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# Autonomous Flood Rescue Robot

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***Abstract:*** Rising sea levels, climate change and dependency on river basins or coastlines will increase frequency and probability of flooding in many regions of economic activity worldwide in coming decades. Existing rescue operations risks life's of rescuers and doesn't provide quick response. This paper presents the design of Autonomous Flood Rescue Robot. This is first of its kind - automated solution to search and rescue operations, which can be quickly transported hundreds of kilometers and deployed. Powered by electric powertrain this can be controlled easily and can go in up streams. The objective of this paper is to present design and develop: mechanical structure of the hull, analyze the flooding condition, powertrain and propulsion system, control systems, battery, electronics, Image recognition and AI systems. The motto behind this design is to provide cost-effective, minimal maintenance, safe operation and quick response for the rescue teams to increase their overall performance and efficiency.

***Index Terms* - Flood Rescue, Robotics, Rescue, rescue robot, flood Rescue robot, Image recognition, automated boat.**

## I. INTRODUCTION

An autonomous robot which can be deployed quickly in flood region by air or land. Equipped with Thermal and RGB imaging sensors it is capable of performing rescue operations at day and night. Using AI the location of trapped people using Image processing and heat signatures. Full fleet of such boats can be controlled from Remote ground station using Radio telemetry systems. It can carry upto 5 people and can outrun a fast stream of water. Equipped with 100m winch it is able to perform rescue in rivers and streams.

## II. MECHANICAL DESIGN

The structure of this Boat should be very compact that it can be transported quickly by cars and Helicopter. So it weighs 42 kgf and dimensions are 87 x 39.5 x 22 cm (refer **Figure 1**). Once dropped in water it will automatically raise the telescopic Sensor unit and analyses situation while inflating the main Boat as seen in **figure 1**.

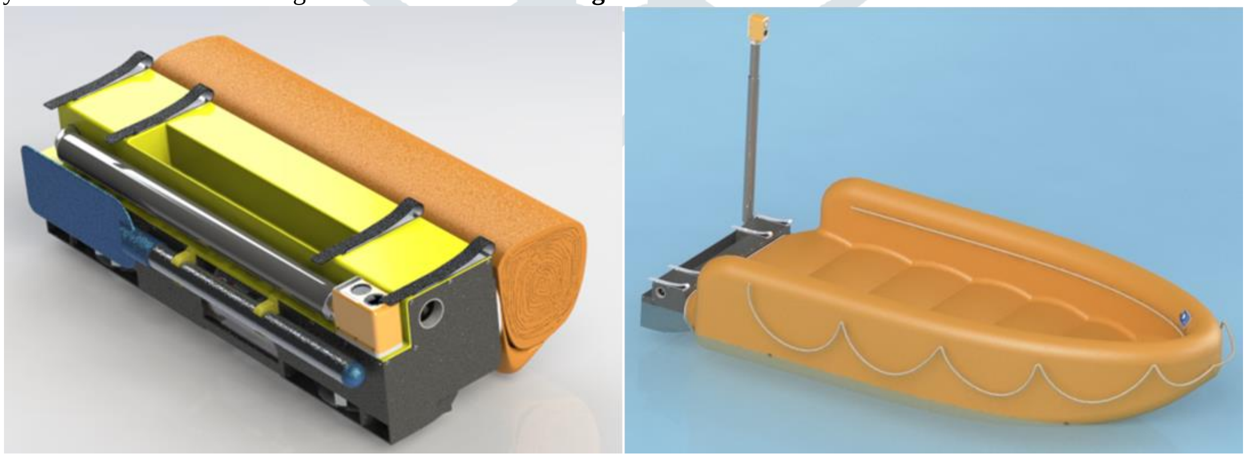


**Fig. 1**. Folded & Unfolded boat view

### 2.1 Boat hull:

The hull is constructed by using Hypalon rubber due to its anti-puncture properties. Hull is internally divided into 7 different chamber each with a non-return valve, which is a safety feature if any side or front of boat is punctured due to external environment. It is equipped with inner and outer lifeline ropes for ease in climbing boat. (Refer **figure 1**)

### 2.2 Main body:

Refer **figure 3** - On the backend of boat has a rowing shovel which can be used during equipment failure. Other than these there is a socket for modular devices on top. As well as 4x Velcro pads to attach essentials on top of boat.

Refer **figure 3** – The 2 round nets are to protect the impellers from debris in water. The Copper plate is mounted below the boat which is heat exchanger between internal components like Motors, controller and battery.

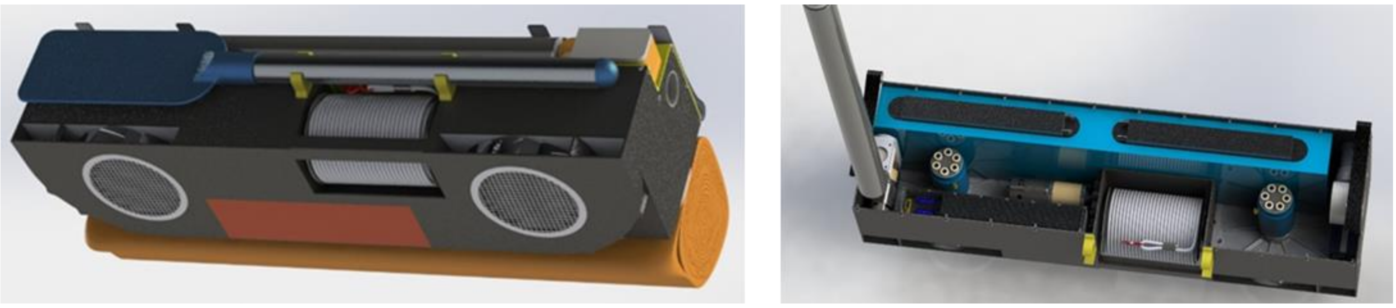


**Fig. 3**. Boat bottom-rear view & Boat Internals (right)

A 100m Steel Cable Automatic Winch is attached on back for emergency uses in streams and rivers. As we can see in **Figure 3**, integration of components inside the main body. Without displaying any wiring it has many components like actuators, motors, computer casing, controllers, cooling system and a big battery unit.

