The Practicality of the Internet of Underwater Things: MATLAB & Simulink AUV Application

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Abstract

As Oceans cover approximately 72% of the Earth's surface, it is imperative to extend the Internet of Things (IoT) principles to the existing bodies, paving the way for a new digital trend: the Internet of Underwater Things (IoUT). The IoUT refers to the worldwide network of smart interconnected underwater objects, which enhances monitoring unexplored and vast water areas. It enables various applications like environmental monitoring, disaster prevention, and underground exploration. The Internet of Underground things with such applications is among the leading applied technologies in smart cities. This paper aims to focus specifically on determining the potential applications of the IoUT applications, which can help in examining the challenges that are and will be faced during its modeling and implementation. The study aims to investigate the challenges of designing and implementing such a network. The research includes communication networks and *MATLAB & Simulink* simulation. Based on previous reviews, an optimal network of IoUT enhances the development and integration of various systems for the robust evaluation of water ecosystems. The study's outcomes include a tested AUV simulation model, which is a crucial part of an IoUT system that can be adjusted to suit local water conditions. The idea of IoUT should be embraced due to its positive impact on social and economic factors.

Keywords

IoUT, Plant Model, Communication, Sensors, Relays, State Estimator, AUV, PID Controller

1. Introduction

Because of its multiple uses, such as submarine monitoring, detecting volcanoes, and pipeline monitoring, real-time monitoring of underwater habitats, particularly the ocean bottom, is critical (Khalil and Saeed, 2021; Saeed et al., 2019). As a result, research into building the Internet of Underwater Things (IoUT) network technology is promising for its economic advantages from oceans and predicting natural disasters. Underwater wireless communication (UWC) is the key technology that enables the IoUT architecture. Traditionally, three wireless communication methods have been used: acoustic, optical, and magnetic induction (MI) (Khalil et al., 2021; Li et al., 2018). Magnetic induction (MI) relays and sensors are used to pass information over multi-kilometer lengths via sea and ocean waters, often at frequencies ranging from 10 Hz to 1 MHz. Moreover, underwater MI communication is a promising approach that can transport larger data rates of up to tens of Gbps across a few hundred meters (Khalil and Saeed, 2021). Because of its unique qualities, such as low multi-path fading and homogeneous channel conditions, are already being widely used in both underground and underwater sensor networks. The IoUT idea is supported by a network architecture known as the Underwater Wireless Sensor Network (UWSN) (El-Rabaie et al., 2015). Because of their mobility and energy (long battery life), autonomous underwater vehicles (AUVs) play an important part in this technology. AUVs are self-propelled, unmanned vehicles that can move freely in six degrees of freedom (6DOF) while also carrying out predetermined missions. AUVs are utilized in military and homeland security applications and industrial and commercial uses (Okereke et al., 2021).

Despite increased study into the enhancement of IoUT applications, there are still several issues to be solved in designing and implementing of IoUT applications (Jhaveri et al., 2022; Yisa et al., 2021). The IoUT may contribute to two sustainable development goals (SDGs) (UN, 2022), namely goal 9 (infrastructure, industrialization, and innovation) and goal 14 (life below water). This paper aims to focus specifically on determining the potential applications of the IoUT applications, which can help examine the challenges that will be faced during the modeling and implementation of the IoUT. Working closely with controllers will clarify the evaluation process and the investigation of the channel models. Also, investigating the importance of implementing IoUT to evaluate the types of communication devices and sensors incorporated within the system will narrow down the specifications and mechanism of the required AUV. The idea of the paper dives into the control system of AUVs and controllers along with parameter input and detection, methods, and procedures where AUVs are broken down part by part to understand their role in IoUT.

The remainder of the paper is structured as follows: section two examines the relevant literature review on IoUT; section three outlines the research methodology and presents the method used in this study; section four outlines the findings and discussion, and section five highlights the major conclusions of the study.

