A Novel Low Cost ROV for Aquaculture Application

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***Abstract*—Marine aquaculture is deeply rooted in Norwegian national economics and traditions, especially in the Møre og Romsdal region. This paper presents the development of a novel ROV for aquaculture inspection in marine application to provide first-hand information in fishery nets. The ROV is a part of so called "Sea Farm" project. When the ROV doesnot work, it will be carried by a floating platform. A winch on the platform could lift the ROV down to the sea water and lift it out of water after operation. The basic concept of this ROV is low-cost, built with off-shelf and easily manufactured components. There are three wings on the body part. One thruster is embedded into each wing to provide the propulsion. Based on the cooperation of three thrusters, the ROV has omnidirectional movement capability. A serial tests in the water tank were implemented including motion comparison, speed and turning tests to verify the concept and its propulsion mechanisms. In the end, conclusions and future work are given.**

***Index Terms*—ROV, Concept design, motion control, marine aquaculture applications.**

I. Introduction

Norway is the world's leading producer of Atlantic salmon and the second largest seafood exporter in the world [1]. The Mid-Norwegian regions play a major role in salmon production and fisheries, with a first-hand value of over 60 billion NOK [2]. A healthy marine environment is a prerequisite for marine production, and for the future sustainable growth of the aquaculture industry in Norway.

Due to various factors, such as new technology and equipment, restructuring, international competition, varying quotas, etc., the traditional fishing industry has undergone a number of changes in the past few years. Sustainability is of increasing importance in fisheries as well as in national and regional aquaculture. The development of tools for monitoring and conservation of the marine environment is of utmost importance for the primary seafood producing sector and technology and service providers, as well as for environmental researchers, policy makers and authorities.

In recent years, the growth of the Norwegian salmon aquaculture has been hampered by the impact of diseases and parasites. While actions have been taken and systems to protect fish have been implemented on technology and management level, the biological pressure on farmed salmon remains high. Proper environmental monitoring is necessary to understand aquaculture environment interactions, transport processes and pathogen dynamics associated with farmed fish in sea cages in order to further improve upon existing practices to develop efficient new solutions based on detailed knowledge about harmful organisms, fish farm structures and the environment, including their complex interactions.

A range of relevant sensors and analytical methods exist, but today these are mainly used at few discrete locations. With sea cages encompassing large volumes of water and up to 200.000 fish, such measurements are not sufficient to properly map and monitor the cage and farm environment. The use of mobile carriers allowing proper dynamic positioning of relevant sensors under water will allow to monitor the cage and farm environment and the state and behaviour of fish. Such information will support decision making processes to safeguard the health of fish and to improve fish welfare, for example by detecting harmful organisms or unfavourable environmental situations at an early stage or by enhancing our understanding of the dynamic interactions of farmed fish with their environment, which is the basis for optimizing farm and coastal zone management.

Therefore, this project aims to develop a novel low cost ROV for use in aquaculture settings and for environmental investigations. This paper is organised as follows: Section II will present related work on the topic. Section III gives an introduction of development of the ROV system from concept design, buoyancy calculation, and to control implementation. In the section IV, the motion realisation will be explained in detail. Conclusions and future work are shown

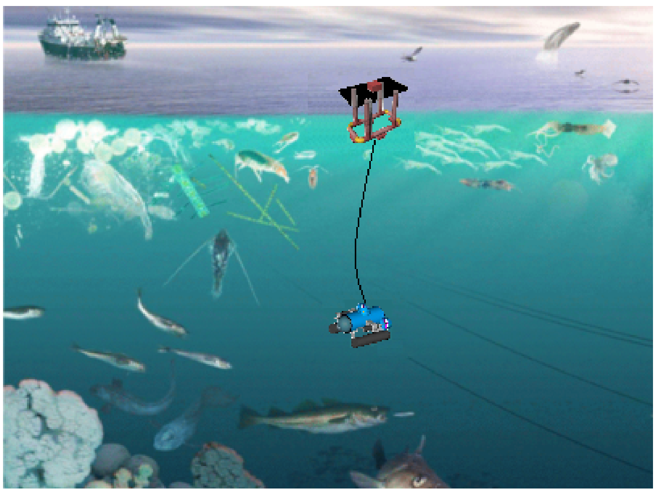

Fig. 1. Project concept.