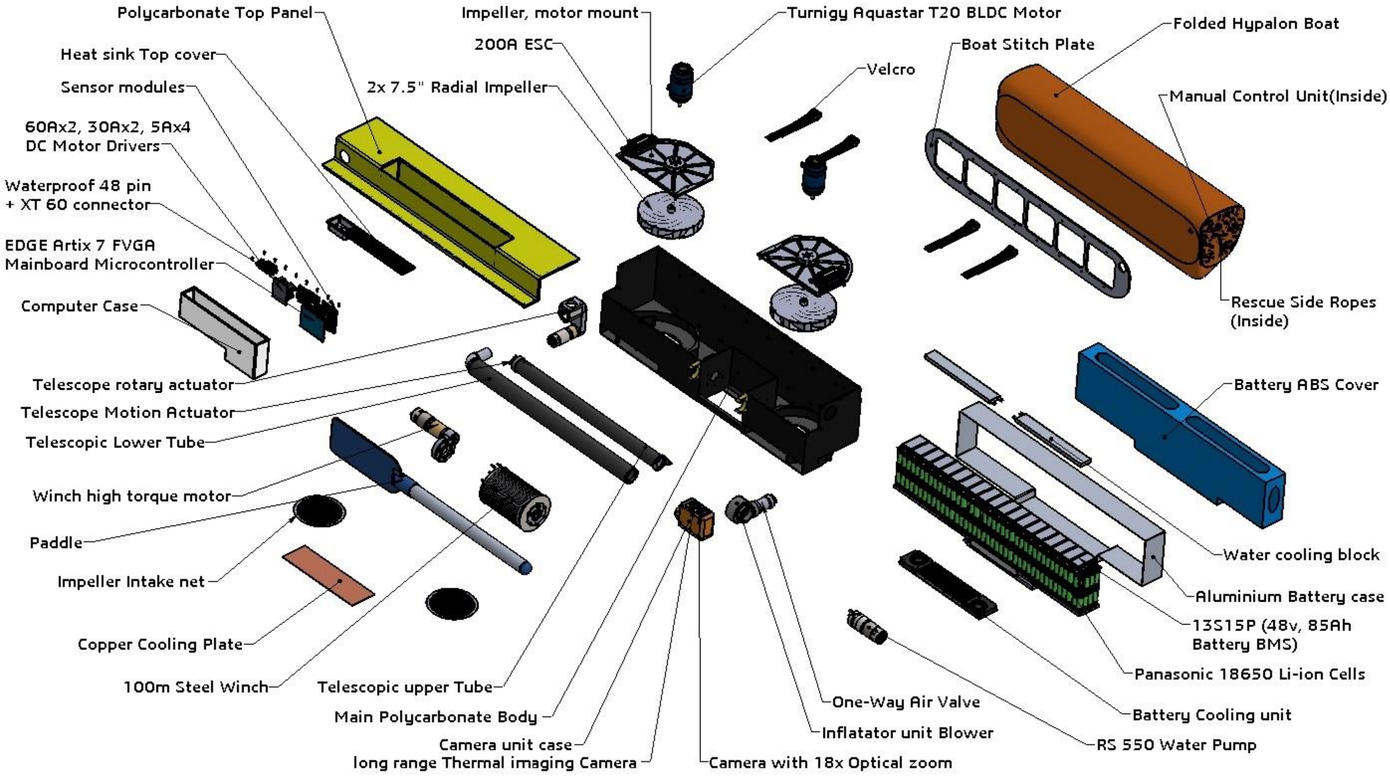



**Fig. 4**. Exploded view

**Figure 4** shows the exploded views of subassemblies:

a) Power electronics
b) Battery Unit
c) Computer Unit
d) Telescopic link
e) Sensor unit
f) Winch assembly
g) Propeller system
h) Cooling system

## III. DYNAMIC SIMULATION

The water level of the boat/raft under loaded condition can be figured by considering the maximum amount of water displaced by the boat/raft, and the maximum water displaced can be calculated by considering the buoyant force produced on the boat/raft at the maximum loading condition.

