BEHAVIOURS IMPLEMENTED USING A VISION SYSTEM BASED ON CODED LIGHT PROJECTION

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Abstract

Looking for new sensorial systems and new methods to implement some behaviours related to underwater vehicles positioning based on visual servoing, this paper presents a computer vision system based on coded light projection. 3D information is taken from the underwater scene. This information has been used to test an obstacle avoidance behaviour. In addition, the major ideas to achieve a stabilisation of the vehicle in front of an object, are presented.

1. Introduction

In the last few years, the development of AUV has experimented an important impulse. Actually, there is no doubt that it is very interesting to develop robots to carry out the unpleasant and dangerous underwater tasks which, nowadays, are done by humans. In this way, most of the efforts are focused on visual servoing, that is, on self-positioning of the robot with respect to an object of the underwater scene by using computer vision. It is well-known that underwater visual servoing becomes harder due to the unstable sea movement and the difficulty to grab properly images of the scene. There is no doubt at all that this task is the first approach that has to be solved in order to carry out tasks like underwater inspection or more complicated tasks like object manipulation. In this way, some research has been done in the aim of doting the Vortex underwater vehicle by a visual sensor based on the projection of a laser beam slit[5]. This sensor has been used in underwater pipe inspection[9]. However, the main problem of single slit projection is the reduced area to be analysed and the difficulty to self-position the robot by using a single stripped image. Of course, this problem can be solved acquiring more scene information by the projection of more than a single slit. However, the correspondence problem between captured and projected slits has then to be taken into account. Our approach is based on using a projecting pattern which has been coded in order to solve completely the correspondence problem. Then, this sensor has been used in the aim of implementing the following behaviours : a) **Obstacle avoidance**. The robot must avoid static and dynamic obstacles which can be placed on the path, b) **Robot stabilisation.** The robot must be stabilised and positioned keeping a determined distance with respect to an object.

The presented sensor has been set in our ROV called GARBI[1,4]. GARBI is a project financed by the Spanish government[+] and jointly developed with the Polytechnical University of Catalonia. The robot has been mostly used in tele-operated tasks like underwater inspection[2]. It has been also used in underwater object manipulation by using its two tele-manipulated arms[3]. This sensor has been proposed in the aim of increasing the autonomy of the robot.

The paper is structured as follows. Firstly, the GARBI underwater robot is briefly described analysing its capabilities. Secondly, the new sensor based on coded stripped projection is presented and the principle to infer 3D information explained. Thirdly, the proposed behaviours are explained, and the paper ends with conclusions and further work.

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+ CICYT Program, No. TAP92-0792, 1992/1994 ; TAP95-0426-C02-02, 1994/1996 ; MAR97-0925-C02-02, 1997/1999.

2. The Underwater Robot

The vehicle developed has been conceived for exploration in waters up to 200 meters. The robot has 4 degrees of freedom, corresponding to a) the linear movements of direction b) descending c) Turn, and d) Pitch. These movements are obtained by 4 propellers as shown in fig. 2.1.

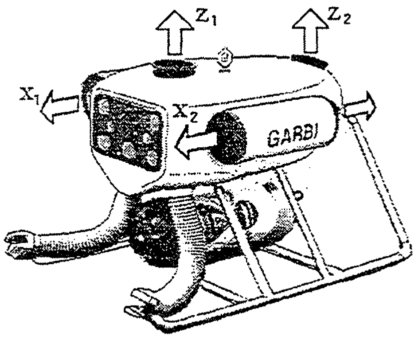


Figure 2.1. The Garbi Underwater Robot.

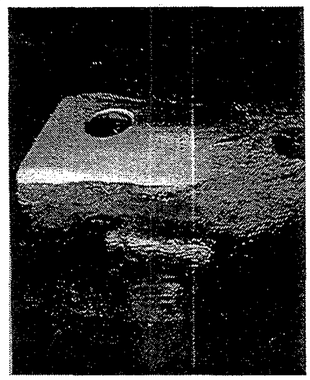


Figure 2.2. Garbi carrying out a task.

