



## Low-Cost Unmanned Underwater Vehicle Design

Talha Gülgün<sup>1\*</sup>, Göksel Alankaya<sup>2</sup>, Muhammet Emin Duran<sup>3</sup>, Mertcan Erdoğan<sup>4</sup>, İsmail Yalçınkaya<sup>5</sup>, Akif Durdu<sup>6</sup>, Hakan Terzioğlu<sup>7</sup>

<sup>1</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0003-4896-8611)

<sup>2</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0001-7158-112X)

<sup>3</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0001-9686-8602)

<sup>4</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0003-4613-8729)

<sup>5</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0002-6567-399X)

<sup>6</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Elektrik Elektronik Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0002-5611-2322)

<sup>7</sup> Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Elektrik Elektronik Mühendisliği Bölümü, Konya, Türkiye (ORCID: 0000-0001-5928-8457)

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### Abstract

Unmanned underwater vehicles have become a tool needed in military, commercial and research review areas. underwater vehicles can take an active role in underwater search and rescue activities to remove objects from underwater and to make repairs with the arms to be mounted. In addition, they can undertake tasks such as target tracking and mapping at low depths with the cameras to be used in the vehicle. In this study, designed two low-cost unmanned underwater vehicles that could be used for missions such as underwater exploration and cleaning. While the number of engines were kept the same in the designed vehicles, two different sequences were used. When starting the design, they were a lot of titles take as a reference such as safety, cost, usability and ease of manufacturing. The designs that were drawn on paper with hand drawing were carefully examined and any negativity such as negligence, error, miscalculation was prevented. The manufactured vehicle has a high mobility in water and can maintain its own balance in water against external factors that may occur. This high mobility was achieved by using a six underwater thrusters. In order to maximize the buoyancy of the vehicle, the materials used in the vehicle were carefully selected. The vehicle chassis is made of Plexiglas and a sealed acrylic tube is used to protect the electronic components. In the front of the chassis, there is a robot arm made of PLA filament material in order to fulfill the planned tasks. While designing the mechanical equipment, the final design was created by considering the static and flow analysis.

**Keywords:** Desing, Low Cost, Mobility, Position of Thrusters, Unmanned Underwater Vehicle.

## Düşük Maliyetli İnsansız Su Altı Araç Tasarımı

### Öz

İnsansız su altı araçları askeri, ticari ve araştırma inceleme alanlarında ihtiyaç duyulan bir araç haline gelmiştir. Su altı araçları, monte edilecek olan robot kol veya kollar ile su altında arama kurtarma faaliyetlerinde çalışabilir, su altından cisim çıkarabilir ve onarım görevlerinde aktif rol oynayabilirler. Bununla birlikte araçta kullanılacak kameralar ile suyun derinliklerinde hedef takibi ve haritalama gibi görevleri de üstlenebilirler. Bu çalışmada, su altı keşif ve temizlik gibi görevlerde kullanılabilecek düşük maliyetli iki adet insansız su altı araç tasarımı gerçekleştirilmiştir. Tasarlanan araçlarda motorların sayıları aynı tutulurken, iki farklı dizilime yer verilmiştir. Tasarıma başlarken öncelik olarak güvenlik ön planda tutulup; maliyet, kullanılabilirlik ve imalat kolaylığı gibi birçok başlık

\*Corresponding Author: Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Konya, Türkiye, ORCID: 0000-0003-4896-8611, [talhagulgunn@gmail.com](mailto:talhagulgunn@gmail.com)

referans alınmıştır. El çizimi ile kâğıda dökülen tasarımlar dikkatle incelenerek herhangi bir ihmal, hata, yanlış hesaplama gibi olumsuzlukların önüne geçilmiştir. Üretilen araç su içerisinde yüksek hareket kabiliyetine sahip ve oluşabilecek dış etkenler karşısında su içerisinde kendi dengesini sağlayabilen bir yapıdadır. Bu yüksek hareket kabiliyeti altı adet su altı motoru kullanılarak sağlanmıştır. Aracın yüzerliliğini maksimum seviyeye çıkarmak adına araçta kullanılan malzemeler özenle seçilmiştir. Araç şasisi pleksi-glas malzemeden üretilmiştir ve elektronik bileşenlerin korunması için sızdırmazlığı sağlanmış akrilik tüp kullanılmıştır. Şasinin ön kısmında, planlanan görevleri yerine getirmek amacıyla PLA filament malzemesinden üretilen robot kol bulunmaktadır. Mekaniksel donanım tasarlanırken statik ve akış analizleri göz önünde bulundurularak nihai tasarım oluşturulmuştur.

