Self orientation of robot in zero gravity environment using optical camera and reaction torque of electric motors

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Abstract

This project aims at the self-orientation of a robot in zero gravity and similar environments towards a given object, stored in its memory as reference object, using an optical camera. The robot has been programmed to self-orient until the object is focused in the centre of the image captured. The positional error of the object in the image captured to its position in a reference image is used to drive the attitude controlling system. This system comprises of a circular disc of a suitable mass attached to a motor to generate a reactive torque causing the robot to rotate in the opposite direction. The final tests carried out in water demonstrated the self-guided orientation by the robot towards the reference object; however, further work needs to be carried out to bring about accuracy and precision in its functioning.

Keywords

Optical sensing, PWM, Reaction Torque, Self Orientation, Zero gravity

1. Introduction

Unmanned space missions are preferred, as outer space constitutes a hostile environment to humans and also due to the high expense incurred to provide them safety and transportation. Taking these factors into consideration, robots are generally preferred and used during such missions (Thro E., 2003). The mMain function of a robot in most of the space missions is repairing and maintenance of the spacecraft on its outer surface. In the most advanced cases, robots may have to work autonomously e.g. Spirit, Opportunity (Mars exploration mission, 2005). These robots are expected to explore the environment, analyse and take appropriate actions by themselves.

The primary aim of this project, the Zero G robot, is to develop a technique for self orientation orient itself in the absence of gravity and free space. This project was initiated with an implementation of a combination of various concepts, previously used by various workers independently and thereby resulting into a new concept in robot building which has explained in section 2. Section 3 describes the scope of this project which has been to build a robot that will perform tasks such as acquiring details of its orientation and then self-orient towards the targeted object. In order to build such a robot, an optical camera was used to perform the function of a visual sensor which helped the robot to identify the target object. After knowing the orientation the robot aligns itself in the desired position using the reaction torque of an electric motor as a controlling element. The design of the motor assembly is described in section 4 and test of the performance of the system are described in section 5, in the case of floating robot.

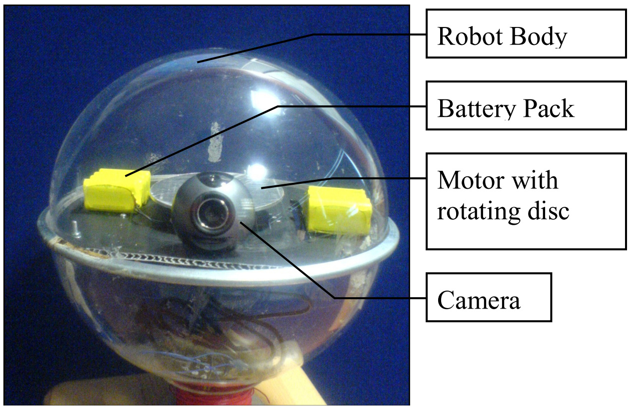

Fig. 1 Robot body showing layout of the components mounted in it

2. Literature Review

2.1. Vision-based sensing of orientation

There are number of ways for a robot to achieve self-orientation in the space where there is no surface to get support from. The conventional method of sensing the orientation in zero G environment is by using gyroscopes (Wikipedia, 07/09/07). Various drawbacks in using gyroscopes include their bulkiness and a need to keep them rotating continuously. Moreover they sense only 'change' in the orientation and not the absolute orientation. Another way of achieving a self-orientation sensing is by using electrical and magnetic fields (Patent Storm, 2007b). These fields are generated by the components in the robot itself. However, there is uncertainty in this approach, when the situation arises to work in a strong external magnetic field or electrical field wherein sensors may get confused between the reference field and the external field.

Vision-based approach used for the self-orientation has many advantages. This approach is found to be similar to that of the method used by *Atkins et al., 2002*. In their research, the robot was made to follow the astronaut in space as a helper, wherein the astronaut was used as a target object. The task of following was achieved by the vision-based approach, which showed appreciable results and demonstrates a good scope in the future.

Submarine activities is another field wherein the conditions are similar to that of space application, as a body under water faces less drag, gravity due to the buoyancy, hence most of the applications for submarine and outer space explorations, robotics use a similar approach. Keeping of an underwater station is another application of the vision-based control and orientation, which was used by *Wang et al. 1994*. In this approach, workers have used a computer vision to monitor and maintain the position and orientation of the underwater station.

2.2 Orientation of robot

A conventional method used to bring about motion to an object in the space or zero gravity is to use a thruster. Shen, *et al*., 2003, have used thrusters to give a movement to different bodies orienting in a space and willing to attach with each other. But one drawback in using this technique is the need to provide a reservoir of a fuel for the thruster which increases the overall weight of the body. Moreover, as weight is an important criterion for a robot, the fuel stock needs to be limited which minimizes the life of the robot.