2. Characteristics of IoUT

The IoUT have some similarities with IoT, like the function and structure. It has restrictions through the energy and computation limitations of the devices. There are specific characteristics of IoUT that make them unique and different from IoT (Domingo, 2012; Kao et al., 2017). Most IoUT communications are commonly based on acoustic links (Stojanovic, 2003). This is because radio waves do not propagate well underwater. There is an electromagnetic restriction in freshwater with a large antenna size, and seawater has high attenuation. In extreme cases, there are sound speed variations with depth, causing signals refraction and resulting in the spatially variant channel. This causes shadow zone formation, which causes bit errors and connectivity loss (Raj et al., 2020). The bandwidth of the underwater acoustic channel depends on frequency and transmission range. Long-range systems operating over ten kilometers have a bandwidth of less than kHz, while short-range systems operating over ten kilometers have a bandwidth of more than 100 kHz.

IoUT are commonly tracked with different technologies that depend on the type of data to be collected, fish species and size, and habitat utilization. Acoustic tags are sound emitting devices that have large ranges of detection and use three-dimension technologies to track fish. On the other hand, Radio tags transmit radio frequency signals which are detectable through receivers and antennas. A passive integrated transponder tag uses implantable RFID device technologies (Jouhari et al., 2019). IoUT objects are very prone to failure because of corrosion and fouling. They have limited battery capacities, making it more difficult for them to be replaced or recharged. Combining ambient energy with supercapacitor technologies eliminates battery to use and relies on harvested energy (Arul et al., 2021). IoUT uses energy harvesting technologies that are solar-powered Autonomous Underwater Vehicles (AUVs). They are programmed to sub-merge and operate on the surface so that they can charge the battery through the input of solar energy. IoUT can also use piezo-electric energy harvesting technologies and Microbial Fuel Cells (MFC) (Mary et al., 2021). IoUT does not require large number of devices to communicate if all the things are joined in a network. It uses more sparse devices because of challenges associated with underwater deployment and the cost of the things. This makes it more challenging to maintain and establish communication devices (Qiu et al., 2020). IoUT uses different localization techniques. Localization with scheme of directional beacons uses AUV as a mobile beacon sender. UPS, which is a silent underwater positioning scheme, relies on the arrival of the beacon signal, uses 3-D sensor location via trilateration. In a large-scale localization scheme, they use localization techniques that are TDoA to measure range differences from the sensor to three anchors (Jouhari, et al, 2019). The large-scale underwater wireless sensor uses the localization technique of the asymmetrical round trip localization algorithm.

While IoT has progressed well, IoUT has a long way to go. This is because most network systems are air worked and cannot function underwater effectively. There is a high cost of deploying AUVs, temperature, salinity, and noise (Kao, 2017). IoUT has a challenge in self-management where it needs to do self-configuration, self-protection, and self-optimization capabilities. These are important in co-coordinating operations of underwater AUVs and sensors through configuration exchange, movement, and location information. It becomes challenging to self-handle this automatic discovery and fault correction. Another challenge involves the improvement of tracking techniques. Careful study must be done to avoid harming the animals or obstructing their activity. Energy efficiency poses another challenge in machine-to-machine network architectures. Acoustic communication uses more power and has greater typical transmission distances, requiring high transmitted power (Jiang et al., 2015).

3. Literature Review

A lot of varied research has been done over the last two decades to address IoUT technology, and AUVs as scientists pertain to enhance the Smart Ocean (Khalil et al., 2021; Mohsan et al., 2022; Salam and Raza, 2020; Yisa et al., 2021). The IoUT was discussed first in 2012 (Domingo, 2012) after establishing the Internet of Things (IoT). IoUT is the application of IoT on the water bodies. IoUT is the worldwide network of intelligent objects interconnected underwater, enabling monitoring of vast unexplored water areas. It connects digitally all the water bodies like oceans, rivers, streams and lakes. The innovative process of IoUT has impacted hugely in different sectors like scientific laboratory, medium harbor, and monitoring of undiscovered oceans. It has become one of the powerful technologies used to support various applications like naval military applications, collection of real-time aquatic information, prediction and control of natural disasters, and maritime security. It also helps in exploring oil and gas, archeological expeditions, shipwrecking discovery, marine life observation, and water contamination (Junior et al., 2021). IoUT monitor these underwater operations as liked with smart intricately (Liou et al., 2018). IoUT network is needed due to Earth's configuration. Since water surfaces cover 72% of the Earth, IoT can only connect 28% of the Earth to be in the whole operation. Climate changes and irregularities are the leading cause of natural disasters, and oceans are largely responsible for these disasters. IoUT can regulate these disasters globally. There have been many smart underwater objects that have been recently created like autonomous surface vehicles, autonomous underwater vehicles (AUV), and remotely operated underwater vehicles (ROV). These underwater objects have wireless sensor networks deployed to assist in a successful network system (Domingo, 2012). The sensor uses nodes with acoustic modems to relay information such as temperature, pressure, and water quality through acoustic modems. The sensor can sense, relay, and forward the data it has collected. The data is then transferred to an important component, namely sinks on the water surface. Sinks have both radio and acoustic modems, and they can be ships, buoys, or ASVs. When the data has arrived at sinks, it is then forwarded through radio channels to the remote monitoring center. These centers are at the seashore and are usually responsible for monitoring water areas. The monitoring center can collect, analyze and deal with the information. The AUVs can also act as the same as UWSN in collecting and forwarding data.