**Anahtar Kelimeler:** Düşük Maliyet, Hareket Kabiliyeti, İnsansız Su Altı Aracı, Motor Dizilimi, Tasarım.

## 1. Introduction

Underwater vehicles are robotic systems that can float underwater and are controlled from land by an operator (Stutters, Liu, Tiltman, & Brown, 2008). The main components of unmanned underwater vehicles are the chassis, engine, motor driver, battery (or power supply) and Control Board (Christ & Wernli Sr, 2013; Morgansen, Triplett, & Klein, 2007). If necessary, it can be equipped with different sensors and designed so that its operational capacity can be increased (Eustice, Pizarro, & Singh, 2008). Unmanned underwater vehicles are basically evaluated in two main groups as Cable Controlled and Wireless-Autonomous (CANLI, KURTOĞLU, CANLI, & TUNA). The cable-controlled one is called "ROV (Remote Operating Vehicle)", while the autonomous one is called "AUV (Autonomous Underwater Vehicle)" (Amory & Maehle, 2018; Wu, 2018).

Unmanned underwater vehicles, which play an important role in underwater research, continue to evolve day by day (Cui, Ge, How, & Choo, 2010). These include small size underwater vehicles; It has some advantages such as small volume, flexibility, low cost and easy to transport. Therefore, they are widely involved in undersea exploration, ocean exploration, earthquake and geothermal activity monitoring, and marine environment monitoring (Wynn et al., 2014). The first vehicle to be classified as an unmanned underwater vehicle was named SPURV (special purpose underwater research vehicle), developed in 1957 at the University of Washington laboratory of Applied Physics in the United States and designed to conduct research in Arctic waters (von Alt, 2003). The NPS AUV-II is an experimental unmanned underwater vehicle designed by the Naval Post Graduate School to build testing infrastructure for underwater vehicle modeling and underwater dynamics studies. This elliptical-bodied vehicle has four pairs of coupled rudders and a pair of twin propellers (Healey & Good, 1992). The Autosub is an unmanned underwater vehicle developed by the University of Southampton, capable of performing long-range and deep underwater missions. It was developed for scientific underwater studies that are not possible to be carried out with conventional research vessels. It has different types of physical, biological and chemical measurement equipment (Kimber & Scrimshaw, 1994).

This article aims to explain the appropriate design model of the vehicle intended to be used in underwater exploration and cleaning tasks, taking into consideration the low cost parameter. In order to avoid any negativity such as negligence, error or miscalculation, designs that are drawing on paper with hand drawing should be examined carefully. The vehicle that is planned to be manufactured, have a structure that has high mobility in water and can provide its own balance in water against external factors that may occur. In order to control the balance of the vehicle, the user can design own control cards by means of the appropriate equipment and software integrated into these equipment instead of sold in the sector. The materials used in the vehicle should be carefully selected in order to maximize the buoyancy of the vehicle. To ensure the protection of electronic materials, the underwater vehicle must have a sealing area (Aureli, Kopman, & Porfiri, 2009). Auxiliary mechanical parts such as flange and O-ring are required to ensure the sealing of the area. The robot arm must be mounted on the chassis to carry out the planned tasks. As a result of the titles referenced, the most appropriate design is included in the article.

## 2. Material and Method

Mechanical design is the process of developing a system, component, or process within the framework of the limits that can be produced in order to meet the desired needs. The mechanical design of the vehicle should be made taking into account the static and flow analysis. According to these analyses, it should be decided that the chassis will consist of one or more parts and which geometry it will have.

Considering the assembly and disassembly processes of the vehicles designed, it was deemed appropriate for the chassis to consist of three main plates. The thickness of the plates to be used was determined as 10 mm and 6 mm as a result of the static analysis, both plates did not undergo any deformation. Due to the fact that it is lighter in weight, 6 mm thick plates are suitable for use. As a result of flow analysis, the engine positions were selected to suit the chassis in order to increase the vehicle's underwater maneuverability and balance.

### 2.1. Chassis Design

The chassis is the load-bearing frame of an artificial object, supporting its construction and function. In underwater vehicles, the chassis is used for the placement of the engine, sealing area, robot arm and various purpose-built sensors. The designed chassis should be strong, agile, modular and versatile (Choi, Hanai, Choi, & Yuh, 2003). The structure that forms the chassis must be made of material that provide fast manufacturing, affordable cost and the possibility to be revised.