Another way of achieving the task of movements in a space is by using reaction torque brought about by an electrical motor. This system is being more commonly used in attitude control of satellite. NASA has developed special reaction wheel, which will control the attitude of the small satellite more precisely (NASA, 10/07/07). *He Ping et al.,* (AP – MCSTA, 2007) have reported that a reaction wheel operates 2.5 times better as compared to the torque method if its speed is used to control the attitude of a satellite. The advantages on using a reaction wheel system include the simplicity of the structure, minimal maintenance and economic feasibility as compared to thrusters.

3. Principle of operation

The robot captures the images of the surrounding with the help of an optical camera and compares these images to a reference image stored as a standard in its memory. On detection of a mismatch in the image, the robot calculates the positional error between the two images. This error will then be used to generate appropriate signals, which will drive the electric motor in a desired direction so that using reaction torque (Searle, 2002) generated by electric motor, the robot body can be moved until the positional errors in the two pictures are nullified

The optical camera inside the robot, takes the video of surrounding. A program was written to detect 'yellow' colour in the video, which can be changed by changing the value used for the colour in the program. As soon as the program detects yellow coloured blob in the picture, it imposes a red cross on the centroid of the blob of that colour. Subsequently, the program calculates the position of that red cross on the screen and calculates the difference between the coordinates of centre pixel of the screen and that of the red cross. The aim of this program is to keep that blob and hence the red cross in middle of the screen. If the blob is detected on the left of the middle region of the screen, the program will call the function to turn the motor in the direction opposite to that of blob and vice a versa. The program runs continuously keeping a check on the position of the ball and repeats the above cycle.

On receiving the signals from the program, the motor starts rotating in a specified direction until the red cross reaches the middle region of the screen. The spinning of a circular disc with an appropriate mass attached to the motor by the shaft generates sufficient reaction torque on the robot body. This is explained below as to how the reaction torque produced by the motor rotates the robot body and orients it.

According to Newton's second law of motion,

$$F = ma = m \cdot \frac{dv}{dt} = mv - mu = \text{rate of change of momentum} \quad (1)$$

Since, 'mv' and 'mu' are momentum of body

Where,

F = force exerted on body; *m* = mass of body; *a* = acceleration of body

v, u = final and initial velocities of body

The formula for rotating movements analogous to that of linear movements is,

$$T = I\alpha = MR\alpha \quad (2)$$

Where,

T = unbalanced torque; **I** = polar moment of inertia of mass about the axis of rotation; **M** = mass of body; **R** = radius of gyration of the mass with respect to the axis of rotation; α = angular acceleration

It is evident from the above equations that with increase in an acceleration or final velocity (as initial velocity is 0), there is an increase in force generated that acts on the robot body (Hannah and Hiller, 1999). Figure 2 shows a graphical representation of the relation between motor speed, reaction torque and robot body speed with respect to time.

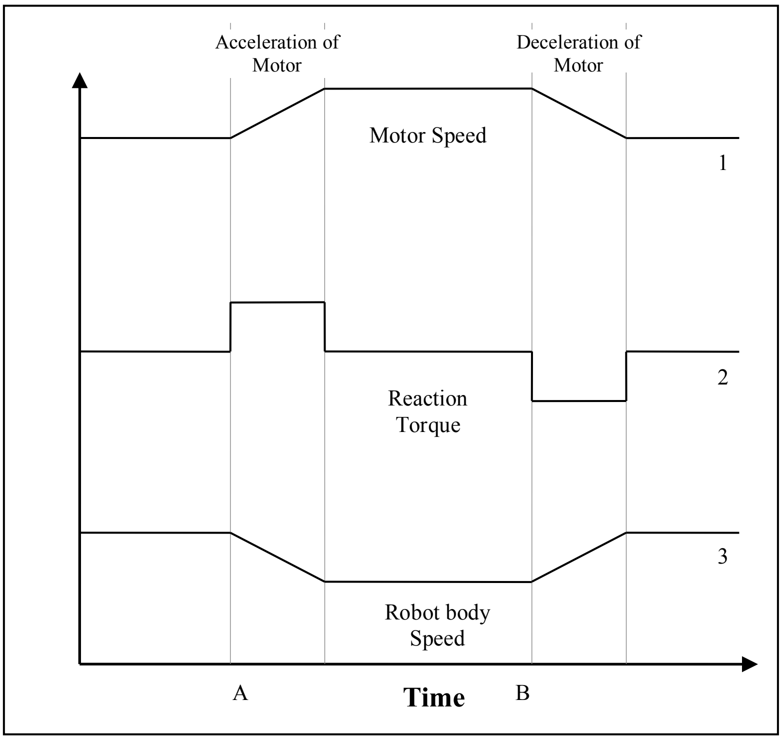

Fig 2: Graphs showing speed of motor, robot body and reaction torque on robot body during the process of finding coloured pixel and keeping it in the middle of screen
A: Found coloured blob in the screen, motor started rotating
B: Coloured blob arrived in the middle region of the screen, hence motor is stopped

