Catamaran Robot "Polaris -I" for Maritime RobotX Challenge 2014

Team: OUXT-Polaris (Osaka-Japan)

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1. Abstract

The Catamaran robot Polaris I designed by Osaka university team is on the purpose of achievement of AUVSI Foundation ROBOTX competition (Fig 1). The first competition of "Maritime RobotX Challenge" is going to be held in Singapore 2014. Our activity has started from making motor system, composed by couple of motors, motor drivers and 12V batteries. Then various sensors are prepared and tested on the sea twice a month. Apart from that two Laser-Range-Finders, one satellite compass, four microphones, one omnidirectional camera and one web camera are selected as sensors. Satellite compass detect its own position. Laser-Range-Finders detect obstacles. These two is fundamental equipment to know its own position and obstacle position. Omnidirectional camera checks the colors, shape and size to recognize whether they are buoys, marks or not. Web camera analyze color of LED light buoy and recognize the order of colors, this is different algorithm from omnidirectional camera's one. Microphones are used to search under water sound. Difference of loudness or time of obtaining sound leads the position. These programs are controlled by two note computers with the help of C++ program. Obtained task data is saved on board computers and send to directors through Wi-Fi network. One kill switch with power indicator on the board and one remote kill switch prevent runaway by cutting off the power supply to motors.

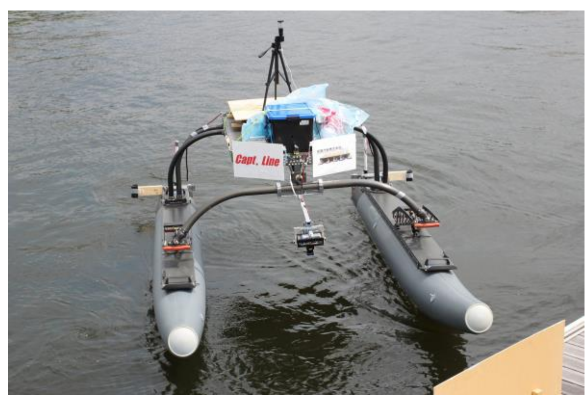

Fig. 1: OUXT-Polaris designed "Polaris -I"

2. Introduction

Nowadays ships, aircrafts and AUV's are autonomously guided and navigated but furthermore intelligent decision making capacities should be incorporated in order to improve autonomous ocean navigational facilities. In future it is required to more emphasize on this kind of research activities to realize autonomous maneuvering of ships or marine robots. It may highlight many more areas of course tragic accidents can be decreased. In our lab, Ahmed *et al.* (Nov., 2013) studied autonomous berthing by using Neural Network[1], and some successful experiments using ship scale down model in Osaka University pond was conducted[2]. We have gone through with many good control theorems [3].

The cost of ship and variety of elements of engineering techniques seems to make it difficult to research or do experiments. Now Catamaran boat called “WAM-V” is provided by organizers and all tasks are described well. Ultimate goal is to contribute for future research by developing an autonomously maneuver ships and marine robots and of course to win this competition successfully. At this first competition, we selected simple way and simple algorithms in order to keep fix deadlines and to learn what we need for future challenge.

3. Technical Approach

3.1 Mechanical and Electronic Systems

In this section mechanical and electronics systems on the boat is described. First in order to run the boat, we use a couple of motors, motor drivers, 12V batteries. Second, in order to find buoys and wall, we use two Laser-Range-Finders, one omnidirectional camera, and one USB Web-camera. Third, we use four microphones to detect under water sound, and one satellite compass to get location information. Another 12V battery supply electric power for those sensors. And they are controlled one note PC through Ethernet or USB. Summarized information can be send to directors through antenna with Wi-Fi. This antenna can communicate about 200m while keeping Singapore and Japanese radio law.