3. Research Methodology

The research methodology consists of developing a MATLAB application in control systems to simulate and control the three-dimensional maneuverings of the AUV underwater with the use of Proportional, Integral, and Derivative (PID) controllers for its purpose of sensor data collection. The mechanism of the system is illustrated in figure 1. References are the input commands like initial conditions that the controller will then change or adjust. The plant model includes the data about the environment, vehicle, and the dynamics solver that aid in the process of the change in position and velocity. It is coupled with a change in the sensor data that consequently evaluates the vehicle's state (i.e. velocity, dimensions, reference frames, and position) using the state estimator. Finally, all the data feeds back into the controller to adjust its propulsion and maneuvering to reach the required destination in accordance with the environment, sensor data, and the state of the vehicle.

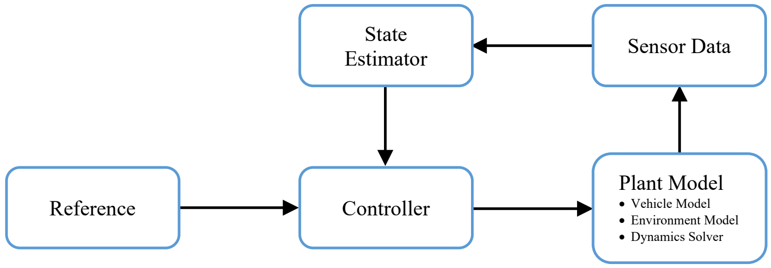

Figure 1 Control mechanism

The maneuverings are demonstrated in figure 2, and they include external factors like a drag (downward), lift and buoyancy (upward), and sway (across), where these factors will be registered into the built model from the general (global) point of view (frame) and the body-fixed reference frame.

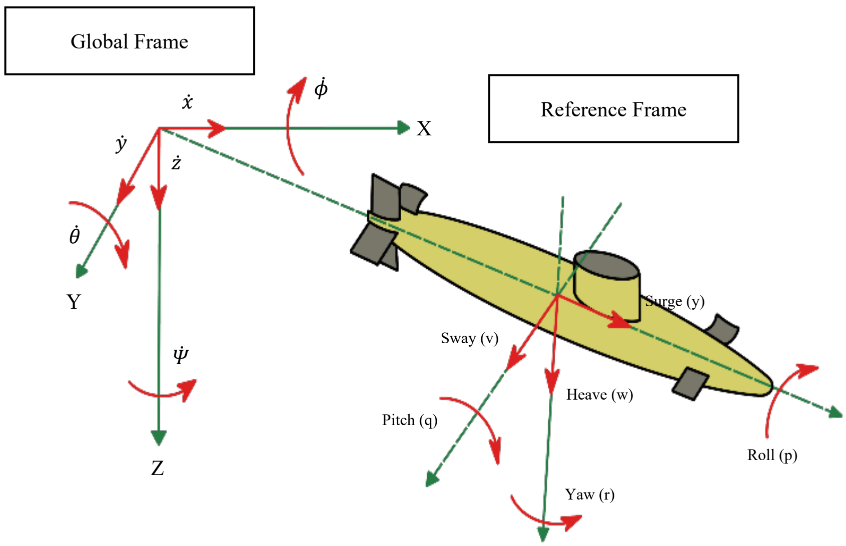

Figure 2 Controller maneuvering frames

The positioning is done according to the data from all parts of the architecture. The main external parameters are obtained from the plant model:

a. Vehicle model – propulsion force and moments parameters:

$$\bar{F} = \int_0^{2\pi} C\big(r\omega(\theta)\big)^2 d\theta = \pi C r^2 (2\bar{\omega}^2 + \omega_A^2) \tag{1}$$

