Journal of Robotics and Control (JRC)
Volume 3, Issue 4, July 2022
ISSN: 2715-5072, DOI: 10.18196/jrc.v3i4.14867

Semi Wireless Underwater Rescue Drone with Robotic Arm

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***Abstract*—Wireless communication with underwater drones plays a vital role in rescuing an after-ship accident, and it is considered one of the most challenging technologies nowadays. The wireless underwater drone also contributes significantly to navy, gas and oil companies, underwater infrastructure, aquaculture industry, commercial diving, and deep archeological investigations. Bangladesh, a developing country with many rivers and seashores used by many water transport vehicles, faces boat and ship accidents as a typical scenario every year. Many lives, dead bodies, ships, boats, and valuable objects do not get rescued because of the lifetime risk of the divers or the rescue team. The rescue operation is exceptionally troublesome because of the absence of wireless underwater drone technology at the cheapest cost, whose innovation and function are very challenging for Bangladesh. Considering these problematic situations, in this paper, we have proposed a prototype of a semi wireless underwater drone designed and structured with the best quality PVC pipe of 6mm diameter, considering the weight as lowest as possible, maintaining its buoyancy properly. In this prototype, we have used three propellers, each connected with three servo motors, to move it up, down, back, and forth. A robotic arm is also utilized to rescue objects from under the water, and a 4K HD EKEN camera and two waterproof fog lights to search and visualize underwater objects on the mobile screen from the land. For wireless communication between the controller and the drone, we have used two nRF24L01 modules; one is for the controller, and the other is for the drone's receiver to send and obtain the signals from the controller to the drone. 12V and 24V lithium-ion batteries are employed as power sources for the controller and receiver, respectively. Finally, real experimental tests of the proposed underwater device were performed in a swimming pool facility.**

Keywords*—Arduino; HD EKEN Camera; NRF24L01 Module; Rescue; Underwater Drone; Underwater Environment

I. Introduction

A drone is a flying robot controlled by a remote and works with onboard sensors and a global positioning system (GPS) [1], [2]. Drones are also formally known as uncrewed aerial vehicles (UAVs) [3]. Based on the operating medium, drones are of three types, i.e., aerial, underwater, and amphibious [4]. Aerial drones operate in an air medium, underwater drones fly or dive in a water medium, and amphibious drones operate both in the air and water medium [5]. Underwater drone technology is analogous to a submarine without any crew and is mainly used for searching and patrolling, rescue operation, sea exploration, etc. [6], [7]. Most underwater drones have a long tether or fastening belt that connecting them directly to the controller box on the land or ship [8]. These drones can help monitor underwater scenarios from the ground in air media with the help of a camera and a smartphone and collect a water sample from the depth to check the aquatic environment suitable for the survival of underwater lives and rescuing lost objects sinking in the water [27]. However, developing the underwater drone with wireless technology and a robotic arm will contribute marvelously to exploring and patrolling the aquatic environment [28]. The controller can also control underwater vessels very easily without any hassle [29]. These drones can move freely underwater since there would be no risk of getting the tether twisted with or damaged by both land and aquatic plants and animals [30]. The advantages of wireless drones are that they can operate very deep under the ocean and stay for a long time, which is impossible for a diver to discover new creatures that people have never seen or imagined and discover the peaceful underwater world [31]. Because of its wireless technology and robotic arm, it can find and collect aquatic natural resources with easy control and movement [32].

Works have been done to design underwater drones with wireless and various advanced techniques [33], [34]. Some of the recent papers on developing wireless underwater drones have been briefly discussed in the following paragraphs. In [9], the authors designed an underwater robotic system panoramic camera for automatic fish detection based on deep learning techniques, which will recognize different species of fishes living in various water bodies, e.g., sea, lake, pond, etc. First, the authors designed the body of the underwater drone with the software 'OpenSCAD' [10] and the printed circuit board with 'MakePro.' Next, they created 100 images of four kinds of fish as a dataset and traditional data augmentation approaches were performed.

