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Underwater Cable Following by Twin-Burger 2

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Abstract

In this paper, a sensor fusion technique is proposed for Autonomous Underwater Vehicles (AUVs) to track underwater cables. The work presented here is an extension of the vision based cable tracking system proposed in [1,2,3,4]. The focus of this paper is to solve the two practical problems encountered in vision based systems; namely 1) navigation of AUV when cable is invisible in the image, and 2) selection of the correct cable (interested feature) when there are many similar features appearing in the image. The proposed sensor fusion scheme uses deadreckoning position uncertainty with a 2D position model of the cable to predict the region of interest in the image. This reduces the processing data increasing processing speed and avoids tracking other similar features appearing in the image. The proposed method uses a 2D position model of the cable for AUV navigation when the cable features are invisible in the predicted region. An experiment is conducted to test the preformance of the proposed system using the AUV "Twin-Burger 2". The experimental results presented in this paper shows how the proposed method handles the above mentioned practical problems.

1. Introduction

Recently, vision based AUV navigation had got much attention However, due to undesirable optical behaviour underwater, there were many occasions where the cable is not visible enough for the vision processor to track the cable. In addition the environment itself makes the cable invisible with time, due to the growth of underwater plants etc..

This paper looks at this particular problem and proposes a system which could take care of the situation when the cable is invisible optically. The proposed system uses multi-sensors fused together to keep track of the cable even when it is invisible to the CCD camera mounted on the AUV. A rough layout model of the cable is used with uncertain deadreckoning data to predict a region where the cable is expected in the image. This confines the visual processing to a smaller area avoiding misinterpretations of other similar features and also decreasing the processing time due to the reduction in image data. The performance of the proposed algorithm is tested using the test-bed AUV, the "Twin-Burger 2" with a cable setting highlighting the above mentioned practical situations. It is shown that the proposed multi-sensor fusion method manages to over come the above difficulties which arise when using visual servoing.

Section II discusses the overview of the proposed system and highlights the fusion techniques used to overcome the above mentioned problems. Section III presents the experiment conducted to demonstrate the performance of the proposed algorithm and section IV shows the results obtained. The discussion and the conclusions are made in section V.

2. System Overview

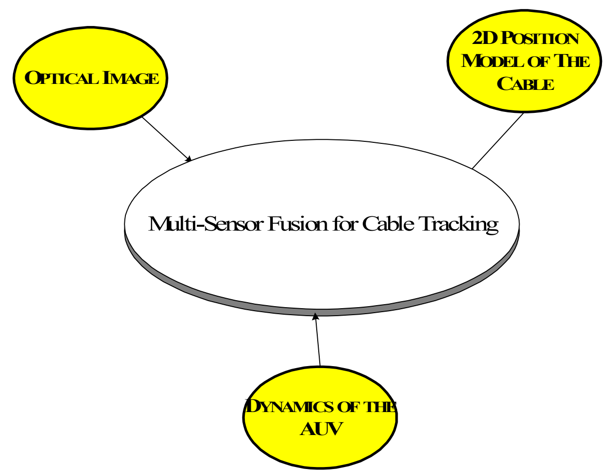

Fig. 1: Multi-Sensor Fusion

The system proposed is diagramatically shown in Fig. 1. In this technique, information other than the optical information is used in decision making for the navigation of the underwater vehicle. Position of different points on the cable is measured and this information is used as a rough position model of the cable. The rough position data model of the cable is used to predict the most likely region of the cable in the image, which reduces the amount of image processing data decreasing the processing time. Due to the narrowing of the region of interest in the image, the chances of misinterpretation of similar features appearing in the image can be avoided. In the proposed technique, dynamics of the AUV are also used to predict the position of the cable in the image [1,2,4]. This compensates the delays introduced by the image processing algorithm [4].

A. 2D Position Model of the Cable

A rough model of the layout of the cable is generated by taking the position (x_i,y_i) of a few points along the cable as shown in Fig. 2.