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in section V.

II. Related work

The latest decade has witnessed an increasing interest in developing and employing modern machinery and robotic systems for use in aquaculture as well as for a wide range of environmental monitoring applications. Remotely steered and autonomous underwater vehicles have the potential to allow the collection of data almost continuously in large water volumes, in opposition to traditional measurements in few discrete locations. High working efficiency, environmentally-friendly work practises, high manoeuvrability and stability are always necessary for such equipment and systems.

Underwater vehicles are being developed and introduced to undertake more and more work in the EU, Asia and the United States for many different applications [3]–[6]. For example, recently Ingrid Schjølberg introduced a ROV project and the goal is to improve the capabilities of the ROV leaving the operator mainly to supervise operation in subsea inspection, maintenance and repair (IMR) operations with non-cabled systems [7]. The EU FP7 TRIDENT project presented a new type of submersible, the intervention AUV (I-AUV), and presented the different mechatronic components including, the hardware and software integration, and the performance of the vehicle during the project trials [8]. The other project introduced ROVs to shallow and deep water to perform the monitoring and the planned maintenance activities required to prevent the biological colonisation in an underwater archaeological site [9]. The system is equipped with a custom arm and an opto-acoustic camera. To simultaneously satisfy position and force trajectory constraints, the vehicle-manipulator system is also controlled through a hybrid position force control scheme.

For ROVs, many important issues including control system, underactuated condition, pose recovery or station keeping, coupling issues and communication technique are well introduced in [10]. In parallel, low cost and robustness are also important for industrial partners to adapt the advanced robotic technology to the transitional fishery domain. Recently, a low cost ROV unit was designed and constructed at Universiti Teknologi Malaysia (UTM) [11]. Equipped with a network camera and manoeuvred by three motors through 12 volts battery power supply, it is controlled by joystick controller through network cable and is able to submerge up to 20 meters into water to perform underwater observation operation. The Blueye Pioneer is developed and tested in rough conditions in Arctic waters. The robot could be controlled by using your own smartphone, tablet or goggles and the Blueye App [12]. The robot is around 8 kg, could work down to 150m. The other famous project is OpenROV 2.8 Kit [13]. The robot weights just 2.6kg, with the dimensions 30cm long, 20cm wide, and 15cm high. Nominal battery life for one-time recharging could run for around 2-3 hours. More importantly, the robot is equipped with HD Webcam, red scaling lasers for different applications.

In the literature, some researchers tried to employ biomimetic technologies in order to develop fish-like robots to applications [14]. Related research based on various motion pattern has been studied and new prototypes of fish-like robots have been developed [15]–[18]. However, current research on this type of fish-like robots focus on propulsive efficiency. The swimming performance payload capability are still limited.

Noted that, there is few ROV or underwater robots designed for aquaculture application so far. Several features including noisy (disturbance to surrounding environments), low manoeuvrability and low efficiency in limited working space are critical for ROVs in order to carry out successful and efficient work in practical aquaculture environments. Nowadays the research society is urgently required to deal with these problems and has to propose environmentally sustainable aquaculture robotic automation systems and services that minimise risks to the marine environment and to biological diversity, which is a prerequisite for long-term growth and development [19].