3.2 Technical Description of the Boat

First challenge is to make original motor drivers, fixtures to attach motors and knowing the behavior of the boat. We prepared 55 lbs electric hand control motors which are used for mini boat which weight is about 200kg - 250kg to fishing in general. It is attached behind the boat, and power and direction can be change by hand. We made motor drivers to match the time when our boat arrives and to do experiment as soon as possible. This idea is right, since our motor drivers burned twice. First we don’t know why, second time we find the reason by feeling burning smell. It works well on the ground. But there is strong resistance in the sea and electric current are there as we expected. We decided to make robust motor drivers as not break if 100A current flow. After 2 month from 2nd experiment, it is completed. While making motor drivers we made fixtures to attach motors behind of the hull by aluminum flame fixtures as shown in fig. 2. These fixtures are installed as it strongly holds the metal flame of the hull; it can't be detached easily. The wooden frame is used to avoid the slipping of the motors. After that we made connection between motor and motor driver, the motor drivers control the motor power according to the command from PC through Ethernet. This system can change motors power 511 level. Max 55 lbs. to 0 (No power) are separated to 256 level, and inverse rotation is separated to 255 level until -55 lbs. We can change its power freely by game controller, directly inputting value, pushing shortcut order as stop or turning. (Fig. 3)

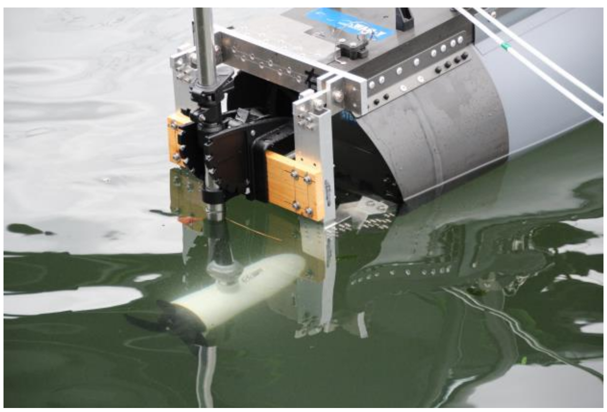

Fig. 2: motor and fixture

Fig. 3: motor control through PC

At experiment, we controlled the motor by controller and check the movement of the boat. It went straight about 1.33m/s when both motor's output is full power. Speed of back space was almost 1.28m/s in full power because of the effect the resistance of fixtures and it also turned in a circular motion by changing the output of each motor, instead of general ships change with the help of rudder. The boat has one very important and unusual movement, it can turn at that point by outputting one motor go ahead and another reverse. This movement seems to make it possible to run as a tank though there is also a weak point. This boat is easily flowed by wave. We conducted this experiment at Kobe University experiment pond which is also surrounded by the land as Singapore Marina bay. Side slipping of the boat was very difficult to control. As one idea to solve this problem, we thought to put four motors as omnidirectional robots as Pliveira *et al.* (May, 2008) studied [4]. The idea is to put four motors; each hull has two motors at front and back, facing the tangential direction to the center of gravity. By adjusting the output of four motors, we can control the boat in multiple directions. For example, two motors on the same hull outputs to same direction; it can move side-way. If we can install this theory, side slipping can be reduced. We prepared four motors and motor drivers but we can't adjust programs to control the boat by four motors due to the shortage of time. As the relic of this idea, we experienced in the condition that two motors facing tangential direction (Fig. 4) which makes the speed of turning very fast, at the expense of the speed to go ahead and back. The increase of the turning speed is useful in strong wave condition or when we need precise movement. We will decide whether to use the direction or not by watching the sea and field condition at the venue.

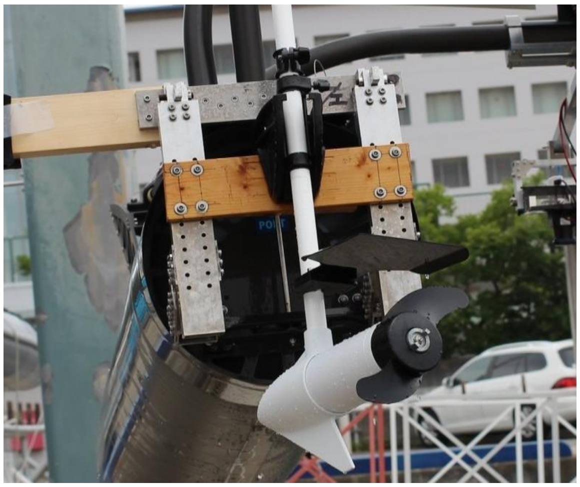

Fig. 4: a motor facing tangential direction to the center of gravity

3.3 Self-location and Control

The SC-30 Satellite Compass provides highly accurate attitude information to our PC through CAN bus. It provides GPS position in 3m accuracy and heading position in 0.1 degree accuracy for each one second. This satellite compass correct by using two antennas installed in it. We use this position information for communicating about the tasks, to know the position of ships and to predict the position of buoys. We did autonomous maneuvering experiment by using this. We installed it on the board straightly as shown Fig. 4. First, point a GPS position latitude and longitude. Next, move away the boat and change direction randomly by remote control. Then start the program and check whether it will go to the point correctly. The experiment succeeds. This autonomous maneuvering is working in simple algorithm as represented by Flow chart of the algorithm in fig. 6. This is the basic algorithm of autonomous maneuvering for almost all tasks.