This work used various deep learning techniques for object recognition, i.e., LeNet, AlexNet, and GoogLeNet [11], [12]. Finally, they used a 360-degree panoramic camera equipped with two 235-degree fisheye lenses and OpenGL ES2 embedded framework [13] as hardware and Raspberry Pi computation module. Finally, the authors showed an experimental result with a higher than 85 percent recognition rate and recognition time of 6 seconds for 115 images.

In a recent work [14], M. Adhipramana et al. designed a remotely controlled rover to monitor the aquatic parameters, such as pH values, PPM values, and water turbidity, using internet of things (IoT) technology. The proposed system can navigate and control electronically from the center with a hydraulic or electric thruster [15] employing human commands. First, the authors designed the robotic system where the input is a remote control, then the Arduino Nano, motor driver L298N [16] implement processing task, and DC motors drive the system output. Next, they constructed the monitoring system using turbidity, TDS, and pH sensors. They configured those devices as network inputs. Arduino Uno and ESP826601 modules [17] have been applied as a system processor, and the output displays the measured parameter values on the ThingSpeak IoT cloud platform [18]. Finally, a software designing program algorithm has been developed from both robot and monitoring systems. The authors showed all necessary experimental results with a speed of 0.46 km/h for the robot, and it can be operated over a distance of 140 meters.

In [19], an underwater vehicle based on a twin-rotor system has been proposed. First, the authors designed and simulated the project model with the SolidWorks software [20] with actual dimensions for using two thrusters frameworks. Next, corresponding hardware materials have been utilized to develop the components. In this proposed device, PVC foam board nozzle thruster, electronic case (plastic material) and thruster's holder (aluminum plate) have been used. Next, the authors measured the center of gravity of the proposed device with the SolidWorks software to maintain stability. Finally, the authors demonstrated some real-time data on the implemented system's static thrust production, hovering, and submerging tests.

In [21], M. Moustanir and his colleagues designed an underwater drone titled four propeller underwater drone modeling without rudders or dining bars and the resources of the drone. First, the authors made a general concept as the model proposal for the drone, a torpedo-shaped underwater robot. Next, they have completed the modeling of the ROV, which includes the kinematic part and active part. The kinematic part deals with the movement geometric relationships of the submarine and the active region with the forces and torque acting on the machine. Next, they simulated the proposed design in MATLAB programming language to visualize the movement of the vehicles. Lastly, the author has shown the results of the robot's behavior in each case by taking several cases of combining the thrusters' power.

In [22], the authors designed a remote-controlled submerged submarine robot, controlled by decoded beat signals, that will find natural boundaries underwater ways, trenches, and seashores. It has two primary parts, viz. submerged contact and control, where the control station initially sends an order to the transmitter. Next, the transmitter creates sound wave signals of 8-16 Hz that the collectors collect. The authors have used a high definition 1080P camera and a cell phone for the underwater view. The authors have shown the result of the robot's speed as 2meters in 21s.

In [23], a wired hydrobot has been designed, made up of polyvinyl chloride pipes, capable of 360^0 rotation and changeable depth. The whole system is composed of 3 parts, i.e., mechanical structure and control, sensing system and control, and sampling framework. The authors have used a robotic arm to pick the objects from underwater in this work. They have also used different sensors, e.g., accelerometer, hall effect sensor [24], and temperature sensor. Finally, they have shown data taken by various sensors and a screenshot of the underwater device from the live video footage taken by a waterproof web camera with a night vision facility.

In [25], the authors proposed an underwater rescue robot with a body made of acrylic sheets. In this device, the Raspberry Pi embedded device is used as a communication and control system directly connected to the central computer by the Ethernet cable and a Pi camera is employed for taking live video streams. The authors control the robot's speed with the help of five brush-less motors and electronic speed control modules. Finally, the authors observed the robot's different speeds in the Python Shell.

In [26], S. Deb and the coauthors designed and constructed a completely wireless underwater robot at a low cost for the oceanographic survey, environmental monitoring, and debris inspection. The robot has mainly two parts, i.e., transmitter and receiver. The authors have used an Android smartphone connected to a Bluetooth module without using the joystick to control the robot's movement. They have used RF modules for wireless communication. The robot has six thrusts for forwarding, vertical, and horizontal directions. The proposed device can run underwater for 25-30 minutes with a fully-charged battery.