Where the instantaneous force was integrated over a full rotation to produce a hypothetical thrust to the system ($\bar{F}$), propeller radius (r), minimal angular velocity ($\bar{\omega}$) and the sinusoid amplitude (ω_A).

b. Environment model – hydrodynamic forces and moments (lift, drag, weight, and buoyancy) parameters:

$$F_B = \rho g V \tag{2}$$

Where the parameters of the buoyancy force (F_B) are the fluid density (ρ), standard gravity (g), and the submerged volume of the AUV (V).

$$F_D = 3\pi\mu U d \tag{3}$$

Where, the dynamic viscosity (μ), the relative velocity of the fluid particle (U), and the particle diameter (d) are the parameters of the Stoke's drag force.

4. Data Collection: System Overview

The primary system shown in figure 3 includes the subsystems mentioned on the workflow diagram of the control mechanism in figure 1: translational reference, translation controller, plant and environment model, sensor data, and state estimation. All operations were executed with respect to robot dynamics and control system parameters and procedures, and the outputs are displayed on the custom gauges for ease of observing.

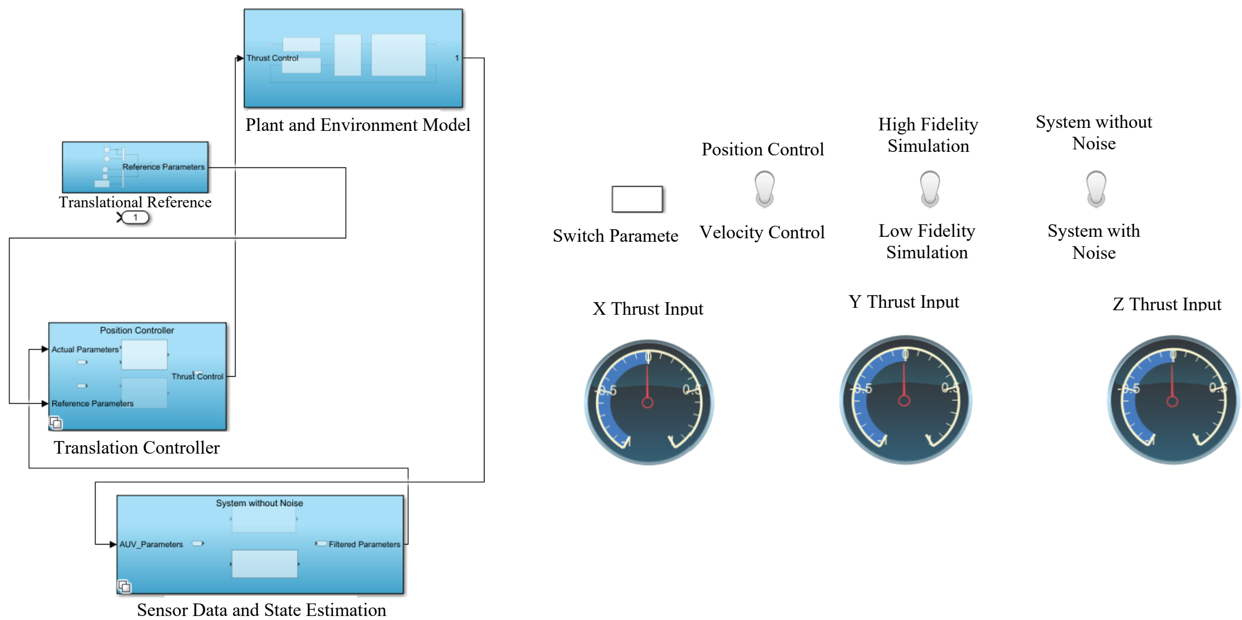

Figure 3 Main system architecture

The translational reference subsystem is broken down in figure 4. It is in charge of storing the input initial conditions of the AUV system of position and velocity – the vehicle's starting point. Referring back to figure 2, the inputs of this subsystem would be the elements of both the global and reference frames: $\dot{\Psi}$, $\dot{\theta}$, $\dot{\phi}$, roll, pitch, and yaw. The input references will not necessarily be done according to what was planned. The reference points will be accurate when it comes to starting and ending points; however, it does not mean that the AUV will be able to take the ideal path/route of execution to get to the destination.

