinlar/articles/counter-drone-systems-tailor-made-system-solutions-based-on-open-system-architecture.

[106] Wolff, C. *Physical fundamentals of the radar principle*. Retrieved November 21, 2022, from https://www.radartutorial.eu/01.basics/Physical%20fundamentals%20of%20the%20radar%20principle.en.html.

[107] Bhatta, N. RADAR and its applications. Retrieved November 22, 2022, from https://www.researchgate.net/publication/316696944_RADAR_and_its_applications. January, 2017

[108] Wolff, C. *ALPER Naval LPI Radar*. Retrieved 21 November 21, 2022, from https://www.radartutorial.eu/19.kartei/07.naval/karte023.en.html.

[109] Lv, H., Liu, F., Yuan, N. Drone Presence Detection by the Drone's RF Communication. Journal of Physics, 1-3. Retrieved November 11, 2022. Retrieved 22 November 2022, Semantic Scholar. 2021

[110] STM. (2019). Anti-Drone Savunma Sistemleri. [Brochure]. Çankaya, Ankara

[111] Editor, T. Electro-Optical Systems for Drones & UAV. Technology Editor, Retrieved November 23, 2022, from https://www.unmannedsystemstechnolgy.com/expo/electro-optical-systems/. November 12, 2021

[112] U.S. Department of Defense. Global Positioning System Standard Positioning Service Performance Standard. Retrieved November 23, 2022, from https://www.gps.gov/technical/ps/. April, 2020

[113] Robin Radar Systems. 10 Counter-Drone Technologies to Detect and Stop Drones Today. [Brochure]. Den Haag, Netherland

[114] HK$1 million in damage caused by GPS jamming that caused 46 drones to plummet during Hong Kong show. South China Morning Post. Retrieved 29 November 25, 2022, from https://www.scmp.com/news/hong-kong/law-and-crime/article/2170669/hk13-million-damage-caused-gps-jamming-caused-46-drones#:~:text=The%20GPS%20jamming%20that%20caused,the%20Hong%20Kong%20Tourism%20Board. October 29, 2018

[115] Editorial T. *What is RF Jamming?*. Retrieved November 23, 2022, from https://www.everythingrf.com/community/what-is-rf-jamming. July 07, 2022

[116] Liberatore, S. How do you catch a drone? With an even BIGGER drone and a giant net: Tokyo police reveal bizarre 'UAV catcher'. DailyMail. Retrieved December 16, 2022, from https://www.dailymail.co.uk/sciencetech/article-3356746/How-catch-droneBIGGER-drone-giant-net-Tokyo-police-reveal-bizarre-UAV-catcher.html. 12 December 12, 2015.

[117] Volpicelli, G. ARS Technica. Retrieved December 16, 2022,from https://arstechnica.com/gadgets/2016/03/skywall-anti-drone-bazooka/. October 03, 2022

[118] Trevithick, J. *U.S. Air Force Buying Special Drone-Snagging Shotgun Shells*. Retrieved December 16, 2022. from https://www.thedrive.com/the-war-

zone/8291/u-s-air-force-buying-special-drone-snagging-shotgun-shells. Jun 29, 2019.

[119] Öztürk, S. Drone'ları hack'lemek meğer 'çocuk oyuncağı'ymış!. DHA. Retrieved February 20, 2023, from https://www.dha.com.tr/teknoloji/dronelari-hacklemek-meger-cocuk-oyuncagiymis1640518. May 03, 2019

[120] Where Eagles Dare: French Military Using Winged Warriors to Hunt down Rogue Drones. Fox News, Retrieved February 22, 2012, from https://www.foxnews.com/world/where-eagles-dare-french-military-using-winged-warriors-to-hunt-down-rogue-drones. February 22, 2017

[121] High-Energy Lasers. (n.d.). Retrieved February 23, 2022, from https://www.raytheonintelligenceandspace.com/what-we-do/advanced-tech/lasers.

[122] Aselsan. (2017). İHTAR Anti - Drone System. [Brochure]. Yenimahalle, Ankara

[123] Counter Drone Systems:Tailor-Made System Solutions Based On Open System Architecture. (n.d.). Retrieved March 01, 2023. from https://www.meteksan.com/en/yayinlar/articles/counter-drone-systems-tailor-made-system-solutions-based-on-open-system-architecture.

[124] Meteksan Defence. KAPAN Counter Drone System. [Brochure]. Çankaya, Ankara

[125] Meteksan Defence. Drone ve Kara Tehditlerine Karşı Retinar Radar Sistemi. [Brochure]. Çankaya, Ankara: M. Tolga ÇELİK

[126] ES-60 MB Electromanyetic Anti Drone Gun. (n.d.). Retrieved February 10, 2022, from http://www.harparge.com/en/es-60-anti-drone-gun.

[127] Yıldırım, G. Milli drone savar 3 kilometreden drone uçurmayacak. Anadolu Agency. Retrieved March 10, 2023, from https://www.aa.com.tr/tr/bilim-teknoloji/milli-drone-savar-3-kilometreden-drone-ucurmayacak/1766630#. March 15, 2020

[128] UAV Cave. (n.d.). Retrieved March 12, 2022, from https://ulusalsavunma.com.tr/en/iha-kafes/.

[129] İLTER Drone Detection and Neutralization System. (n.d.). Retrieved March 12, 2022, from https://www.bogazicisavunma.com/en/ilter-radar-drone-detection-and-neutralization- system-2/.

