Robotics Vision-based System for an Underwater Pipeline and Cable Tracker

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***Abstract*-This paper presents a robotics vision-based system for an underwater pipeline and cable tracker. This system is introduced to improve the level of automation of underwater Remote Operated Vehicles (ROVs) operations which combines computer vision with an underwater robotics system to perform target tracking and intelligent navigation. This study focuses on developing image processing algorithms and nonlinear control method for tracking the pipeline or cable. By using the proposed image processing method, at first the picture frames are converted to gray pictures and these images should be applied for an edge detector at last by using Hough Transform the angle of the robot can be found. This angle is used as a reference input of heading controller. By using the adaptive sliding mode controller, the ROV can easily track the cable or pipeline. The system has been tested using sequences coming from a video tape obtained in several tracking sessions of various cables and pipelines with an ROV.**

I. INTRODUCTION

Nowadays, the surveillance and inspection of underwater installations, such as power and telecommunication cables and pipelines, is carried out by operators that, being on the surface, drive a remotely operated vehicle (ROV) with cameras mounted over it. This is a tedious and high time-consuming task, this task is often requiring continue attention and knowledge/experience of human operators to maneuver the robot. In these operations, human operators does not require an exact measurement from the visual feedback, but based on the reasoning. Besides, the complexity of the task is increased by the lack of quality of typical seabed images, which are mainly characterized by blurring, non-uniform illumination, lack of contrast and instability in the vehicle motion. In this paper, the development of a vision system guiding an ROV able to detect and track automatically an underwater pipeline or power cable laid on the seabed is the main concern[1].

Underwater pipelines need to be periodically inspected to prevent failures. Some of surveys which the robot has to do are: Visual Inspection, Cathodic Protection and Weight Coat. On the one hand, marine stream, waves or even seismic activity can cause important changes in the seabed. As a result, the cable or maybe pipeline can become hanged between two rocks, giving rise to an anomalous situation known as free-span. Free-span is not desirable since can lead to a cable failure due to both the cover rigidity and a larger likelihood of an anchor hooking the cable. On the other hand, the corrosion affecting the cable due to the loss of the cover caused by the impact of anchors, fishing nets trawling, marine flora growth or shark attacks accelerate the ageing of the cable. Obviously, the automation of any part of the inspection can greatly improve the speed, the safety and the cost of the inspection program. The first step to automate the pipeline or cable inspection process is the tracking of them.

For these reasons, it is desirable to develop robotics vision system with the ability to mimic the human mind (human expert's judgment of the terrain traverse) as a translation of human solution. In this way, human operators can be reasonably confident that decisions made by the navigation system are sound to ensure safety and mission completion. Current position based navigation techniques cannot be used in object tracking because the measurement of the position of the interested object is impossible due to its unknown behavior. The current methods available to realize target tracking and navigation of an AUV used optical, acoustic and laser sensors. These methods have problems mainly in terms of complicated processing requirement and hardware space limitation on AUVs. Other relevant research consists of neural-network based classifier of the terrain can be found in several literatures. Also, existing method using Hough transform and Kalman filtering for image enhancement has also been very popular [1].

In this paper, we have two parts; Image Processing and Vision-based Navigation. In image processing section, at first, picture frames is converted to gray pictures. It is clear; cameras used in underwater vehicles often receive picture frames in colored format because of usage of colored images in some application such as visual survey. But, in our application we need these images to be applied for an edge

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detector. Novak and Shafer found [3],[4] that 90 percent of the edges are about the same in gray value and in color images, but by using the gray images, the amount of computing will increase significantly. Therefore, there is no need to use color image and required edges can be detected in gray ones. In the next step, we applied Sobel Edge Detector [5] to these pictures. There are many ways to perform edge detection [2],[5]. The most famous and commonly used edge detector is Sobel Edge Detector because of high accuracy and low complicity. Nevertheless, this edge detector has some weaknesses in the existence of noise but in the next step by using of Hough Transform [2],[7],[8] this weakness is decreased, because Hough Transform is very strong against noise and by finding houghpeaks in this transform we can find the deviation angle of the robot.