As we have the total mass of the raft under maximum capacity as 385Kg (where 45Kg – weight of equipment's and raft), For the raft float the buoyant force must , almost be equal to the weight of the object/raft, as weight of the floating object must be equal to the weight of water displaced by the object. So by equating buoyant force as (385 x 9.8) N= $F_b$

So, $\mathbf{F_b = 3773N}$, as

$F_b = \rho v g$, where, ρ- water density (997 kg/m$^3$), ν- water displaced volume & g- 9.8m/s$^2$

From above relation by inputting the density and gravitational acceleration we get the amount of water displaced as," $\mathbf{\nu \sim 0.3861\ m^3}$. ", so for the floating, the raft must displace a volume of 0.3861m$^3$

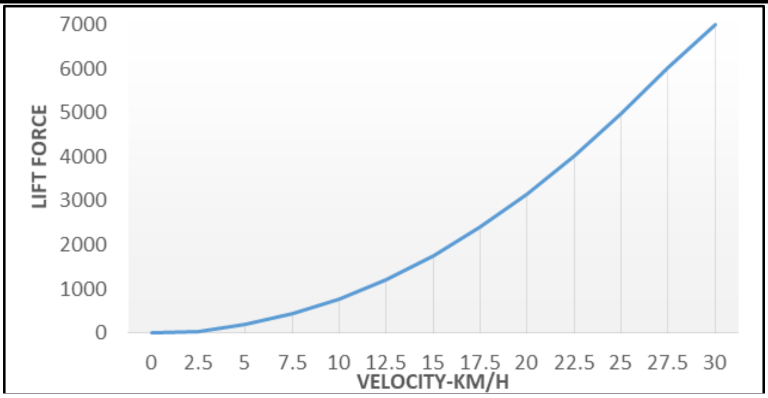



**Fig. 5.** Lift force – Velocity chart

**Flow Simulation of the raft profile:**

From the above calculations, the water level of the raft can be identified, by which we could perform the flow simulation of the raft , the simulation was performed in Ansys-Workbench by using Ansys-Fluent Analysis system. The simulation was done in steady state , The model used in the flow simulation was "K-Omega" turbulence model as this model is better for predicting flow near the boundary , the type k-Omega model used was "k-Omega SST" ( shear stress transport) which helps in a better prediction and approximation of flow separation than the other Reynolds-averaged Navier-Stokes (RANS) family **[1].**

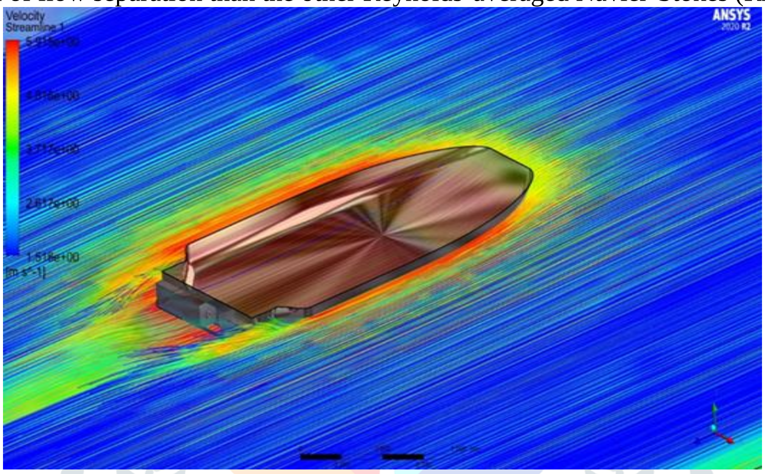



**Fig. 6.** Raft flow simulation

From the above analysis, we are able to calculate the lift and drag, produced on the lower –profile of the raft at different speeds, The Lift and Drag Force acting on the raft is plotted in (**Figure** 7), from which we can see both increases exponentially with speed.

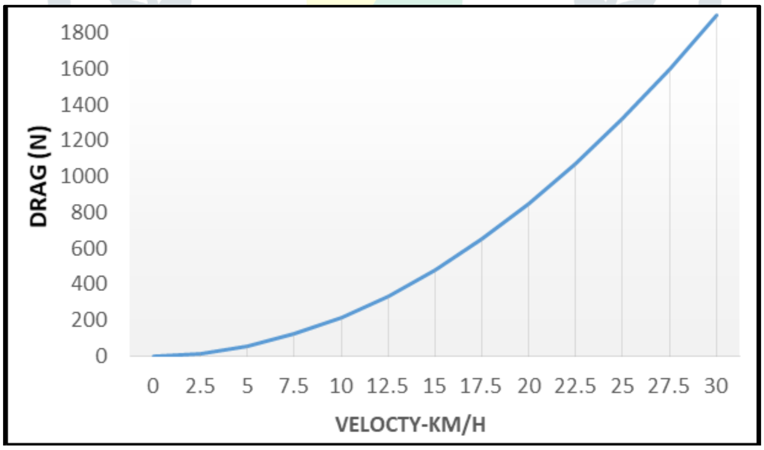



**Fig. 7.** Drag force – Velocity chart

### IV. Finite Element Analysis

Electric Winch was used for the given design, the selected motor has rating of "0.15Kw ", a reduction ratio used was of "2.25". Considering the maximum tension developed on the winch cable as 500N (pulling the boat at roughly 15Km/h through water) , the following static structural analysis was done, Static structural analysis was done in Ansys workbench and it was found that the design satisfies the load requirements as shown below:

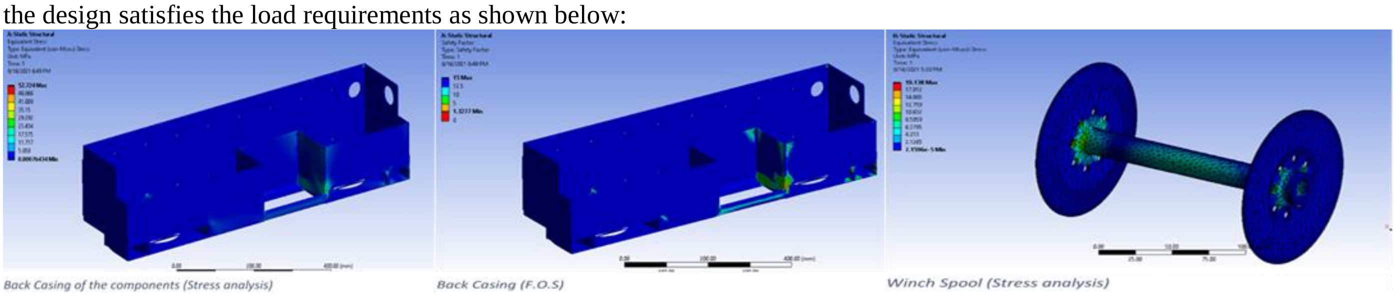
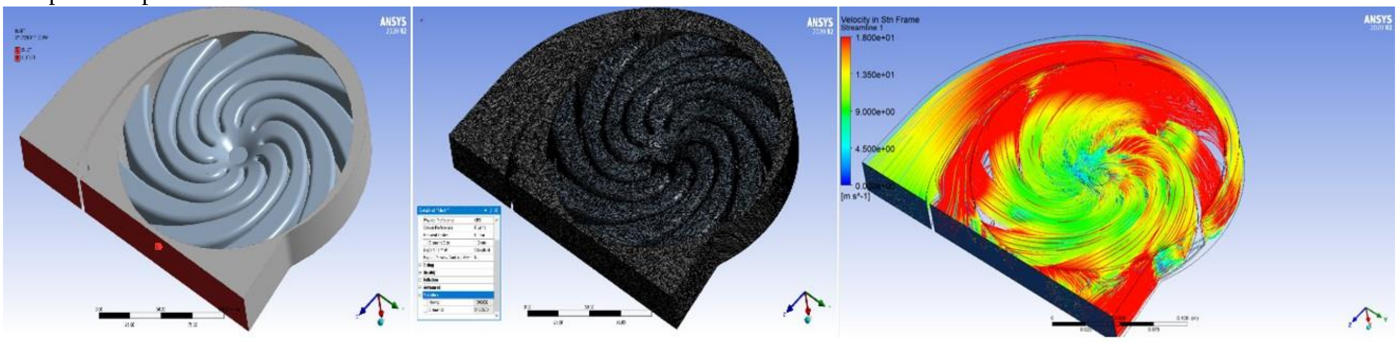



Fig. 8. Structural simulation results

The material used for the back casing was Polycarbonate and for Winch Spool was Mild-Steel. The winch cable used are steel cables of 6mm Diameter

## V. Thrust Unit Validation

For providing thrust custom made impellor was used, the impellor was designed by making use of the centrifugal principle, for the impellor transient simulation [by mesh motion] was considered, we had used the "K-Epsilon" –"RNG" Model with scalable wall function for the simulation as it is the most commonly used model for flow simulation in case of turbulent flow conditions [2]. We have used the "PISO" (The Pressure-Implicit with Splitting of Operators) rather than the "COUPLED" because of the limited computation power.



*Impellor Fluid Domain CAD* *Impellor Fluid Domain Mesh* *Flow Simulation of Impellor @3500rpm*

**Fig. 9.** Impeller flow simulation results

It was found that **@3500 rpm** from flow analysis:
Mass-flow rate (**M**) at the outlet was **82Kg/s** and
Exist velocity - (**$V_o$**) was approximately **-12m/s**
By considering the max free-flow velocity ($V_f$) of water as 5.88 m/s, we could calculate the thrust force as:
$F = ma = M (V_o - V_f) \sim$ **501.8 N**
The thrust force required for the boat to move at 21Km/h is around **937 N**, as we have approximately 501 N of thrust per impellor, so for the two impellor's present, the total thrust will be "**1002N**" which clears our requirement
At 3500 rpm the torque requirement obtained from the flow simulation was 13.4Nm, which give us a power requirement of approximately "**6.6Hp**" or "**4.91Kw**".

## VI. Power Electronics

BLDC motors and an Electronic Speed controller are major components of power electronics.

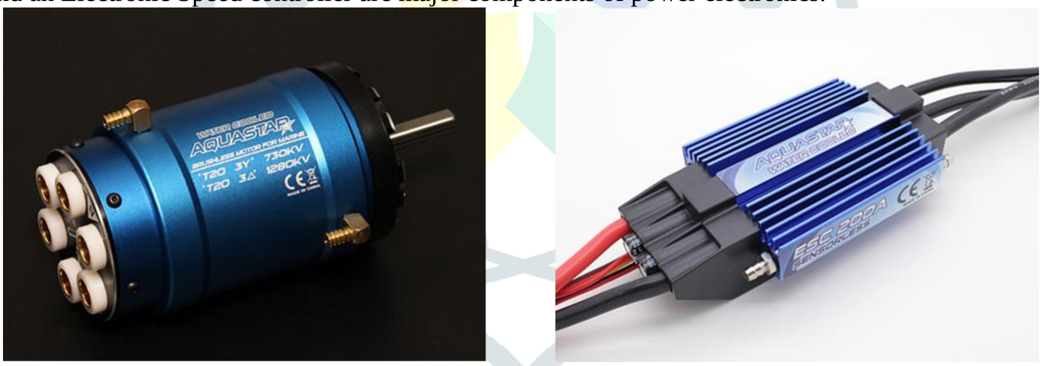


**Fig. 10.** Turnigy T20 Aquastar BLDC motor (left) & Turnigy Aquastar 200A controller (right)

### 6.1 Motor Controller:

Motor Type: Brushless, sensorless motor only
Input Voltage: 22-45V
Operation Current: 200A Continuous / 250A peak
Thermal Protection: 95°C
Weight: 290g
Reverse Type: forward only, forward / reverse
Reverse Amount: 25%, 50%, 75%, and 100%
Starting Power: Low, normal, high
Motor Timing: Low / normal / high

This controller is Programmable and is compatible with the motor. It is also water cooled so that it doesn't creates heat inside main body.