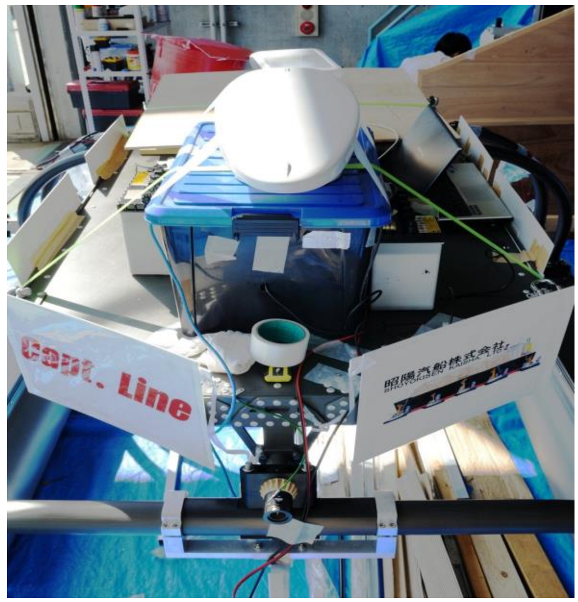

Fig. 5: SC-30 installed on the board

At first, decision of the goal point is important, it may be berthing point, space between GATES buoys or side of buoys to avoid obstacles. GPS point or relative position from the target will be selected and decide how distance it needs to close. After that checked the heading to evaluate how angle differ from direction. If it is bigger than +- 5 degrees, turn at that point and change direction. If the difference between heading and direction becomes less than 5 degrees, it will go ahead adjusting its heading.

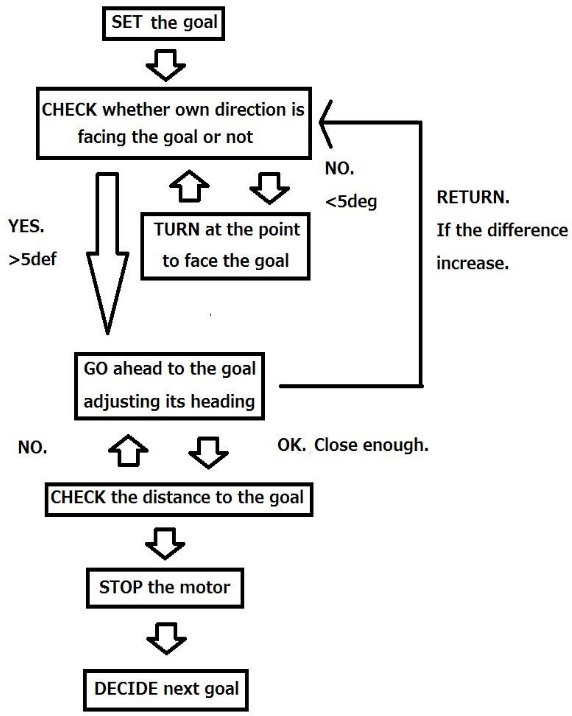

Fig. 6: algorithm of autonomous maneuvering

When the difference becomes bigger it tries to adjust and stop to go ahead. When the goal becomes closer than decided distance it tries to stop and adjust additional terms if needed. For example, it checks not to hit the buoys or float. At last search next target and go to first.

3.4 Target Detecting

For detecting buoys, float and marks, we are mainly using these two equipment as a sensor.

