UNMANNED SURFACE VEHICLE (USV) WITH OBSTACLE AVOIDANCE SYSTEM

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UNMANNED SURFACE VEHICLE (USV) WITH OBSTACLE AVOIDANCE SYSTEM

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

UNMANNED SURFACE VEHICLE (USV) WITH OBSTACLE AVOIDANCE SYSTEM

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Supervisor: Dr. Sibel Özyer

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Unmanned Surface Vehicles (USV) is one of the most widely used in open water technique. It has attracted wide attention in recent decades as it tries to integrate monitoring with communication.

In this thesis, investigation and implementation of a prototype of unmanned surface vehicles (USV) has been done, that has been widely used in developed countries in various fields. The USV has been protected from barriers that may obstruct the USV or prevent it to reach the target. The protection system has been an assistant system for the operation of the vehicle controller in case he fails to see the obstacle, whether due to bad weather conditions or omission by the controller. The proposed system has been worked by means of a set of sensors with multi techniques which has been placed on the vehicle including Light Detection and Ranging (LIDAR) sensor, LIDAR-Lite sensors and ultrasonic sensors that will work to send data to the crash avoidance system (CAS) and the main computer for making a right decision to take the vehicle out of danger area. This has been done by determining whether USV in safe or not.

The performance has been increased by increasing system accuracy to be able to work faster and coincides with the speed of the vehicle. On the other hand, the system has the ability to direct the vehicle to conduct manoeuvres with high professionalism. Accuracy and speed in transmitting system data to the microcontroller and driver have also been considered when building the system. In this work, algorithms to help CAS to make the most appropriate decision and Python language have been used to program the system in general.

Keywords: Unmanned Surface Vehicles (USV), Crash Avoidance System (CAS).

ÖZ

ENGELDEN KAÇINMA SİSTEMİ İLE İNSANSIZ SUÜSTÜ ARACI (İSA)

AL-TEKREETI, Mahmood Muthanna

Yüksek Lisans, Elektronik ve Haberleşme Mühendisliği Bölümü

Danışman: Dr. Sibel Özyer

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İnsansız Suüstü Araçları (İSA) açık su tekniğinde en yaygın kullanılanlardan biridir. İzlemeyi iletişimle bütünleştirmeye çalıştığı son on yıllarda büyük ilgi görmüştür.
Bu tez çalışmasında, gelişmiş ülkelerde çeşitli alanlarda yaygın olarak kullanılan insansız suüstü araçlarının (İSA) prototipinin araştırılması ve uygulanması yapılmıştır. İSA, İSA' yı engelleyebilecek veya hedefe ulaşmasını engelleyebilecek engellerden korunmuştur. Koruma sistemi, kötü hava koşulları ya da kontrolör tarafından atlanmaması nedeniyle engelleri görmemesi durumunda araç kontrol cihazının çalışması için yardımcı bir sistemdir. Önerilen sistemde, araca yerleştirilen Işık Algılama ve Değişme (LIDAR) sensörü, LIDAR-Lite sensörleri ve çarpışmadan kaçınmaya veri göndermek için çalışacak ultrasonik sensörler dahil olmak üzere çoklu tekniklere sahip bir dizi sensör aracılığıyla çalışılmıştır. Sistem (EKS) ve ana bilgisayar, aracı tehlike alanından çıkarmak için doğru kararı vermeye çalışmaktadır. Bu İSA' nın güvenli olup olmadığını belirleyerek yapılmıştır.

Daha hızlı çalışabilmek ve aracın hızıyla çakışabilmek için sistemin doğruluğunu artırarak performans arttırılmıştır. Öte yandan, sistem aracı yüksek profesyonellikte manevralar yapmaya yönlendirir. Sistem verilerinin mikrodenetleyiciye ve sürücüye aktarılmasındaki doğruluk ve hız da sistem oluşturulurken dikkate alınmıştır. Bu çalışmada, EKS'nin en uygun kararı vermesine yardımcı olacak algoritmalar ve sistemi genel olarak programlamak için Python dili kullanılmıştır.

Anahtar Kelimeler: İnsansız Suüstü Araçları (İSA), Engelden Kaçınma Sistemi (EKS).

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LIST OF ABBREVIATIONS

CAS	: Crash Avoidance System
cRIO	: Compact RIO
DEM	: Digital Elevation Models
DTM	: Digital Terrain Models
EKF	: Extended Kalman filter
GPS	: Global Positioning System
IDE	: Integrated Development Environment
IoT	: Internet of Things
KF	: Kalman Filter
LCD	: Liquid Crystal Displays
LIDAR	: Light detection and ranging
MCDA	: Multi-Criteria Decision Analysis
MSD	: Mine-Sweeper Drone
PCB	: Printed Circuit Board
RFS	: Random-Finite-Sets
SLAM	: Simultaneous Localization and Mapping
SR	: Sonic Ranger
UAV	: Unmanned Aircraft Vehicles
USV	: Unmanned Surface Vehicles
UUV	: Unmanned Underwater Vehicles
WSM	: Weighted Sum Model

INTRODUCTION

1.1 Introduction:

Water rescue is a difficult task. Lifeguards must adapt to their particular area's currents and landscape, and much of the response hinges on quick recognition of persons in trouble. When conditions are particularly challenging, it is even more difficult to retrieve an individual from the water [1].

The past decade of research in marine and field robotics has led to the establishment of a new class of small-sized unmanned surface vehicles (USVs) [2].

The USV is a watercraft that operated without the crew. USV can be controlled remotely by an operator from different locations such as another vehicle or ground. Moreover, it can be used to explore and map the sea environment. In this way, tracking of the sea animals, the rescue of the people and many operations in the sea will be possible to research and industrial studies [2].

The work is done on a composite construction project that has the ability to operate under all environmental circumstances. Furthermore, works to accomplish all the tasks assigned to it in relation to the work of the USV. For instance, the survey and provide specialists with the required information. In addition, it saves people who are vulnerable to drowning. It will be the main work of the vehicle so as to reduce the drowning conditions and access to people under different circumstances and at high speed. In this research, USV will be studied and worked on a part of this project which is to protect the vehicle from hazards and obstacles that may hinder the work of the vehicle.

During the USV freely tours, it might be an exhibition of some of the obstacles that may be stationary or moving. These obstacles may cause damage to the vehicle or the obstruction of the movement. With the help of some equipment and the information obtained from the GPS and further the information stored in advance in the database of the USV, it can avoid those barriers.

The Internet of Things (IoT) indicates the conception of extending Internet connectivity beyond customary computing stages such as personal computers and portable devices, and into any extent of customarily "dumb" or non-internet-enabled physical gadgets and regular objects [3]. The sensors and components that contact with the Internet and will be used in Unmanned Surface Vehicles (USV) are just kinds of IoT.

A navigation algorithm supplying a robust localization technique is needed as the speed of information and the position of the vehicle is to be decided with high precision via the usage of faulty measurements [4].

The autopilot algorithm essentially renders the motion of a surface vehicle without continuous human intervention possible. Moreover, it is required to existing complex and agile maneuvers guarantying the steadiness of the vessel. However, the procedure plan of the autopilot is quite difficult regarding the nonlinear and coupled dynamics of the system [4].

1.2 Motivation:

The vehicle has been built to carry out humanitarian and scientific work together to provide a lot of things, including material, the tasks were collected in one vehicle, as well as provide the effort and energy

The vehicle will operate with a lower amount of energy and will be powered by clean energy, which in turn will be an auxiliary factor to protect the environment from the risk of pollution

a) Humanity:

It has been mentioned previously that the vehicle was built for humanitarian work and this will be its main work as the main task of the vehicle is to save the lives of citizens from drowning. There are many drowning cases occurring every day and the whole world has noticed the events of 2016 that claimed the lives of many innocent people. It is the responsibility of everyone to take care of the lives of the innocent. This is why the responsibility rests with the researchers. The efforts have been directed towards contributing to finding a solution to this issue. The shape and capabilities of the vehicle enable it to reach places that are difficult to reach by the Coast Guard and are also lighter than ordinary boats, which helps to get more quickly from the rescuers to the place required. On the other hand, the vehicle is designed to work in various environmental conditions and this is what distinguishes it from others, which is why the world today is interested in such type of projects and work on developing them. The self-driving or remote-controlled vehicle is easy to move and equipped with a number of sensors and cameras, which the commander can easily control. This means that they can reach shipwreck sites or fireplaces in the water and rescue people there.

b) Scientifically:

The construction of the vehicle was also designed to carry out research and scientific studies. The body of the vehicle is equipped with many sensors and measuring devices. It is equipped with a sonar device to measure the depth of water and also helps to know the places of obstacles and provided the vehicle with a temperature measuring device and many sensors and cameras. All these devices collect information from the external station and send it to a central calculator for the purpose of storage, and also upload a copy of the information to the cloud through the Internet to see this data all those who need it.

1.3 Problem Statement:

The basic problem is basically humane. Many people have lost their loved ones because the coast guard did not arrive in the right place at the right time or had difficulty getting in because the weather conditions were not appropriate.

Previous research has built a vehicle for scientific purposes and a vehicle has not been built to save people from drowning and exploring together.

In the case of the subject of rescue, the vehicle is based on the determination of the points and be directed in a straight (linear) means that the vehicle is exposed to the dangers of obstacles encountered in the way.

1.4 Aims and Objectives:

The applications of the unmanned vehicles in the previous few decades especially in the army and civil sectors have seen a big tendency in developing. Additionally, the tasks, which can't be carried out with required precision and effectivity through human abilities or might also possibly endanger human life, are expected to be primarily performed with the aid of these vehicles in the near future. Unmanned surface vehicles (USV) that have been designed to cross in continuous contact with a surface of the water is the substance of this study about in actuality concentrates upon

The USV is a watercraft that operated without the crew. USV can be controlled remotely by an operator from different locations such as another vehicle or ground. Moreover, it can be used to explore and map the sea environment. In this way, tracking of the sea animals, rescue of the people and many operations in the sea will be possible to research and industrial studies [2].

The aim of the research is to protect the vehicle from the obstacles it faces. As the vehicle can make the right decision when it reaches the stage of danger. That is, if the controller is busy or not seeing obstacles, the central calculator in the vehicle makes the most appropriate decision. By taking the most appropriate route based on data from sensors and a positioning device that works simultaneously with the movement of the vehicle.

That will be carried out a novel vehicle design with real-time obstacle avoidance using IoT devices. To best of our knowledge, there is no previous study that investigates the USV system by using RPLIDAR sensor, LIDAR-Lite sensors, and Ultrasonic sensors via LattePanda Alpha, which is a single-board computer.

1.5 Thesis Structure:

In this study, new applications for the unmanned surface vehicle (USV) are studied and implemented. A brief overview of the subject matter is given and the motives for this work are presented in Chapter 1

Chapter 2 provides a review of critical literature, the history of USV platforms and a brief explanation of the vehicle's operation and protection system (the crash avoidance system CAS) that will protect the vehicle from hazards. This part of the thesis will also examine the components and the software of the protection system installation and how it works in general.

Different path mapping algorithms are the most common algorithms, and some of these types will be talked about: A * algorithm, weighted sum model (WSM) also there are Kalman filter (KF) and SLAM algorithm. There will also be a full explanation of the parts of the system and how each part of these islands and how to link. All this information will be mentioned in chapter 3.

The main results of this study, as well as the simulation results that were constructed to obtain high accuracy results and ensure the proper functioning of the system are summarized, will be in Chapter 4.

Chapter 5 concludes the thesis by providing a brief summary of the study and incorporating recommendations for further possible research work.

LITERATURE REVIEW AND REQUIREMENTS

2.1. Overview:

In this section, some similar studies are identified in the past and some methods and principles of work are explored. Similar research studies are presented below:

In [5] the author simulated and implemented a boat. To control it autonomously, and he used a fusion algorithm based on EKF is developed. Model is derived based totally on experimental tests, the algorithm used to be evaluated in different situations with different values of environmental disturbances (wave, wind, and current) as long as different obstacles.

In [6] the author used SLAM-robot, based on the concept of random-finite-sets (RFS). An overview of the RFS-based SLAM algorithm was presented showing its advantage when using low-cost high-error sensors. This robotic platform is remotely managed to move and scan unknown environments using a differential algorithm of drive system, sending immediate function feedback to the faraway operator. The platform was able to successfully explore and map surrounding indoor environments providing reasonably high accuracy with the estimated paths also very accurate.

In [7] the author proposed sensing system for vehicles based on lidar. The ability of the lidars is measuring distance up to 40 meters. The lidars were mounted onto the stepper motors. The Lidars have been installed on the composite engine where the contact with the lidars and movement of vehicles controlled by a Compact RIO (cRIO). The Compact RIO (cRIO) managed the communication with lidars and motion of the motors, additionally, the algorithm ran on the real-time section of the cRIO. The algorithm is constructed on the idea of the nearest neighbour method and indicates promising consequences on the synthetic data.

In [8] This paper indicates the use of less costly sensors fusion for obstacle detection and avoidance: Sonic ranger (SR) and Light detection and ranging (LIDAR). Further sensors are also set up on the UAS. Experimental statistics results indicate that sensors integration is very beneficial when climate conditions come to be critical, in precise when the temperature increases.

In [9], the author used in this paper uses the Global Positioning System (GPS) capabilities with fixed, linear, and exponential scale configurations used to slow down USV when the victim's site USV approaching.

The USV controlled by using LIDAR sensor, LIDAR-Lite sensors and ultrasonic sensors. Ultrasonic sensors principle is to use ultrasound in the known air velocity and measure the time when sound waves reach obstacles and reflect back, then calculate the actual distance [10].

The Lidar-Lite measures the distance of an obstacle by sending a Near-Infrared laser signal and when the signal reflected by an obstacle. It calculates time delay between the transmission and reception of the signal. This translates into the distance using the speed of light [11].

RPLIDAR is an improved generation of the LIDAR-Lite. It uses the same principles for calculations.

All operation will be carried out using LattePanda Alpha which is a single-board computer that runs a full version of Windows 10 [12].

2.2. History of USV:

The Second World War witnessed the first experience with the USVs. Canadians developed the concept of the COMOX torpedo in 1944 as a pre-Normandy the USV before the invasion of designed to smoke during the invasion as an alternative to the plane. At the same time, the US Navy and showed several types of "Demolition Rocket Craft" earmarked for demining and obstacles in the surf area [13].

Expanded USVs applications after the war, where USN unmanned boats used to collect samples of radioactive water after the explosions of atomic bombs Able and Baker at Bikini Atoll in 1946. The draft “Drone" is of the navy of the defence of the mines in the United States which dates back to the era of the 1950s, the experience and testing demining boat for after 1954 [13].

By the 1960s of the last centuries, the Navy used unmanned boats "aviation rescue" rely on remote control boats after the exercise of launching missiles and use Ryan

Firefish boat target in the Artillery Training. As unmanned aircraft UAV continued development and use of USV and evolved over the years [13].