### 6.2 Motor:

#### 6.2.1 Features:

- Dual Configuration for 730KV / 1280KV Operation
- Powerful Sintered Neodymium Magnet
- Water Cooling Jacket Pre-installed

#### 6.2.2 Specifications:

RPM/v: 730kv @ "Y" configuration / 1280kv @ "Δ" config.
Max voltage: 41V
Max Current: 128A @ "Y" 730kv / 229A @ "Δ" 1280kv
Max Power: 5280w
Resistance: 0.0132ohm@"Y"730kv / 0.0046@"Δ"1280kv
No Load Current: 3.2A @ "Y" 730kv / 4.2 @ "Δ"1280kv
Can Diameter including Water Jacket: 63mm
Length: 102mm
Shaft Size: 8mm
Weight: 971g

#### 6.2.3 Motor Characteristics:

(From **Figure 11**) We can conclude that this motor has very high torque i.e. 5.99 N.m for short duration for 10 seconds maximum. But for long term/continuous operations Turnigy T20 Aquastar can sustain 2.68 N.m upto 18000 rpm after which Torque declines steadily with speed. Power consumption is electronically limited at 5.28 kW due to efficiency and reliability concerns.

The optimal efficiency range (0.82-0.89) lies between 16000-28000 rpm, and propeller requires speed of 3500rpm. Hence motor is paired with 7:1 planetary gearbox. Refer **Figure 12** for torque and speed with gearbox.

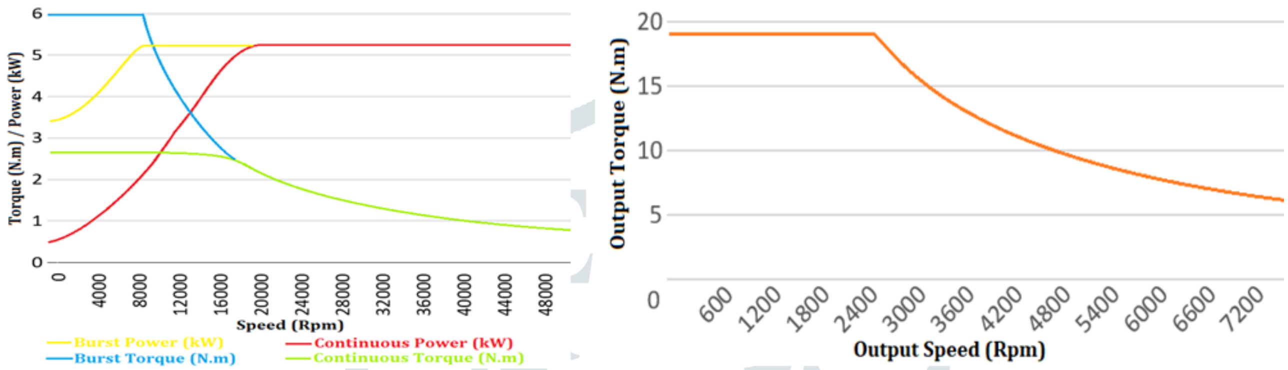



**Fig. 11.** Motor performance curves (left) & Torque vs. Speed with gearbox (right)

## VII. Lithium-Ion Battery

Battery is internally separated into 3 chambers for better internal airflow. Top panel of battery mounts BMS inside and 2x water cooling jackets outside. Internally at bottom of battery, there are 2 centrifugal fans pumping air through heat sink and are responsible for air circulation inside battery. The heat sink is connected to main water jacket outside which cools the whole power electronics of boat. (Refer **Figure 12**)