From the literature reviews mentioned above, we have observed that most researchers worked with wired underwater drones with different sensors, HD cameras, and flexible designs to make the device more minor. Research on controlling the drone and its robotic arm underwater with wireless technology is primarily unavailable, which inspired us to utilize wireless technology to control the drone and its robotic arm deep underwater. Thus, this paper proposes a prototype of a semi wireless technology that maintains a drone's movement deep underwater and its robotic arm to pick up or rescue objects from the aquatic surface.

This work aims to design an underwater drone, a hardware-based system at an affordable cost used in rescue operations for the military and maritime forces. This drone helps identify boats' position after an accident or any valuable object to rescue them. It can take the real-time data of rivers or other water bodies by using its waterproof camera and WiFi module. The main body of the proposed underwater device has been constructed with polyvinyl chloride (PVC) synthetic plastic material to make it lightweight and at a low cost. Major contributions of this research have been discussed below:

- The most significant contribution to this work is to design an underwater drone with wireless technology in sending and receiving signals from the controller to the receiver circuit with the help of nRF modules and the Arduino Uno microcontroller.
- Another most challenging contribution is the design procedures of the proposed drone. PVC material of 6mm diameter has been utilized for the chassis structure after making the 3D design model in the AutoCAD software application. The chassis dimension of the implemented device is 1.5ft long, 1.5ft in width, and 1ft in height. Three brushless water-resistant servo motors are connected to three different propellers instead of a DC motor.
- A 4K HD EKEN camera has been placed at the center of the device's front side to search for objects underwater and fog lights are placed at the right and left sides of the camera. With the help of a smartphone application and its WiFi feature, the live stream of the underwater environment can be examined in real-time.
- In the proposed underwater drone, a robotic arm is installed. The robotic arm is one of the essential devices to grab and rescue the objects from underwater and bring them back to the land.
- The nRF module, floating on the water surface, receives signals from the controller's nRF module. This module is connected to the drone with the help of a long umbilical wire of 100m.
- In the controller circuit, two joysticks have been used to control the propellers, and two toggle switches control the lights and a potentiometer governs the robotic arm.

Section II presents a fine-grained analysis of the design of the proposed underwater wireless robotic system. Relevant results of the implemented drone are discussed in Section III. Lastly, some future explorations of this work have been demonstrated in the last chapter of this manuscript.

II. Proposed System

This section illustrates the construction technique of the proposed underwater, remotely operated drone. We have created the system at a considerably lower cost so that it can be used for non-industrial light works. Individuals with minimal technological knowledge may efficiently operate and manage the system interface. This system will provide the impression of being user-friendly. The block diagram representation of the proposed device has been demonstrated in Fig. 1. There exist three implementation parts of this work, i.e., designing, hardware assembles, and programming. In the following paragraph, the 3D design model of the proposed underwater vehicle has been presented.

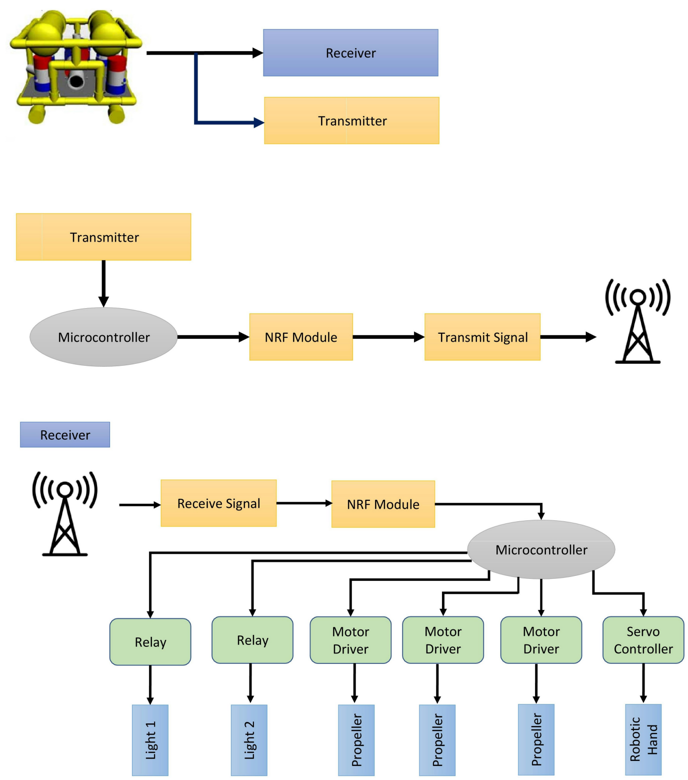

Fig. 1. Block diagram of the proposed underwater drone.