The line connecting x_iy_i to $x_{i+1}y_{i+1}$ acts as the model of cable and is used to predict the most probable region in the image for image processing and is used for navigation command generation when the vision processor cannot recognize the cable in the environment.

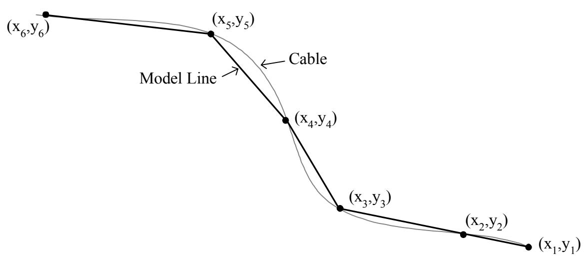

Fig. 2: Rough Layout Model of the Underwater Cable

The use of the model for cable pose prediction is explained in Fig. 3. The region of interest corresponds to the region of uncertainty of the rough model. Using the camera model, the corresponding position of the model line is determined and the interested region for image processing is selected according to this position. The interested region is selected according to the uncertainty of the cable model. Uncertainty is considered as the maximum possible deviation of the actual cable with respect to the model line. Narrowing of the region of interest in the image reduces the chances of misinterpretations of other similar features in the image and also increases the speed of processing due to the reduction in the input data for image processing. If the cable is not detected in this region then, the navigation is carried out by following the model line. The model line features (ρ,θ) are used in the Hough plane too as shown in Fig. 4.

The cable image introduces a high concentration of pixels in a particular direction forming a line in the image plane.

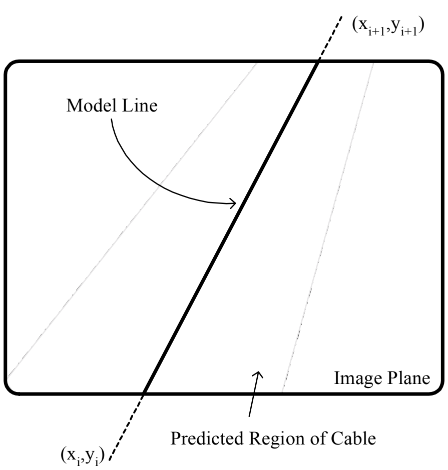

Fig. 3: Region Estimation for Image Processing

This line feature introduces a peak in the Hough space and its existing region can be predicted using the uncertainty of the model line as shown in Fig. 4. This technique avoids the extraction of other peaks in the Hough plane. In other words, it is possible to distinguish the cable of interest even when there are similar cables appearing in the image.

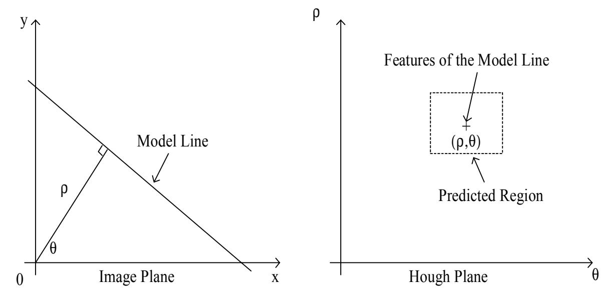

Fig. 4: Region Estimation in the Hough Plane

If a peak representing the cable cannot be found in the region predicted, the features of the model line is used for the navigation of the AUV. The integration of different components for cable tracking can be schematically represented as shown in Fig. 5. The low-level controller provides the dynamic state of the AUV and the optical image, captured by a CCD camera. The optical image is pre-filtered for optical noises using the SoLoG filter explained elsewhere [4]. The position of the AUV determined by deadreckoning is used to predict the region of interest in the image plane and that region is transformed into the Hough plane. Also using the position data of the AUV, the interested region in the Hough plane is predicted and the features of the cable image are extracted from the Hough plane. The size of the region varies from frame to frame and as a result, the image processing time will not be a constant.