III. A novel ROV for aquaculture inspection

A. *Project concept*

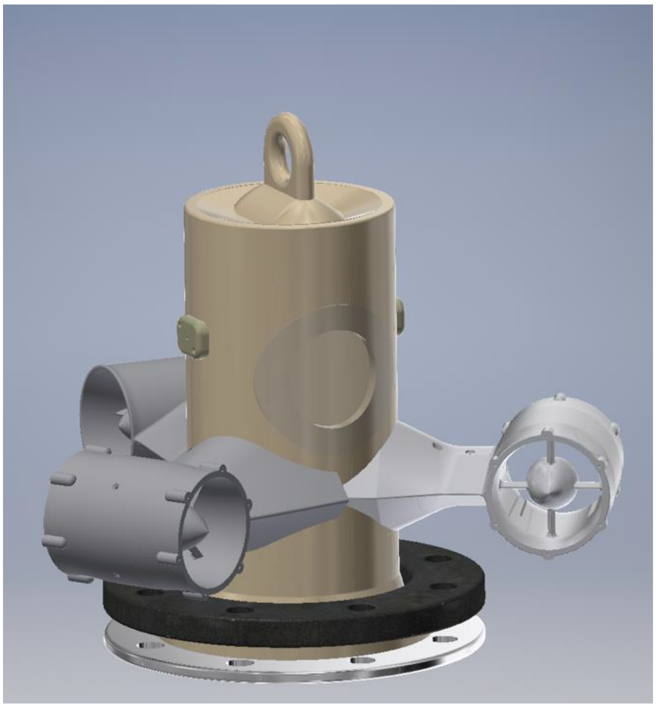
This project strives to equip the local aquaculture industry with advanced bionic technology, and also to utilize and improve technology to support environmental exploration and monitoring. The whole project concept is shown in figure 1. There are two parts in the whole system including a "Sea Farm" mobile platform and a low cost ROV. The "Sea Farm" will carry the ROV to move to the operation location. A winch on the platform could lift the ROV down to the sea water. Then the ROV will work independently following by a cable which provides the power and transfer the control signals. After the operation, the winch on the platform will lift the ROV out of water, then move to the next location.

This project supported by Mechatronics lab at NTNU Ålesund aims to develop a prototype ROV that can provide the following requirements.

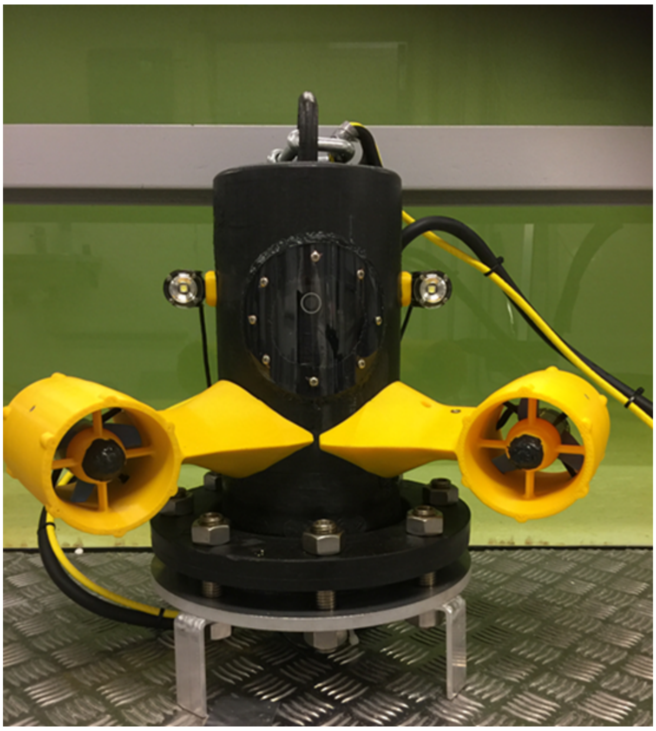
- Camera to inspect the net in aquafarm
- Locomotion capability inside the net, down the the fish net bottom
- Umbilical for energy, control and video signal
- Flexible motion control including
  - Controlled in the YAW axis
  - Heave be controlled by winch
  - Minimise the roll motion during the operation
  - Friendly GUI

The goal in this project was to create an ROV with good underwater capabilities with a robust construction. The ROV design and prototype is shown in figure 2. There are three wings on the body part. Therefore, the framework is built with materials that have good properties such as PE plastic, Plexiglas, 3D-printed thruster casings, and a flange combined with a gasket. The Plexiglas is mounted to be able to see through the framework with a camera, and the flange is used for cable entry. These materials combined makes a robust and waterproof ROV, with good underwater characteristics.