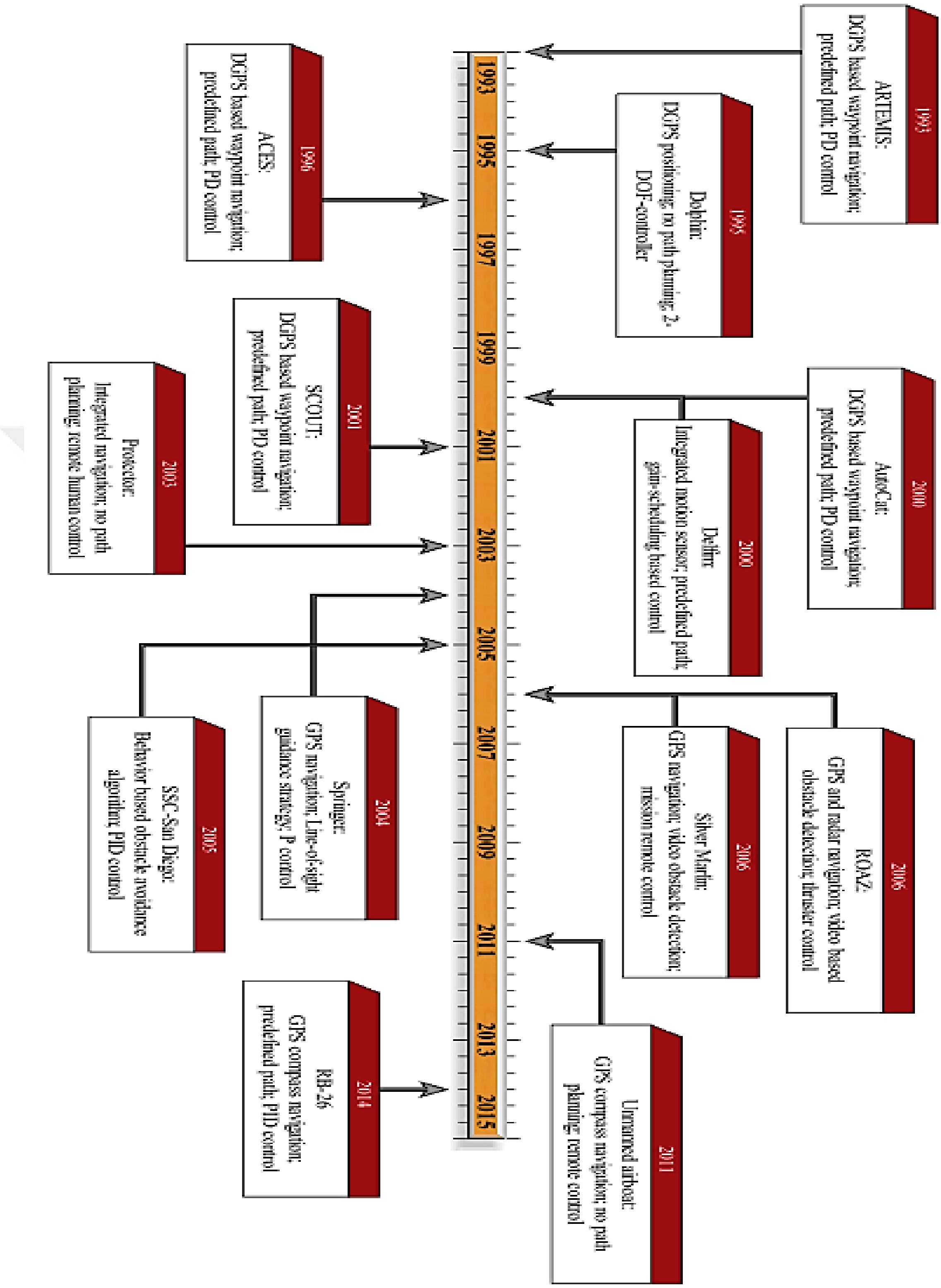
Continued interest in USV as unmanned surveillance aircraft and minesweeping and other dangerous tasks in growth after the 1950s for obvious reasons and ensure further development of the American navy the small "Unmanned vehicle"-a 15 feet USV to deploy unmanned ammunition, that was developed quickly and deployed in 10 sets a vehicle fleet in 1965 during the Vietnam War. As developed the USVs great mine-sweeper drone (MSD) and published in Vietnam in the late 1960s [13].

Many countries have recognized the value of recruitment systems unmanned mine-clearance and the development and dissemination systems. For example, Danish STANFLEX and Troika groups in Germany (the ship manned three unmanned planes), unmanned aircraft in the Netherlands, RIM drones in the United Kingdom, the SAM II ACV drones in Sweden, and SAM ACV Japanese worked by Hatsushima Class MCM vessels [13].

Since the 1990s, expanding the use of USV with a number of important research and development programs, for example, the OWL MK II and Roboski. Nevertheless, in the last decade years, USV has an attractive role in different activities, such as the exploration of the ocean and the coastal lines and control the environment. To track and control the USV to complete the task. The system monitors the subprogram for navigation of the traffic data in real-time and gets from the various maritime navigation sensors to determine the location, speed, and path of the USV. The sub-system is responsible to initiate safe routes, in accordance with the specific task, using the information that is provided from the sensors sub-system by the movement [14].

2.2.1 USV prototypes:

Figure 2.1 illustrates the main model USV models and overview in the timeline. Focusing on the control strategies and development of navigation should be noted. Follow this platform path in advance and lacks the ability to plan the route, including the avoidance of a collision. Since 2005, detect and avoid obstacles has gained prominence in the development of USV systems. The USVs audit found that have developed in the past two decades, they are used in a wide range of educational, military tasks and civil [14].



Figar2.1: an overview of USV in the timeline [14]

2.2.2 Employment of USV

The governments have been greatly expanded it used the USV, where it has recently worked in various fields, including Environmental missions, Scientific research, Military uses, Ocean resource exploration, and other applications [15].

- **Scientific Research**: The USV recently entered into many scientific subjects, to reduce risks to humans and decrease effort and time to complete the task. On the other hand, it reduces the material cost of labour. Some scientific research by using USV: the bathymetric survey, changes and migration in major ecosystems and ocean activities, the biological phenomena of the ocean, cooperation of multi-vehicle (like cooperative work between air, ground, underwater, surface waters vehicles); operating and propulsion systems, and experimental platforms for the purpose of test structures, also the communication and sensor equipment's, as well as control strategy [15].
- **Environmental missions**: The USV contains many sensors to collect data, which can predict the notification and reporting of cases before they occur based on that information. some environmental tasks actions of the USV: they are monitoring, evaluation, and sampling; catastrophes (such as tsunami, the eruption of a submarine volcano, hurricane) helped predictability and management, and the response of emergency; measurements of pollution and cleaning [15].
- **Ocean resource exploration**: Some types of USV specializes in research and collection of information for the exploration of the resources of the oceans, such as oil, gas and my explorations; or the tasks of building the platform, building pipeline and maintenance abroad [15].
- **The military uses**: The basis for building the USV was to carry out military actions to protect the armies during the battles and normal cases. Therefore, considerable interest by developed countries in this type of vehicles, which carried out the following: the harbour, port, the coastal surveillance, patrolling, and reconnaissance, rescue and search; mine Countermeasures; anti-terrorism force protection, weapons platform remotely, Unmanned boat target [15].

- **Other applications**: Recently the USV has been used in most applications that make life comfortable and less cost. The most important applications that the USV provide it is Transportation; The relays of mobile communications, the platform to refuel the vehicles of USVs, unmanned underwater vehicles (UUVs), unmanned air vehicles (UAVs), and other populated [15].

2.3. Crash Avoidance System:

The Crash Avoidance System (CAS), also known as a collision mitigation system, is the Auto Safety System in vehicles that designed to reduce or prevent the collision severity. The CAS is using the radar (in all weather conditions) and sometimes laser (LIDAR), the camera (which are used to recognize the pictures) to detect an imminent accident. GPS sensing devices can detect fixed dangers through a database on site.

Once the collision is detected, these systems provide a warning to the driver. When a collision is imminent, they acted independently without any action from the driver (through the brake or the router, or both). Such a case of high speed's vehicle has to consist appropriate braking, while at low speeds vehicle (for example, less than 50 km/h (31 mph)) the avoiding crash by router might be more appropriate than higher vehicle speeds if the passages are clear.

2.4. The sensors:

A device that detects and reacts to some input type from the physical environment is called a sensor. The particular input may be heat, light, moisture, motion, pressure, or any of a great number of environmental phenomena. in general, the output is a signal that is transformed into a human-readable display at the location of the sensor or transmitted electronically over further processing or a network for reading.

There are so many kinds of sensors as said before but, this thesis will be talked about the movement sensors.

Motion sensors in various systems including crash avoidance, automatic doors, home safety lights, and etc., typically they issued some types of energy, like ultrasonic waves, microwaves, or light/laser beams and detect when the flow of energy is discontinuous by entering something its path.

2.4.1. Ultrasonic sensors:

Ultrasonic sensors are regularly used in automation tasks to level measurement, position changes, measure distance, such as the detection of the presence or in exclusive applications of detection sensor to discover obstacles is an ultrasonic sensor. This kind of sensor depends on the principle of the ’time-of-flight’. The transmitter periodically sends ultrasonic pulses (usually forty kHz). If there is an object within range, then this object will reflect sound waves and that will be obtained through the receiver. Because of the velocity of sound is finite, there will be a measurable difference in time between the transmitting and the receiving of the pulses. Knowing the velocity of sound and the difference in time, and then can be calculated the distance to this object [16].

These sensors are inexpensive sensors and that is the benefit to the users and can operate in different environmental conditions where other sensors would fail also they have low strength consumption [17].

One of the limitations of Ultrasonic, if there are many ultrasonic sensors used close to each other that may happen an interference and the signals that receive to the receiver become from another sensor, one of other limitation of ultrasonic sensors is that they generally cannot see obstacles which have their normal at an angle larger than forty-five degrees to the transmitter. That is because the sound will deflect from this obstacle and will not reflect. Therefore, the pulses that sent out of the sensor will not receive. The absorbing materials certainly will not reflect the sound waves also, so these will be invisible also to the ultrasonic sensor [17].

As the name indicates, by using ultrasonic waves the ultrasonic sensors measure distance.

2.4.1.1. Fundamentals of ultrasonic waves:

The propagation of waves in a frequency range above twenty kHz, where the frequency is inaudible conventionally to human hearing that is considered known as Ultrasound. The travels of ultrasound wave from one material to another depending on the medium mechanical deformation. The power transmitted is in a systematic movement as kinetic energy within the particles of the medium move.

Ultrasonic strategies have been utilized to measurement and monitoring in engineering and another field such as medical sciences, materials, and construction since the late 1990s. It is a non-harmful and non-intrusive technique that constantly measures the ideal properties of the material interface [18]. Figure 2.2 shows the frequency range and the number of kinds of ultrasound through it.

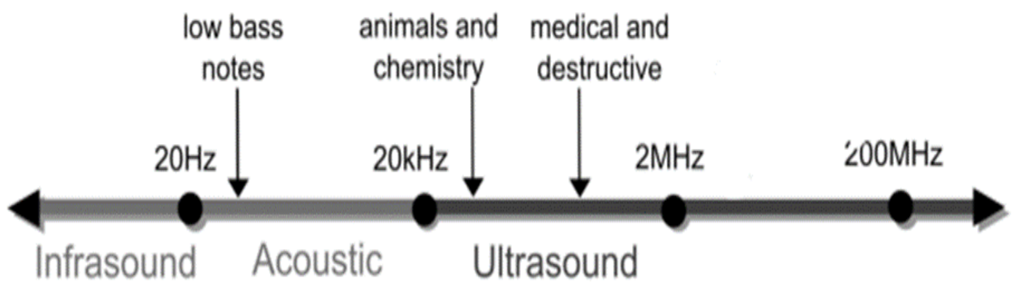


Figure 2.2: Acoustic sound ranges and frequency values

The first range is known as infrasound, from 0 - 20Hz. This is followed by the frequency range of 20 Hz - 20 kHz than known as the acoustic sounds. Finally, the last frequency ranging from 20 kHz to 200 MHz that is the ultrasound, Therefore, the frequency is the number of the accomplished cycles of the sound of a wave per unit time and is measured in cycle per seconds (cps) or Hertz (Hz) [18].

2.4.1.2. Ultrasonic measuring:

The principle of Ultrasonic ranging is to use ultrasound in the velocity of the air as the known and measurement of the time when the waves of sound reach obstacles and reflect back after that the actual distance can be calculated [35].

The time that taken by the pulse is actually the time of the travel of ultrasonic signals, however, we need only half of this. Therefore, the time is taken as T/2.

$$Distance = Speed * Time/2$$

The speed of sound in the materials depends on the temperature. The speed in the air is approximately 345 m/s, in a bar of steel is 5000 m/s and in water is 1500 m/s.

To measure the distance of a sound sign transmitted, it should be reflected. This sound sign is a longitudinal sound wave that strikes a flat surface. The sound is then reflected, provided that the dimension of the reflective surface is large compared to the wavelength of the sound [19].

- **Surface**

The perfect target surface is smooth and hard. This surface reflects a greater signal amount than a soft surface or rough surface. A weak echo is the conclusion of a soft or small object. This minimizes from the operating distance of the ultrasonic sensors and reduction its accuracy [19].

- **Distance**

The shorter the range from the ultrasonic sensor to an object, the returning resonance is stronger. Therefore, as the distance raise, the object requires higher reflective traits to return an adequate resonance [19].

- **Size**

A massive object has a greater surface to reflect the sign than a small one. The surface location recognized as the goal is usually the location closest to the sensor [19].

- **Angle**

The objects surface inclination facing the ultrasonic sensor influences how the object reflects. The element perpendicular to the sensor returns the resonance. If the whole object is at a larger angle, the sign is then reflected away from the sensor and no resonance is detected [19]. Figure 2.3 is to explain all these four cases.

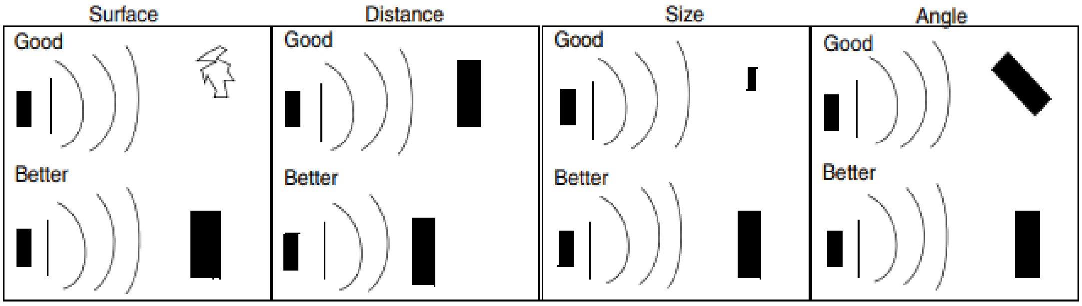


Figure 2.3: the things that affect of ultrasonic sensor measuring.[19]

2.4.1.3. JSN SR04T:

The transducer is a component used to convert an electrical signal into an acoustic signal (on the sending side) or convert an acoustic signal into electricity (at the receiving end). as shown in figure 2.4.

Figure 2.4: the shape of JSN SR04T.

This sensor is an ultrasonic distance measuring module with a non-contact distance detection function it provides 2-400cm non-contact measurement function with the ranging accuracy can reach up to 0.3 cm. The modules include ultrasonic transmitters, receiver and control circuit. This product adopts an industrial-grade integrated, ultrasonic design with waterproof type, and has stable performance.

The specifications of this sensor are measuring an angle is 75-degree, Small size, easy to use -Low voltage, low power consumption, High accuracy and Strong anti-jamming.

The distance d follows Eq.

$$d = (T.a) / 2$$

Where T is high-level time and a is the speed of sound (340 m/s in dry air at 20°C). If no obstacle is detected, in a fixed time delay, the output pin gives a 38 MS high-level signal [18].

2.4.2. Light Detection and Ranging (LIDAR) sensors:

LiDAR is a remote sensing technology that uses a laser pulse to collect measures, which can then be used to create three-dimensional models and environments and maps of the objects. LiDAR is a shortcut of Light Detection and Ranging. LiDAR operates in a manner similar to the Sonar and Radar, but it uses alternative than sound or radio waves, the light waves from a laser.[20]

A LiDAR System calculates the duration of the Light to reach an object or surface and reflected once again on the scanner. Then the distance is calculated by using the speed of light (The speed or velocity of light is 299,792,458 m/s). these measurements are known as the ‘Time of Flight’. LiDAR systems can about 1,000,000 pulses/s. [20]

The LiDAR systems are used commonly in the functions of the survey. In view of their capacity to collect 3D measurements, the scanning systems of laser are common to clear the built environment (like buildings, railways, and roads) as well as the establishment of Digital Terrain Models (DTM) also the Digital Elevation Models (DEMs) of the particular landscape.[20]

The lidar a measures distance by calculating the time delay between the transmission of a Near-Infrared laser signal and its reception after reflecting off of a target. This translates into the distance using the speed of light.

Due to the shorter wavelength of light, LiDAR’s can be a lot more accurate than RADARs in detecting obstacles

2.4.2.1. Lidar-lite sensors:

Lidar-Lite targets the need for very compact optic distance measurement, and high-performance sensors for applications like UAV's, drones, and robotics where a high performance, low-power, very small, reduced cost sensor and it is desirable [21].

The single-chip processing solution in combination with minimal supporting hardware enables a new class of optical distance measurement sensors. Lidar-Lite's goal is to make an easily configurable sensor module with the availability of technology that may be used as the basic block building for sensor applications in projects [21].

In fact, the Lidar-Lite has a wide distance detection. There are many factors that may have an effect on the sensor's maximum range. The angle of the sensor and the target reflectivity are the two that have the most influence [21].