- Laser-Range-Finder (UTM-30LX-EW)
- Omnidirectional Camera (VS-C450U-200-TK)

Laser-Range-Finder, UTM-30LX-EX (Fig. 7) is presented from HOKUYO. This will scan semicircular area of horizontal plane, 30m radius and 270 degrees; by laser beam (λ is 905nm). Its step angle is 0.25 degrees. Then, it can analyze the distance and angle to targets. Each scan can be done in 25ms. In our research, it can work when the target or anybody is moving smoothly. It does not recognized water as an object, as long as it is become dirty or shallow. This will also be useful in the sea condition. But we found that pitch of the boat shake about 2.5 degrees in a strong wave condition. Its height can change 1.3m at 30m distance. So we prepared a stabilizer to keep it parallel to the sea surface. This stabilizer is installed on the front arch and its height can be changed easily by tools as needed. This main Laser-Range-Finder will be used to find GATE buoys, wall, A-7 and A-5 buoys. About float, A-2 and A-3 buoys, they are very small to find by searching horizontal line. If we fit the height to find them, there is high risk to the equipment get wet by sea water. In order to detect small buoys, we thought to shake the stabilizer up and down. Then Laser-Range Finder will search not only horizontal direction but also height direction as 3D scan system. In this competition, in order to overcome the problem we made a ramp stand by 3D printer (Fig. 8). It will be installed the front of the board. This allows us to find obstacles which enter adjusted radius.

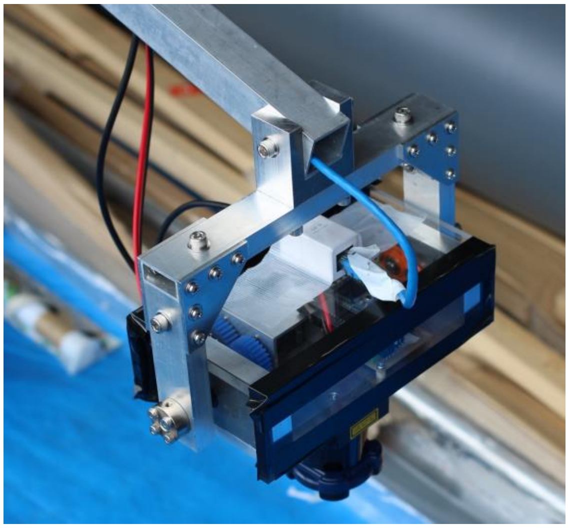

Fig. 7: Laser-Range-Finder and stabilizer

Fig. 8: ramp stand for Laser-Range-Finder

Omnidirectional camera (VS-C450U-200-TK) has 1600 X 1200 resolutions and a bipolar surface mirror on upper side, so it can overlook all the directions. (Fig. 9) They are used to detect targets. When detecting buoys, the algorithm is Flow chart of the algorithm (Fig. 10). Laser-Range-Finder is used for detecting any object and to calculate its direction.

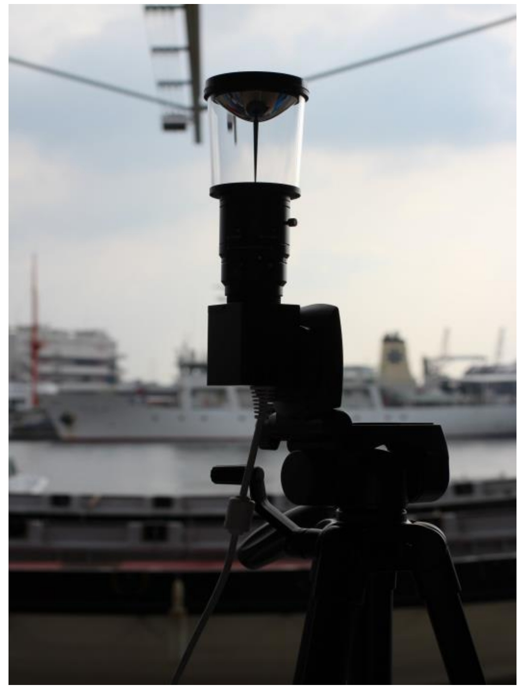

Fig. 9: omnidirectional camera

Omnidirectional camera is used to scan the color around there. After colors are extracted, labeling processes is done. Basic theory for image processing is used [5]. First it checks its color whether it is used color or not in the task. Next, check its shape to judge it is really buoy. If it is different shape from buoy, then it is ignored. At Last, check its size, if it is too small, it may scrap or any reflection. If it is too big, it may be fishing boat or something. Fig. 11 shows the example of detecting red buoy by this program. First picture is original picture taken by omnidirectional camera. Second picture is filtered by colors. Third picture is filtered edge program. This can be used to check shape. Last picture is checking size of detected things. This standard of labeling process is necessary to adjust by time, weather and place at the venue. In our experiment, brightness of the sky affects the color the camera is taken into account (For example shiny day, In Fig. 11 reflection of sunlight is recognized green buoy by mistake.) Also, sometimes there are many reflections or scrap on the sea. After getting the information of buoys color, next it plans what it needs to do for each task. At task 1, setting the route which will through the GATE buoys, at task2 it needs to calculate the distance and guess the target buoy position, at task 4 it needs to close to observe LED buoys. More detailed information about task 4 is described in next section. For task 5, it needs to select right GATE by comparing colors of two buoys. Some colors like white are very difficult to find because of low pixel of omnidirectional camera. If we want to detect it, we need to stay as close as possible.