[130] Leonardo Electronics. Falcon Shield Counter Air System. [Brochure]. United Kingdom:Leonardo UK Ltd

[131] Rosoboronexport. Repellent. [Brochure]. Moscow, Russia: Str. Stromynka 27

[132] ELI-4030 Drone Guard. (n.d.). Retrieved May 15, 2022, from https://www.iai.co.il/p/eli- 4030-drone-guard.

[133] Fuze Types And Functioning. (n.d.). Retrieved March 15, 2022, from https://www.tpub.com/gunners/23.htm.

[134] DORUK. (n.d.). Retrieved March 17, 2022, from https://www.rstteknoloji.com.tr/tr/project/doruk-insansiz-hava-araci-tespit-radari/.

[135] THALES. (2021). Most compact & light-weight Ground Surveillance Radar Ground Observer 12. [Brochure]. Ditzingen, Germany

[136] Transvaro. TV-904 3D ANTI-UAV RADAR. [Brochure]. Çankaya, Ankara, Türkiye

[137] Aselsan. (2022). IFF Mk XIIA(S). [Brochure]. Yenimahalle, Ankara, Türkiye

[138] Wolff, C. *Airfield Surveillance Radar ASR 9*. Retrieved October 29, 2022, from https://www.radartutorial.eu/19.kartei/03.atc/karte003.en.html.

[139] HGH. SPYNEL-X Wide Area Surveillance Solution. [Brochure]. Igny, France

[140] Transvaro. TV/GUARD. [Brochure]. Çankaya, Ankara, Türkiye

[141] Sathyamoorthy, D. A Review of Security Threats of Unmanned Aerial Vehicles and Mitigation Steps. Retrieved October 30, 2022, from https://www.researchgate.net/publication/282443666_A_Review_of_Security_Threats_of_Unmanned_Aerial_Vehicles_and_Mitigation_Steps. October, 03, 2015

[142] ICAO. Aeronautical Information Publication ENR 1.10 Flight Planning. Retrieved January 18, 2022, from https://s282b0dcad154b49f.jimcontent.com/download/version/1492443364/module/12595814890/name/LT_ENR_1_10_en.pdf. January 05, 2017

[143] ElevonX Scorpion. (n.d.). Retrieved November 12, 2023, from https://www.elevonx.com/solutions/elevonx-scorpion/.

APPENDICES

Appendix A: The Entirety of the Proposed Pseudo-Code

Appendix A - The Entirety of the Proposed Pseudo-Code

```
START

REPEAT
   RESET_SENSOR()

   data = READ_SENSOR_DATA()

   IF data is detected THEN
      PRINT("Detection in the air")

      IF data is aircraft THEN
         PRINT("Detected object is an aircraft")

         status = CHECK_DATABASE_FOR_FRIEND_OR_FOE()

         IF status is foe THEN
            PRINT("Threat UAV detected")
            SEND_ALERT_SIGNAL()

            known = CHECK_IF_UAV_IS_KNOWN_IN_DATABASE()
            IF unknown THEN
               size = DETERMINE_UAV_SIZE()

               IF size is small THEN
                  SELECT_KAMIKAZE_DRONE_WITH_LOW_PAYLOAD()
                  PRINT("Low payload kamikaze drone selected")
                  SAVE_SENSOR_DATA_TO_DATABASE()

               ELSE IF size is medium THEN

                  SELECT_KAMIKAZE_DRONE_WITH_MEDIUMPAYLOAD()
                  PRINT("Medium payload kamikaze drone selected")
                  SAVE_SENSOR_DATA_TO_DATABASE()

               ELSE IF size is large THEN
                  SELECT_KAMIKAZE_DRONE_WITH_HIGH_PAYLOAD()
                  PRINT("High payload kamikaze drone selected")
                  SAVE_SENSOR_DATA_TO_DATABASE()
               END IF
            ELSE
               SELECT_DATABASE_DEFINED_KAMIKAZE_DRONE()
               PRINT("Appropriate kamikaze drone ready")
            END IF

            SAVE_UAV_SIGNAL_DATA_TO_DATABASE()
            PRINT("UAV saved to database")
```

```
            uav_parameters = GET_UAV_POSITION_SPEED_DIRECTION()

            LAUNCH_KAMIKAZE_DRONE_TOWARDS_TARGET()
            PRINT("Kamikaze drone directed towards target")

            IF uav_parameters are not stable variable THEN
               USE_NON_AUTONOMOUS_CONTROL_FROM_GCS()
            ELSE
               DRONE_PROCEEDS_AUTONOMOUSLY()
            END IF

            IF Target_Not_Destroyed And Drone_Is_Reusable THEN
               CONTINUE
             IF Target_Not_Destroyed And Drone_Is_Not_Reusable THEN
               NEW_KAMİKAZEDRONE_LAUNCH()
            END IF

            ELSE
               PRINT("Mission successful, target destroyed")
               LOG_THE_MISSION()
            END IF

         ELSE
            PRINT("Detected entity is friendly")
         END IF
      ELSE
         PRINT("Detected object is not an aircraft")
      END IF
   ELSE
      PRINT("No detection in the air")
   END IF
UNTIL SYSTEM_SHUT_DOWN

END
```

CURRICULUM VITAE

Photo

PERSONAL INFORMATION

Name Surname :
Date of Birth :
Phone :
E-mail :

EDUCATION

High School :
Bachelor :
Master Degree :

PAPERS AND PROCEEDINGS

WORK EXPERIENCE

Officer :

TOPICS OF INTEREST

-