There are ways to increase the speed of measurement. However, the sensor will lose the sensitivity of the laser and possibly decreasing the maximum range.

2.4.2.2 The RPLidar:

RPLIDAR is a 2D Laser scanner (LIDAR) Low Cost and 360 degrees was developed by RoboPeak. The system can survey the 360 degrees in different ranges started from 6 m to one km. The producing two-dimensional cloud bitmap data can be used in localization, mapping, and modelling of object/environment [22].

RPLIDAR's frequency scanning arrived at 5.5 Hz when taking in each round 360 points. Can be configured with a maximum of 20 Hz. RPLIDAR is the laser triangulation measure system in basic. Also, it can work well in all types of the internal environment and the external environment without the rays of the sun [22].

RPLIDAR has a system of a range scanner and system of a motor. After Playing Each sub-system, start RPLIDAR in recycling and scan in a clockwise direction. The user can obtain the survey data through the contact interface (serial port or USB) [22].

- **Mechanism:**

RPLIDAR depends on the principle of the laser triangulation ranging and used in the acquisition and processing of high-speed vision hardware developed by RoboPeak. the distance data that measures by the system are more than 2 thousand times per second and with the output of high-precision distance (contains an RPLIDAR development unit standard (A1M1-R1). The engine control unit logical RPLIDAR integrated, for the command (3.3 volts) which can be used to configure the scanning frequency by adjusting the engine speed, the developer can also choose to turn off the engine for the purpose of providing energy. The mechanism of RPLiDAR is shown in Figure 2.5 [22].

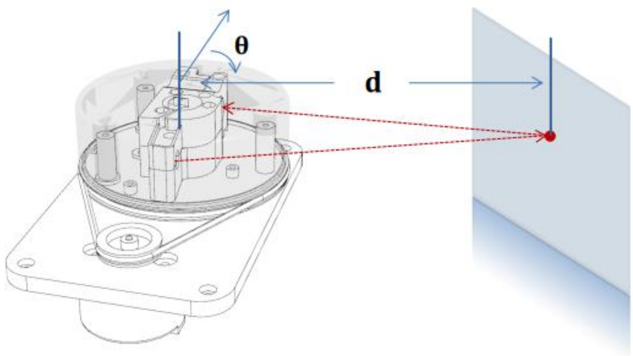


Figure 2.5: The mechanism of RPLiDAR [22]

- **RPLIDAR can be used in some applications** :

• Localization and General robot navigation and (Home cleaning robot/service robot)

• Obstacle avoidance in smart toy’s

• 3D re-modelling and Environment scanning

• Generally Simultaneous Localization and Mapping (SLAM)

2.5. The development boards:

To develop integrated, they need two things: the development board and the integrated development environment (IDE). The printed circuit board (PCB) with the circuits and devices designed to facilitate experimentation with some of the features of the microcontroller boards all these are under the name of the microcontroller development board.[23]

The development board is a single printed circuit board that the microcontroller is mainly entered into board manufacture. This board has all of the necessary circuitry for a helpful control task such as processor, chipset, memory, and accessories peripherals such as liquid crystal displays (LCD), keyboard, serial port, USBs, slot card of SD, Ethernet, etc. with features of debugging. The intent is that the board will be immediately beneficial to a developer of the applications, without necessary to spend effort and time to develop the hardware controller. Also, this will keep them far away from tampering with being in touch with the boards and the jumper wires.[23]

2.5.1. Arduino:

The Arduino is the most popular electronics prototyping platform that is the open-source based on a development environment and a simple Input/output board that implements the Processing and Wiring language. used to create electronic interactive applications. The free open-source IDE can be downloaded for Windows, Mac OS X, and Linux [24].

To download the program from the computer via USB, it creates an interface of serial communication. For the microcontroller, there is in the operating requirements such as the oscillation circuit, connecting the external circuits by connecting the board's pins to other pins and operating power. The Arduino works on a simplified version of the programming language (C language) [24].

The Arduino microcontroller contains a feature that is an important one. that Arduino feature is containing the universal serial port (USB) is used to connect to the computer for the purpose of interchange of programming or data. Because of that, there is no need for an external programmer which reduces the time and cost [24].

2.5.1.1. Arduino Uno:

"Uno" means in the Italian (one). The Arduino UNO board contains all the necessary support to the microcontroller. The Arduino UNO microcontroller board is absolutely very familiar for experts and beginners. UNO Should be considered as one of the first development boards that work microcontroller-based. [23]

The Arduino UNO is the simplest and most powerful prototyping accurate based on the ATmega328P microcontroller. It has 14 digital i/o pins (6 of them can be used as outputs pins), and other 6 of them as analogue inputs, a USB connection, a power jack, a reset button, and an ICSP header. It contains everything necessary to support the microcontroller. The specifications of the Arduino UNO are shown in Figure 2.6 and Table (2.1).[23]

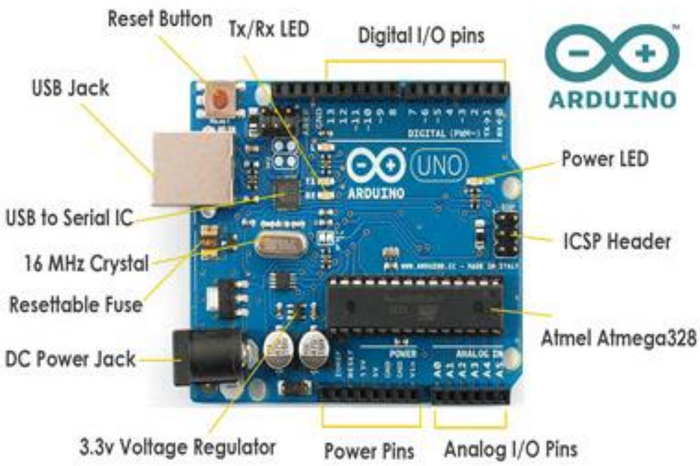


Figure 2.6: The specifications of Arduino UNO [23]

Table 2.1: The specifications of Arduino UNO

Parameters	Description
Microcontroller	ATmega328P
Input Voltage (recommended)	7-12V
Operating Voltage	5V
I/O Pins	14 digital pins (6 of that supply PWM output and 6 Analog Input Pins)
Input Voltage (limits)	6-20V
DC Current for 3.3V Pin	50 mA
DC Current per I/O Pin	40 mA
SRAM	2 KB
Flash Memory	32 KB of that 0.5 KB utilized by bootloader
Speed of Clock	16 MHz
EEPROM	1 KB
Language of Programming	A simplified variance of the C language

2.5.1.2. Arduino Mega:

The Arduino Mega is a board based on the ATmega2560 microcontroller and it is designed for more complex projects than Arduino UNO. It has 54 digital I/O pins (14 can be used as PWM outputs of which), (16 inputs analog), four as a UARTs (hardware serial ports), (a 16 MHz crystal oscillator), a power jack, a USB connection, a reset button, and an ICSP header. To support the microcontroller, the Arduino Mega includes everything needed. simply connected it to a computer by using the USB cable or power it by using an AC-to-DC converter or by using a battery to get started. Figure 2.7 shows the …. And table 2.2 shows the description of Arduino Mega [25].

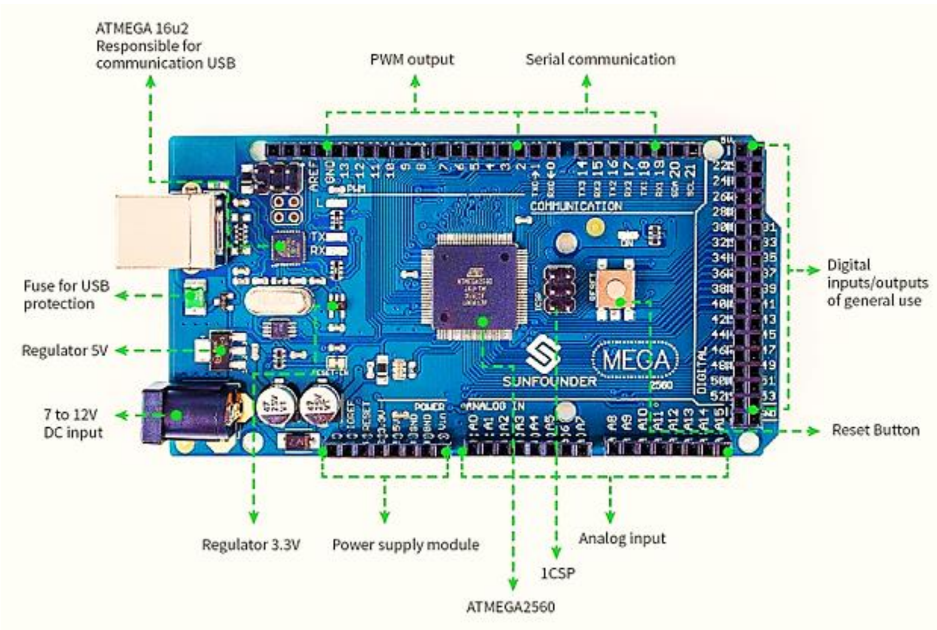


Figure 2.7: The description of Arduino Mega [25]

Table 2.2: The description of Arduino Mega

Parameters	Description
Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output) Analog Input Pins 16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

2.5.2. LattePanda Alpha (mainboard)

Back at the tail end of 2015, a single-board computer, and it had a Quad-Core Atom processor, that was under the name of LattePanda

A LattePanda is a single board computer with complete Windows 10. It can do anything that a systematic PC does and has everything an ordinary PC has. The LattePanda is compatible with almost every device known such as printers, cameras, joysticks, and more. Any peripheral devices that work on the PC will work on it [26].

A LattePanda arrives pre-installed with a (Windows 10 Home Edition), that means can run powerful apparatus such as Java, Visual Studio, NodeJS, Processing, and more applications. With present APIs, the developer can develop their own software and hardware projects on a LattePanda as they would on a PC by using C#, JavaScript, Python etc [26].

The company is back two years later (in 2017) with new boards, the LattePanda Alpha and the LattePanda Delta.they became more powerful than LattePanda. Table 2.3 below shows the description of those three kinds of boards [26].

Table 2.3: The description of those three kinds of LattePanda boards [26]

Features/Products	**LattePanda**	**LattePanda Delta**	**LattePanda Alpha**
RAM	2/4 GB	4GB	8GB
Memory	32/64 GB eMMC 4.0	32GB eMMC 5.0 1x M.2 B Key Supports SATA SSD 1x M.2 E Key	64GB eMMC 5.0 1x M.2 M Key Supports NVMe SSD 1x M.2 E Key
Connectivity	WIFI 802.11 b/g/n Bluetooth 4.0 100 Mbps Ethernet	WIFI 802.11 AC/b/g/n 2.4/5G Dual Band Bluetooth 4.2 1000 Mbps Etherent	WIFI 802.11 AC/b/g/n 2.4/5G Dual Band Bluetooth 4.2 1000 Mbps Etherent
Onboard Arduino Co-processor	√	√	√
USB Ports	1x USB 3.0 2x USB 2.0	3x USB 3.0 1x Type-C Supports PD, DP, USB 3.0	3x USB 3.0 1x Type-C Supports PD, DP, USB 3.0
Displays Support	HDMI Output Extendable MIPI touch Displays	HDMI Output Extendable MIPI touch Displays Type-C DP Output	HDMI Output Extendable MIPI touch Displays Type-C DP Output
GPIOs	20x Arduino Pins	2x 50-pin GPIOs including I2C,I2S, USB, RS232, UART, RTC, Power Management, Extendable Power Button	2x 50-pin GPIOs including I2C,I2S, USB, RS232, UART, RTC, Power Management, Extendable Power Button
Dimension(mm)	85 x 70	110 x 78	110 x 78

2.6. Electrical Motors

An electrical motor is a machine that has introduced one of the largest developments in the fields of engineering and technology ever since the invention of electricity. A motor is nothing however an electromechanical system that converts electrical power into mechanical energy. The following chart is the kinds of electrical motors as shown in Figure 2.8 [27].

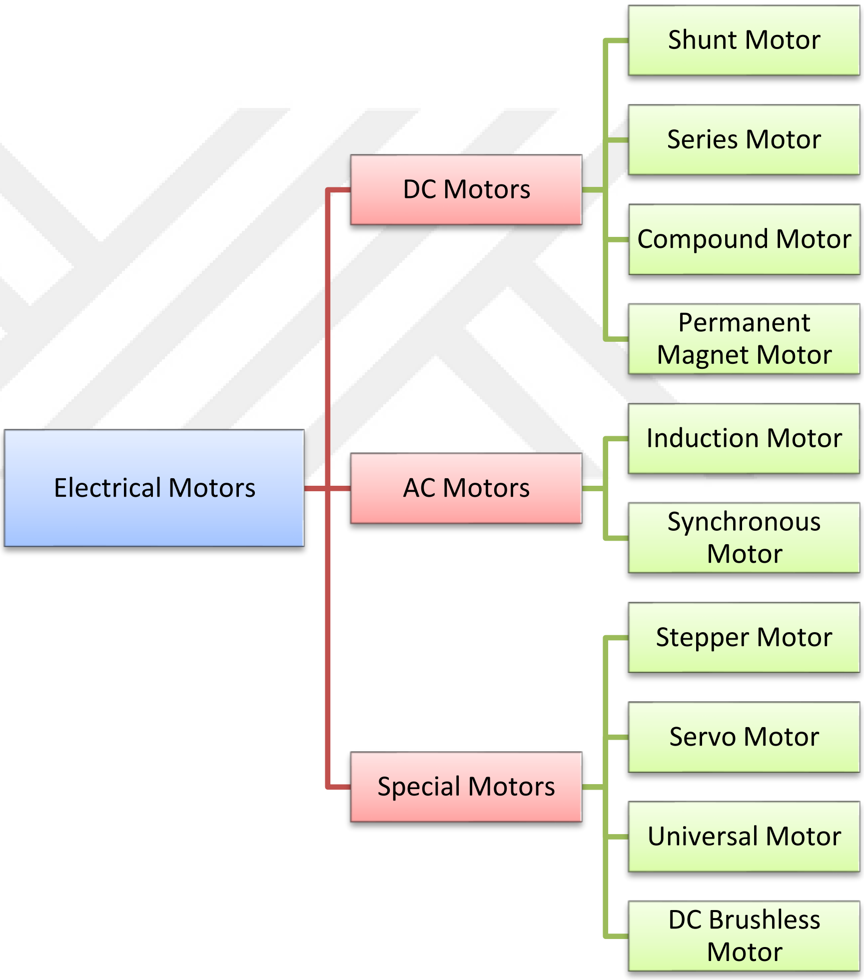


Figure 2.8: Types of electrical motors.

In this thesis will choose Servo motor for its advantages.

2.6.1. Servo motor

A servo is a small device which has an output shaft which positions on the coded signal. It is a rotary or linear actuator that allows for precise control of the angular or linear position, velocity and acceleration. Figure 2.9 shows the types of servo motors [28].

Advantages:

- High efficiency.
- High output power is relative to motor size and power.
- High-speed operation is possible.

Disadvantages:

- Complex, require an encoder.
- High cost.
- The motor can be damaged by sustained overload.

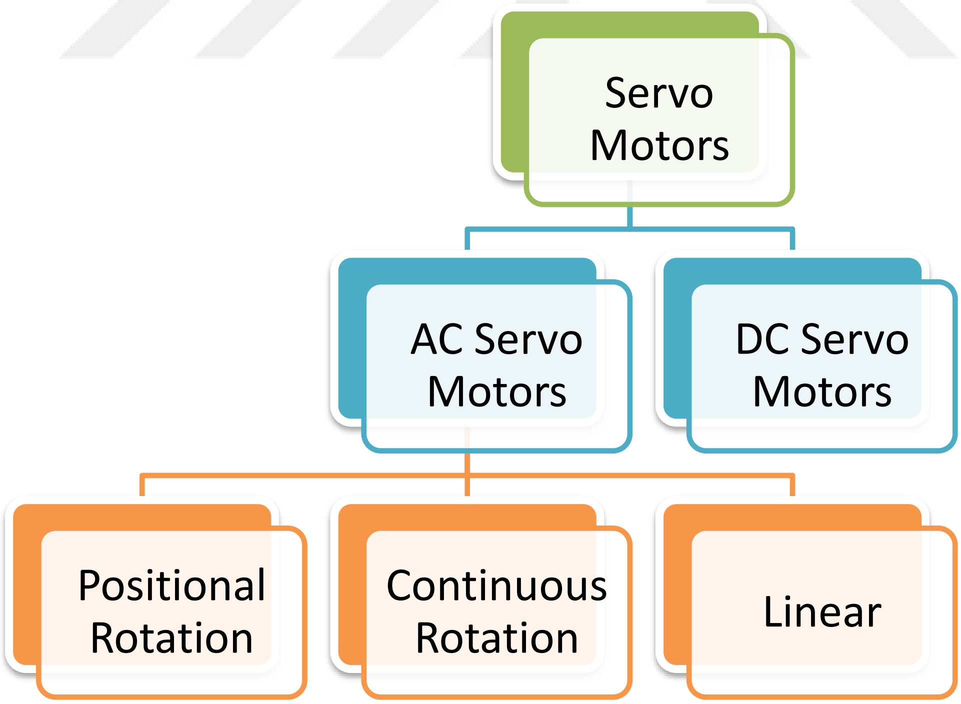


Figure 2.9: The types of servo motors.