In the designed vehicle, the Plexiglas plates are designed to be interlaced with channels so that the bottom and side plates of the chassis are simple to assembly. In addition, the connections of the chassis parts are strengthened with the help of corner mounting apparatus and shaft. It is placed in a sealed acrylic tube for the protection of the electronic components required for the vehicle from water. The acrylic tube is placed in the center of the undercarriage so as not to disturb the underwater balance of the vehicle. The tube seat, made of Plexiglas material, is designed and mounted on the chassis so that the tube can be mounted comfortably on the chassis underside. Thanks to the designed seat, the position of the tube is fixed. In addition, two touch and close fastener were used on the front and rear of the tube. Thanks to the touch and close fastener attached to the fixing holes in the lower plate, the tube is fixed to the lower plate. Metal connection clamps are also used to provide this function in underwater vehicles on the sector. For stable vectorial movement of the vehicle, the connections of the thrusters are adjusted so that the thrust center cross through the center of mass.

## **2.2. Electronic Enclosure**

In machines containing electronic components, the preservation of these components is an important consideration in order to protect the machine from external factors. If underwater, a waterproof structure must be created to preserve electronic components (Choi et al., 2003; Gonzalez, 2004).

It was decided to use a Plexiglas tube to keep the electronic parts designated for the vehicle underwater. An aluminum flange with o-ring channels for sealing is designed to mount to the back and front of the tube. The reason for the choice of aluminium material is that the flange used for sealing purposes has an easy to handle structure compared to industrial plastic materials and the risk of being distortion during the manufacturing phase is lower. In the event of any distortion, the o-rings cannot be fully pressed against the surface of the tube and the tube cannot be fully sealed. In addition, aluminum flange is lighter than other metals and does not react chemically with water. Again, the back and front cover were used to apply pressure to the o-rings on the surface of the flange. The front cover is designed in The Shape of a semicircle to increase the camera angle. The seat is designed in the tube for the regular positioning of the electronic components to be used in the vehicle. This seat is designed to provide easy assembly and disassembly in case of any negative situation. The tube is kept large enough for heated electronic parts (ESC, DC-DC Converter) and the surface area is increased. This allows the tube to cool faster.

## **2.3. Thrusters**

Thrusters are used to provide movement of the vehicle by means of the propeller, nozzle and rotor. In underwater vehicles, thrusters are used to create the direction of movement of the vehicle, as well as to maintain the balance of the vehicle (Omerdic & Roberts, 2004). For underwater vehicles, thrusters available on the market can be used or personal designed and printed with the help of a 3D printer engines are also used.

Six thruster motors will be used in the vehicles and two different motor sequences have been designed. The main factors in the choice of motors are the cost, low weight and reliable structure, so the motors printed on the 3D printer are used. The first of the designs used four thrusters for the X-Y plane movement of the vehicle and two thrusters for the Z plane movement. The other design uses two thrusters for X-Y plane movement and four thrusters for Z-plane movement.

In order to ensure the safety of the equipment and to prevent negative effects such as foreign objects being trapped between the propeller, the engine and propeller section of the thrusters are placed in the nozzle.

## **2.4. Manipulator (Robot Arm)**

A robotic arm can be described as a whole of programmable mechanical parts or as part of a vehicle. The robot arm which will be used underwater should be designed and developed in accordance with the planned tasks and environmental conditions.

Robot arm is used to perform the desired tasks in the designed vehicles. The mouth opening is designed in maximum sizes to enable the robot arm to perform tasks successfully. In order to reduce the inertial force in robots, robots need to be designed lighter. The search for the creation of lighter activators has increased interest in pneumatic artificial novices. Displaying muscle-like properties, these novelizers offer attractive features such as high power/weight ratio, structural flexibility and adjustable rigidity (Colbrunn, Nelson, & Quinn, 2001). Accordingly, the points taken into consideration in this process are that the robot arm is unique, strong, has maximum mobility, is waterproof and does not pollute the water. As a result of the use of two servo motors and two gear wheels in the robot arm, the degree of freedom was increased by the opening-closing movement in the jaw part as well as by the rotation movement in the body part and a unique structure was obtained. The ability to grip objects is enhanced by making the inner surface of the jaw part curved and serrated.

## **2.5. Buoyancy**

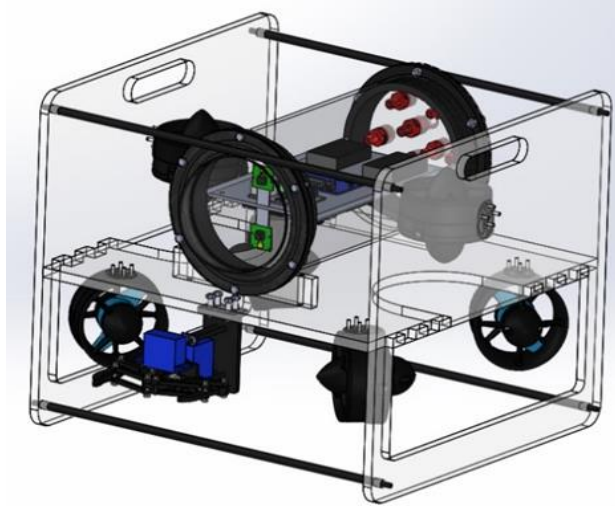
Buoyancy is the ability of the underwater vehicle to remain constant at any depth. Buoyancy is a very important parameter in order to ensure the mobility of underwater vehicles.