One thruster is embedded into each wing to provide the propulsion. Based on the cooperation of three thrusters, the ROV has omnidirectional movement capability. Since the ROV is going to be controlled by an external winch, we use three thrusters located 120 degrees from each other to get movement in the two-dimensional plane. By using vector calculation, it is possible to control the force and direction of each thruster to get omnidirectional forces. A twisted pair cable made for underwater applications is used as umbilical cable to hold the weight and communication with the ROV. This cable has specification working strength of 35kg and



(a) Design



(b) Prototype

Fig. 2. ROV design and prototype

a breaking strength of 155kg. This together with a power cable feeds it with all necessary electrical supply.

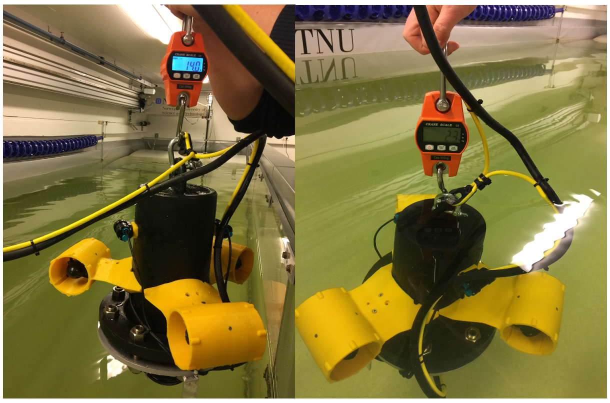
With a combination of camera, lights, cooling fan, oxygen, pressure, depth, moisture, temperature, gyroscope, compass, accelerometer and voltage sensors makes it possible to monitor the environments both internally and externally. Two led lights from Bluerobotics are attached on the side of the frame, one led on each side. The lights provide a clear sight for the camera attached inside the ROV, where the dimming of the lights is controlled by the microcontroller inside of ROV. The led can reach a brightness of 1500 Lumen, and waterproof down to a depth of 300 meters.

All electrical components inside the ROV is integrated on a frame. This frame is connected inside a tube for protection of the electrical wiring and components. The tube is further on mounted inside the ROV. At the opening of the tube, there is connected terminal blocks for all I/O which creates the opportunity for easier changes in the future by exclude the need to detach any components to reach the desired connection. All connections in the terminal blocks are named for better overview along with spare connections to add further equipment.

The integrated GUI is designed with the purpose of both manual control, and monitoring of the ROV surroundings, including video and sensor information. From the GUI the user has the opportunity to control the light, thruster speed and movement of the ROV. The monitor displays all sensor information gathered by the microcontroller and a live video feed of the ROV surroundings. The sensor values include information as temperature, pressure and oxygen level of the water, and temperature, movement and acceleration of the ROV itself.

B. Buoyancy Calculations

Basic buoyancy calculation is carried out to balance the ROV mass to its displacement/own buoyancy, see Table I. It was aimed for a small amount of negative buoyancy, to keep the ROV manoeuvrable in the testing pool. For active operations/further testing in deeper water, it is however advisable to add further ballast in form of a weighted flange-ring between the loose flange of the hull and the interface-flange to enhance stability. Stability and balance in the XY-plane were easily achieved through the symmetry of the design itself, but care had to be taken to balance the craft to avoid too much roll and pitch during manoeuvring with the thrusters. To combat roll, pitch, and the pendulum effect that can occur at shorter umbilical-lengths the thrusters is placed above the vessels centre of gravity (COG), and approximately at its centre of buoyancy (COB).



(a) In air (b) Submerged

Fig. 3. ROV buoyancy testing.

C. Control realisation

The software of the ROV is design by combining three different systems into one. Two of them are embedded inside the ROV, which is a Raspberry Pi and an Arduino microcontroller. The other one runs on any external computer. Each platform has its own developed communication protocol for

Item	Volume [dm^3]	Mass [kg]	Buoyancy [N]	Weight [N]	Sum [N]
Hull	2,400	2,285	24,135	22,416	1,719
Air in hull	4,762	Neglig.	47,887	N/A	47,887
Flange	0,861	3,120	8,655	30,607	-21,952
Blind flange	0,612	1,652	6,152	16,206	-10,054
Thrusters	0,588	0,624	5,916	6,121	-0,206
Misc. equip.	N/A	2,000	N/A	19,620	-19,620
Fasteners	Neglig.	2,000	N/A	19,620	-19,620
		11,681			-21,845

TABLE I
BUOYANCY TABLE.

data exchange between each other. These protocols are based on byte-arrays, where each byte is dedicated its own function or value.