The next part is control and navigation of the robot based on this angle. In other words, the angle is a reference input for the autoheading of the ROV. Due to the highly nonlinear dynamics of an ROV and the difficulty of modeling the environment and its interaction with the ROV, controlling the head of an ROV in an uncertain and unstructured environment presents many challenging control problems. The adaptive sliding mode controller, one of the nonlinear and robust control methods, is based on estimating of uncertainties and tracking of inputs. In this method, don't need to have an accurate model of system [9],[10],[11],[12].

In this paper, firstly, the proposed image processing method is presented and then a robust nonlinear control method for navigating the underwater robot is explained. Finally, the system has been tested using a video tape obtained from cables and pipelines with an ROV.

II. COMPUTER VISION

This Section is divided in two parts: Edge Detection part, Hough Transform and angle deviation estimation part.

A. Edge Detection

Edge detection is an important process in low level image processing. Although color images provide more information than gray value images, but the amount of computations will increase and so the speed of computations will decrease. Besides, Novak and Shafer found [..] that 90 percent of the edges are about the same in gray value and in color images. Consequently, we only miss 10 percent of edges and in our application such accuracy is not necessary and the speed of response is more important. Therefore, at the first stage, we convert colored picture frames to gray. Cameras used in underwater vehicles often receive picture frames in colored format because of usage of colored images in some applications such as visual survey; so we often need to do this conversion. The most common formula which converts an RGB image to an intensity image is [6]:

$$I' = 0.30 I'_r + 0.59 I'_g + 0.11 I'_b \qquad (1)$$

Then we apply Sobel edge detector to this grayscale image. There are two masks for Sobel edge detector [5], one for detecting image derivatives in X and one for detecting image derivatives in Y. To find edges, a user convolves an image with both masks, producing two derivative images $(dy \,\&\, dx)$. The strength of the edge at any given image location is then the square root of the sum of the squares of these two derivatives. The orientation of the edge is the arc tangent of dy/dx. Because of greater weights given to the central pixels in Sobel Kernels, they can also be thought of as 3 * 3 approximations to first-derivative-of-Gaussian kernels and because of only this reason they can be more resistant against noise compared to some other edge detectors. Although there are other edge detectors that are stronger against noise but they will increase the complexity and decrease the speed of computations noticeably. Meanwhile, as will BE discussed later in the next step we will apply Hough Transform to the output of this stage and the effect of noise will decrease in this stage. The equations of Sobel kernels are presented below.

$$\begin{aligned} Gx(x,y) = [\, & f(x+1,y-1) + 2f(x+1,y) \\ & + f(x+1,y+1) - f(x-1,y-1) - 2f(x-1,y) \\ & - f(x-1,y+1)] \end{aligned} \qquad (2)$$

$$\begin{aligned} Gy(x,y) = [\, & f(x-1,y+1) + 2f(x,y+1) + \\ & f(x+1,y+1) - f(x-1,y-1) - 2f(x,y-1) \\ & - f(x+1,y-1)] \end{aligned}$$

In addition, the thresholding issue is also important. For getting enough information about thresholding refer.

B. Hough Transform and Angle Detection

In the next step in image processing section we will apply Hough Transform [2],[8] to the output of edge detection step. The Hough Transform is considered as a very powerful tool in edge linking for line extraction. Its main advantages are its insensitivity to noise and its capability to extract lines even in areas with pixel absence (pixel gaps).

The normal parameterized version of the HT[2],[8], states that if a line whose normal makes an angle with the x axis, and has distance from the origin is considered (Fig. 1), the equation of the line corresponding to any point (x_n, y_n) on this line is given by the formula(3).

$$\rho = x_n \cos\theta + y_n \sin\theta \qquad (3)$$

In the image analysis context, the coordinates of the points of the edge segments (x_n, y_n) in the image are known and therefore serve as constants in the parametric line equation, while ρ and θ are the unknown variables we seek.

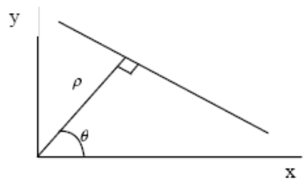

Fig. 1 Normal HT representation of a line

The possible (ρ , θ) values defined by each (x_n, y_n) , points in the image space map are plotted to curves (sinusoids) in the Hough parameter space. When viewed in Hough parameter space, points which are collinear in the Cartesian image space become readily apparent as they yield curves which intersect at a common (ρ , θ) point.