In the aim to build a low cost underwater vehicle, GARBI has been constructed using low cost materials, such as fibre-glass and epoxy resins. To solve the problem of resistance to the underwater pressure, the vehicle is servo-pressurised to the external pressure using a compressed air bottle, like those used by divers in immersion missions. The bottle air consumption is required uniquely in the vertical displacements, during which, the decompression valves release the required amount of air to maintain the internal pressure at the same level than the external one. The vehicle is equipped with two arms and thus it can, through tele-operation, perform some tasks of object manipulation. However, the number of degrees of freedom of each arm is reduced to three for commodity reasons, although this sometimes considerably complicates the manipulation[2]. The robot interior has been organised so as to install the following equipment inside : (1) Laser beam projecting system, (2) RGB Camera, (3) PC computer, (4) Power interface for the propellers and the arms motors, (5) Batteries. For more information about GARBI, the reader is referred to the articles[2,4].

3. The new coded stripped pattern projection

In underwater autonomous applications the big challenge is to achieve that the robot obtains 3D information from the undersea environment in order to carry out a task. Most of the sensors used are based on laser beam projection, and 3D information is obtained by triangulation. They are mostly based on single slit projection which acquires a one-dimensional image useful in several applications like obstacle avoidance and vehicle positioning. However, it is obvious that both tasks could be developed more efficiently by projecting more than a single slit as a pattern which permits to take a 2D image.

The projection of regular patterns like a grid or a stripped pattern are subjected to the correspondence problem. The correspondence problem deals with the knowledge of the position from where the light comes when this light is imaged by the camera. Obviously, if the number of slit projections increases there exists the problem of recognising each slit by analysing the camera image plane. Our approach is based on avoiding the correspondence problem by codifying the light projected on the scene. When the light is imaged by the camera, this codification permits to obtain the position from where the light comes (decodification)[11]. Our pattern is based on the projection of four laser beams. The kind of the light projected on the scene and the position of the laser beams related to the camera permit to solve the correspondence problem among the slits. A schema of the position of laser beams is shown in fig. 3.1. The schema shows that each laser beam is placed at a fixed distance from the camera. The beams have also been oriented with a disparity related to the camera in order to increase the resolution. The angle of orientation has been set considering the range of distances that can be measured by light under the sea, which is in the order of 3-5 meters[8].

An structure has been set where the camera and laser beams have been fixed. The structure has been located inside the underwater robot and placed at the front part behind the window. Then, the system has been calibrated.

Equations 1 and 2 describe the camera model which has been used in order to approach the behaviour of the camera to a geometrical model. The camera has been calibrated by a modification of the Newton-Raphson method, modelling lens distortion, and inferring the initial solution by the linear method proposed by Toscani[12].

$$U = X_u - X_d - k_1 r^2 X_d \qquad V = Y_u - Y_d - k_1 r^2 Y_d \qquad \text{where,} \tag{1, 2}$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{bmatrix} \mathbf{R} & t \end{bmatrix} \begin{pmatrix} x_r \\ y_r \\ z_r \\ 1 \end{pmatrix} \qquad X_u = f\frac{X}{Z} \qquad Y_u = f\frac{Y}{Z} \qquad r^2 = X_d^2 + Y_d^2$$

$$X_d = \frac{(u_k - u_0)}{k_u} \qquad Y_d = \frac{(v_k - v_0)}{k_v}$$

Fig. 3.2 shows the relation between the RWCS (Robot World Co-ordinate System) and the CPWCS (Calibrating Pattern World Co-ordinate system). The Calibrating pattern consists of two orthogonal planes. A set of 5 x 4 equidistant squares has been drawn on each plane, defining up to 160 3D points, as we have considered the square vertexes as the calibrating points. Fig. 3.3 shows the 3D square vertexes of the calibrating pattern, the 2D points segmented from the camera image plane, and finally, the parameters inferred by Toscani as the initial guess, and the parameters obtained by the iterative method of Newton-Raphson.