The Raspberry Pi is for calculations, video feed transmission and communication between systems, and the microcontroller is for sensor input and thruster control and the external system for control, and data display with custom made GUI. The Raspberry Pi has several tasks including processing data received from the user's interface, vector thruster, adaptive light control calculations, video feed transmission to user's interface and intermediate in communications between devices. This is accomplished with a Java based program that handles all this automatically.

The Arduino microcontroller handles all sensors' inputs, thruster outputs and communication. Serial communication is used for two-way communication with the Raspberry Pi. To make it possible to perform changes in the code on any of the embedded ROV systems, it is activated remote control. By doing this, it is possible to perform changes in both the Raspberry Pi and the microcontroller from an external device through network connection.

The external system is the user's interface made by Java. A user-friendly GUI is developed to control the movement and light of the ROV, and read of sensor information. The movement and light is controlled by the user's inputs, which will trigger commands to be sent to the Raspberry Pi by UDP communication. These commands will then be processed by the Raspberry Pi by vector based calculation and sent to the microcontroller with output values for each thruster. The light can be controlled automatically or manually by the user, by simply toggling automatic on or by changing the value of the lights manually.

As mentioned above, the ROV is equipped with two dimmable led lights that can each generate 1500 Lumen from Bluerobotics. It is also developed adaptive light control on the Raspberry Pi, by image processing. This checks the brightness of the live video feed and corrects the light values if the brightness is lower than a threshold value. This is accomplished by using an algorithm created in Java that corrects the light value on the microcontroller by applying some filtering in order to avoid light flickering. The light values are then sent to the microcontroller to dim the lights accordingly.

All control hardware is installed inside the ROV main body for water-proofing. In total, 13 internal and external sensors are integrated onboard. One camera is mounted on the ROV for image monitoring. Specially, adaptive light control function is designed to adjust light power actively according to image brightness. The test is shown in figure 5.

A 10-DOF IMU from Sparkfun is equipped inside the ROV, which is a single component with several units. It uses I^2C communication that enables us to get information such as acceleration, gyroscope, compass, barometric pressure and temperature. This gives us good data of the movement as well as temperature readings inside the ROV. It is very useful to monitor the temperature inside ROV, and if it reaches a certain threshold a cooling fan will prevent the electrical components from overheating.

To detect water leakage inside the ROV, it is equipped with a moisture sensor from Sparkfun. This component has two pads functioning as probes for the sensor. When this is exposed to moisture, this sensor will give out an analogue value accordingly, and the user can monitor this in the user's interface(GUI). This moisture sensor is located at the bottom of the ROV in order to detect any leakage as soon as possible and enable the operator to retrieve the ROV before essential electronics is damaged.

For environmental monitoring the ROV is equipped with dissolved oxygen, pressure and temperature sensors. The dissolved oxygen sensor is from Atlas Scientific, and this sensor can easily be connected to the microcontroller and can be configured to either be through serial or I^2C communication. The pressure and temperature sensors are from Bluerobotics, which are two units combined into a single component with a depth rate of 300m. It has a depth resolution of 2mm and ±1°C, and uses I^2C communication. The ROV is equipped with three thrusters from Bluerobotics, T200 thruster. These are specially designed for use ROV's, AUV's or robotic surface vessels in ocean environments. Operation voltage is 6-20VDC with a max power of 350W, and can be controlled through an electronic speed controller by pulse width modulation signals. A circuit diagram is shown in figure 4.

D. *Materials and costs*

The prototype has been built by some parts purchased for this project specifically and other parts are taken from our lab stock supply. The ROV hull is comprised of a house made of PE pipe and a bottom blind flange made of aluminium and fastened to each other with bolts across a rubber gasket to make a water proof seal. In our workshop the PE pipe has been welded (plastic welding) together at the top and the blind flange is cut out of an aluminium plate. Four legs has been welded onto the blind flange plate in order to protect the environmental sensors that protrudes through it, otherwise they would be damaged when the ROV is put down on the ground. The thrusters, electronics and sensors is purchased mostly from Bluerobotics and Sparkfun. Table II lists the main parts, their supplier and approximate cost (excluding labour and shipping costs).