The transform is implemented by quantizing the Hough parameter space into finite intervals or accumulator cells. Since the edge detected image is a multispectral image with N bands, the HT is computed for each band in the image. As the algorithm runs, each (x_n, y_n) is transformed into a discretized (ρ , θ) curve and the accumulator cells, which lie along this curve, are incremented. Each time the HT is computed, an accumulator array is created. N accumulator arrays are created since there are N bands in the image. The accumulator arrays are added together to form only one global accumulator array for the whole image.

Resulting peaks in the global accumulator array represent strong evidence that a corresponding straight line exists in the image. The different (ρ_n, θ_n) that result from the peaks in the global accumulator array are used in computing the lines back in the image. Each different (ρ_n, θ_n) gives an infinite line in the image space whose normal makes an angle θ with the x axis, and has distance ρ from the origin (Fig. 1).

What we did in this part was in this way: At first we applied HT to the edge detected image and then in respect to the peaks in HT we estimated angle deviation. This angle is the output of computer vision section and the input of control section.
For instance, we have two captured image in the following and their angle deviation from our process.

III. VISION-BASED NAVIGATION

In this part, the robust nonlinear controller is designed to automate control the head angle of the ROV system which is generated by image processing algorithm. It is well known that the heading control of the remotely operated vehicle is not an easy task, because, dynamic of ROV includes uncertainty hydrodynamic parameters, highly nonlinear, coupled and time varying and also because of existence of disturbances, such as cable force and sea currents. Various advanced underwater robust control methods have been proposed in literature, such as sliding control, nonlinear control and adaptive control [9-14]. Some nonlinear control schemes require an accurate system model. Some of control schemes require bound of parametric uncertainties. However, it is not easy to obtain an accurate system model of the ROV system due to uncertainties in hydrodynamics.

The adaptive sliding mode controller, one of the nonlinear and robust control methods, is based on estimating of uncertainties and tracking of inputs. In this method, don't need to have an accurate model of system. In this paper, by using the combination of adaptive estimator and sliding mode controller, control system can estimate the parameters of equations and also track the heading reference which is entered from the image processing algorithm. Moreover, the adaptive-sliding controller can reject the disturbances.

A. *Model of ROV*

ROV is an underwater robot with 6-degree of freedom.(Fig.2).

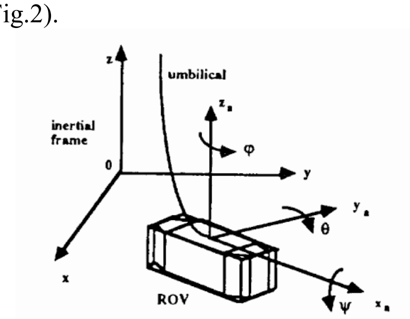

Fig 2. Operational configuration of ROV

It can move in all directions $x, y, z, \varphi, \theta, \psi$. But almost ROV is stable in θ, ψ directions, it is desired to control of ROV in 4 directions (x, y, z, φ). A set of nonlinear differential equations, describing the ROV, is given in equation 1 to 6.

$$a_x \ddot{x} + b_x \dot{x}|\dot{x}| + f_x(\dot{y}, \dot{z}) = F_{cx} + F_u + T_x \tag{4}$$

$$a_y \ddot{y} + b_y \dot{y}|\dot{y}| + f_y(\dot{x}, \dot{z}) = F_{cy} + F_v + T_y \tag{5}$$

$$a_z \ddot{z} + b_z \dot{z}|\dot{z}| + f_z(\dot{x}, \dot{y}) = F_{cz} + F_w + T_z \tag{6}$$

$$a_\varphi \ddot{\varphi} + b_\varphi \dot{\varphi}|\dot{\varphi}| + f_\varphi(\dot{\theta}, \dot{\psi}) = M_p \tag{7}$$

$$a_\theta \ddot{\theta} + b_{\dot{\theta}} \dot{\theta}|\dot{\theta}| + f_\theta(\dot{\varphi}, \dot{\psi}) = M_q \tag{8}$$

$$a_\psi \ddot{\psi} + b_\psi \dot{\psi}|\dot{\psi}| + f_\theta(\dot{\psi}, \dot{\theta}) = M_r \tag{9}$$

In these equations, $M_r, M_q, M_p, T_z, T_y, T_x$ are forces and torques that supplied by motors of ROV. F_{cx}, F_{cy}, F_{cz} are cable forces as disturbances and u_f, v_f, w_f are undersea currents as disturbances too.