A. Designing Part

The primary object of this work is to design a balanced system capable of carrying components underwater. We tried to make the chassis of the vehicle as balanced as possible by placing the camera correctly at the center on the front side, flashlights at the edges, and the box of the receiver circuit inside the chassis in a secured position. In the following paragraph, we have shown a calculation of the distance of a sound wave traveling in the aquatic environment [35].

The speed of a sound wave is $1500m/s$ in water [36]. Again, the time interval of sending and receiving a sonar sound to detect a submarine in the seabed is $0.12s$. Therefore, according to the sound wave equation, the required distance is $180m$. Consequently, the proposed underwater vessel must be $90m$

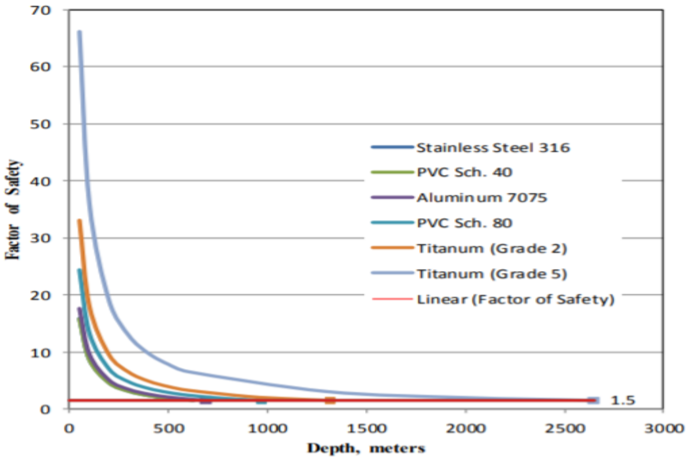

Fig. 2. Different materials factor of safety vs. depth in meter graph.

PVC Sch. 40		Stainless Steel 316		Aluminum 7075		PVC Sch. 80		Titanium (Grade 2)		Titanium (Grade 5)	
Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS
50m	15.817	50m	15.887	50m	17.634	50m	24.403	50m	33.093	50m	66.199
100m	8.636	100m	8.675	100m	9.628	100m	13.324	100m	18.069	100m	36.145
200m	4.526	200m	4.546	200m	5.046	200m	6.983	200m	9.47	200m	18.944
300m	3.067	300m	3.08	300m	3.419	300m	4.732	300m	6.416	300m	12.835
400m	2.319	400m	2.329	400m	2.586	400m	3.578	400m	4.852	400m	9.706
500m	1.864	500m	1.873	500m	2.079	500m	2.876	500m	3.901	500m	7.803
600m	1.559	600m	1.565	600m	1.738	600m	2.405	600m	3.261	600m	6.524
610m	1.534	610m	1.541	650m	1.606	770m	1.881	900m	2.186	1300m	3.038
620m	1.509	620m	1.516	690m	1.515	900m	1.612	1100m	1.793	2000m	1.98
624m	1.499	627m	1.499	697m	1.499	969m	1.499	1317m	1.499	2644m	1.499

Fig. 3. Durability of PVC pipe under the water.

far below the ship. We have also found out the depth to cost ratio in this design. However, according to Fig. 2, the safety factor almost exponentially reduces with the underwater depth of the device [37]. From Fig. 3, it is visible that PVC Schedule 80 with a heavy wall has a superior depth cost ratio than PVC Schedule 40, although having a moderately higher price [38]. That means PVC Schedule 80 went down to 969 meters, whereas PVC Schedule 40 only went down to 624 meters. All the other materials except these two comprise a low depth-to-cost ratio, which means they will be significantly costlier than the two PVC tubes. Fig. 4 and Fig. 5 demonstrate the 3D model of the final design of the proposed underwater drone in AutoCAD [39]. Thus Using AutoCAD, we constructed a 3D depiction of the material's solid work. Solidworks supplied another option for determining the material's response under pressure. There are eight edges in the proposed design of the device. It is worth mentioning that, only the edges would be subject to hydrostatic pressure. We made our chassis almost the same as we have designed in AutoCAD.