All of the components listed above have been approved with the selected algorithm in addition to the CAS system. The details will be mentioned in the next stages and will mention the way each part works, in addition to some types of algorithms that help facilitate the work of the system with high accuracy to predict the risks and to protect the vehicle from obstacles.

ALGORITHMS & SYSTEM DEVELOPMENT

3.1. Introduction:

This chapter presents the core development concepts, including engineering issues that have been identified and diagnosed to build the model of unmined service vehicle (USV). The primary concern of this part of the work is to adapt the algorithm system to the required model and to develop the system to work in real-time. Concisely, the journey from theory to prototype, and the evolution of novel requirements which required to be handled are explained in detail. The first part of this chapter state of the art for algorithms that already used within USV.

The section discusses the motion model and the observation model developed for the system. The next part discusses the need for calibration of the sensor with respect to the robot and the development of a calibration system to be able to transform the coordinates in the sensor frame of reference to the robot's frame of reference.

3.2. A* Algorithm

A* algorithm is one of the search algorithms for discovering the minimum cost path via a given map to signify uniformed dimension cells. It has been widely used in many real-time method games and is likely the most famous route-finding algorithm.

It offers values to the nodes in many ways. Each value node is the sum of the actual cost to that node from the start and the heuristic estimate of the final value from the node to the goal [32].

This algorithm makes the most efficient use of the heuristic characteristic of the search, as an alternative than some other algorithm that uses the same heuristic that product fewer nodes and finds an ideal path.

The optimality of A* algorithm represents the smallest quantity of nodes (cells) located by using the heuristic search that ensures to locate the path. Due to this optimality and the reason for producing the direction with the least distance cost [32].

A* algorithm uses a starting point and a destination point to produce the desired path,

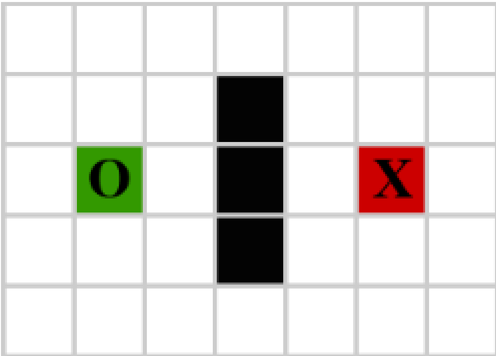


Figure 3.1: Starting and Destination Points in A* Search Algorithm [32]

A* algorithm starts to execute by looking at the starting node first and then expanding to the surrounding nodes (Figure 3.2).

This operation continues until the destination node is found.

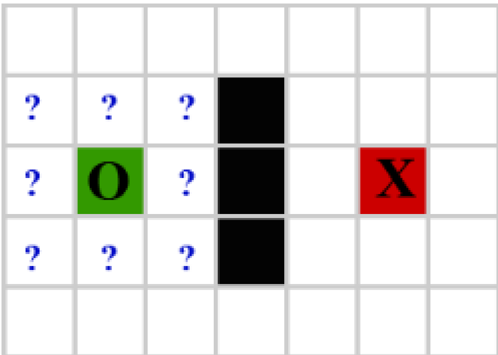


Figure 3.2: Starting the A* Search Algorithm [32]

f(n), is the combination of two scores for calculating the values of the algorithm:

$$f(n) = g(n) + h(n)$$

Where g(n) is the cost of the path from the starting node to any node n, h(n) is the heuristic estimated cost from any node n to the goal.

The complexity of time for A* algorithm depends on the number of nodes that have been explored from the searching map.

The flowchart of the conventional A* algorithm is shown in Figure 3.3.

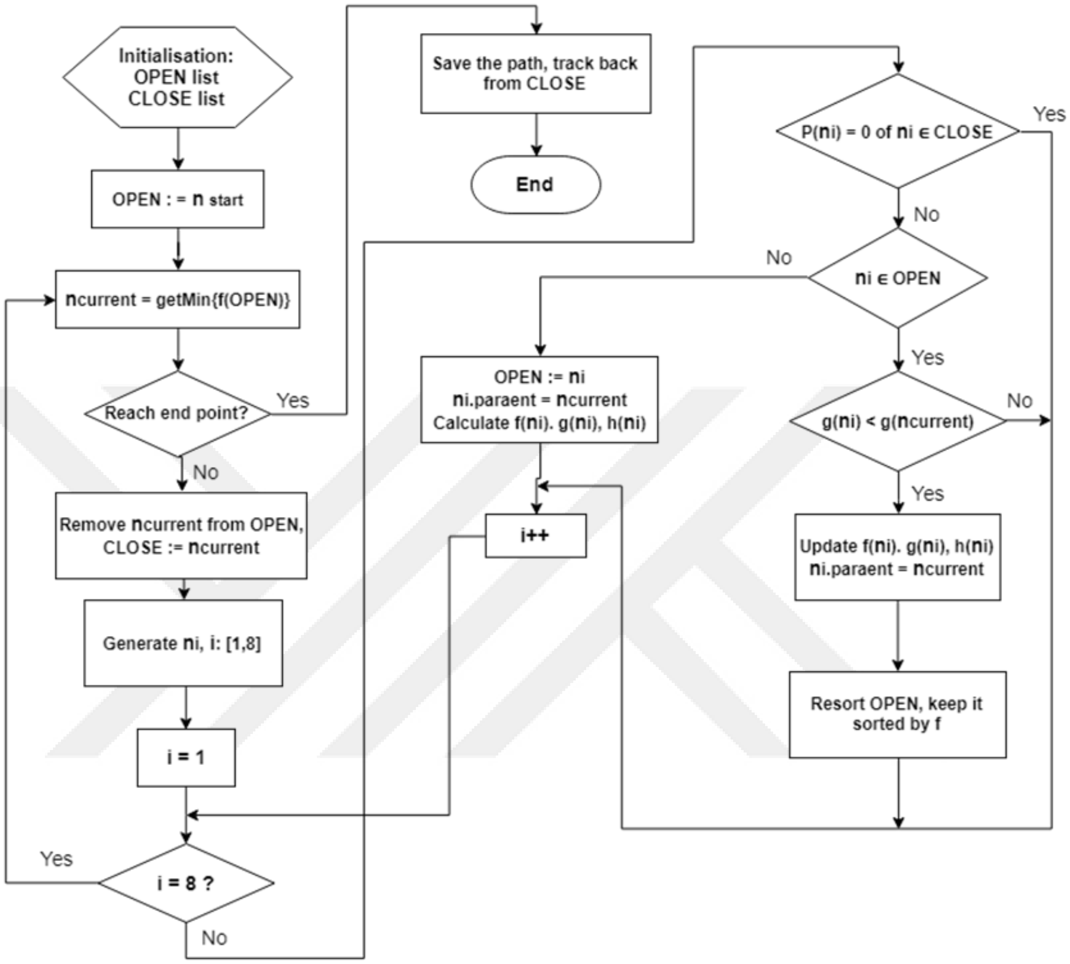


Figure 3.3: Flowchart of the conventional A* algorithm

3.3. Weighted Sum Concept:

The weighted sum model (WSM)is the first-class acknowledged, most commonly used in decision-making techniques and simplest multi-criteria decision analysis (MCDA) / multi-criteria decision-making technique for evaluating a number of alternatives in phrases of a range of decision criteria. It combines the several goals and weights corresponding to these targets to create a single rating for every choice to make them comparable.

3.3.1. Weighted Sum Model:

The Weighted Sum Model (WSM) is the most widely used technique in the problems of the optimization in multi-objective. Because it tries to combine a lot of goals and weights referring to these objects to make a single rating for every choice that could be compared among these weights. The following equations used in WSM model as shown.

$$A_i^{WSM} = \sum_{j=1}^{n} W_j \, a_{ij} \quad \text{...Eq 3.1}$$

$$A_*^{WSM} = MAX_i \sum_{j=1}^{n} W_j \, a_{ij} \quad \text{...Eq 3.2}$$

In these equations, the WSM score for an alternative values $\boldsymbol{Ai}$ denoted as $AiWSM\text{−}score$ can be computed by adding the products of a weight wj with its referring parameter, where aij is the value of the objective. For instance, the cost of the weight which has to be spent to perform the desired. The maximum WSM score is the best alternative value chosen as the one which has the maximum WSM score for given parameters. The multi types of objectives can be assumed to be positive: the higher the score, is the better the alternative. Assuming that objective to be negative (in case of cost models), the best alternative has equivalently the lowest score [31].

3.3.2. The WSM Method:

The weighted sum model (WSM) is probably the most commonly used approach, especially in single-dimensional problems. If there are m alternatives and n criteria then, the best alternative is the one that satisfies (in the maximization case) the following expression

$$A_*^{WSM} = MAX_i \sum_{j=1}^{n} W_j \, a_{ij} \,, for \; i \; = 1, 2, 3, \dots, m.$$

Where: *A* WSM* is the WSM score of the best alternative, *n* is the number of decision criteria, *aij* is the actual value of the *i-th* alternative in terms of the *j-th* criterion, and *Wj* is the weight of importance of the *j-th* criterion.

The idea that governs this model is the additive application assumption. However, the entire fee of alternative is identical to the sum of the products as proven in the subsequent phase. In one-dimensional, all units are the same (e.g., money, meter), the WSM can be used reliability. In the other side, the most difficult part of this method is emerging when it is implemented to multidimensional MCDM problems. Nevertheless, in combining one of a kind dimensions, and therefore exceptional gadgets, the additive software assumption is violated and the result is equivalent to "adding apples and oranges"[29][31].

3.3.3. The Weighted Sum Implementation:

Example I

Suppose that an MCDM problem involves four criteria, which are expressed in exactly the same unit, and three alternatives. The relative weights of the four criteria were determined to be:" ***W1 = 0.20, W2 = 0.15, W 3 = 0.40, and W 4 = 0.25*** ". Also, the performance values of the three alternatives in terms of the four decision criteria are assumed to be as follows [29]:

$$A = \begin{bmatrix} 25 & 20 & 15 & 30 \\ 10 & 30 & 20 & 30 \\ 30 & 10 & 30 & 10 \end{bmatrix}$$

Nevertheless, the following decision matrix shows some data for MCDM problem that can be summarized as follows:

	Criteria			
	C_1	C_2	C_3	C_4
Alts.	(0.20	0.15	0.40	0.25)
A_1	25	20	15	30
A_2	10	30	20	30
A_3	30	10	30	10

When equation (2-1) is implemented in the previous example data the scores of the alternatives could be:

$$\boldsymbol{A1\ WSM - score} = 25\ xO.20 + 20xO.15 + 15\ x\ 0.40 + 30xO.25$$
$$= 21.50.$$

likewise, we can get:

$$\boldsymbol{A2\ WSM - score} = 22.00,$$

$$\boldsymbol{A\,3\ \ WSM - score} = 20.00.$$

To sum up, the best alternative value (maximum value of the given data) is alternative ***A2***, due to the value has the highest WSM score among the others which is 22.00.

Example II

The table below consist of many parameters of alternative and values of criteria for choosing the best value of alternative among these **A1, A2, A3, A4** and **A5**. In the other side, the criteria values that determine the picking process is **K1, K2** and **K3**.

Table 1. Sample of Value Criteria

Criteria	K1	K2	K3
Alternative	0.3	0.4	0.3
A1	15	10	10
A2	20	10	15
A3	30	15	10
A4	20	25	15
A5	15	15	10

Refer to Table 1, the value of criteria **K1** is known and given by 0.3 or 30%, the value of criterion **K2** is 0.4 or 40% while the criterion value **K3** is 0.3 or 30%. To compute the value of each alternative by using WSM formula eq. 1. Refer to equation 1, **A4** is chosen as the best choice, due to the magnitude of **A4** is the highest value of all the given alternatives. Table 2 shows the result as follow [30]:

Table 2. Ranking Results of WSM

Alternative	WSM values
A4	**23.5**
A3	18
A2	14.5
A5	13.5
A1	11.5

3.4. Kalman Filter

Kalman filter (KF) is a mathematical equation set to produce effective calculations offering options for the least-squares method. KF has many effective aspects: it helps estimations of the previous, present, and even subsequent states, KF could be estimated the variables of a variety of processes. In mathematical terms, the Kalman filter estimates the states of a linear system [33].

The fundamental operation is achieved by using the KF that generate estimates of the preferred values, first off predict a value, then estimating the uncertainty of the above value and discovering a weighted common of each the expected and measured values. The least uncertainty weighted is given to the value [33].

The Kalman filter has been notably used in estimating the country situation of a process. It has been broadly applied in a number of fields like navigation, monitoring object, control systems, robotic movement planning, laptop vision and many extras.

In this thesis aims to take a more teaching-based strategy to current the Kalman and Extended Kalman Filters from a practical usage perspective. One of the principal differences between this work and the contemporary state of the art Kalman filtering tutorial is that the statistical concept.

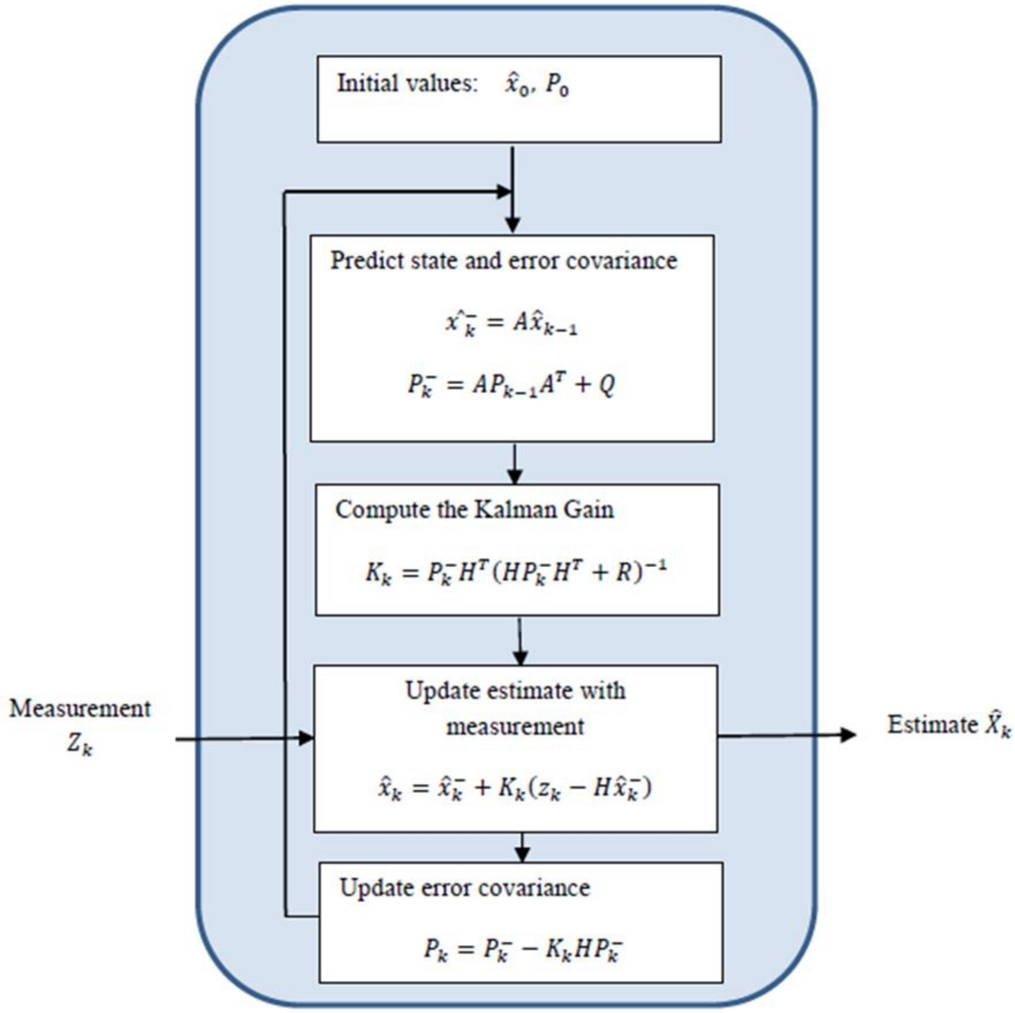


Figure 3.4: Kalman filter algorithm [33]

Figure 3.4 depicts the everyday step of the Kalman filter algorithm. It consists of several iterative processes including the prediction of country and error covariance, dimension updates with computation of Kalman reap and an estimation process, and lastly, there is computation of error covariance which shows how correct estimates are. The Kalman filter structure has one measurement enter Zk and one estimation output Xk. There are 4 system model A, H, Q, and R. A is the state transition matrix, H is the state to measurement matrix, Q is the covariance matrix of transition noise, and R is the covariance matrix of dimension noise. In step III, Kk is the Kalman gain which depends on Pk error covariance. Error covariance indicates the difference between Kalman filter estimation and the real value [33].