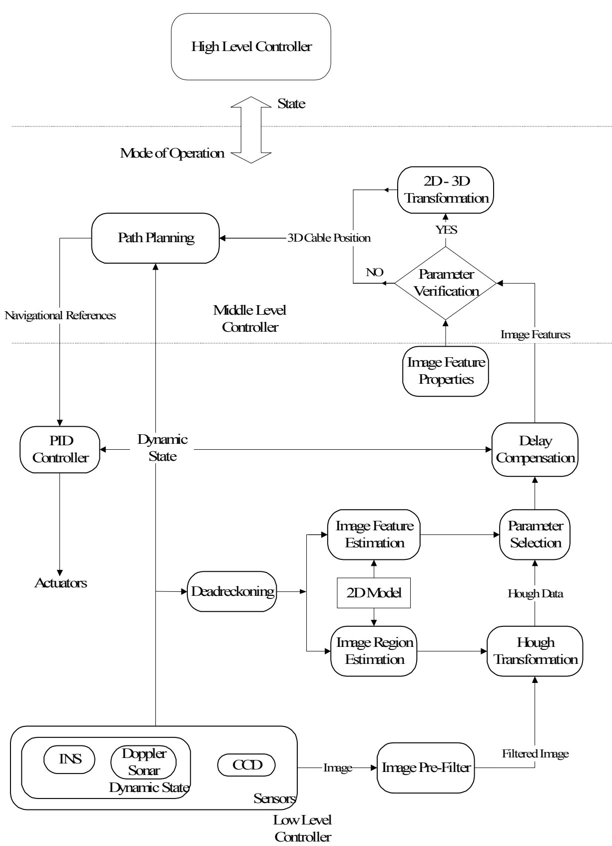

Fig. 5: The System Architecture

Therefore, in order to compensate the delays caused by image processing, a predictor based on the dynamics of the AUV which is explained in detail in [4] is used as the delay compensator. Once the instantaneous features of the cable is determined, these features are verified to check whether they represent the cable. The properties of the cable features are; 1) there are no abrupt changes, and 2) number of pixels on the line feature should be greater than a defined threshold. If the features extracted by image processing represents the properties of the cable then those 2D features are transformed into the vehicle coordinate system for determining the navigational references. Else the model line features are used for determining the navigational references. The generation of navigational references are discussed in [1,2,3,4].

The high-level controller explained in [4] is modified in this algorithm as shown in Fig. 6. It is important to use the same coordinate system for both 2D model of the cable and AUV positioning. This task is achieved by positioning the AUV initially with respect to a defined target (initial mark) using visual data. The initial mark is selected in such a way that it has two line features falling in the x and y axis of the coordinate system used for AUV positioning. The direction of the cable at the initial location is selected as the y axis and a perpendicular line feature (mark) to that direction is selected as the x axis as shown in Fig. 7. The intersection of these two lines is taken as the origin of the coordinate system.

Two modes of operation are carried out to initialize the position at the cross point of the mark shown in Fig. 7.