B. Hardware Part

This paragraph briefly discusses the required hardware components to implement the proposed underwater drone. The hardware part has mainly two parts, i.e., transmitter and receiver. The receiver part consists of an Arduino Uno microcontroller, nRF wireless module, robotic hand servo, brushless propeller, camera, battery, and two fog lights. Conversely, the transmitter

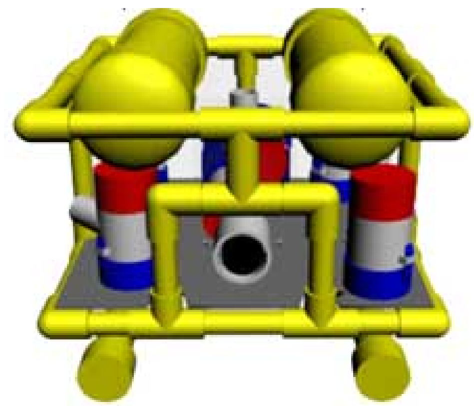

Fig. 4. Front view design in AutoCAD.

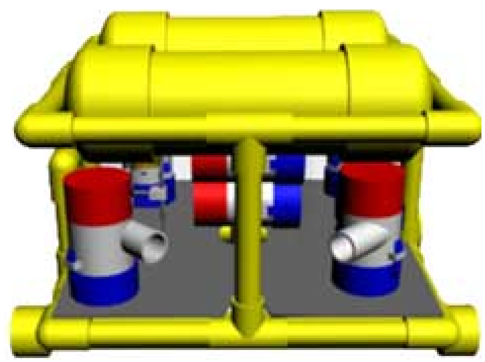

Fig. 5. Side view design in AutoCAD.

part has an nRF module, Arduino Uno, two joysticks, two toggle switches, a LED, a potentiometer, and a battery.

- Arduino Uno R3: In the proposed underwater vehicle, the Arduino Uno R3 microcontroller [40] has been used to receive corresponding data from the camera receiver and transmitter and nRF module. It sends the data to the robotic arm and propeller mount.
- nRF module: nRF24L01 is a wireless transceiver module that operates at 2.4GHz, making the proposed underwater system semi wireless [41]. This component employs the GFSK modulation approach [42] for wireless data transmission, which can be expressed as:

$$M_i = \frac{2 \times \sigma_{out}}{f_s \times (M-1)} \quad (1)$$

where M_i and M denote the modulation index and corresponding alphabet size, respectively [43]. For 2GFSK and 4GFSK modulation approaches, $M = 2$ and $M = 4$, respectively. f_s indicates the symbol rate in baud (Bd) [44]. With the help of this equipment, we can receive the transmitted signal in water without having a coaxial cable connection. Nevertheless, an umbilical cable is required to

control the drone from the ground so that it does not travel out of its range.
- Robotic Arm: In this work, a 2-DOF robotic arm [45] has been employed to get the necessary data from the microcontroller and grab various desired objects according to the needs. The used robotic arm can drift at an angle of 0 to 180 degrees.
- Propeller: A four-wheel propeller [46] has been utilized in the proposed drone. The additional blade area grips the water better, allowing for quicker acceleration.
- Camera receiver and transmitter: A water-resistant EKEN camera receiver and transmitter has been used to receive the data and display the scene in the implemented underwater drone.
- Battery: A 24V lithium-ion battery has been used in this research to supply the required power of the proposed underwater device. We use the batteries with higher ampere hours because they can deliver more power, and in the water medium, extra energy is required compared to the air medium.