3.4.1. Design the Kalman Filter:

The Kalman filter is a statistical algorithm which can estimate the state of the process given noisy data. The go with the flow of Kalman filter iteratively predicts and estimate the prediction with entering dimension until some criteria are met. For indoor positioning, the Kalman filter method consists of a vector of moving object X in (x,y) coordinates and pace with the coordinates as the sole measurement. The state and dimension model is given below:

State model:

$$Xk = AXk - 1 + W$$

Measurement model:

$$Zk = HXk + V$$

Matrix A is the state transition matrix that describes the movement of the machine which in this case the equation relationship of position and velocity. Matrix H indicates the relationship between the measurement and state variable [33].

$$\hat{X}_k = \begin{bmatrix} x_k \\ y_k \\ v_{xk} \\ v_{yk} \end{bmatrix}, \ A = \begin{bmatrix} 1 & 0 & \Delta_t & 0 \\ 0 & 1 & 0 & \Delta_t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \ H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$Z_k = \begin{bmatrix} x_k \\ y_k \end{bmatrix}$$

Q and R are the process noise covariance matrix and dimension noise covariance matrix, respectively. These two parameters will have an effect on the measurement and prediction of the Kalman filter process. Between these parameters, process noise covariance is difficult to determine, which is decided via experiment or experience. J. Yim et al. [33] have highlighted primarily based on their experiment the ratio between Q and R that actually consequences the performance of the Kalman filter. By following the step, it was discovered that Q equals to 0.00001 gives greatest results. The initial circumstance as follows was once setup:

$$Q = \begin{bmatrix} 0.00001 & 0 & 0 & 0 \\ 0 & 0.00001 & 0 & 0 \\ 0 & 0 & 0.00001 & 0 \\ 0 & 0 & 0 & 0.00001 \end{bmatrix}$$

$$R = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$P_0 = \begin{bmatrix} 5 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 5 \end{bmatrix}$$

$$\hat{x}_k = \begin{bmatrix} 32.75 \\ 2.75 \\ 0 \\ 0 \end{bmatrix}$$

3.5. Simultaneous localization and mapping (SLAM) Algorithm

It is the computational issue of building or constructing a map of an ambiguous situation while at the same time monitoring an operator's area inside it. In another word, it is learning a map and trying to locate the robot with each other.

SLAM algorithm tries to estimate the position of a certain robot with the same time finds the map of the circumference. However, the map used by SLAM is required for localization and to obtain a good position estimator is required for mapping.

The SLAM algorithm has many significant properties that direct the development of vulnerability in both the map and vehicle estimates. These properties incorporate the convergence of the guide state assesses, the need to keep up consistency in the estimation procedure and the computational multifaceted nature engaged with keeping up the covariance framework. three important convergence properties of the SLAM filter. The three key results can be obtained as follows [34].

1. covariance matrix decreases gradually in the observed data for the determinant of any submatrix in the map.

2. In the point of confinement, as the number of perceptions builds, the milestone assessments become completely corresponded.

3. the accuracy of the limited map play a function for initial vehicle uncertainty when the first landmark is observed [34].

These properties of the SLAM algorithm have significant ramifications for its utilization of true frameworks. The confirmations successfully exhibit that the uncertainty in the guide appraisals will in general diminishing to some lower bound and that the connections between highlights or tourist spots will turn out to be impeccably known. Given two mean and covariance estimates,

$\{\hat{x}_a^-(k), P_{AA}^-(k)\}$ and $\{\hat{x}_b^-(k), P_{BB}^-(k)\}$, the covariance intersect update, $\{\hat{x}_c^+(k), P_{CC}^+(k)\}$ is computed as:

$$\mathbf{P}_{CC}^{+}(k) = (\omega \mathbf{P}_{AA}^{-1}(k) + (1-\omega)\mathbf{P}_{BB}^{-1}(k))^{-1}$$
$$\hat{\mathbf{x}}_c^{+}(k) = \mathbf{P}_{CC}^{+}(k)(\omega \mathbf{P}_{AA}^{-1}(k)\hat{\mathbf{x}}_a^{-}(k) + (1-\omega)\mathbf{P}_{BB}^{-1}(k)\hat{\mathbf{x}}_b^{-}(k))$$

where $0 \leq \omega \leq 1$ and ω can be computed to minimize a certain measure such that determinant and maximum eigenvalue, etc. of the covariance matrix. This approach provides a computationally efficient mechanism for performing SLAM. Furthermore, for the most part, permits enhancements in the vehicle and guide appraisals to be spread all through the guide when a notable component is watched and is the way to the combined properties of the calculation [34].

The algorithms mentioned earlier are a simple number of algorithms that help to choose the most suitable route for vehicles. WSM has been adopted in the simulation program which will be mentioned in Chapter 4 which is a small part of the real system. The simulation program is built only to ensure the effectiveness of the system and to choose the most suitable algorithm.

3.6. PROPOSED WORK

In this thesis, Unmanned Surface Vehicle (USV) has a discrete controlled computer system to control the USV, sense the around of the USV and process data to avoid obstacle collisions. This computer system's schematic has been explained as shown below:

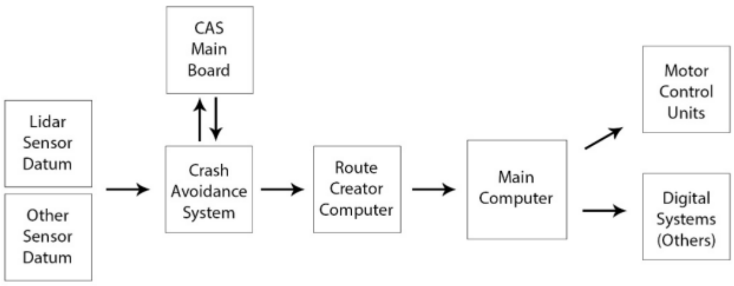


Figure 3.5: System control units of USV

There is a CAS (Crash Avoidance System) Instruction which gets data from LIDAR sensors and other sensors and sends this datum to CAS main board computer to process this datum. After the processes of sensor datum, CAS sends analyzed sensor datum to route creator computer to create available free routes. Route Creator Computer decides the most secure route to avoid any crash and sends new route information to the main computer. Finally, the main computer calculates needed parameters and sends appropriate signals to the Motor Control Units and other digital systems to move. All these algorithms and instruction systems manage by LattePanda Alpha main computer which is located into the USV as shown in Figure 3.6 [36].

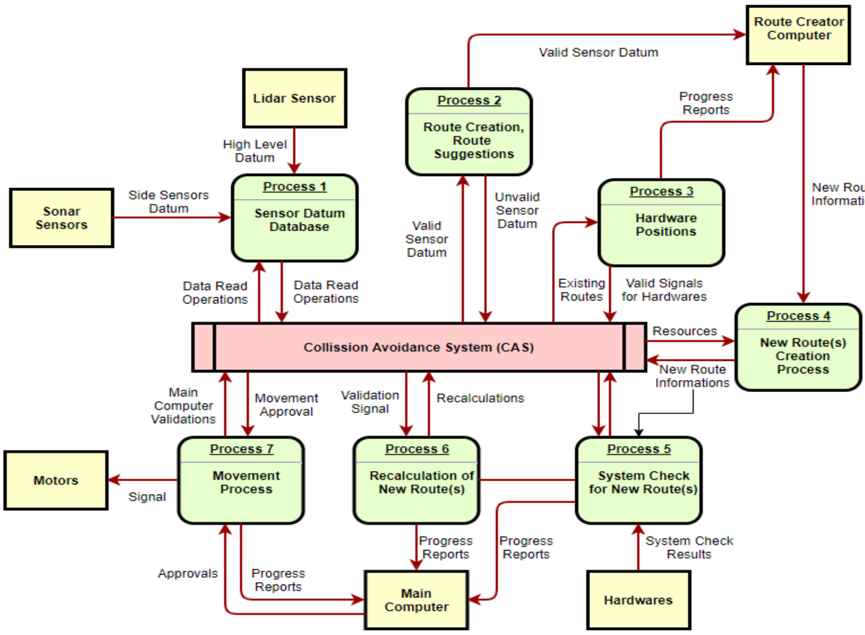


Figure 3.6: The (CAS) *Detailed Explanation of Figure 3.5

The USV will be controlled to avoid obstacles by using Ultrasonic sensors, Lidar-lite and Lidar. All steps in the flowchart of (CAS) had been implemented based on python language which explained below:

3.6.1. Python language:

Python is a high-level programming language, object-oriented with integrated dynamic semantics primarily for app development and web.

Python is pretty simple and easy to learn because it requires a special syntax that focuses on readability. Developers can read and translate Python code a lot easier than other languages.

Additionally, Python supports the use of modules and packages, which ability that programs can be designed in a modular fashion and code can be reused throughout a variety of projects. Also, one of the most promising benefits of Python is that both the popular library and the interpreter are accessible free of charge, in both binary and supply form.

That makes Python reachable to almost anyone. If you have the time to learn, you can create some top-notch matters with the language.

3.6.2. Hardware description:

the proposed system that was explained before in Figure 3.6 consist of sets of different elements which can be described as follow:

1. 12 of Ultrasonic sensors is used on both sides that mean six Ultrasonic sensors for the left side and six Ultrasonic sensors for the right side of the USV. Ultrasonic protect the USV from the nearest obstacles which floating on the sea within range 0.25 to 5 m with a field of view between 15 to 70 degrees depending on the sensors company. In another side, the number of sensors may be increased or decreased depending on the field of view. The rays are emitted from these sensors and if an obstacle found in the sea the echo wave is received by the ultrasonic sensor and computing of distance between the obstacle and USV in order to change the USV path. Figure 3.7 shows the range of Ultrasonic sensors on USV prototype. All connection of Ultrasonic sensors can be explained as shown in Figure 3.8.

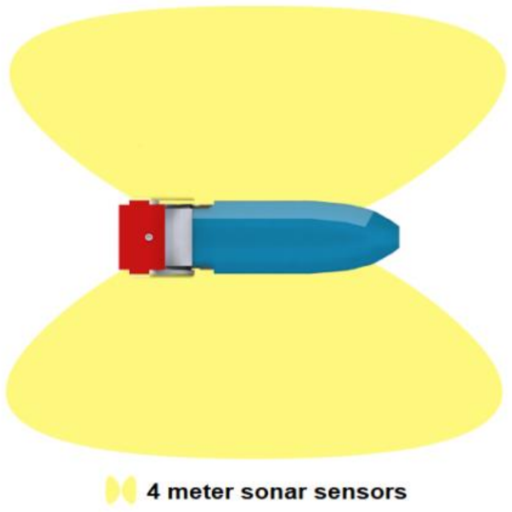


Figure 3.7: The range of Ultrasonic sensors

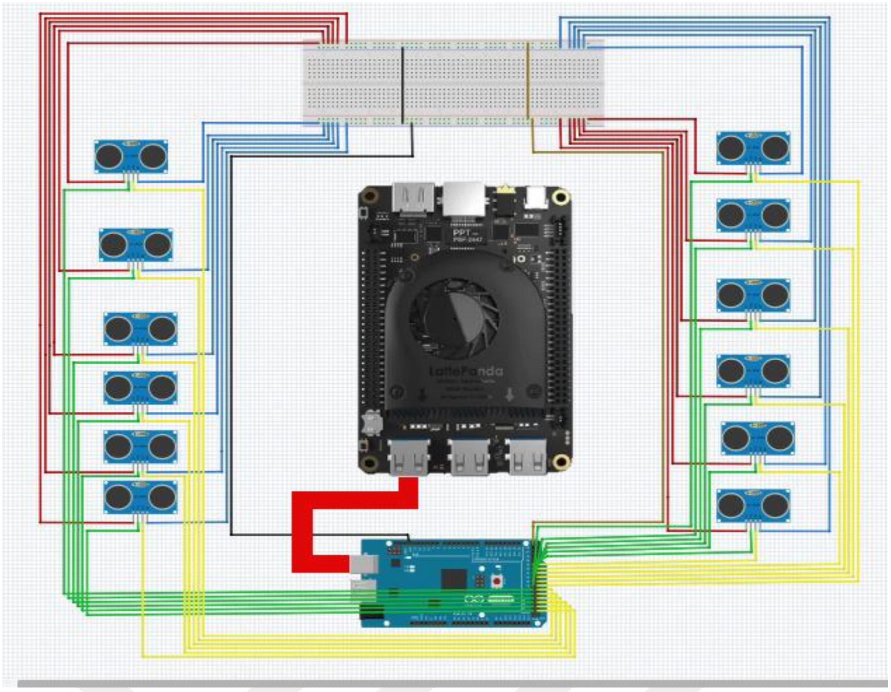


Figure 3.8: Ultrasonic sensors connection

2. A LIDAR-Lite sensor is used and located in front of the boat and another one at the end of the USV. They move in 80 degrees as a field of view by using a servo motor. That allows to detect the objects or obstacles that may hit or cause damage for the USV, its operation in somehow likely the sonar but the LIDAR rays could reach up to 15 m distance away from the USV [8]. These sensors are installed on the Servo motor because the LIDAR sensors laser beams have directly puled. Figure 3.9 shows the range of LIDAR-Lite sensors on USV prototype, and lidar lite sensors connection can be explained in figure3.10.

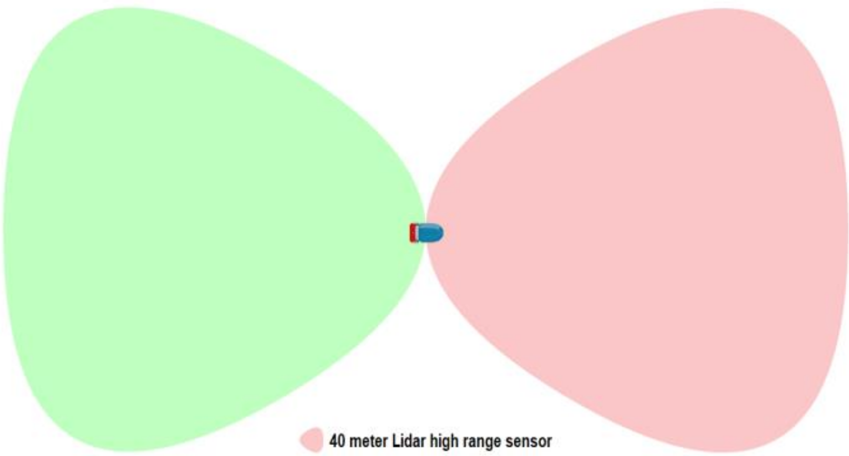


Figure 3.9: The range of LIDAR-Lite sensors

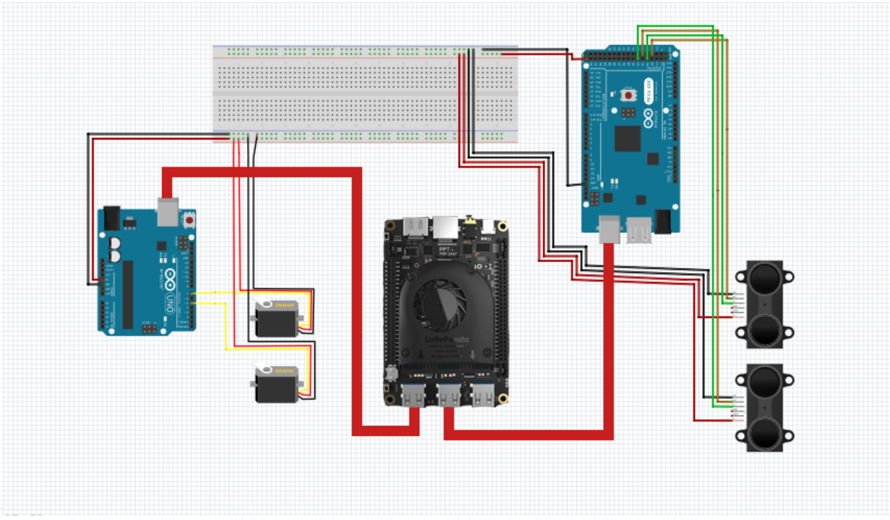


Figure 3.10: Lidar lite sensors connection

3. RPLIDAR is the next generation of laser range scanner developed by SLAMTEC (A Software and Hardware Company That Uses the SLAM Algorithm Specially). It works at high turnover speeds and with a range distance more than 16 meters currently for A2 and 25 meters for A3. It makes available to 360-degree laser range scanning. Furthermore, the RPLIDAR is equipped with SLAMTEC OPTMAG technology that works to reduce the lifespan of the traditional LIDAR system to work steadily for a longer period. The RPLIDAR is an ideal sensor for working in cost-sensitive projects because it is a cost low device [10]. Figure 3.11 shows the range of RPLIDAR sensor on USV prototype.