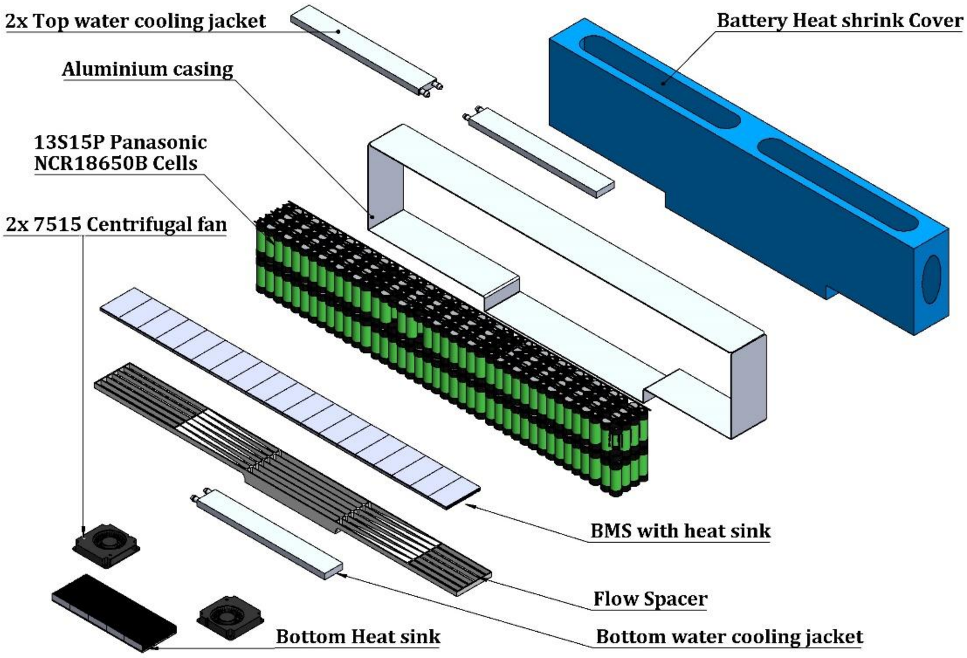



**Fig. 12.** Battery exploded view

## VIII. Electronics

### 8.1 List of major parts:

1. Raspberry pi 4 (4gb RAM)
2. RGB and thermal Cameras
3. Micro SD card (32gb)
4. Micro SD card adapter
5. Micro HDMI cable

6. Wi-Fi module

Pi is a credit card sized computer and consumes very less power which makes it ideal for our project to save space while efficiently transmitting data.

**8.2 Assembly of parts:**

1. Pi camera stream: The whole setup is put inside sensor unit.
2. Theoretical working: we are capturing live footage from the raspberry pi builds as a video streaming server and using Raspberry Pi receiver setup at the base station to receive the video.
3. Installing the Pi OS: firstly we load the code (OS) onto the SD card which is then inserted into the micro SD card slot of the raspberry pi. With help of the IP address of the Pi we can access the video stream.
4. Library dependencies, git repo etc. in coding
5. Latency depends on internet connection and coverage.

This section will elaborate on the microcontroller and components used for designing the proposed system. Starting with the most important element of the design which controls the entire system is the PIC microcontroller, here a PIC18F series high performance 8-Bit A/D microcontroller can be taken into consideration. The system will also consist of a Raspberry Pi module which will be utilized for the transmission and reception of video data.

**8.3 Working of the components:**

1. Waterproof Temperature sensor: DS18B20
   The communication of this sensor can be done through a one-wire bus Protocol which uses one data line to communicate with an inner microprocessor. Moreover, this sensor gets the power supply directly from the data line so that the need for an external power supply can be eliminated.
2. Accelerometer: DMU11
   6-Axis Accelerometer & Gyroscope is a cost-effective Grove sensor. It is provided with a detailed SDK, which makes the prototyping process quick and easy.
3. LED strip: 5050 LED’s 6500K
   Paired with long range reflectors, it is used for visibility during night and dark environments.
4. Servo motor: MG90S - Used to control movements of telescopic actuators and sensor unit.
5. Motor driver: MDD10A - To power motors used for inflation pump, water pump, winch and telescopic unit
6. GPS module: NEO-6M
   With 4 or more satellites connected, the receiver can determine 3-D position of robot (latitude, longitude and altitude). Once the position is determined, the GPS unit calculates other information, such as:
   - Speed
   - Bearing
   - Track
   - Trip distance
   - Distance to destination

**8.4 Telescopic Sensor Unit**

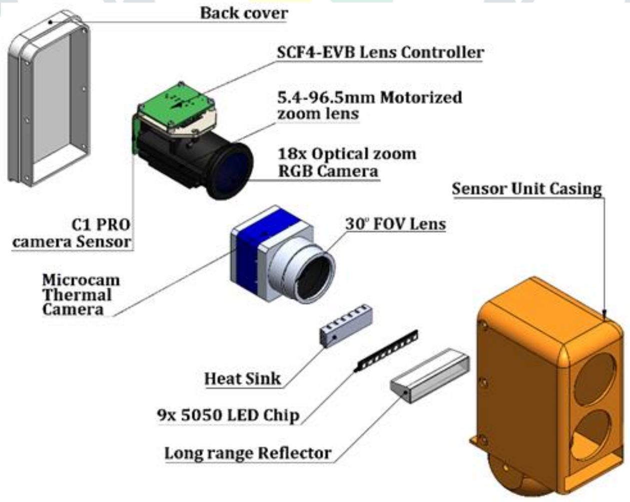



**Fig. 13.** Exploded view to sensor unit

The Sensor unit is mounted on Telescopic tubes (**Figure 13**) for higher Point of View and easy actuation for directions. This casing has 6 DoF which lets us use full potential of camera system for rescue operations.

**8.4.1 Cameras:**

1] RGB camera

C1 Pro imaging sensor with 5.4-96.5mm zoom lens enables us to capture photos/videos at 18x optical zoom.
Resolution: 1920 (H) x 1080 (V)
Frames / Sec: 30
Refer (**figure 13**) for more details of camera build

2] Thermal camera

For night scenarios, we are using a thermal camera to sense heat signatures of trapped people in flooded regions. So we are using MicroCAM 3 low power thermal imaging sensor in a custom camera frame and paired with a 30° FOV lens. It has resolution of 640 x 480 pixels.

## IX. Image Detection

The Objective is to detect objects using You Only Look Once (YOLO) approach **[3]**.