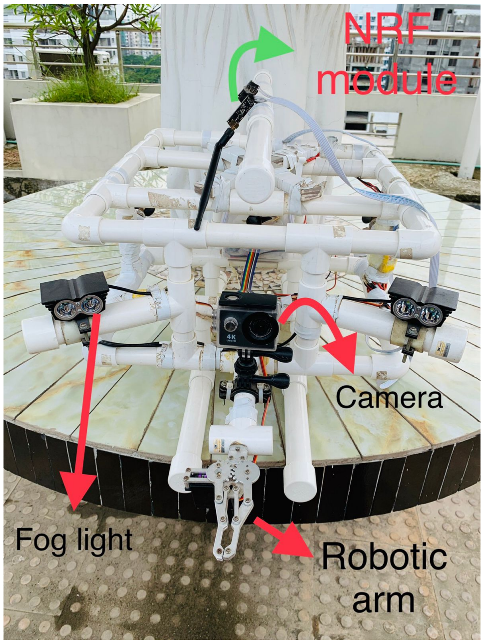

Fig. 6. Front view of the proposed underwater drone.

After creating the software design and acquiring the hardware components, the connection of the proposed underwater drone is completed. Connections of all the above modules are pretty straightforward except for the nRF module. The proposed drone is semi-wireless and cost-effective, thanks to the nRF Module. It is semi-wireless because an nRF module has been used to receive and transmit signals in water without a coaxial cable connection. Still, an umbilical cord of 100m has been utilized to control the drone from the ground in case of any

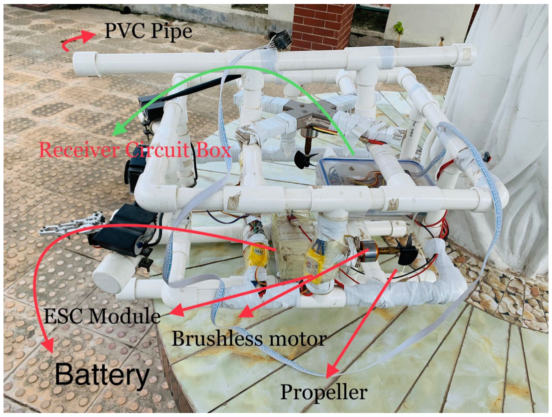

Fig. 7. Side view of the implemented underwater device.

emergency. It is almost impossible to generate a high frequency to penetrate the water surface properly and reach the receiver circuit. Consequently, a cable of 100m length has been added to link the nRF module to the main body of the drone. Next, a floating entity is created to transport the nRF module across the water surface. The controller circuit will transmit the signal frequency to the floating nRF module, sending the signal to the drone via wire. The controller, including the nRF modules, is shown in Fig. 8.

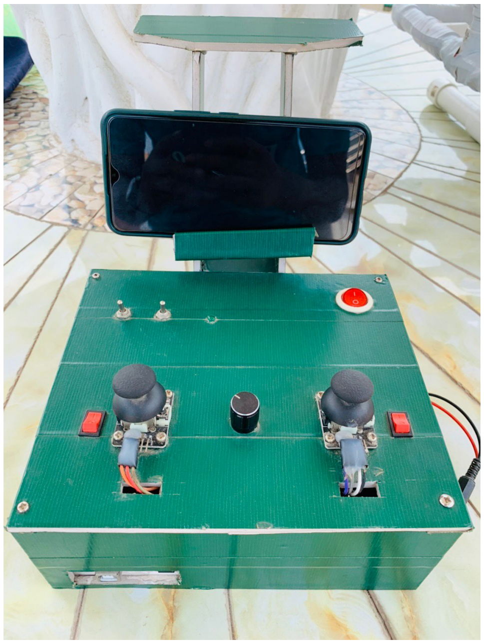

Fig. 8. Frontal view of the used controller.

In this work, a brushless motor [47] has been used instead of a DC motor because of the high density of water, approximately 997 kilograms per cubic meter area, compared to 1.225 kilograms per cubic meter for the airy atmosphere. As a result, the resistance would be much higher in water than in air medium. The DC motor will not be able to take the water pressure. Thus, we used a brushless motor to solve the problem of high density, as shown in Fig. 9,

Fig. 9. Brushless motor with the propeller.