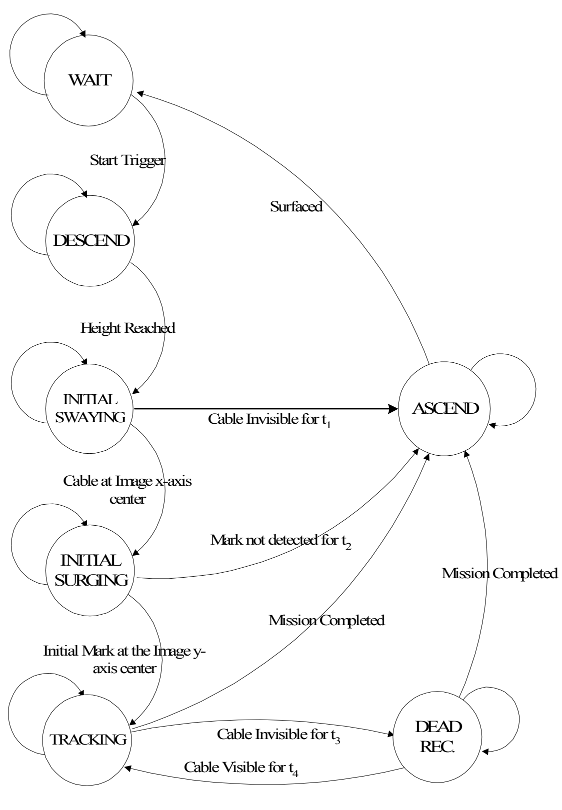

Fig. 6: High-Level Controller

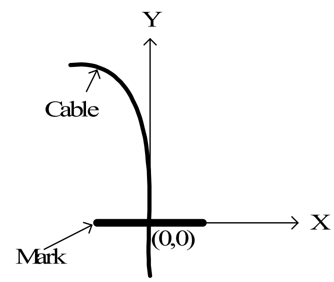

Fig. 7: Initial Positioning Mark

The initial dive of the AUV is done by keeping the heading direction, determined prior to the mission, along the Y axis. Once the defined height of the AUV with respect to the bottom is reached the AUV switch into the INITIAL SWAYING mode. Here, using visual feedback the AUV is navigated in the direction parallel to X axis only with sway actuator. At this instant heading and height references are kept constant. This mode is carried out until the image of the cable appears at the horizontal centre of the image. In this task the camera is kept in a forward-down looking position. The camera axis is parallel to the centre axis of the AUV. Once the cable is at the centre of the image the X-axis position of the AUV is made zero. Next, by keeping the same sway position, heading and height the AUV is moved forward by surging until the mark appears at the vertical centre of the image. It is called the INITIAL SURGING mode. Therefore, the mark-cable intersection point is taken as the (0,0) point of the coordinate system used for the 2D model of the cable, and for the positioning of the AUV. If the initial positioning is failed, the AUV ascends to the surface indicating that it could not recognize the initial mark. Else it starts tracking the cable and during tracking if the vision system cannot recognize the cable, the mode of operation is switched to the DEADRECK mode which uses the 2D model line for navigation until the cable is visible to the CCD camera mounted in the front of the AUV.

The proposed algorithm therefore, can handle the situations when the cable is invisible to the CCD camera and when there are many similar cables appearing in the image. The introduction of the 2D model of the cable improves the performance of the autonomous underwater cable tracking system.

3. Experiment

In order to demonstrate the performance of the proposed cable tracking algorithm an experiment is carried out using the test-bed AUV, “Twin-Burger 2” shown in Fig.8, available at the University of Tokyo, Japan. The dynamic state of this AUV is measured using the on-board sensors such as Rate Gyros, CCD camera, Doppler sonar, Compass, etc..

The experiment is carried out in a testing tank, whose depth is 3.5m and the setting of the cable is as shown in Fig. 9. The aim of the experiment is to test the performance of the proposed system to handle the two main practical points mentioned in section 2. The problem in vision processing to recognize the cable to be tracked when there are similar features appearing in the image is tested by laying a similar cable close to the cable of interest. The problem in vision based cable tracking to track a cable when it is invisible in the image is tested by discontinuing the cable. Also a similar cable, whose layout is different, is introduced to the image when the tracking cable is invisible in the image.

In this experiment a yellow colour hose pipe is used as the underwater cable to be tracked. The relative vertical distance between the cable and the AUV is controlled to be at 1m. An aluminium beam is used as the mark at the starting point.