In other algorithms like Convolutional Neural Network, Fast Convolutional Neural Network the algorithm will not look at the image completely but in YOLO the algorithm looks the image completely by predicting the bounding boxes using convolutional network and the class probabilities for these boxes and detects the image faster as compared to other algorithms.

YOLO algorithm is fast as compared to other classification algorithms. In real time our algorithm process 45 frames per second. YOLO algorithm makes localization errors but predicts less false positives in the background.

### 9.1 Bounding box predictions:

YOLO algorithm is used for predicting the accurate bounding boxes from the image. The image divides into S x S grids by predicting the bounding boxes for each grid and class probabilities **[5]**.

Then the algorithm checks each grid separately and marks the label which has an object in it and also marks its bounding boxes. The labels of the gird without object are marked as zero.

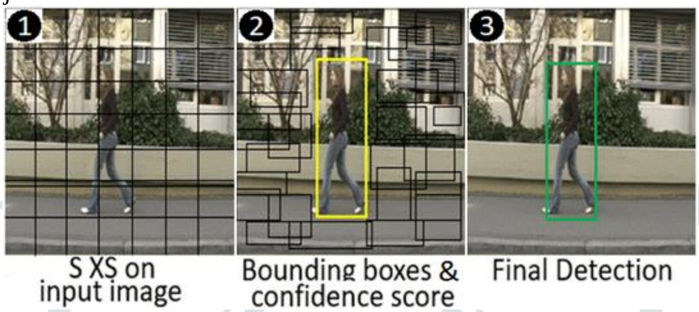



Fig. 14. Bounding box prediction

Consider the above example, an image is taken and it is divided in the form of many matrixes. Each grid is labelled and each grid undergoes both image classification and objects localization techniques. The label is considered as Y. Y consists of 8 values.

#### 9.1.1 Elements of Label Y

| | |
|---|---|
| y = | pc |
| | bx |
| | by |
| | bh |
| | bw |
| | c1 |
| | c2 |
| | c3 |

pc – Represents whether an object is present in the grid or not. If present pc=1 else 0.

bx, by, bh, bw – are the bounding boxes of the objects (if present). c1, c2, c3 – are the classes.

1 represents the presence of an object. And the object in that grid is a human so the classes are (1, 0, 0).

The matrix form of Y in this is Y=3x3x8.

If the object is a car then c1 and c3 will be 0 and c2 will be 1.

We will use YOLO algorithm to detect objects in our images by training our model with COCO (Common Objects in Context) dataset and with a few modifications.

#### 9.1.2 Anchor Box:

By using Bounding boxes for object detection, only one object can be identified by a grid. So, for detecting more than one object we go for Anchor box. Anchor box works according to the **Figure 15**.

Considering (**Figure 15**) in that both the human and the car's midpoint come under the same grid cell. The red color grid cells are the two anchor boxes for those objects. Any number of anchor boxes can be used for a single image to detect multiple objects. In our case, we have taken two anchor boxes.

The value of the class in anchor box 1 is (1, 0, 0) because the detected object is a human.

In the case of anchor box 2, the detected object is a car so the class value is (0, 1, 0).

In this case, the matrix form of Y will be Y= 3x3x16 or Y= 3x3x2x8. Because of two anchor box, it is 2x8.

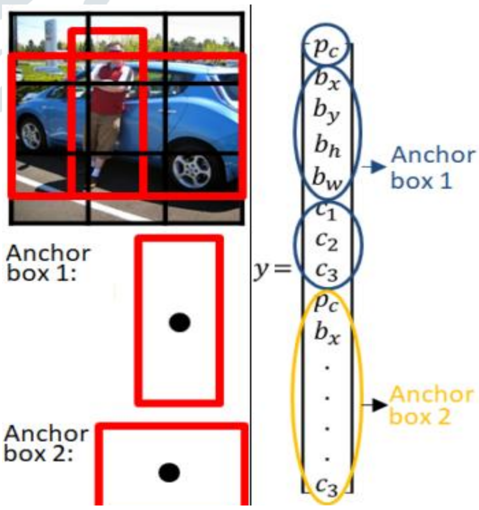



**Fig. 15**. Anchor box

#### 9.1.2.1 Test:


**Fig. 16.** Input image (left) & Output image (right)

Using anchor box we are able to detect multiple objects correctly even if they are overlapping as tested in (**Figure 16**.)

### 9.2 Thermal Cameras:

To further add some improvements we have used Thermal cameras to detect heat signatures of humans. In some cases with image classification some miss predictions can take place which are unavoidable, also mainly for night vision we need thermal camera setup. In that case other techniques like thermal cameras can be implemented to help our model. As living beings emit infrared radiations. A thermal imaging camera can detect this infrared-emitting objects .As shown in the below figure:

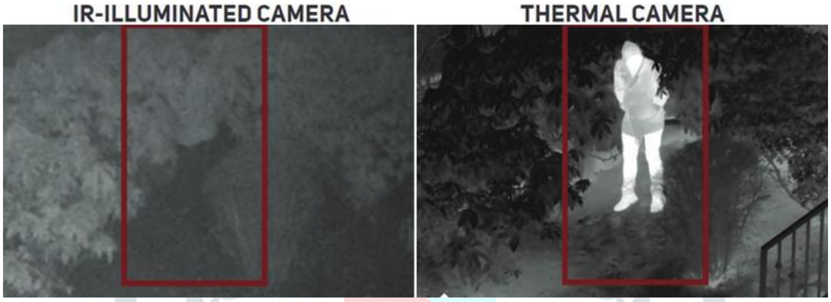



**Fig. 17**. IR and MicroCAM 3 thermal camera – night photo

### 9.3 Pixel Binning Technique:

We are using the technique of pixel binning at night which will improve the efficiency of an image by brightening it. The term 'pixel binning' means taking a group of four adjacent 'pixels' (arranged in a 2 x 2 quad) on a camera's image sensor and treating them as one big 'super' pixel **[4]**. So a camera sensor with tiny 3 micron pixels will produce results equivalent to 12 micron pixels when taking a pixel-binned shot. 12 MP camera will be converted to 3 MP as it is capturing in the dark. This will trap 4 times more light compared to normal sensors. After capturing with pixel binning we will get bright images.
The image below shows the effect of using pixel binning. The image brightens immediately and it is easy to detect objects.