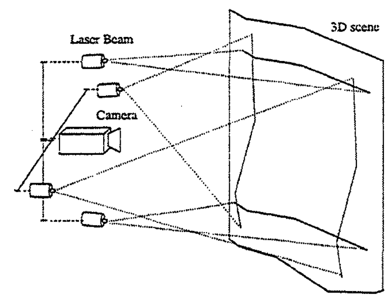


Figure 3.1. The 3D imaging system. Relation between the laser beam and the camera.

The laser beam model has been obtained and calibrated by using the same principle used in camera calibration. However, some geometrical assumptions have to be taken into account. Consider the following fig. 3.4 which shows the geometrical relation of vertical and horizontal laser beams.

In this case, we have only modelled the position and orientation of each laser beam with respect to the world co-ordinate system. Note that, only the t_y and t_x displacement have to be considered for vertical slit laser beam, and the t_y and t_z displacement related to horizontal slit laser beam. On the other hand, we have modelled only a single rotation, the α angle (Pitch for horizontal slits, and Yaw for vertical ones). In order to calibrate the system we have used the projective geometry as all the equations are linear.

Once the system is calibrated, then it can be used to infer 3D information from an unknown scene. We have used the triangulation principle which is widely known[6].

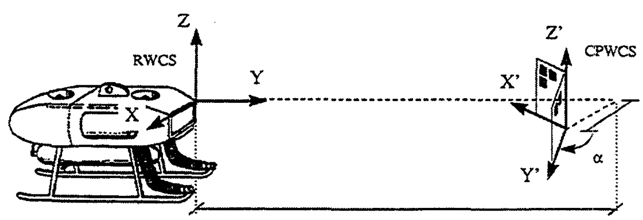
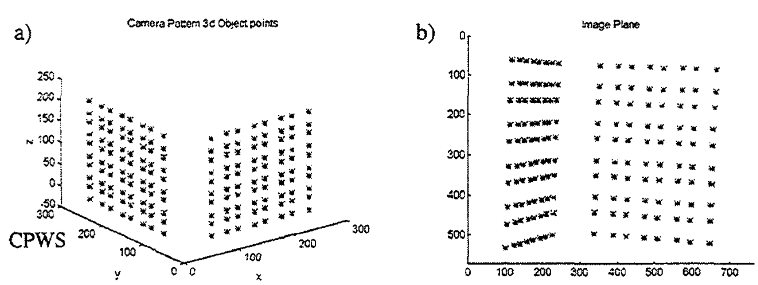


Figure 3.2. Relation between RWCS and CPWCS.



c)	Toscani (initial guess)	Newton-Raphson (after 20 iterations)
α (rad.)	1.66	1.72
β (rad.)	-1.20	-1.25
γ (rad.)	-3.09	-3.03
Tx (mm.)	230.54	212.46
Ty (mm.)	-144.90	-106.40
Tz (mm.)	-298.56	-246.65
f (mm.)	10.00	10.00
ku (pix./mm.)	316.05	345.07
kv (pix./mm.)	332.57	338.86
u0 (pix.)	223.43	340.54
v0 (pix.)	227.25	345.35
k1	0.00	-0.03

Figure 3.3. Camera Calibration : a) 3D points corresponding to the square vertexes of the pattern, b) 2D projective points on the image plane, and c) table shown camera parameters inferred by calibration.

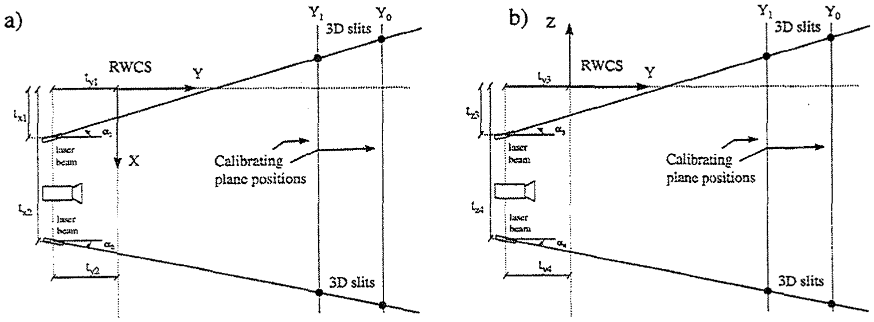


Table 3.1. The orientation and position of the lasers obtained by calibration.