Algorithm to detect marks is a little different from detecting buoys. These colors are only black, so it can reduce first process from previous one. In Fig. 12 Flow chart of the algorithm is shown. First expansion of the data of omnidirectional camera is done. Then labeling is done mainly black colors and checked its label's shape whether it is matched to the circle, triangle or cross. Especially about cross, we need to take sample in practice time because it can change its form due to its thickness.

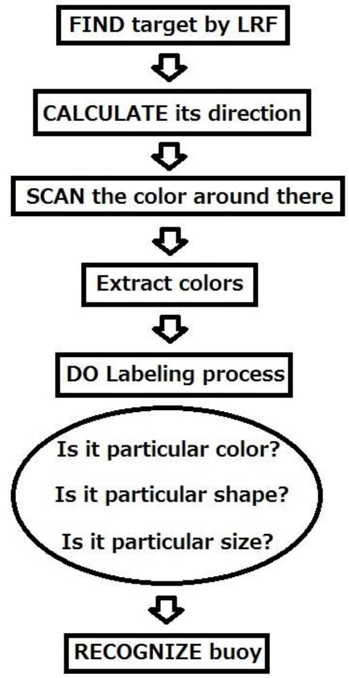

Fig. 10: algorithm of detecting buoys

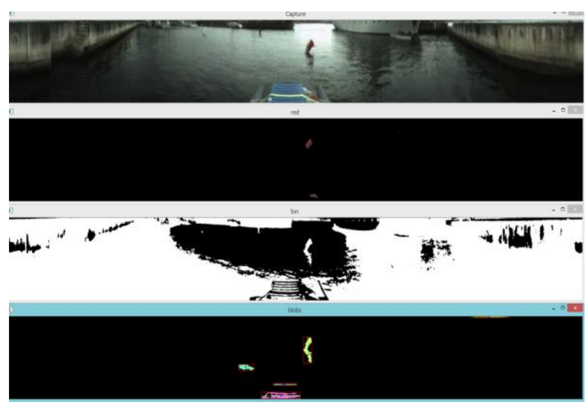

Fig. 11: example of the program

If the matching ratio is sufficiently bigger than the threshold it is recognized as the mark. After finding target mark, the boat will go to the mark straightly and stop its motor when it closes in 5m distance. If there is float beside the boat, it needs to adjust to prevent it from hitting.

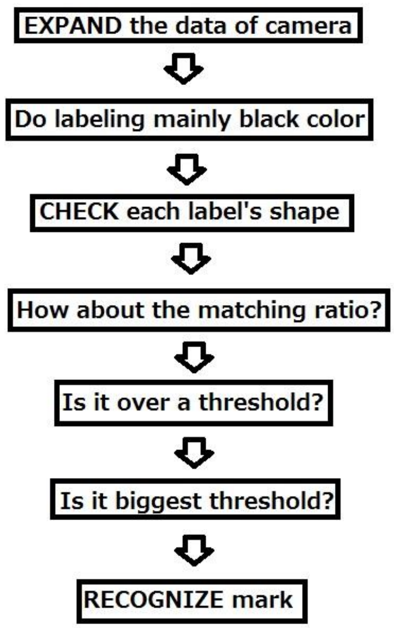

Fig. 12: algorithm of detecting marks

3.5 LED Light Color Detection

Thousands of ships and surface vehicles can navigate through any sort of markers (Lighthouses, light buoys etc.). In this paper researcher tried to explain the image processing based algorithm to detect the Light Buoy in the search area with help of camera placed on the autonomous surface ship (Fig. 13). In this research, light source buoy composed of high brightness LEDs is used, because LEDs have gain widespread use in lightning application since LED lights maintain more stable state and less power required also they have a good recognition properties in both day and night conditions.