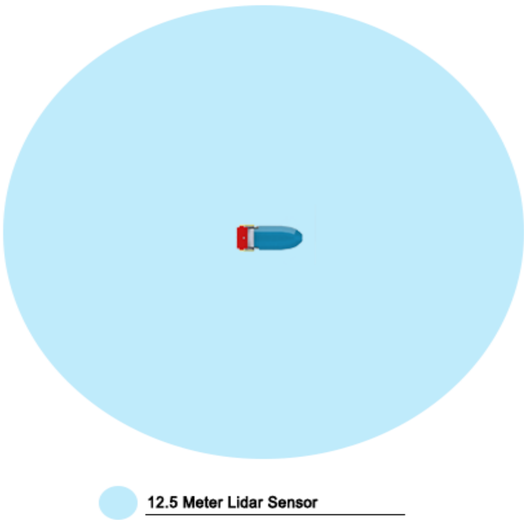


Figure 3.11: The range of RPLIDAR sensor

RPLIDAR A3M1 is a new generation of low-cost laser scanner developed by SLAMTEC. It can take up to 16000 samples of a laser can be released per second with high rotation speed. The device will be the most dependent on the vehicle [22]. Figure 3.12 shows the shape of RPLIDAR A3M1.

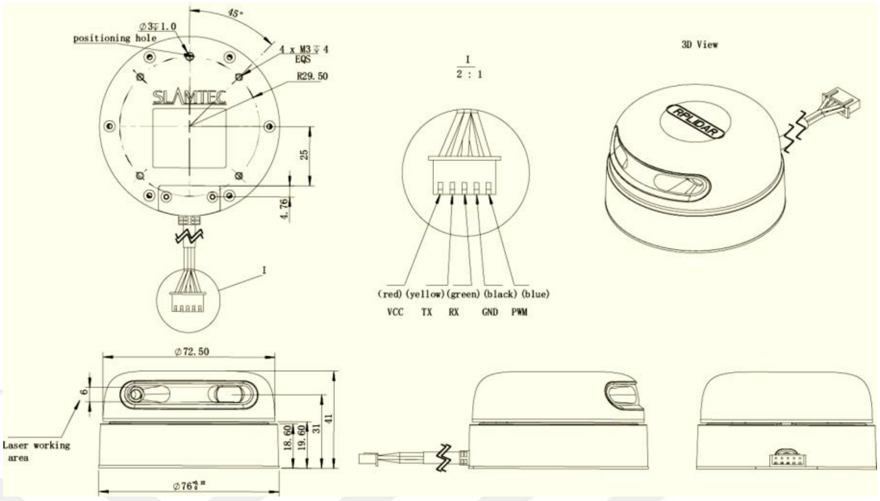


Figure 3.12: The shape of RPLIDAR A3M1

4. A LattePanda Alpha is the first small and advanced panel that can run a full version of Windows 10. It is equipped with an Intel Quad-core processor and has excellent connectivity with three USB ports, built-in Wi-Fi and Bluetooth. It also includes a common processor will be used as a central processor to process and issue orders in USV [26]. Figure 3.13 shows the shape of LattePanda Alpha [11]. of Arduino that does all the Arduino works with high quality [37].

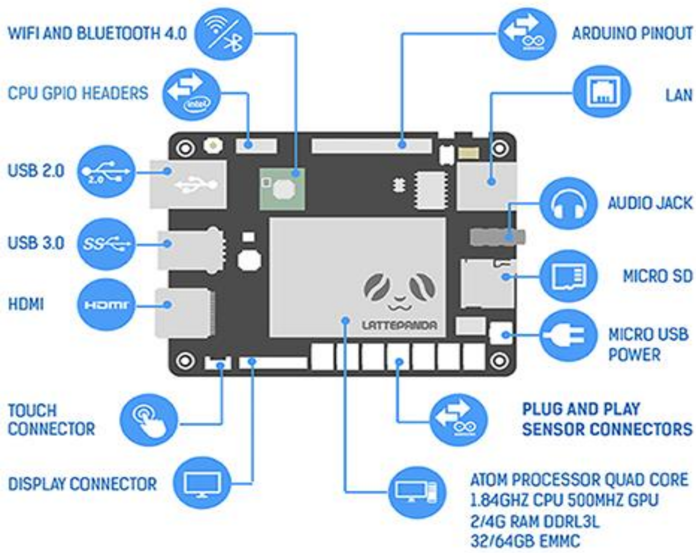


Figure 3.13: The shape of LattePanda Alpha

5. Arduino UNO is used as a control board that controlled the servo motors and check them and their movement. The board collects the information and send that information to the main computer and controller.

6. Arduino Mega is used to connect to the ultrasonic sensors and lidar-lite sensors because of the kind of microcontroller that makes that board is faster than (UNO). In another side, the number of pins that the board have is also important because there are many sensors connecting to the board.

The connection of all hardware components can be explained in Figure 3.14.

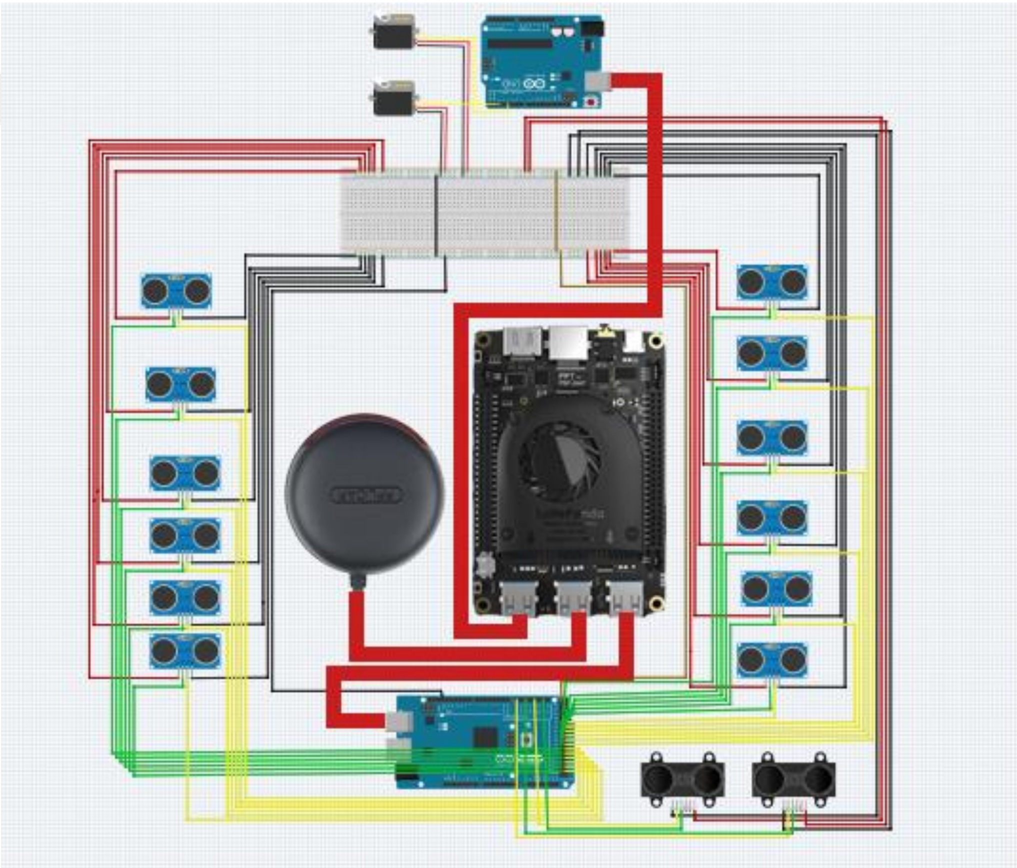


Figure 3.14: hardware connection of the proposed system

IMPLEMENTED CIRCUIT AND SIMULATION

4.1. Introduction

In chapter four, the implemented circuit and the findings which are obtained from the simulation of the USV are presented and discussed. In another side, the problems that happened in a work also are discussed.

4.2. Integrated circuit:

In this part of the thesis will include the final form of the components and how to link them and the sequence of work. Figure 4.1 shows that the USV system, when it starts up, is the first thing that the main controller works as well as those controlling other parts such as the camera and the sensor. Thereafter the action of temperature and weather sensors and other sensors, which in turn begins to take the values and study the ocean surrounding the vehicle. At the same time, the GPS function starts, which locates the vehicle on the map and gives the controller information about the area. This is followed by all the work of the CAS system, including the movement sensors and calculates the distance of the obstacles surrounding the vehicle, if any. This part of the system is the subject of research, which has been studied parts as well as the algorithm. Which has been built a simulation program for some parts to make sure the accuracy of the results, the components of which are illustrated in Figure 4.2. The last part of the figure shows the lighting of the vehicle, which contains the headlights of the vehicle as well as lighting alerts for marine navigation. All these components combined are the integrated circuit of the USV.

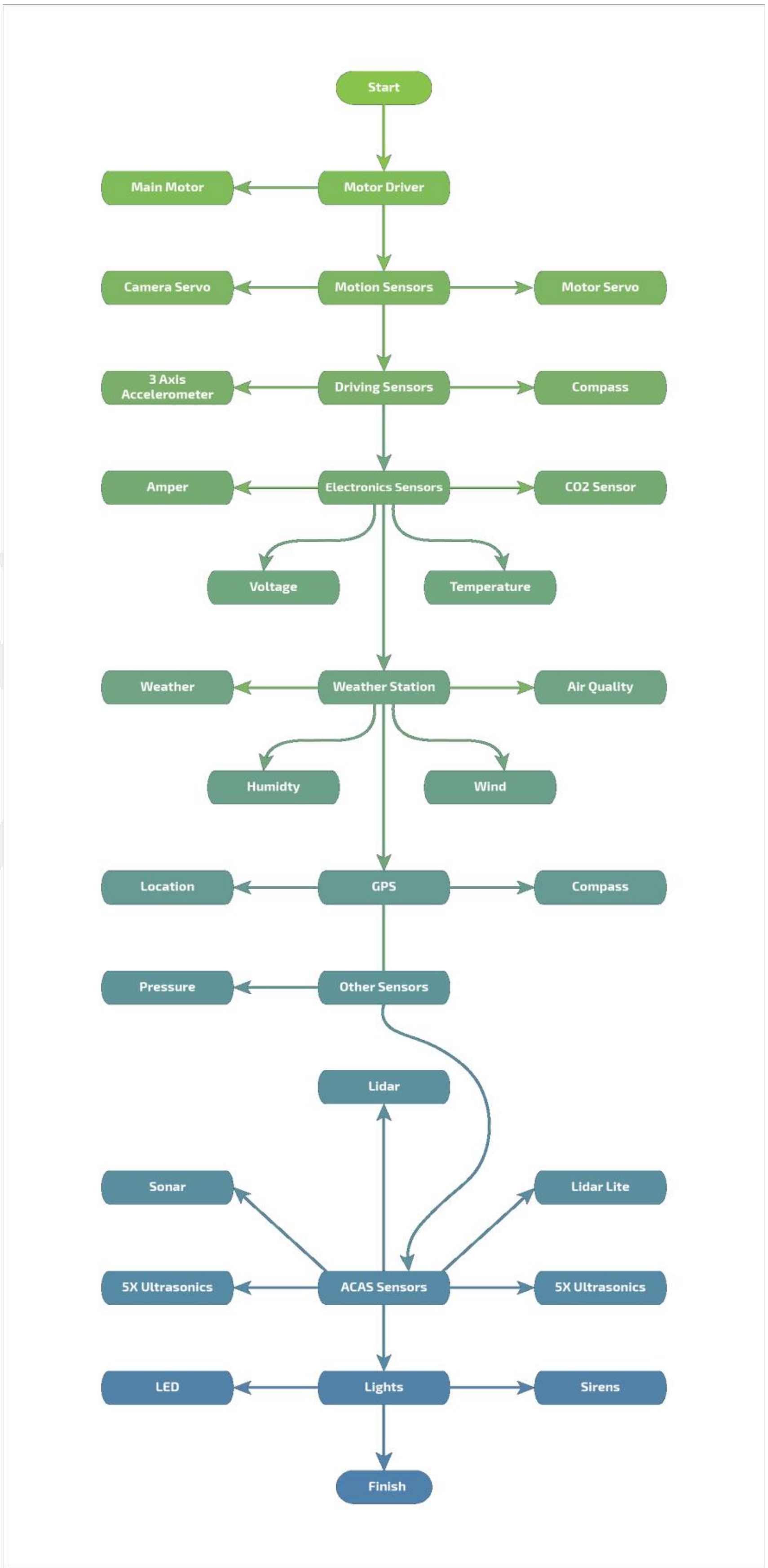


Figure 4.1: The components of the USV system

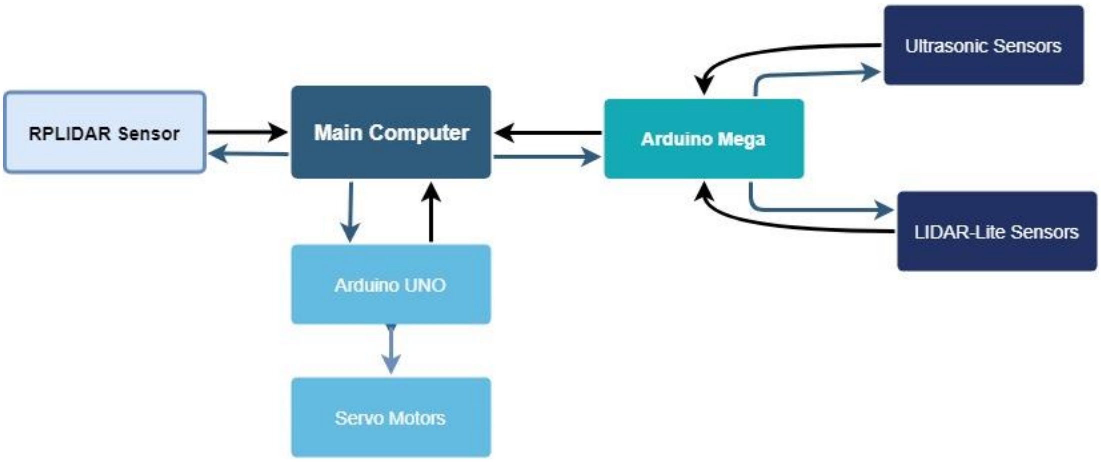


Figure 4.2: The components of the CAS system

4.3. Simulation of Obstacle Avoidance System on USV

In this section, Obstacle Avoidance System has been mentioned with the initial simulation of some sensors that protect the USV.

Simulation of this process prepared with Python development tools, Python language and libraries. Simulation backend recovers an autonomous route calculation algorithm to find the fastest route on the sea. The simulation will be able to perform better calculations with the contributions of TensorFlow machine learning in each new route request by continuously collecting the generated route data.