The vehicle is designed to minimize the load on the thrusters and achieve a more stable drive. The control of the underwater vehicle does not depend solely on the skill of the operator. If the vehicle is suspended in water, it will need less operator intervention. In order to achieve this, according to Archimedes principle, the weight of the vehicle in the water must be equal to the lifting force (Gonzalez, 2004). Because the stability of the vehicle in the water increases its mobility, the operator performs the tasks easily and the efficiency taken from the vehicle increases. Acrylic tube used in the protection of electronic components, due to the presence of air in the total volume of the vehicle  $8613\text{cm}^3$ , 61.53% of the water in the extra lifting effect makes. According to the calculations, the

lifting force acting on the vehicle is 8.613 kg – force. The vehicle is approximately 8 kg. Based on these results, a mass of 0.613 kg is needed to float the vehicle. Metal parts with high density are placed in the vehicle so as not to disrupt the vehicle's center of mass.

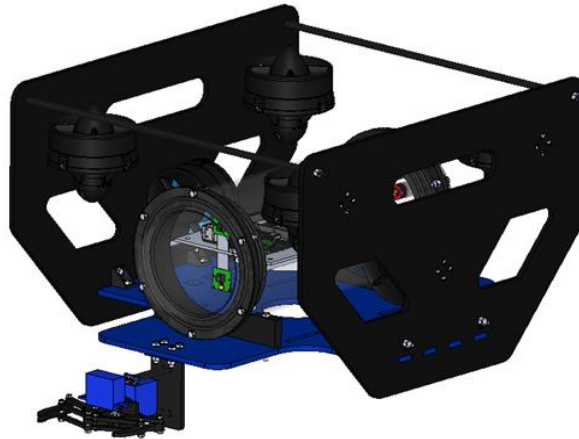
### **3. Results and Discussion**

Four thrusters are positioned at a 45° angle to the X-axis for X-Y plane movement in the first line-up. Two thrusters are used for Z-axis movement. The first design is shown in Figure 1.



*Figure 1. The first design*

In the other type of design, two thrusters are positioned at a 90° angle to The X axis in the center of the vehicle. For the Z-axis movement of the vehicle, four thrusters are positioned at the upper corners of the plates. The second design is shown in 2.



*Figure 2. The second design*

The balance of the vehicle is provided by the PID control system, which is software integrated into the appropriate hardware. The second sequence model, in which four thrusters are used for Z-axis movement, is designed because it is considered possible that two thruster motors for z-axis movement may cause possible balance problems in PID control system. The second sequence model allows both front – back and left – right movements on the vehicle to be easily intervenable.

Both designs were subjected to flow analysis and the results were compared. In the analyses, it was observed that the thrusters angles had a direct effect on the thrust force. It was calculated that the total thrust force of the design with thrusters angles of 45 degrees was lower than that of the vehicle design with thrusters angles of 90 degrees. While the mass of the vehicle remains constant, a decrease in thrust force will mean a decrease in acceleration. Since the acceleration of the second design model, whose thrusters are positioned at a 90° angle relative to the X axis, is greater than that of the first design model, which is positioned at a 45° angle relative to the X axis, this positioning will be suitable for applications requiring speed and time gain. It was observed that 45° thrusters positioning relative to the X axis would be appropriate for applications requiring precise positioning, as the thrusters arrangement positioned at an angle of 90° relative to the X axis may pose a problem due to its high acceleration in applications requiring precise positioning.



## 4. Conclusions and Recommendations

In this study, two unmanned underwater vehicles with different thrusters sequences were designed, explaining the main topics required for the design of low-cost unmanned underwater vehicles that can be used for tasks such as underwater exploration and cleaning. Printing the propellant engines from the 3D printer, selecting the Plexiglas for the chassis material used in the design, using the original control card design instead of ready to fly control cards for the balance of the vehicle, are the main factors that make the underwater vehicle cost-effective.

As a result, our country is surrounded by sea on three sides, underwater observation, reconnaissance, search and rescue, disposable operational missions in the defense industry are increasingly important parameters required for the low cost of unmanned underwater vehicles are explained.

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