Fig. 8: Test-Bed AUV the "Twin-Burger 2"

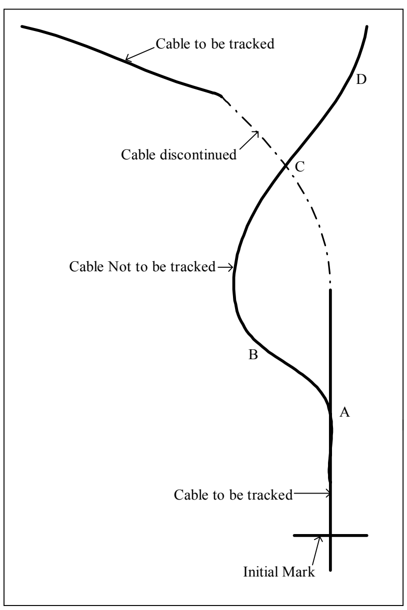

Fig. 9: The Experimental setting of the Underwater Cable

The CCD camera, mounted in the front of the AUV, is positioned with pan zero and with a tilt angle of 55° with respect to the horizontal. The surge, sway, yaw and heave motions are controlled for the autonomous underwater cable tracking mission. Path planning according to the visual features are carried out as explained in [4]. The cable is laid for a distance of about 27m and is invisible for a distance of about 8m.

Similar hose pipe is laid close to the interested hose in order to check the performance of the tracking algorithm. The surge speed control reference is kept at 0.1 m/s for vision based tracking and 0.2m/s for deadreckoning. Sway speed control reference is dependent on the change of position of the cable in the image in vision based tracking and is dependent on target position for deadreckoning. Yaw rate control reference is dependent on the position change of the cable in the image and is dependent on the position model line in the case of deadreckoning. Heave reference is generated to maintain a constant height with respect to the cable.

5. Results

The 2D position model of the cable is constructed by obtaining the position of eight points on the cable as shown in Table 1. The trajectory taken by the Twin-Burger in following the cable shown in Fig. 9 is presented in Fig. 10.

Table 1: The 2D Position Model of the Cable

X	Y
0.0	0.0
-0.1	5.0
-0.3	10.0
-0.8	15.0
-1.3	17.0
-2.5	19.0
-4.0	21.0
-5.0	22.0

The trajectory taken by the Twin-Burger is shown by the dark line in Fig. 10. Initially there is a deviation from the 2D model line due to the search of the initial mark. Position data is captured using the Doppler sonar on board Twin-Burger 2.

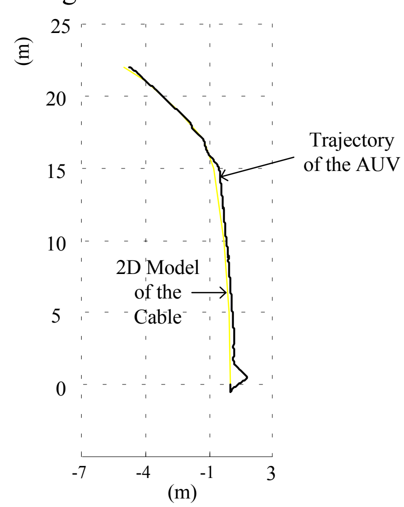

Fig. 10: Trajectory of Twin-Burger 2

Different modes commanded by the High Level Controller in following the cable is shown in Fig. 11. Heave controller uses the range to bottom to maintain a constant height with respect to the cable as shown in Fig. 13.

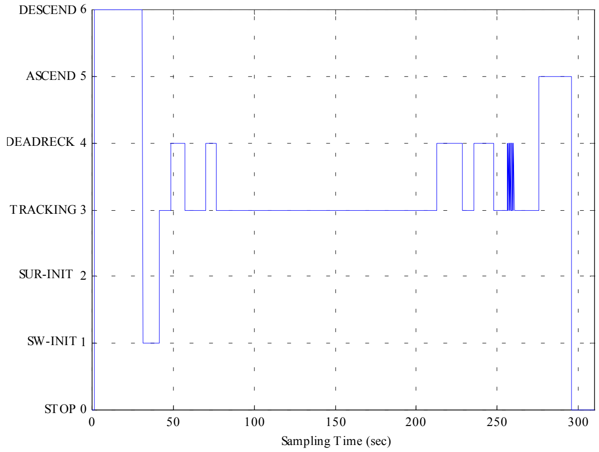

Fig. 11: Modes of Operations

DESCEND mode initializes the mission and will descend to the bottom until the desired height, in this case 1m, with respect to the cable is reached. As shown in Fig. 13, the height is reached around 30sec sampling time and as shown in Fig. 11 the mode changes to the SW_INIT where visual data is used to search for the cable. From Fig. 12 it can be seen that the cable is visible around the 30sec sampling time. The value 200 in Fig. 12 indicates that the cable is invisible. Once the cable in the image reaches the horizontal centre zone, in this case image parameter $\rho > 70$, $\rho < 120$ and $\theta < 30^o$, $\theta > -30^o$, the mission mode changes to the SUR_INIT as shown in Fig. 12.