The position and velocity controllers (figure 5) have two inputs: actual and reference parameters. The reference parameters are the input passed to function from the translational reference block memory regardless of external disturbance (ideal parameters). On the other hand, actual parameters are the output received by the called function, which is the real, modified parameters that factors like buoyancy and drag had influenced. The controller commands are fetched from the sensor data and state estimation block in figure 6.

The data sensor and state estimation process includes the system being with noise and the system being without noise. Without noise indicates that the parameter data signal of position and velocity was filtered upon receiving, whereas the noise system is the raw, uncorrected data signal. State estimation is the current data being collected from the environment by the use of the sensor to properly maneuver the vehicle from the starting point to the ending point.

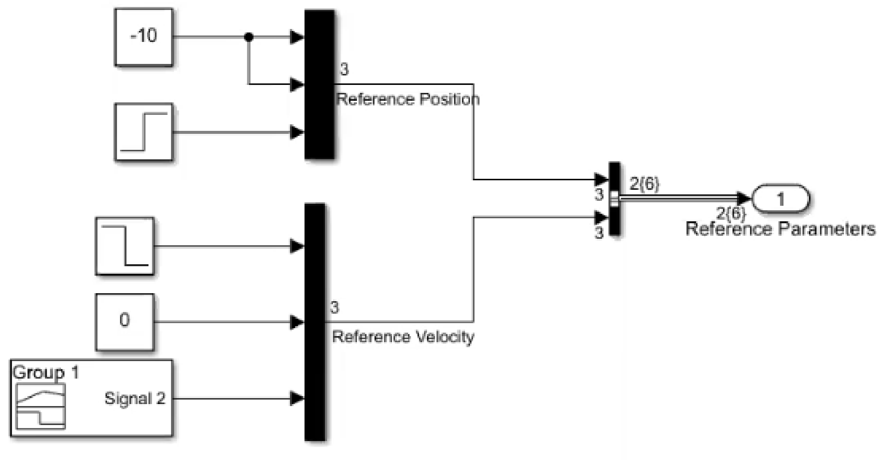

Figure 4 Translational reference subsystem

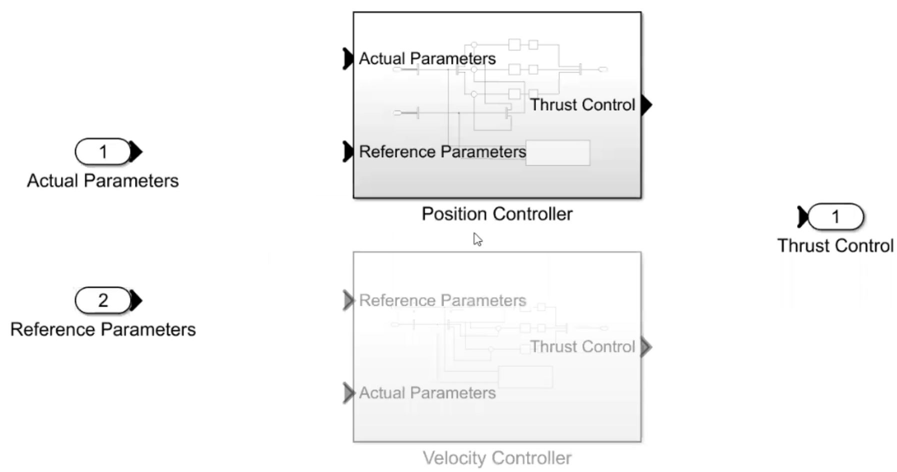

Figure 5 Translation controller subsystem

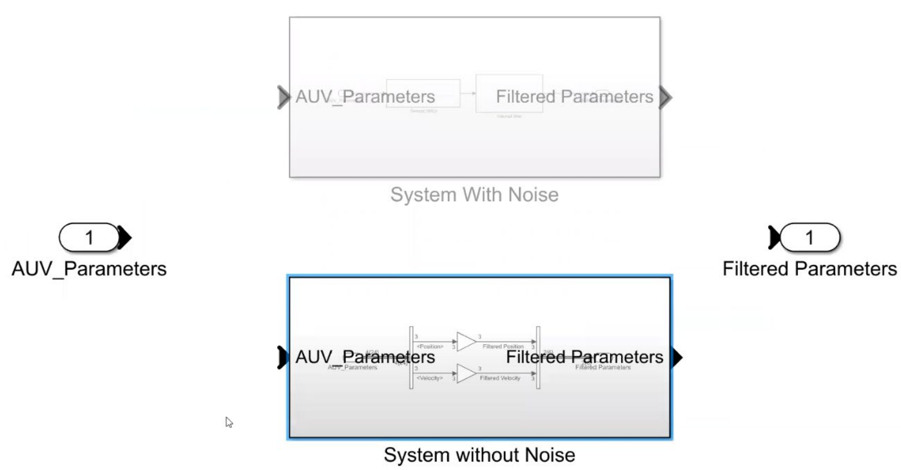

Figure 6 Sensor data and state estimation subsystem

The plant and environment model, subsystem, figure 7, is where the controlling of the forces are actuated. The forces are divided into two categories: propulsion forces and environmental forces. These forces will then be combined together, and their moments (the turning or bending effect of a force on an abject) will separately get combined as well. After the forces combine, the signal passes through the dynamic solver, which feeds back into the environmental forces and moments block. The dynamic solver has the total force as one input and the total moment as another and it utilizes the Euler method (Euler angles of the body) to identify and depict a body's rotation