Simulation has been used to recognize USV's movements towards the obstacles. The purpose of this simulation is to calculate the route from point A to B, without crashing the obstacles, and to calculate the distance of the vehicle to the obstacles. The sensors which are around the vehicle, continuously measure the distance of these obstacles during the simulation of the vehicle's motion. After these measurements, the simulation delivers the vehicle to the fastest way from point A to point B. This tells us how the sensors interact with obstacles.

As shown in Figure 4.3, and after the target is determined, the USV is started to work on the information that stored from the database and showed that there were maritime obstructions in the vehicle's road that had already been stored into the cloud from the GPS.

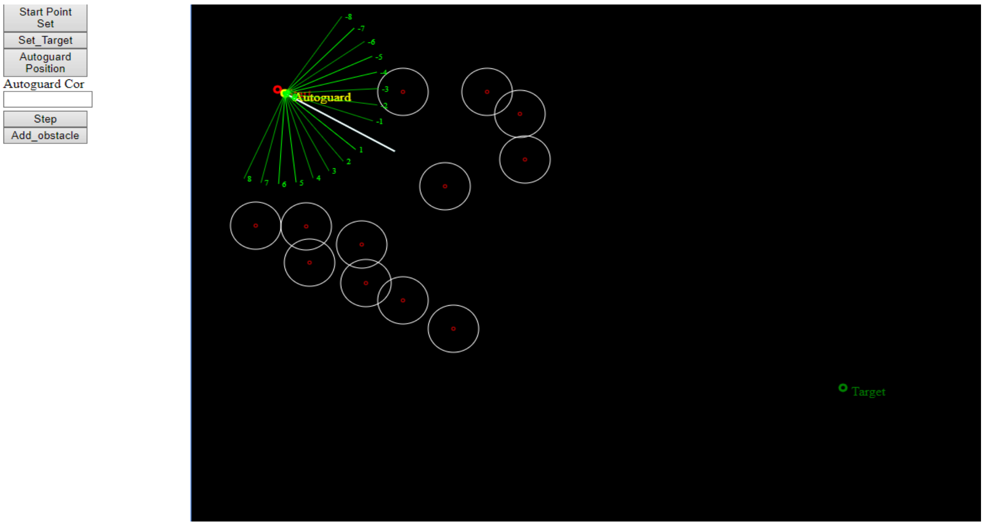


Figure 4.3: USV (auto guard) initial position

The USV is worked on a new survey of the area to verify the information stored and to update that information as shown in Figure 4.4.

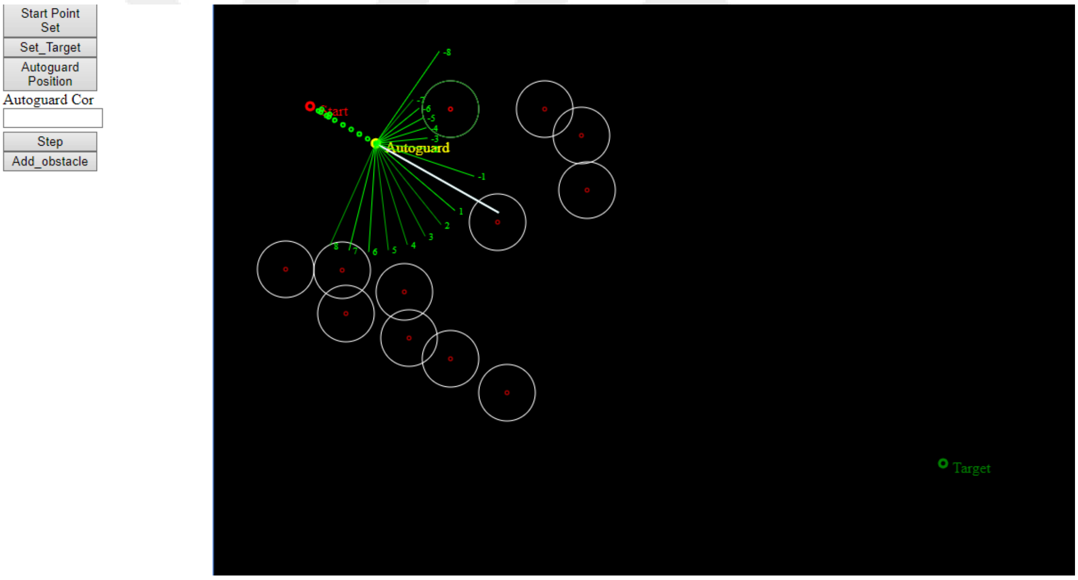


Figure 4.4: USV (auto guard) next position

The USV will also avoid these obstacles and send the alarm to the controller system to change the path of USV by choosing an alternative safe way to reach the target as shown in Figure 4.5. The blue line is going straight to the target and the white line is the new way that was chosen by the algorithm depend on the sensor information.

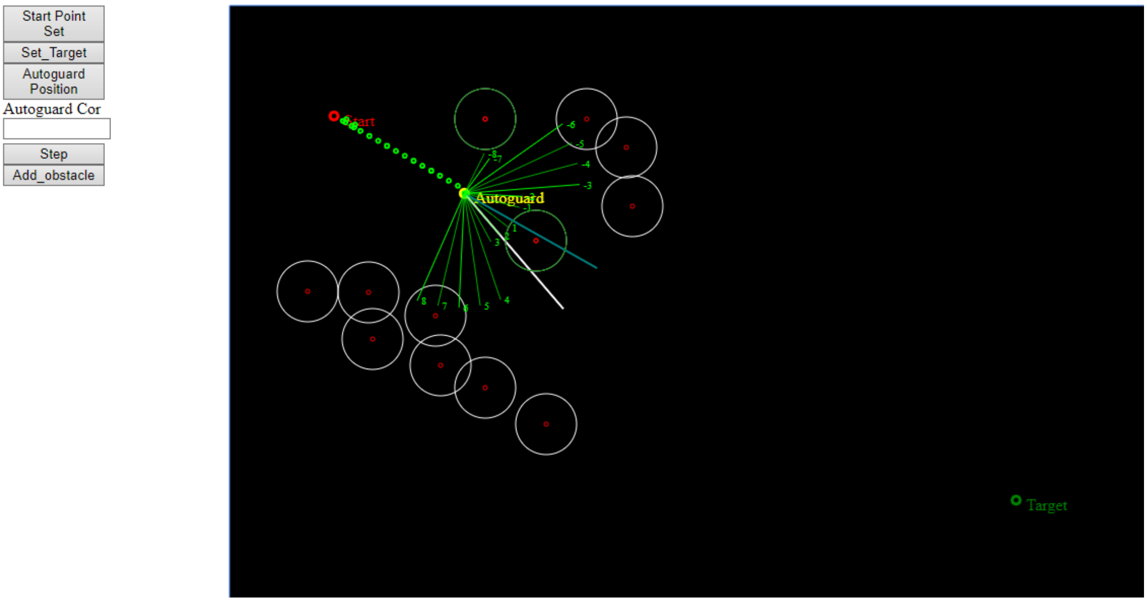


Figure 4.5: USV route update

The system is sending the new information time by time and waiting for the response from the driver, but when the USV become in the danger zone the system makes the decision and change the USV to the autopilot case as shown in Figure 4.6 and Figure 4.7. In this initial time, the CAS works to calculate and get action to avoid crash to the obstacle.

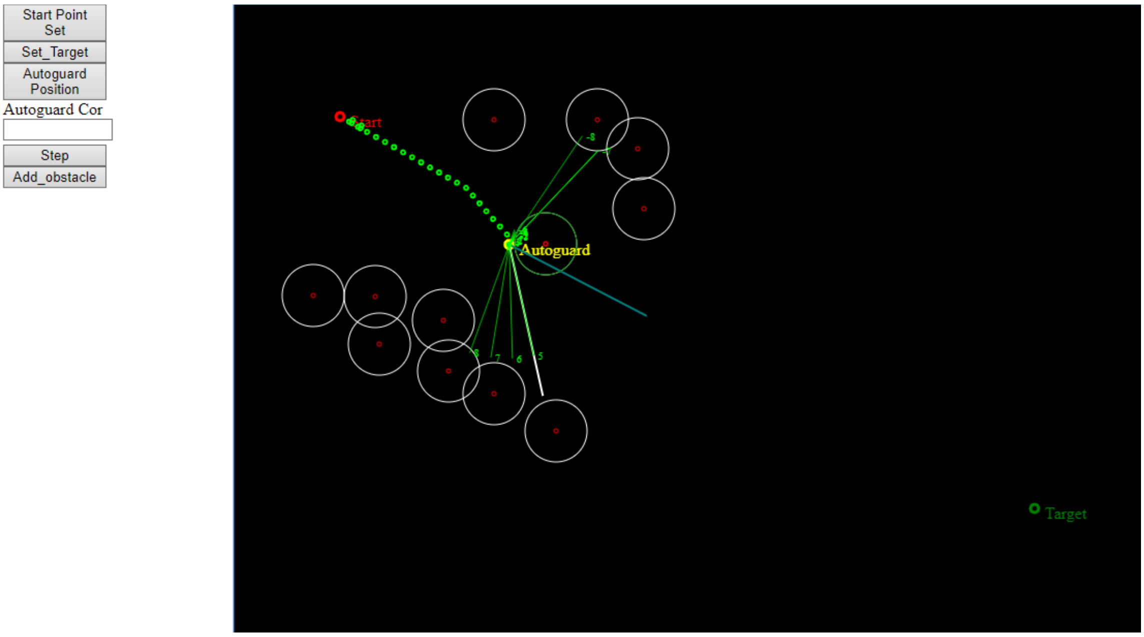


Figure 4.6: USV with autopilot case

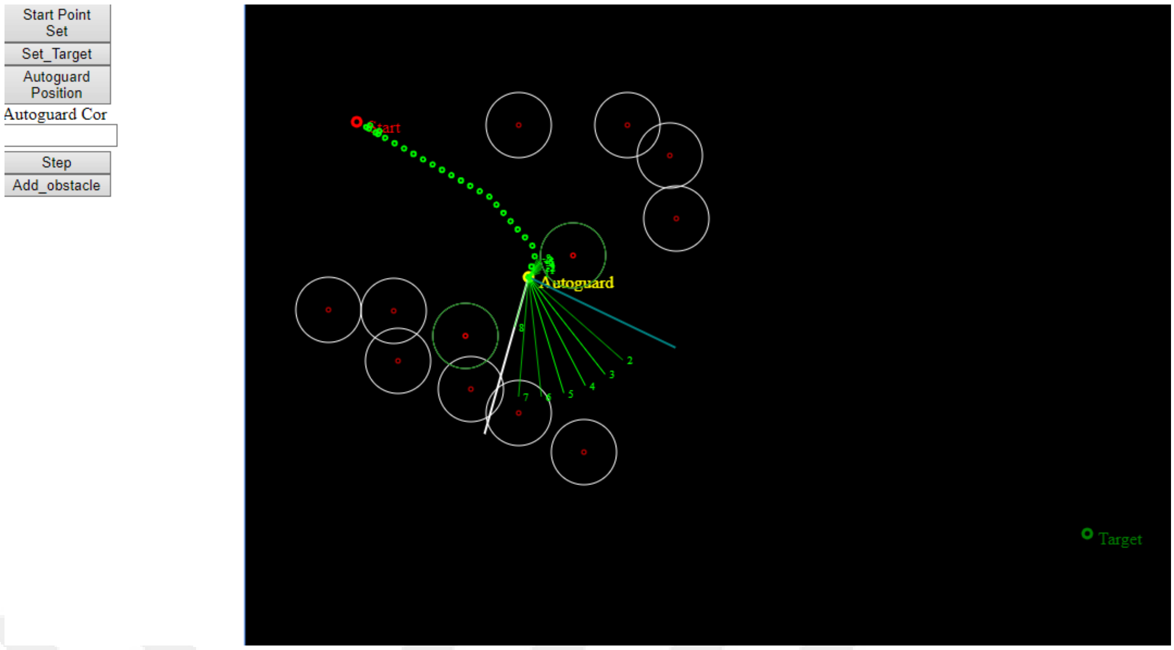


Figure 4.7: USV with autopilot case

After the boat is out of danger zone, CAS will be off and the USV returned on track and return to the control of the driver of the vehicle as shown in Figure 4.8.

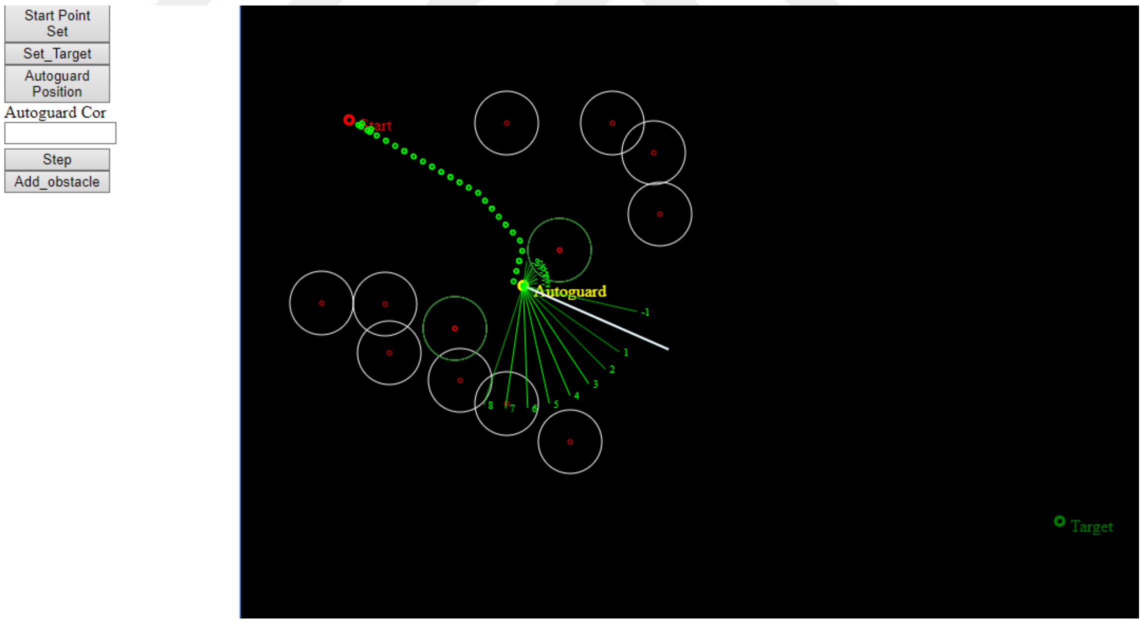


Figure 4.8: The USV return to the control

If the sensors have discovered any new obstacle in that way and make them as new information in that area, the new information is stored in the database of USV and on thecloud as shown in Figure 4.9.

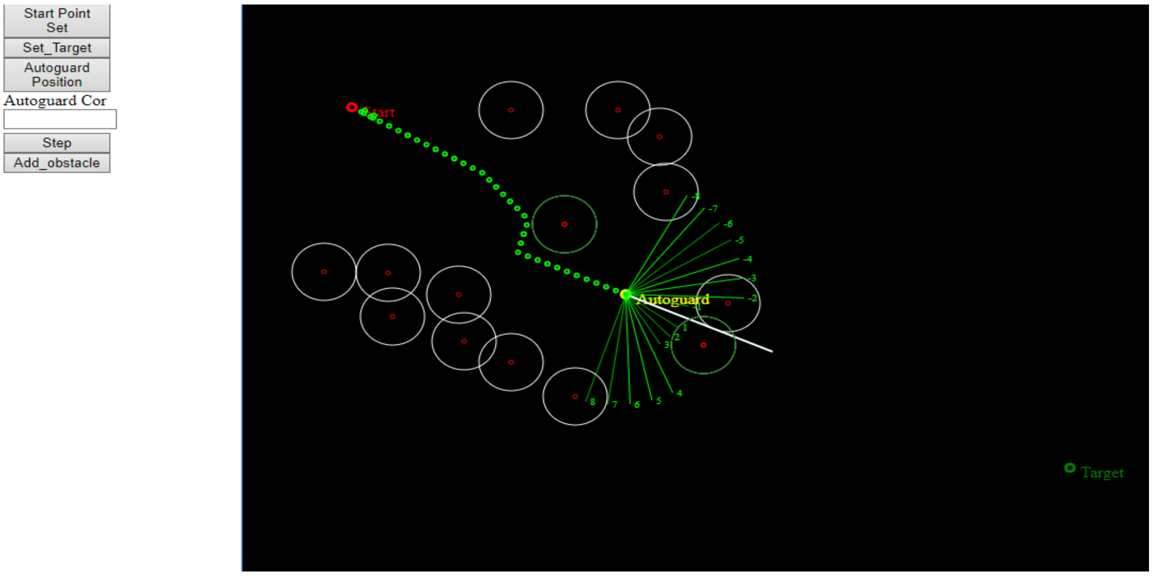


Figure 4.9: The USV discovered the new obstacles

The sensors checked the way by time and when they received the new information about obstacle they send their information to the appropriate systems (Main Controller, Main Computer and CAS) and it will work with those obstacles like before (the system is sending the new information time by time and waiting for the response from the driver, but when the USV become in the danger zone the system makes the decision and change the USV to the autopilot case) as shown in Figure 4.10 and Figure 4.11.