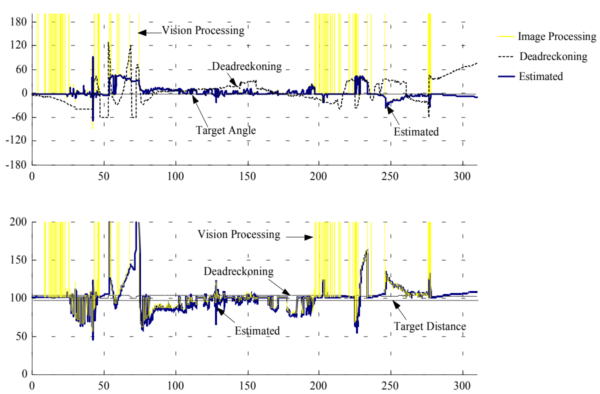

Fig. 12: Visual Parameters

The sway position is marked as the initial location or in other words as the origin of the x-coordinate used for position of the AUV. In the SUR_INIT mode the AUV is navigated with initial heading, and the sway control reference target is set to the sway position at which the mode of operation changed to SUR_INIT from SW_INIT and surge control reference is set to 0.05 m/s as shown in Figs. 14 - 16. It is clear from Fig. 12 that there is some difficulty for the vision processor to recognize the cable and as a result the mode of operation is changed to the DEADRECK mode. Due to the discontinuity of the cable, around sampling time 210 sec. the cable is invisible to the image processor as shown in Fig. 12 and as a result the mode of operation is changed to the DEADRECK mode and is back on TRACKING mode around the 250 sec. time.

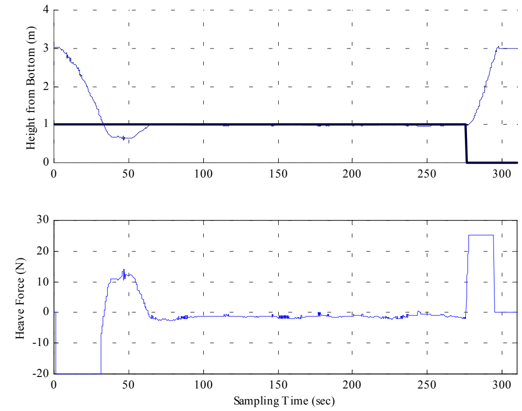

Fig. 13: Heave Controller

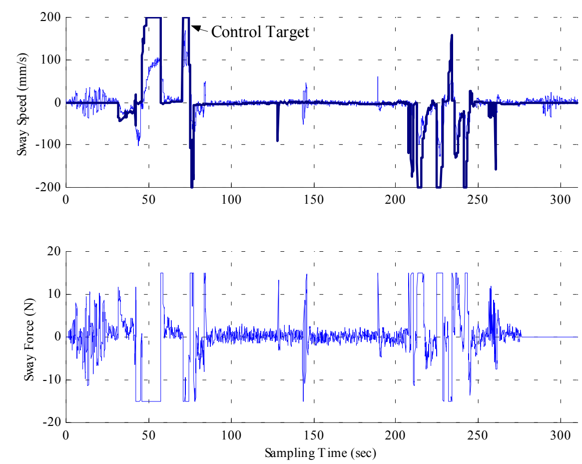

Fig. 14: Sway Controller

Considering the data points around sampling time 230sec. in Fig. 12, it can be seen that the vision processor recognizes a feature similar to the cable. However due to the difference between the deadreckoning based features and estimated features by dynamics, the mode switches back to the DEADREC mode. After 250sec. there is a region where continuous switching between DEADREC and TRACKING modes. This phenomena is due to the appearance of the cable just inside the region estimated in the image.