Next, we implemented the receiver circuit according to the Arduino IDE code. We connected the nRF wireless module's transmitter pin to the Arduino pin 9, and the receiver pin is attached to Arduino Pin 10 as programmed in the code. According to the code, other modules have connected, and the proposed system's final receiver circuit has been presented in Fig. 10.

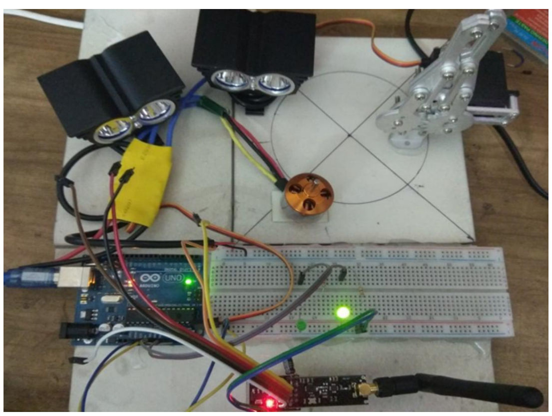

Fig. 10. Receiver circuit of the proposed system.

In this research, the open-source design software, Fritzing [48], has been used to show the final circuit diagram of the proposed underwater drone. Fig. 11 shows the resultant circuit diagram of the receiver part designed in Fritzing software.

C. Programming Part

Finally, in this work, we developed and uploaded the essential code to the Arduino Uno chip using the Arduino IDE 1.8.15 to send relevant signals to the controller and receiver parts. Accordingly, the drone will get instructions to grab the object or turn on the flashlight using these corresponding commands.

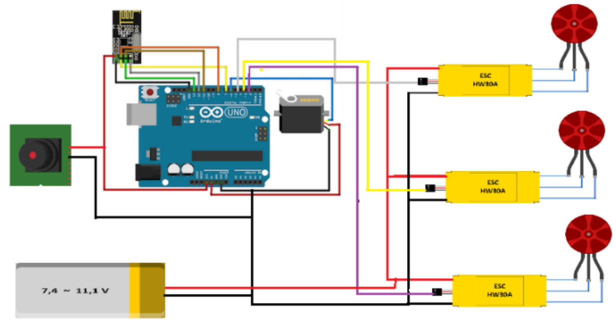

Fig. 11. Circuit diagram of the receiver circuit.

III. Result and Discussion

In this section, various types of outcomes of the proposed underwater drone have been discussed. Expected consequences have been achieved after designing and implementing the receiver circuit. The approximated dimensions of the proposed chassis are 1.5 ft, 1 ft, and 1 ft in length, width, and height, respectively. The approximate weight of the drone is 5.728 kg (12.628 lbs) and the controller is 714 gm (1.574 lbs). The approximate cost to build the proposed prototype is 22,000 BDT ($250 USD). The runtime of the 24V and 12V batteries is almost 1.5 hours, i.e., for the given input load of the proposed device, they can sustain for 1.5 hours.

A. Features of the proposed device

The features of the proposed underwater device are as follows:

- Explore the world beneath the water with the help of a HD camera and lights.
- Locate and search the position of the expecting object using the camera.
- Grab any object from underwater with the robotic arm.
- Capturing real-time scenarios of underwater by employing an Android smartphone, HD camera and its application.

B. Underwater Live Streams

Finally, the experimental tests of the proposed underwater device were performed in a swimming pool at Gazipur, an adjacent town to the capital city of Dhaka, Bangladesh. The dimensions of the experiment facility are approximately 15 $\times$ 12 $\times$ 1.83 meters. Finally, the proposed drone navigated through the water at a maximum speed of 0.58 km/h. Fig. 13 demonstrates some of the sample images of the drone in the water during the experiment.