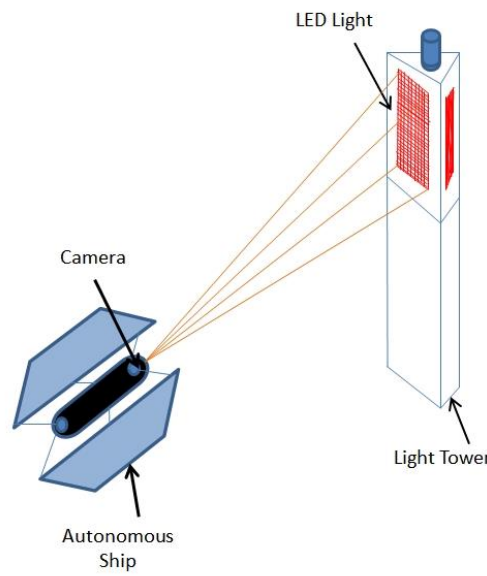

Fig 13: an autonomous ship targeting LED Light Buoy

The buoy with vertical Led light bar is located on the search area and successively display color one at a time to generate a sequential pattern of three colors (red, green and blue) individual color will appear for 500 millisecond after which the light remain off (black) for two seconds. The camera records the video and with the help of algorithm the sequential pattern of the color of LED light buoy can be detected online. In this research the pattern of glowing LED light is already known to us. Camera reads the image on 30 FPS so it is not needed to process every image frame and process time is reduced. Image acquisition toolbox and image processing toolbox of MATLAB is used for the coding [9].

The Flow chart of the algorithm is shown in Fig. 14.

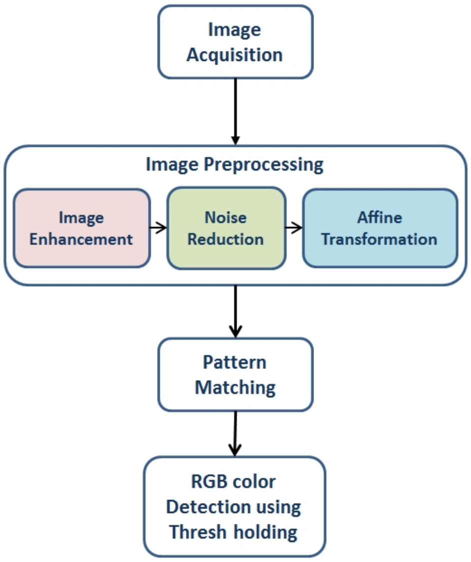

Fig 14: flow chart of the algorithm

First part of the algorithm is image acquisition in which with the help of the camera video is retrieve and read in the algorithm with the help of Image Acquisition toolbox in MATLAB. From the video images are extracted frame by frame for further processing. Image clarity is very much affected by environmental conditions for e.g. lightning and weather condition etc. so in that cases image may loss some information. So Image enhancement is a technique to recover the lost information also makes it brighter and contrast. In this algorithm Histogram Equalization [6] is used to make contrast adjustment using image's histogram. Histogram Equalization redistribute intensity distribution and produce optimal contrast but cannot adapt the local information of the image and preserve the original brightness of the image.

The cumulative histogram from the input image needs to be equalized to 255 by creating the new intensity value by applying equation 1[7].

$$I'(x) = \frac{d}{C_{Max} - C_{Min}} \times (C(x) - I_{Min}) + I_0 \quad (1)$$

Where, is the new intensity level, d is the new dynamic range value, I_0 is the offset point of new dynamic range for I'(x), C(x) is the normalized cumulative value, C_{Max} is the maximum value in normalized cumulative value, and C_{Min} is the minimum value in normalized cumulative value. Lastly, the normalized cumulative histogram is used as the mapping functions of the original image. There are many color images processing well established to remove both linear and nonlinear noise from the image. In the field of image noise reduction several linear and nonlinear filtering methods have been proposed. In these kinds of image acquisition processes both linear and nonlinear noises are presented. Most common noises are impulsive and additive so we used median filter which is a nonlinear filter.

The autonomous ship has its own roll, pitch and yaw sensors fixed with the body coordinate frame which give the rate of change of the angles. The information is fed to the algorithm and according to that image is processed without any distortion.