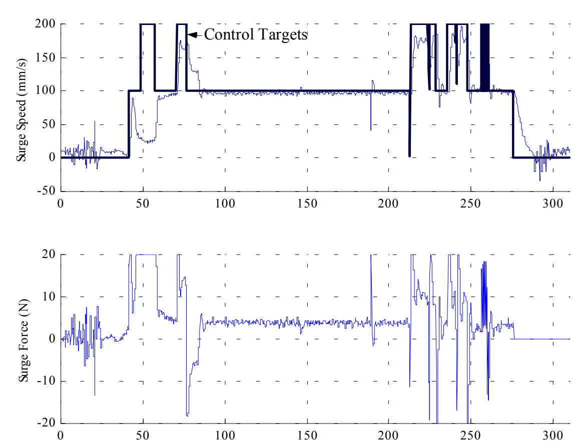

Fig. 15: Surge Controller

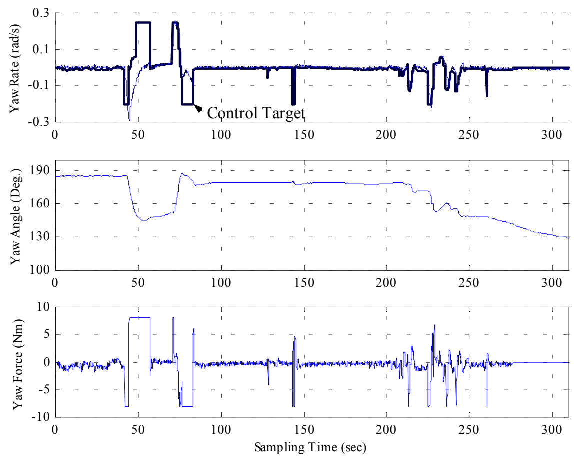

Fig. 16: Yaw Controller

6. Conclusions

In this paper, fusion of multi-sensors for the autonomous tracking of underwater cables is reported. This work is an extension of the previous work presented on vision based underwater cable tracking. Two important practical problems; 1) invisibility of the cable in the CCD image, and 2) selection of the cable to be tracked when there are many cables appearing in the CCD image, arising in vision based tracking are discussed. In this paper, image data, deadreckoning data and 2D position model data are fused together to overcome the above mentioned problems. The performance of the proposed algorithm is demonstrated by conducting an autonomous underwater cable tracking mission in a real-world environment using the AUV 'Twin-Burger 2'.

The Fig. 11 shows how the mode of operation is selected by the High Level Controller, dependent on different sensor data. The reliability of vision based tracking systems are enormously improved with the fusion of a position data model. The use of deadreckoning data for navigation only when the cable is invisible in the image will encounter less problems due to accumulated error compared to total navigation with deadreckoning. Uncertainty in position data by deadreckoning introduces a region in the image in which the cable is most likely be located. This helps the algorithm to reduce the amount of image processing data, decreasing the processing time. Prediction of a region avoid tracking of other similar features appearing in the image. These situation can be seen in the experimental results. The point A in Fig. 9 is a situation to demonstrate the case when there are similar features in the image and the section consisting C is a situation to demonstrate the case when the cable is invisible. Further test had been done by introducing a similar cable in the image when the tracking cable is invisible (point C). It is interesting to note that the image processor recognizes it as a cable as shown in Fig. 12 around sampling time 230. However, the algorithm detects it as a different cable and switches back to DEADREC mode as shown in Fig. 11.

Therefore, it can be concluded that the use of different sensors fused together, even with uncertainties, makes the performance of the entire system more reliable. The use of uncertain deadreckoning data for the prediction of visual parameters improves the visual processing and vision based tracking.

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