With a total cost well below 1500 euros including environmental sensors it is a very affordable ROV. If needed cost reductions may be done and above prises on item costs, bulk would of course be much cheaper. In addition to labour costs comes power supply and a topside PC, but these are items one probably have available.

IV. MOTION REALISATION

The 3 thrusters is able to re-position the ROV in surge, sway and yaw. The depth/heave (Z-axis/down) the ROV

[1] 68 meter 1.75mm PLA filament

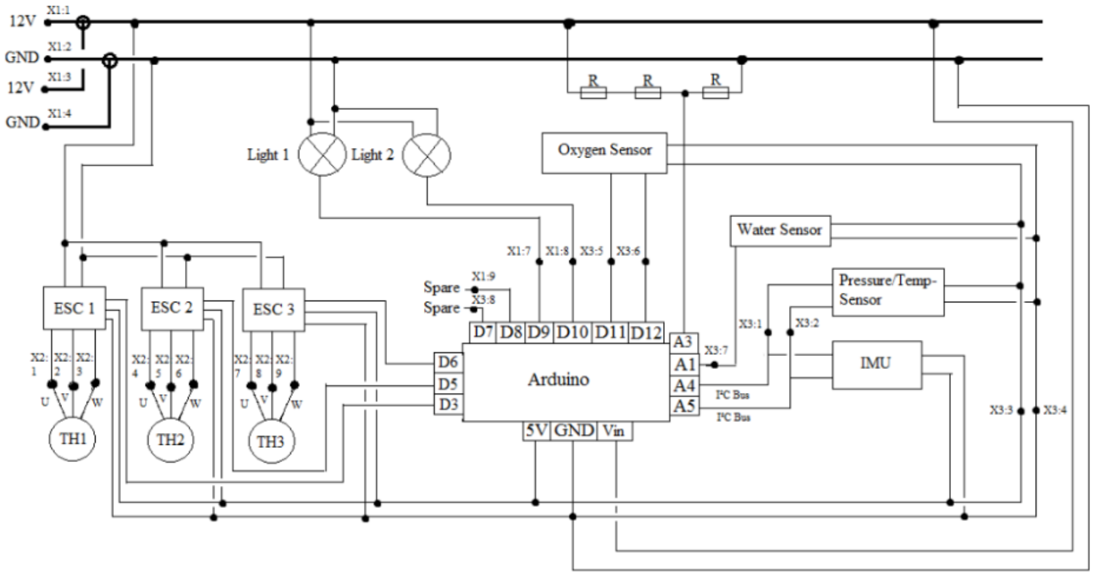


Fig. 4. ROV Circuit diagram.

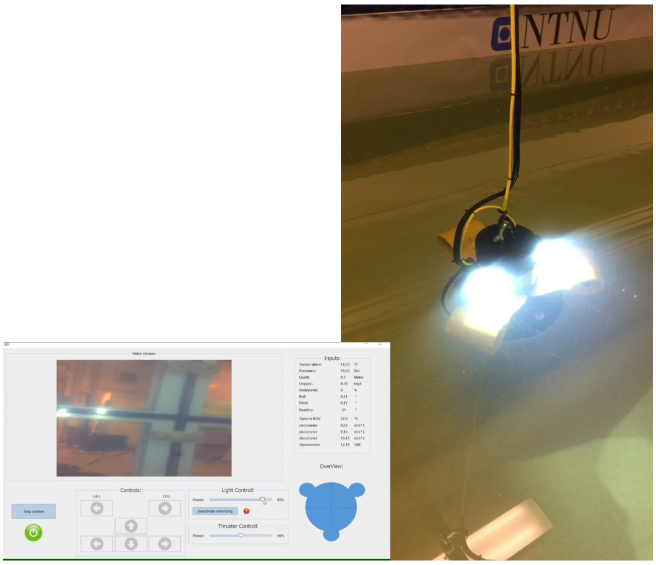


Fig. 5. ROV testing in water tank.