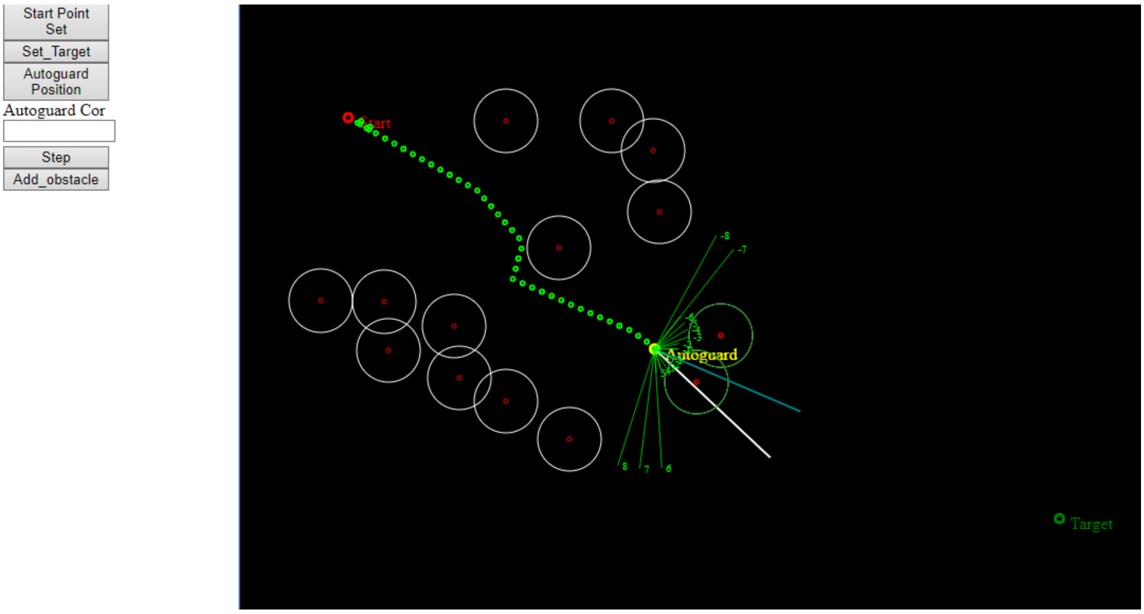


Figure 4.10: New information about obstacles

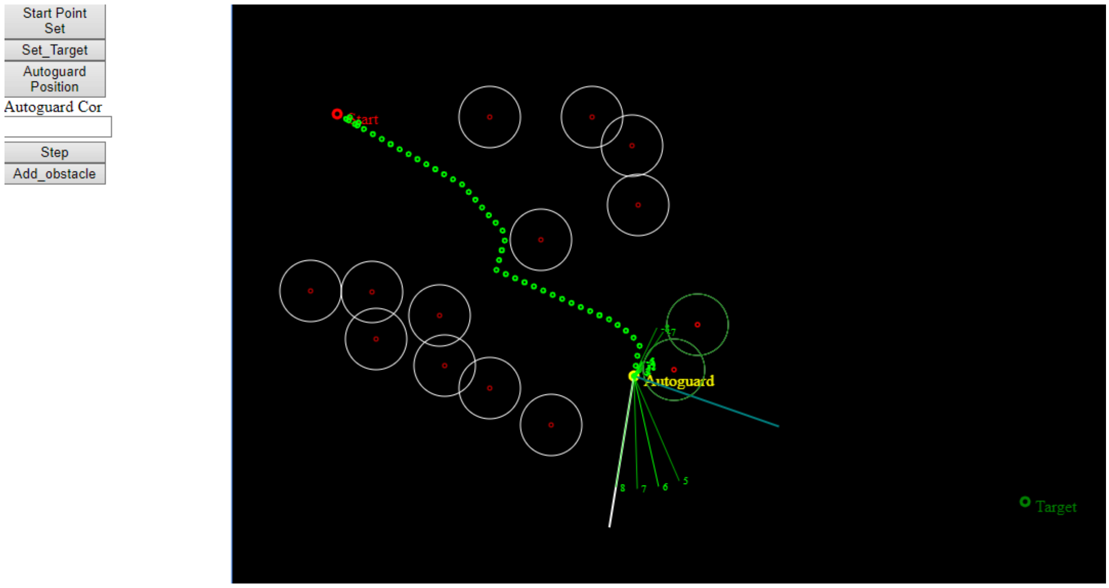


Figure 4.11: New information about obstacles

After getting out of the danger zone, the USV returned back to the focused route as shown in Figure 4.12 and Figure 4.13.

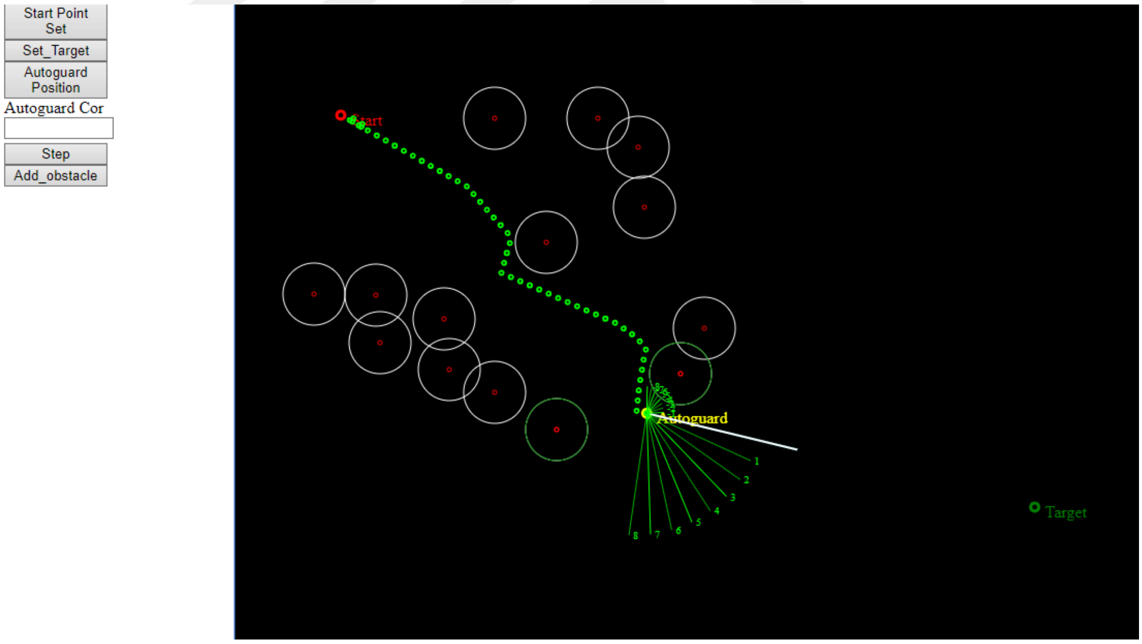


Figure 4.12: USV returned back to the focused route

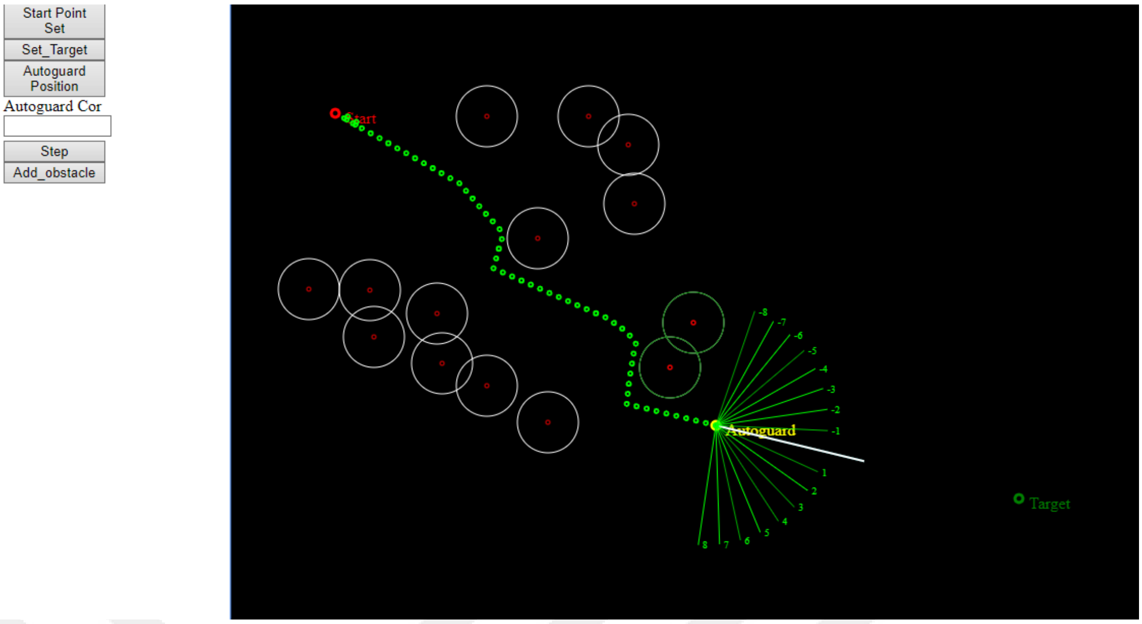


Figure 4.13: USV returned back to the focused route

The operation for the simulated system can be illustrated with the following steps:

- When the USV starts working the speed is increasing from 0 to the maximum level (35 km/h) and the system sends this message to the driver:

```
no alert no diversion
path clear. ignoring recommendation
```

- When the sensors received any signal that means there is an obstacle in the way they will send that information to the system which will send that to the driver:

```
Rec index: 3.0
turn recommended
path clear. ignoring recommendation
```

The first line sends the distance between the USV and the obstacle, the second one is to give the suggestion to the driver, and the third one is checking the USV if there is any problem.

- Also, when the sensors become closer to the obstacle the system will send this message when the distance becomes closer:

```
Rec index: 2.0
```

```
turn recommended
path not clear. following recommendation
```

- But when the USV does not receive anything from the driver and it becomes in a danger area the USV will turn on the CAS and go to the autopilot case and send this message:

```
Rec index: 0.0
alert with no alteration
```

- After the USV getting out from the danger zone the USV will return back to the normal case under the driver and work as normal (send a warning message to the driver)

```
Rec index: 8
turn recommended
path not clear. following recommendation
```

- The USV finds a new obstacle it will send a warning to the driver with the distance:

```
Rec index: 6.0
turn recommended
path not clear. following recommendation
```

all the last steps will return back until the USV arrive at the target.

Figure 4.14 is showing the flowchart of the simulation.

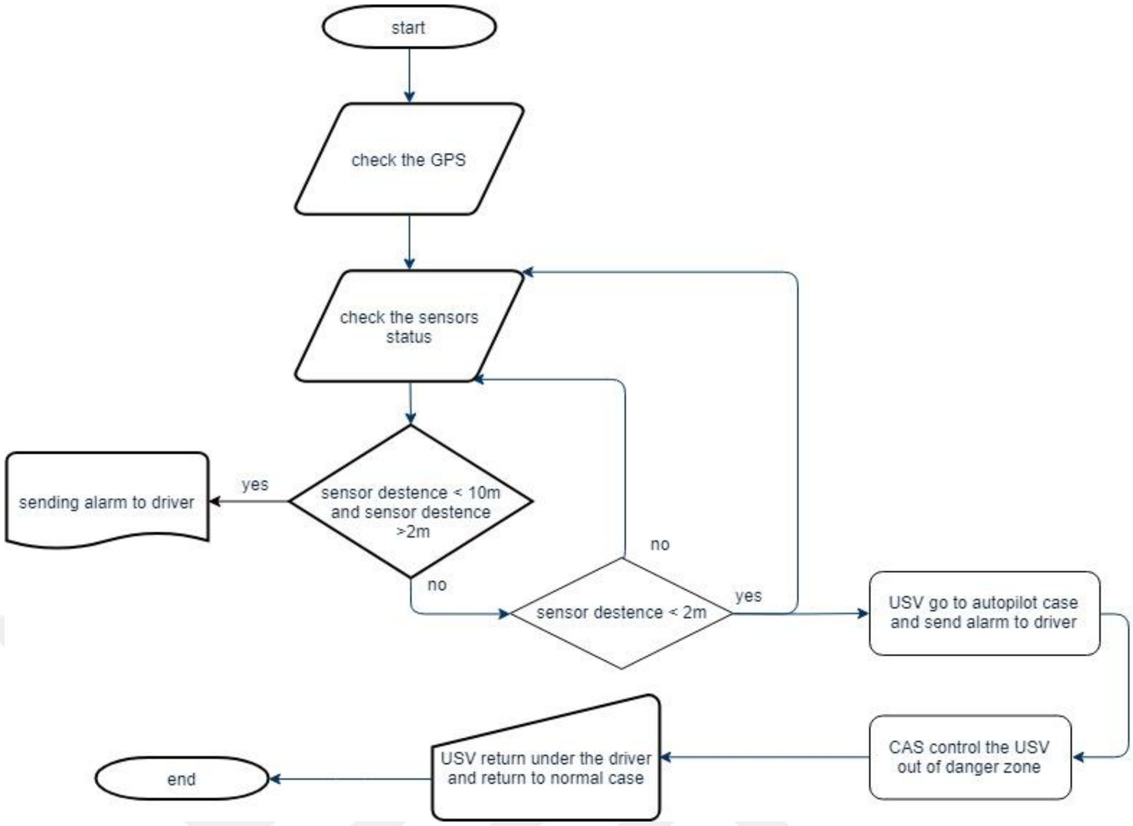


Figure 4.14: The flowchart of the simulation

CONCLUSION AND FUTURE WORK

5.1. Conclusion

Current and past studies and experiments were analyzed worldwide for the Crash Avoidance System (CAS). Attention to this subject and try to develop this system because of the concern to increase the efficiency and accuracy of this car. The objective of this project is primarily to implement a prototype that detects obstacles easily and accurately to protect the USV if there is a risk of impacting the USV path. The following steps have been implemented:

- After the studied (A* algorithm, WSM, Kalman filter algorithm, and SLAM algorithm) was found that the USV system works more efficiently if different algorithms are used in different parts where they can be collected inside the USV system for better results.
- A miniature system has been built to simulate the real system. To this end, the performance of the weighted sum model (WSM) approach is evaluated in that simulation as well as the algorithm is evaluated using the hardware concept.

The use of multiple sensors has proven to play a vital role in protecting the vehicle as the algorithm was evaluated according to different values of environmental obstacles. The simulation results show that the proposed system is able to achieve accurate steering results, as speed and direction of movement are easily controlled while sensors begin to detect the distance between the USV and the obstruction surface within 25 meters and the CAS will begin to protect the USV between 5 and 2 meters depending on the obstruction type, while the distance in some previous work is less efficient than this or more expensive.

5.2. Future work

When talking about the USV, it means a lot of things to do in the future because the subject is under development and some countries are striving to develop unmanned vehicles. There are some points that can be added in the future to develop the vehicle and get better results

1 - Add hardware parts to improve the performance of the vehicle such as an addition of a high-precision camera or thermal camera that makes the work of the vehicle more accurately. Addition of 3D LIDAR which detects the surrounding environment with high efficiency and can be dispensed with the sensors that used before in the case of using this type of LIDAR.

2 - Work to improve the work of algorithms by combining more than one algorithm or reformulation of the algorithm to be more accurate to reduce the error rate if any.

3 - You can also add image processing to this project if you add the camera and using the Kalman filter algorithm or other image processing algorithms.

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