Let us consider an image function f defined over a (w, z) coordinate system, undergoes geometric distortion to produce an image g defined over an (x,y) coordinate system[6] This transformation may be expressed as equation 2.

$$g(x,y) = T\{f(w,z)\} \qquad (2)$$

Where 'T' is a transformation matrix that contains Rotation, Translation and Scaling After that whole preprocessing normalized correlation based pattern matching technique is used as it allows for stable pattern matching without being affected by ambient light also normalize the image vector between the reference image and input image and calculate correlation coefficient with the given equation.3 [6].

$$Y(u,v) = \frac{\sum_{x,y}\left[f(x,y)-f'_{(u,v)}\right][t(x-u,y-v)-t']}{\sqrt{\sum_{x,y}\left[f(x,y)-f'_{u,v}\right]^2[t(x-u,y-v)-t']^2}} \qquad (3)$$

Where t' is the mean of a reference image, f' (u,v) is the mean of f(x,y) in the region under the template.

At last RGB color detection is method is used to detect the LED color change. Thresh holding value is set for Red, Green and Blue colors. In the proposed method, color image is analyzed from RGB color space point of view. Each pixel in the image consists of three color channels known as RGB components. The range of values of each of this components lies within 0 to 255. As it is known from the literature that we can normalize the formula [8]

$$r = R/(R+G+B); \quad g = G/(R+G+B) \ \& $$

$$b = B/(R+G+B) \qquad (4)$$

$$r + g + b = 1 \qquad (5)$$

After applying the algorithm on the video of LED light buoy captured by the camera the following results are obtained fig.15. The sequence of the color pattern is detected but the limitation is no color should repeat just after the same color for example first sequence pattern is obtained as [Red Green Blue]. Similarly second and third is [Red Green Red] and [Blue Green Red]. Image has been enhanced, noise free and free from distortion.

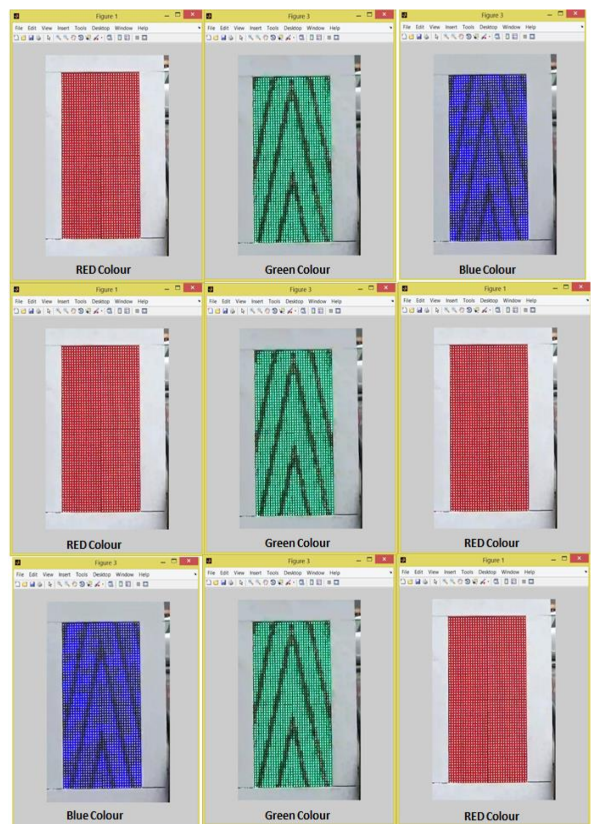

Fig 15: sequence Pattern of change of color of LED Light

3.6 Under water Search

We have two ideas to clear these tasks by using 4 microphones. First idea is to make a directional microphone set by using 4 microphones and 4 vacuums packing as shown in Fig. 16. Attached vacuum packing prevent from the sound transmitting through them. The microphone of the appropriate direction gets bigger sound than others. Other microphones get no direct sound but small reflected or spreading sound. The directions are estimated loosely by one data. As the boat will move around there, we can get more precise direction by correcting with previous data. We did experience twice by using GPS and the pinger, and found that we can almost find direction. If we know the rough idea of the direction of the buoy, we can estimate the target sounding buoy and know its color by combing Laser-Range-Finder and omnidirectional camera. The position will be estimated with the satellite compass data when it became close to the target buoy. Sound will diffuse to a spherical surface. If its distance is “r”, the surface is $4\pi r^2$. So the magnitude of the volume will decrease inverse proportion to the square of the distance. So the depth will be estimated by closing straight. The second method is installing 4 motors separately to the hull. There is difference until the sound arrives. Making one basis microphone and comparing the difference of the time, we can know the difference of distance by multiplying speed of the sound in water 1500m/s to time difference. Then we can get the position by thinking 3 distances.