Item	Supplier	Pices	Cost [Euro]	Sum [Euro]
Hull	PipeLife	1	30	30
Blind flange	EA Smith	1	25	25
Thrusters	Bluerobotics	3	180	540
Thruster casing	(3D printed) [1]	3	10	30
Lights	Bluerobotics	2	90	180
Depth sensor	Bluerobotics	1	60	60
Raspberry Pi camera	Bluerobotics	1	40	40
Oxygen sensor	Sparkfun	1	200	200
Moisture sensor	Sparkfun	1	5	5
Temperature sens.	Bluerobotics	1	50	50
Tether cable	Bluerobotics	1	100	100
10-DOF IMU	Adafruit	1	25	25
Raspberry Pi 3	Sparkfun	1	40	40
Arduino Uno R3	Sparkfun	1	20	20
Misc. equip.		1	100	100
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TABLE II
PART LIST WITH APPROXIMATE PRICES.

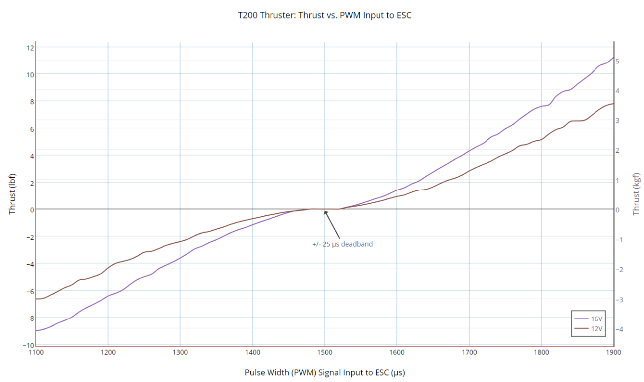

Fig. 6. T200: Thrust vs PWM [20].

operate on is determined primarily by the played-out length of the umbilical cable that hold the ROV since the ROV has negative buoyancy (see section III-B). Primarily because if the thrusters are used to move the ROV in surge or sway then heave is affected unless the played-out length is adjusted or the surface vessel moves accordingly since the ROV is hanging like a pendulum. Typically for small adjustments in surge and sway the distance to the surface will be much greater and the change in heave will be insignificant. In the following discussion we assume this to be the case.

If we assume l to be the played-out length of the ROV's umbilical and x the ROV's distance away from equilibrium then we can calculate ϕ the deviation angle away from equilibrium (vertical umbilical):

$$\sin(\phi) = \frac{x}{l}$$

From this follows that if the buoyancy is G then the force (F_e) that acts on the ROV and pulls it towards the equilibrium is:

$$F_e = G\sin(\phi)$$

$$F_e = G\frac{x}{l}$$

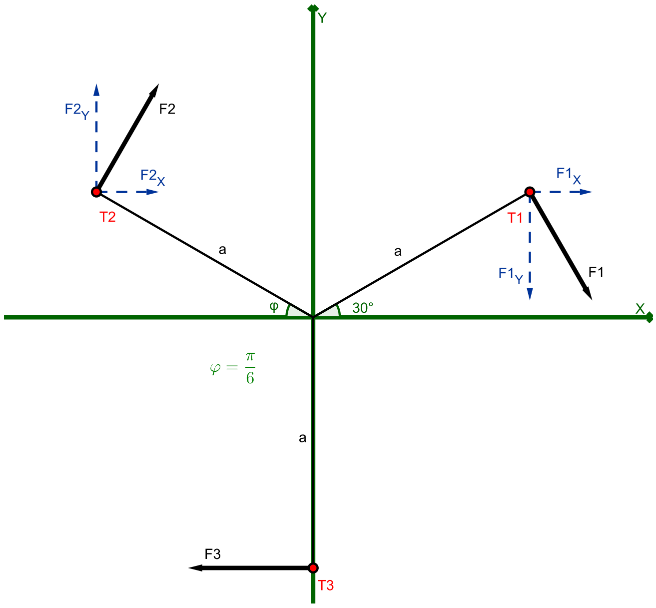

Fig. 7. Thruster forces.