as represented in a given coordinate frame. The resultant will feed parameters of reference frame velocity, reference frame position, orientation angles, angular body rates, body angular acceleration, and body velocity into a post-processing block to obtain the actual values of the AUV parameters be able to specify the thrust control. Moreover, after obtaining the thrust control values, the coordinates go through pulse-width modulation (PWM) and normalization to get the transformed thrust.

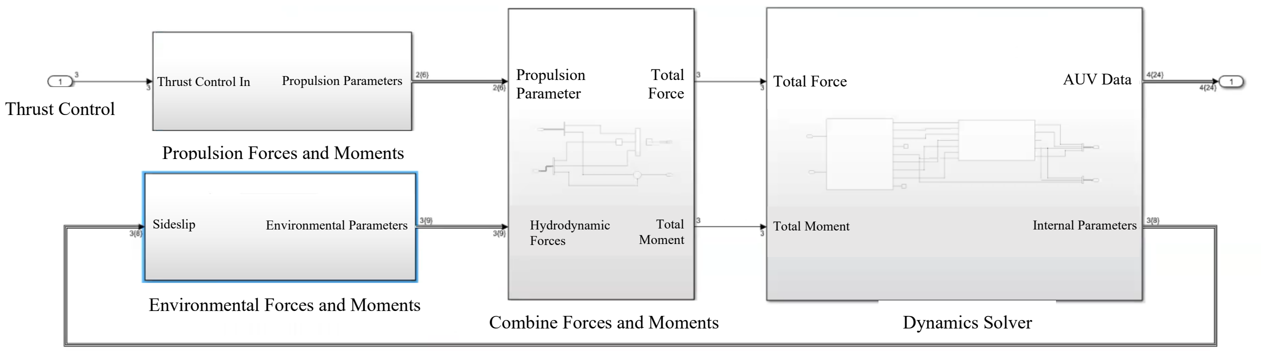

Figure 7 Plant and references model

5. Results and Discussion

Before running the Simulink model, arbitrary values for parameters were used for general testing. One of the outputs is a figure that represents the AUV's actual path. Figure 8 roughly represents an AUV body that moves from the starting point to the ending point according to the translational reference subsystem, but with an actual, three-dimensional path that depends on (and is highly impacted by) the external environment and processing done by the system.

Additionally, the translational controller obtained the results in figure 9. The yellow line represents the ideal, referenced translation, and the blue line represents how the AUV actually moved from one point in space to another: the red dot represents and starting point, the green dot represents the destination, and the line represents the path that the AUV went through to be able to reach its desired location. The actual parameter results were obtained from the plant and environment model block, supplied by the sensor data and state estimation.

The paths and examples demonstrated are a reflection of what happens under certain circumstances in real life, which is the reason for including all the data censors and environment and plant models. These additions to the system enhance the performance and general positioning with respect to frames of the system.