B. *Control Objective*

The objective of control is to regulate the behavior of the ROV heading to the angle which is defined by the image processing algorithm [10],[13].

It is necessary to design a controller to satisfy follow specification:

1- Estimating of uncertain parameters
2- Tracking of input
3- Rejecting of disturbances

C. Design of Adaptive Sliding Controller

Assume that, the model of system is [10],[13],[14]:

$$\ddot{x}+\sum_{i=1}^{r} h_i f_i(x)=bu+d \tag{10}$$

f_i is continuous and nonlinear function. a_i and b are unknown parameters. Disturbance (d) is unknown but has boundary ($|d(t)|\le D$). It is desire to design a controller which can track the $x_d(t)$ as a desired input.
At first, a Lyaponuv function has defined:

$$V(t)=\frac{1}{2}\left[s_\Delta{}^2+b\left(\sum_{i=1}^{r}\left(\frac{\hat{h}_i-h_i/b}{h_{in}}\right)^2-\left(\frac{\hat{b}^{-1}-b^{-1}}{b_n}\right)^2\right)\right] \tag{11}$$

$$s_\Delta=s-\Phi sat(s/\Phi)$$

The sliding surface is:

$$s(x,t)=\dot{\tilde{x}}+2\lambda\tilde{x}+\lambda^2\int_0^t \tilde{x}(\tau)d\tau,\quad \lambda>0 \tag{12}$$

And u (t), control signal is:

$$u(t)=\sum_{i=1}^{r}\hat{h}_i f_i(x)-\hat{b}^{-1}\left[\hat{u}+(D+\eta)sat(s/\Phi)\right] \tag{13}$$

$$\hat{u}=-\ddot{x}_d+2\lambda\dot{\tilde{x}}+\lambda^2\tilde{x}$$

$\hat{h}_i$ and $\hat{b}$ compute in this form:

$$\dot{\hat{h}}_i=-h_{in}^2 f_i(x)s_\Delta$$

$$\dot{\hat{b}}^{-1}=b_n^2\left[\hat{u}+(d+\eta)sat(s/\Phi)\right] \tag{14}$$

$$s_\Delta=s-\Phi sat(s/\Phi)$$

IV. SIMULATION RESAULTS

For simulating the vision-based system, assume that there is a pipeline in depth of 5 meter and there is a bending in this pipeline. The task of algorithm is estimation of the angle using the proposed image processing algorithm and the task of controller is navigation the ROV to follow the pipeline. Figures (3),(4) show the results of image processing simulation and Figures (5),(6),(7) show how the ROV can track the pipeline.