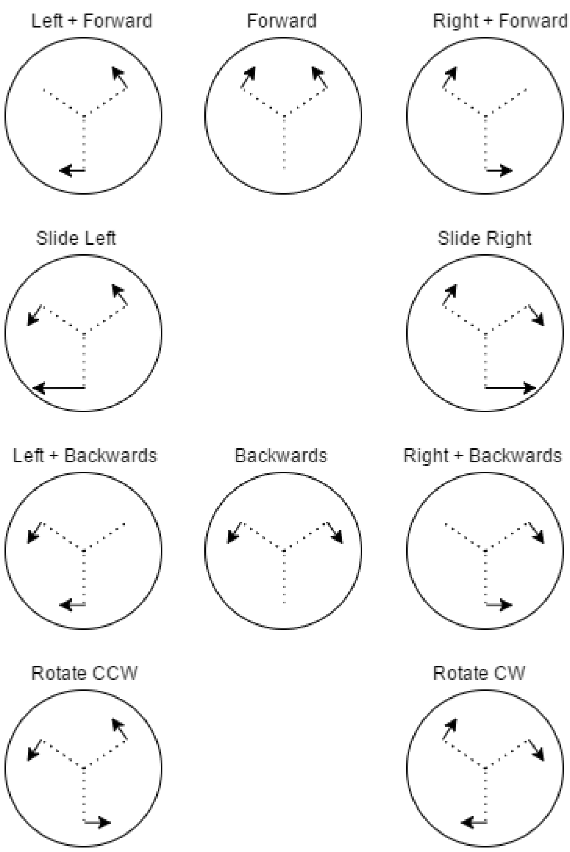

Fig. 8. Some manoeuvring and thrust scenarios.

As an example, if $x = 1$ m, $l = 10$ m and $G = 10$ N then $F_e = 1$ N.

This is a rather small force compared to maximum thruster force 40N@12V (see figure 6).

In the following we assume that $F_e = 0$.

Figure 7 shows 3 thrusters arranged around the ROV body with a distance a from mass centre (COG) and with 120 deg between them. The Y axis is defined as forward (positive surge) direction and is the centre axis of the on-board camera and the X axis is defined as orthogonal to this and origo is in the centre of the ROV. Hence, this reference system is a body-fixed reference frame [21] that rotates with the body, the ROV. For each thruster one force in clockwise (CW) direction has been defined. A force in CCW direction may be represented as a negative force in CW direction. However, it is important to be aware that the performance characteristics and constrains are different between CW and CCW (forward or backward) thrust, see figure 6. Since the propellers are fixed pitch propellers the thrust is regulated by adjusting the rotation speed (RPM) and changing polarity to give thrust in opposite direction. Hence, in the program code it is useful to split the thruster forces into two (CW and CCW) forces.

When navigating the ROV it is necessary to change surge, sway and yaw individually without affecting each other.

Resulting forces (F_r) in sway (X), surge (Y) and clockwise rotation (CW) is given by:

$$\begin{bmatrix} Fr_X \\ Fr_Y \\ Fr_{CW} \end{bmatrix} = \begin{bmatrix} \sin(\phi) & \cos(\phi) & -1 \\ -\cos(\phi) & \sin(\phi) & 0 \\ 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} F1 \\ F2 \\ F3 \end{bmatrix}$$

Hence, in the above equation the two variables that is to remain unaffected must be set to 0 and the variable we want to affect is set to whatever value is desired. Thereafter the equation has to be solved in order to find the forces $F1$, $F2$ and $F3$. However there are other constraints that has to be taken into account such as maximum thrust/output.

Figure 8 shows some possible manoeuvring and scenarios and their corresponding thrust allocation vectors.

V. Conclusions and Future Work

This paper presented a low cose ROV for aquaculture applications. The project concept, product design, and system integration are presented systematically. On-site testing in our water tank lab confirms the effectiveness and robustness of the ROV. The whole system is easy to use. In addition to scientific use it could be of interest to consider the possibility of commercialising the ROV design.

The whole project will include a movable sea farm inspection platform, the ROV and a supporting winch. This paper introduces the ROV design and its implementation. The sea farm inspection platform is under testing in parallel. Soon we will integrate the three subsystems and commence system testing.

Acknowledgement

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