	α (rad.)	ty (fixed) (mm.)	tx or tz (mm.)
laser 1	0.3256	-106.40	153.24
laser 2	0.2567	-106.40	-187.56
laser 3	0.3722	-106.40	253.45
laser 4	0.2789	-106.40	-306.45

Figure 3.4. The geometrical relation between RWCS and laser beams. a) vertical laser beams, b) horizontal laser beams.

By using this sensor, a quite interesting geometrical principle has to be considered. Note that, each slit is coded with respect to a single axe, that is : Both vertical slits are column-coded (X camera axe), and horizontal slits are row-coded (Y camera axe). This fact allows us to decode the crossing points imaged by the camera with respect to both axes, obtaining more accurate results by using least-squares methods. Of course, all the slits are decoded by the system and used to infer 3D information from the scene. However, the experimental results allow us to affirm that the 3D position inferred by the crossing points are more accurate than the position inferred by the other points of the slits.

4. Behaviours Description

GARBI robot is conceived as a ROV. By means of a LabWindows application and a set of peripherals, a user governs the vehicle. Nevertheless, we are interested in endowing the vehicle with a set of autonomous behaviours, mainly for two reasons. First of all, we want to keep the user working-load low enough to allow him to concentrate on the guiding tasks. Secondly, we plan to build a control architecture in order to transform the robot in a truly AUV. As it is well-known, three main approaches are used to build a control architecture for an autonomous robot: deliberative, behavioural and hybrid. Deliberative architectures are based on the sense-model-plan-act principle. In Behavioural architectures a set of autonomous behaviours compete and/or co-operate driving the vehicle to a goal. Finally, hybrid architectures try to take advantage of the two previous ones, minimising their limitations. Usually, they are structured in three layers: (1) the deliberative one, based on planning, (2) the control execution layer (set on/set off behaviours) and (3) the functional reactive layer. GARBI architecture is intended to be hybrid.

Two main issues are related to the implementation of robot behaviours: how to define them and how to merge them in order to solve potential conflicts. With the aim of using a well-defined theory, we propose the use of fuzzy logic. Other works have been done with the same intention. In the field of mobile robotics, there are some works[13,10] quite close to our point of view, and, in the field of underwater robotics, there are some architectures like the PRSA[7] which allows the definition of behaviours through fuzzy logic. The main advantages here are:

1. The if-then rules used for behaviour definition are close to human reasoning (simplification of behaviour description).
2. Instead of inhibiting some behaviour by another with higher priority, behaviours are merged through aggregation, and final response is obtained by defuzzification, so, behaviours' responses are weighted by fuzzy logic algorithm in order to obtain the final response.

Three behaviours have been tested. A WayPointFollowing behaviour is a 2-D simple auto-pilot which drives the vehicle to a goal position. The ObstacleAvoidance behaviour uses the distance to the object and the hit angle to produce a repulsion force. Finally, a self-positioning behaviour allows to keep the robot stable in front of a pipe or some other kind of object. The two last behaviours make use of the proposed sensor.

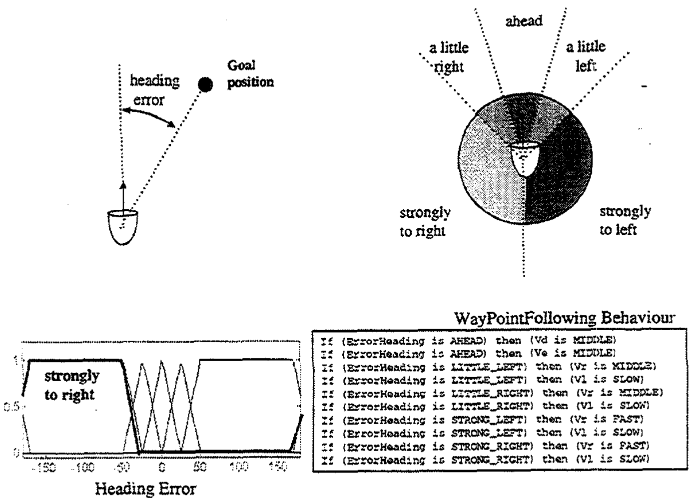


Fig. 4.1. WayPointFollowing behaviour based on the Heading error.