Fig 3.a Original Image with angle 42 Deg

Fig 4.a Original Image with angle -44 Deg

Fig 3.b Grayscale Image

Fig 4.b Grayscale Image

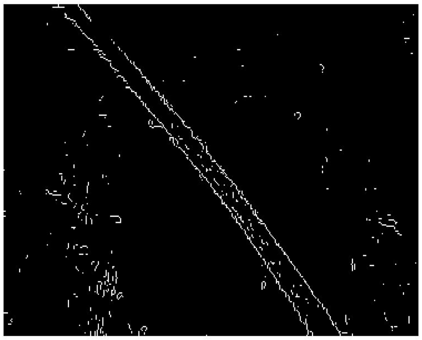

Fig 3.c Edge Detected Image

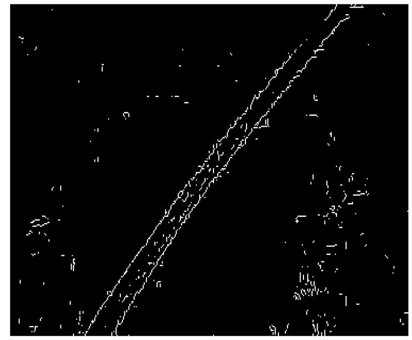

Fig 4.c Edge Detected Image

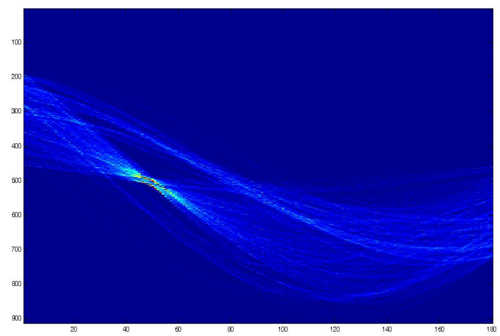

Fig 3.d Hough Transform estimate the angle of Pipeline 42 Deg

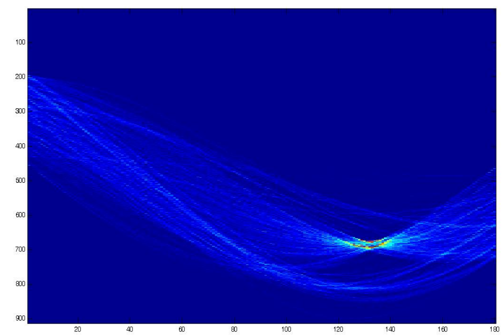

Fig 4.d Hough Transform estimate the angle of Pipeline -44 Deg

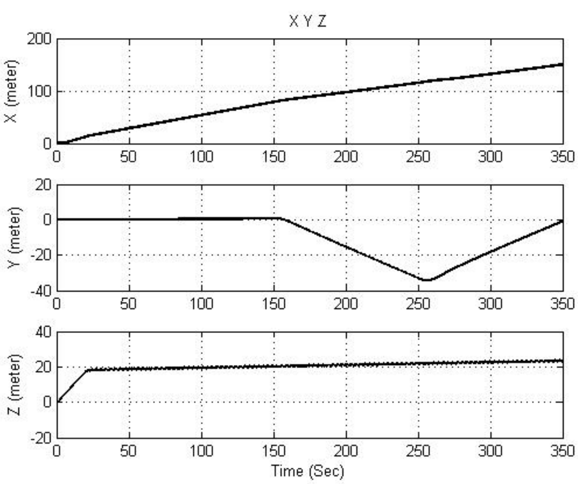

Fig 4. Movement of ROV in X Y Z directions

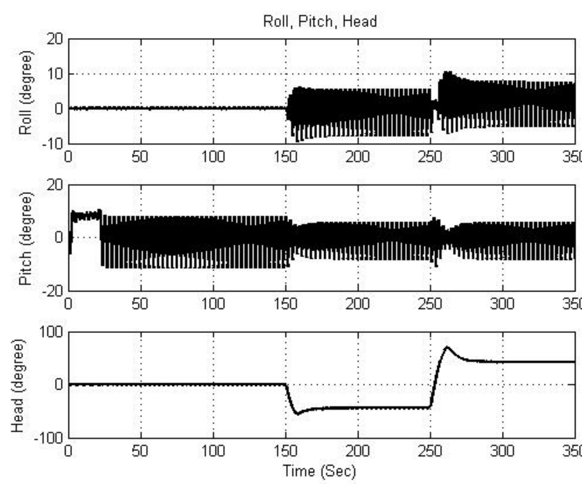

Fig 5. Movement of ROV in Roll, Pitch , Head directions

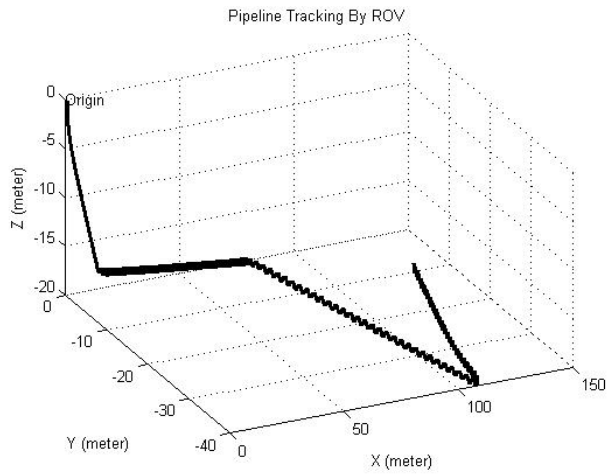

Fig 6. Movement of ROV for Tracking pipeline

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V. CONCLUSION

This paper has introduced a technique for cable or pipeline tracking using ROV based on vision. The image processing algorithm developed is capable of extracting the angle that must be followed by ROV. Also the adaptive sliding controller is able to follow the angle extracted by image processing algorithm. The simulation results show the ability of the combination of these algorithms together.

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