The majority of the concerns are connected to several AUVs, indicating that additional study into the efficient and effective use of numerous AUVs is needed. The notion of cooperative game theory and autonomous persistence where the network lifespan is prolonged is also an area that should be investigated further to determine whether the present applications are optimal or if there will be room for advancements.

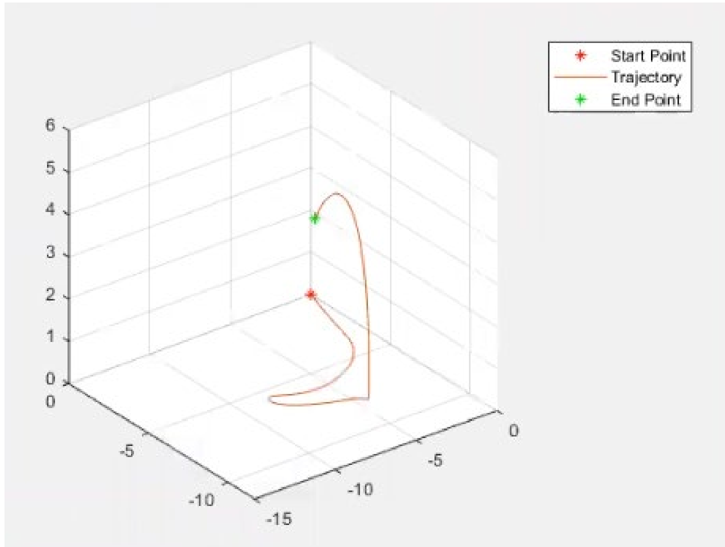

Figure 8 AUV's actual path

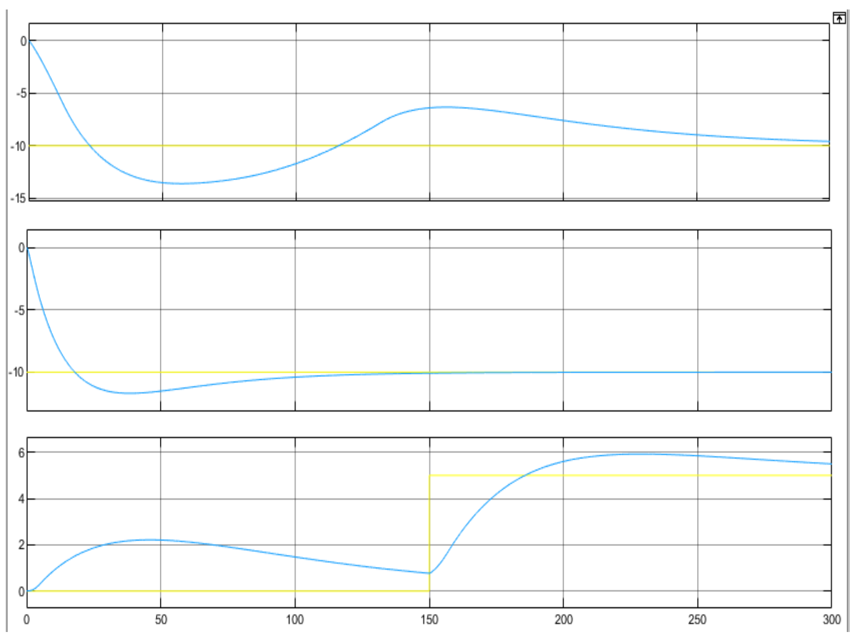

Figure 9 Reference against filtered positions

6. Conclusion

A new class of IoT was investigated: the Internet of Underwater Things (IoUT). It has been proven that it is among the common technologies that will enhance the development of smart cities, which will help take the traditional communication systems to the next generation. Moreover, it helps society in preserving underwater natural resources. Despite the trend of this contemporary topic, only a few studies have been carried out concerning the topic; however, most have not addressed the efficiency and practicality of the system. AUVs play a critical part in the IoUT technology and the implementation of the Smart Ocean. There are, however, concerns and obstacles that must be handled initially. The majority of the problems are caused by several AUVs in a large-scale network which is potentially inefficient to maintain (unsustainable) because every element in the system is dependent on the other: the more elements, the wider the range of error.

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