A real-time live video stream was captured under the swimming pool's water with the help of the drone's waterproof HD

TABLE I
COMPARISON OF THE PROPOSED UNDERWATER SYSTEM WITH OTHER EXISTING WORKS

Reference	Micro controller	Joystick	Camera	Robotic Arm	Distance (km)	Weight (kg)	Dimension (ft)	Cost (USD)
[7]	N/A	N/A	DT-C101A 1080P	N/A	N/A	N/A	N/A	Not reported
[8]	N/A	N/A	Web Camera	mechanical arm	N/A	Not reported	Not reported	Not reported
[9]	Raspbery Pi	N/A	Pi Camera	N/A	Not reported	Not reported	1.2 × 1 × 0.2	$370
[10]	Arduini Mega	N/A	4K Camera	N/A	0.05	Not reported	Not reported	Not reported
This Work	Arduino Uno	2	4K HD EKEN	1	0.800+	5.728	1.5 × 1 × 1	$250

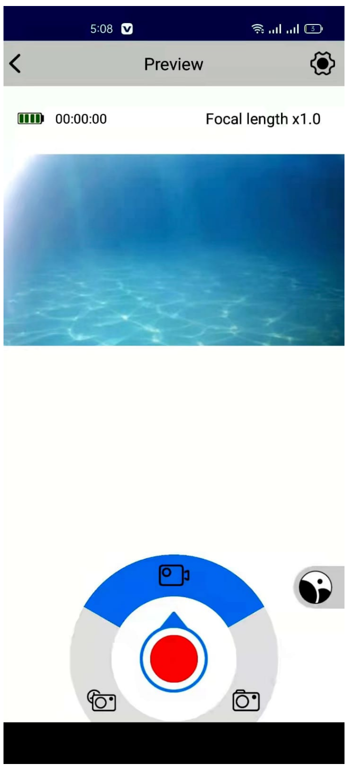

Fig. 12. Underwater real-time view captured by the proposed drone using waterproof camera and an Android smartphone application.

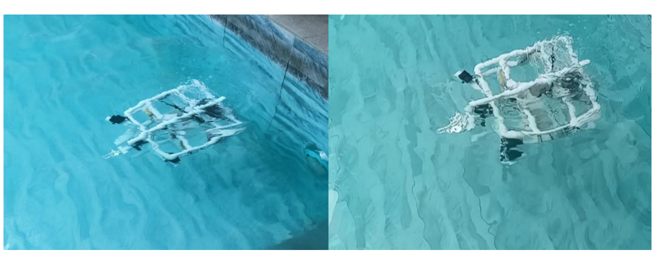

Fig. 13. Sample images of the drone in the aquatic experiment.

EKEN camera. The underwater scenario of the swimming pool was observed on the mobile screen by connecting the camera with the open-access Android smartphone application named EZ iCam. A sample screenshot of the smartphone application's interface with the underwater live view has been depicted in Fig. 12. It is experimentally tested that, the integrated robotic arm of the proposed underwater drone can carry objects of small size up to 700 grams.

C. Comparison to other existing works

Table I demonstrates various features of the proposed underwater drone compared to other existing works. According to this table, most systems did not show their corresponding device's controlling range, hardware project's weight, dimension, and implementation cost. This project's price is lower than others because of the careful selection of various hardware components. It is very enthusiastic to mention that the proposed underwater drone has a robotic arm, which can be utilized to grasp various objects beneath the aquatic medium.

IV. CONCLUSION

In this paper, a prototype of a cost-effective semi wireless remotely controlled underwater drone has been developed. First, the 3D design model of the system has been obtained in the AutoCAD software application. Next, the chassis structure of the proposed device has been constructed using PVC material of 6mm diameter. Three brushless water-resistant servo motors are connected to three different propellers instead of a DC motor. Two nRF modules and the Arduino Uno microcontroller have been used for sending and receiving signals from the controller to the receiver circuit. A 4K HD EKEN and an open-access smartphone application with WiFi features are utilized to examine the live stream of the aquatic environment in real-time. An exciting addition to the proposed device is a robotic arm employed to grip and rescue different objects underwater and return them to the ground. This underwater drone system can be used for patrolling, object searching, rescue operation, sea exploration, etc.

In the future, different complex sensors can be added to detect objects and measure water quality. A high-quality camera can be attached with 360-degree views, and the signal transmission and reception range can be extended. Another extension of this work is to convert it to a completely autonomous system by making it fully wireless.

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