4.1 WayPointFollowing Behaviour

In order to test the object avoidance, a simple 2D WayPointFollowing behaviour has been built. Tested in shallow water, the WayPointFollowing behaviour drives the robot to a XY goal position. The behaviour tries to reduce the heading error (see fig.4.1) between the robot orientation and the heading needed for driving the robot to the goal position. Depending on the heading error, five different zones have been defined. When the error is located at the *ahead* zone the robot must go straight ahead. When the heading error is located at the *little left zone* the robot must turn a bit to the left, and so on. For each zone, a fuzzy set has been defined, and two rules have been used for defining the response of the starboard and port propellers. Obviously, there exists a fuzzy boundary within these regions.

4.2. ObstacleAvoidance Behaviour

The obstacle Avoidance behaviour is based on two input parameters, the *hit angle* and the *obstacle distance* (see fig.4.2 which shows the fuzzy implementation of this behaviour using four rules). The priority of object avoidance rules is higher than the priority of WayPointFollowing behaviour so, this rules dominates the vehicle when it is near an obstacle. Figure 4.2 shows a test experiment where the robot, located initially at point (0,0) avoided an obstacle located at point (10,0) where headed towards the goal point (30,0).

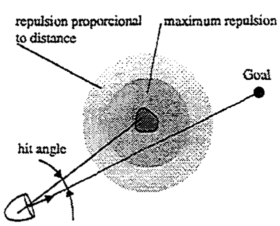


Fig. 4.1. Obstacle Avoidance principle.

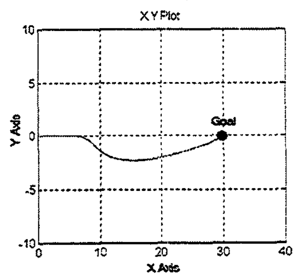
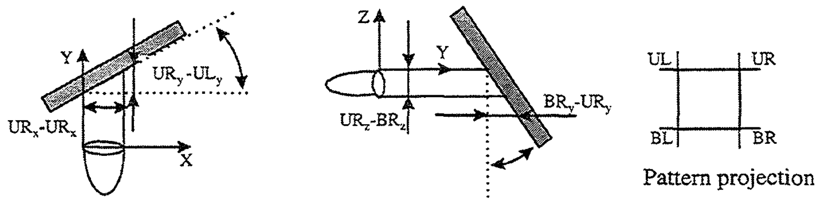


Fig. 4.2 Test of the Object Avoidance Behaviour.

Fig. 3.4 Fuzzy implementation of the obstacle avoidance behaviour.

4.3. Vehicle stabilisation

In tele-operation tasks like pipe inspection, it would be interesting to have available a stabilisation behaviour capable of keeping the vehicle stable in front of an object. This is why we are actually working on the definition of yaw and pitch stabilisation behaviour. Fig 4.5 shows how the 3D information obtained from the sensor may be used to calculate the yaw and pitch angle between the robot and the object.



$Yaw=Atan2(UR_y-UR_y,UR_x-UR_y)$ $Pitch=Atan2(BR_y-UR_y,UR_z-BR_z)$

Fig. 4.5 Yaw and Pitch detection.

Conclusions and Further Work

This paper describes a new 3D sensor based on the projection of laser light and computer vision. The system has been calibrated and used to infer 3D information from the scene. This sensor has been proposed in the aim of improving GARBI to an AUV, then, two behaviours have been defined : WayPointFollowing and ObstacleAvoidance. Further work concerns the increase of the slits projected on the undersea scene in order to extract more 3D information, especially for object reconstruction, and the implementation of the VehicleStabilisation behaviour.

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