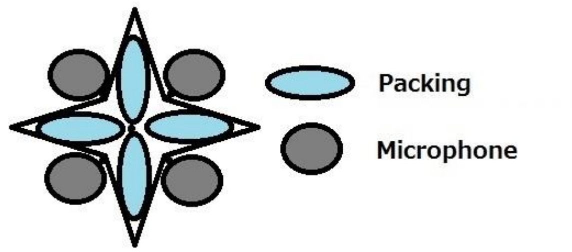

Fig. 16: Directional Microphone

3.7 Main control system

The program is controlled by one main C++ program [10]. The glimpse of the program window is shown in Fig. 17. All information of sensors and motor condition are gathered here. Buoys and wall are displayed as a map. Motor output is controlled and displayed. Task switching is done after finishing previous task and every memory of the task is saved in the PC for each second.

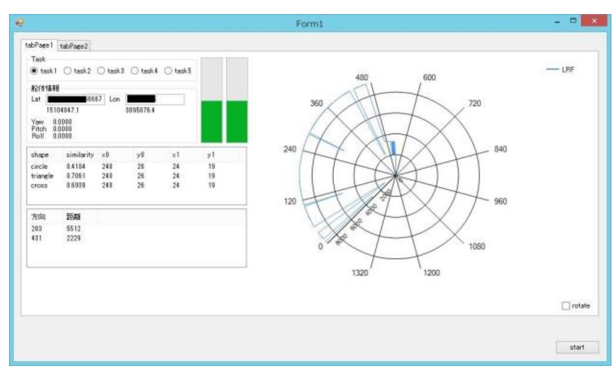

Fig. 17: example of main program

3.8 Emergency kill switch

Two emergency kill switches prevent the boat runaway. One is on board kill switch as Fig. 18 shows. This is the completely separated with other systems. This switch has a mechanical relay and be connected with power indicator (which has three right and show whether there is any power supply or not) between batteries and motor drivers. Once the switch is pushed, power supply will be cut off physically and completely. There is no issue about reconnect naturally, since the switch is necessary to rotate by hand after pushed. Another kill switch helps to cut off the power supply from long range. XBeePRO-ZB and relay is connected between batteries and motor drivers. It gets power supply from its own battery and once received the signal from switch; it will cut off power supply between batteries and motor drivers.

Fig. 18: on board kill switch

4. Collaboration

We want to take this opportunity to thank everybody who have been supported us. Our first collaboration is support from Kobe University. They have a best experiments pond in Japan. We may do first experiments on the sea earliest than any other teams. We did experiments in every 2 weeks. Prof. Hirono and Prof. Fujimoto supported to conduct the experiments well. Our team is grateful to them that we can learn actual spot of handling ships and discipline to work as a group. Our second collaboration is eleven sponsors. We got many support from them. Eight companies gave us their products, connectors, programs and equipment for safety. Two companies give us technical guidance. One company provided us activity funds. Some companies accept for continual support and another company will promise us to offer us powerful computers. Osaka University also supported us fanatically. We have done joint purchase of buoys with Tokyo Tech Team. In order to connect future promotional and make this competition familiar in Japan, we are going to publish an article of this competition in “Ocean News Letter” from Ocean Policy Research Foundation. At last, we are thankful to AUVSI directors and Prof. Uchino conducting such a wonderful competition and supporting us. It is a valuable experience for us.

5. Conclusion

We established a base for the strong team and we successfully prepared necessary sensors and made all required programs for this competition, image processing, obstacle search, acoustic and autonomous control programs. We didn't use complex theory and advanced programs, only simple theories and programming is used. We have work hard to make motor drivers, image processing programs, field buoys, choosing necessary sensors, conducting experiments and sponsorship. We have learned that there is a huge difference between simulation and experiments. The theories are easy to understand but applying it to real situation is difficult. We faced many problems in practical experimentation we did our first experiment on the sea earlier than other teams, but problem occurred the motor drivers burned. We overcome this problem, since we experienced. It is better to do experiments as soon as possible. Then we can think any measures and other requirements. Future work is making omnidirectional boat with 4 motors. This should be completely new idea for ships and will make 3D scan systems by moving Laser-Range-Finder. It should increase the accuracy to find targets. These two are fault this time due to the shortage of time but next time we will try to do.

6. References

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