#### 9.3.1 Test:

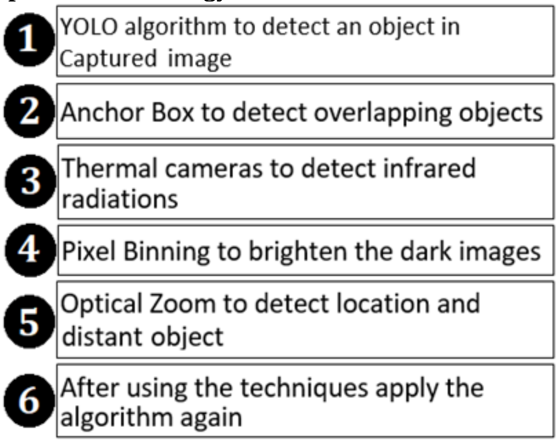
**Fig. 18.** Dark environment (left), Pixel binning result (center) and object detection (right)

In **Figure 18**. the center image is the result after applying pixel binning. Right image is the result of prediction after applying YOLO algorithm.

### 9.4 Optical Zoom:

If the camera detects high contrast or any distant object in the image captured, in that case Optical Zooming will be applied. For first time - image without zoom will be captured. If the camera detects any object at a distant location then the camera will zoom in by 6X then the same YOLO algorithm will be applied again to detect the object. If more zooming is required then 18X zoom in will be applied with same algorithm. In this way the location of the object along with identification of object can be implemented.
In the first example given below the location of the object is far away. However, using optical zoom we are able to zoom in to the location of the object and apply our algorithm.

#### 9.4.1 Proposed Methodology:




#### 9.4.2 Results Obtained:

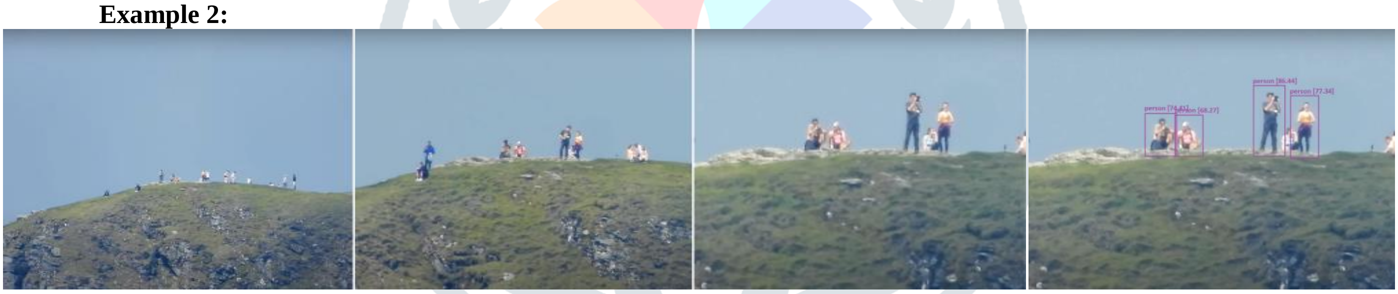
Following are few test images.

**Example 1:**


Zoom level: 1x 6x 18x Object detection using YOLO algorithm

**Fig. 19.** Optical zoom camera samples and results (right)

**Example 2:**



Zoom level: 1x 6x 18x Object detection using YOLO algorithm

**Fig. 20.** Optical zoom camera samples 1 and results (right)

AI will also detect the difference in contrast between the object and the background. In this way images are zoomed in at appropriate locations. Algorithm is also able to give results in case of blurred images which is important as our camera sensors might not be stable enough to take clear images in the situation of flood.

## X. Results and Conclusion

This Robot design is intended to fulfil requirement and tasks in rescue operations as it provides automation and mobility over old rescue operation technologies. This robot has many slots for several different types of attachments. This automated boats can work effectively during grid operations when connected with ground stations. A successful attempt in image recognition by using YOLO algorithm along with techniques like pixel binning, thermal imaging and optical zooming for object detection. This design can easily be transported using mini cars or helicopters and deployed automatically. It can be controlled from remote ground station or using its own AI system under ideal circumstances. Countries or regions at less elevation, coastline, unstable tectonics, valleys, river basins and deltas should maintain a fleet of these autonomous rescue robots at rescue in future.

Battery backup is less which can be increased by breakthrough inventions in energy storage solutions or simply by increasing size and capacity of main structure. Still there are many limitations to autonomous driving of boat in extreme flood conditions. Thermal camera setup can be improved, a UAV/drone surveillance systems can be integrated with swarm of these boats in future. Gas/diesel powered power units can be used in certain regions.

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