When the program finds blob of colour in the picture (line A- fig. 2), it gives a command to the motor to rotate in a direction opposite to the yellow coloured blob. On receiving signals from the program, the motor accelerates from stationary position to a uniform speed (line 1). As explained in the equation (2), force is exerted only during acceleration. This can be seen in the middle line of the graph that reaction torque is present only during the acceleration and deceleration period of the motor. As observed no force is exerted even if the motor keeps rotating with a continuous speed. This reaction torque exerts a force on the robot body due to which the robot body starts rotating in a direction opposite to that of the motor and hence towards the coloured blob (line 3). The robot body would accelerate as long as motor accelerates and when the motor reaches a constant speed there would be no force acting on the robot body but due to inertia the robot body would keep rotating with a uniform speed.

When colour blob reaches the centre of the screen (line B), the program commands the motor to stop. The motor does not stop immediately, but decelerates gradually and during the process a reaction torque is generated on the robot body in an opposite direction. This helps to bring the robot body to a halt; without which it would continue rotating in the same direction due to the absence of any resisting force. The robot body makes over travel due to inertia, displacing the coloured blob from the middle region of the screen. This triggers the program to drive the motor in an opposite direction and the whole procedure repeats, making the robot body turn in opposite direction. After a few such oscillations robot body would eventually focus and maintain the blob in the middle region of the screen.

Figure 3 shows some of the examples of colour ball detection. The camera used in this project is 'Logitech 861205 – 0000' Quickcam Pro – 5000'. The operating system available on the Colibri board is Windows CE 5.0. '*Embedded Visual C++®*' language was chosen for writing codes for robot. The flowchart for this program is explained in Fig. 4. The codes used for this robot are modified from the codes for Butler Bot robot, which was developed earlier and have similar functionality of camera in some aspect.

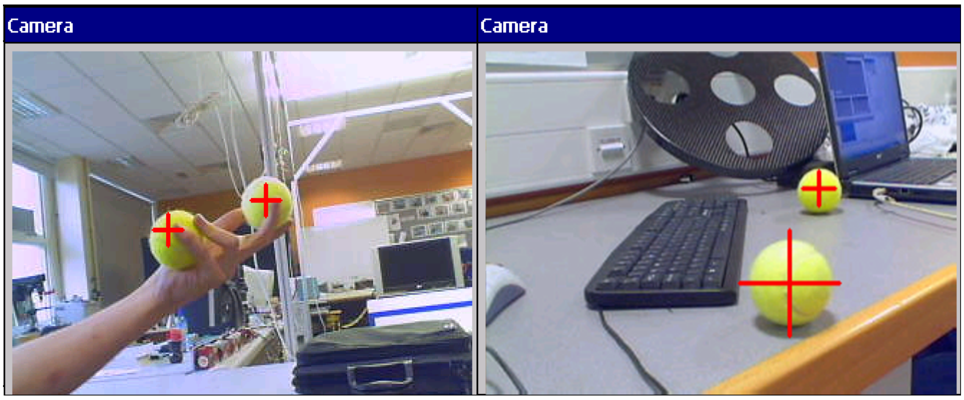

Fig. 3 Colour ball detection using optical sensing

4. Modification and operation of DC motor

To control a DC motor from any digital circuit requires an H-Bridge (Dallas Personal Robotics Group, 2002), whereas servo motors can be controlled directly from suitable digital circuit. Servo motors are equipped with the potentiometer, gear train and its driving card with H- Bridge, which can be driven directly by PWM signals. The servo motor was modified to make it rotate through 360° and continuously by removing its driving card from the motor along with its gear train and potentiometer (Ranchbots, 2007). The potentiometer on the driving card was replaced with equivalent resistor on the card. Also, the motor was isolated from the gear train so that it can give a higher speed. The DC motor in the servo was replaced with the one which was used in the robot, along with the mass attached to it. The signal from the Colibri board, which goes to the motor, comprises of the following three parts; scale factor for the internal 13 MHz clock of the Colibri, suitable frequency for the signal and the duty cycle for ON time period. Fig. 5 shows the modification done on the control card of the servo motor and connection made with normal DC motor, both mounted on the robot body.

5. Testing and results

In order to test the working of the robot, it was placed in a water tub, around which a circular scale was drawn in order to measure the positions of ball and camera. Fig 6 shows the set up for testing the working of the robot. A light weight stick attached to the camera functioned as a pointer. A ball was held at the edge of the screen of the camera of the robot. On sensing the

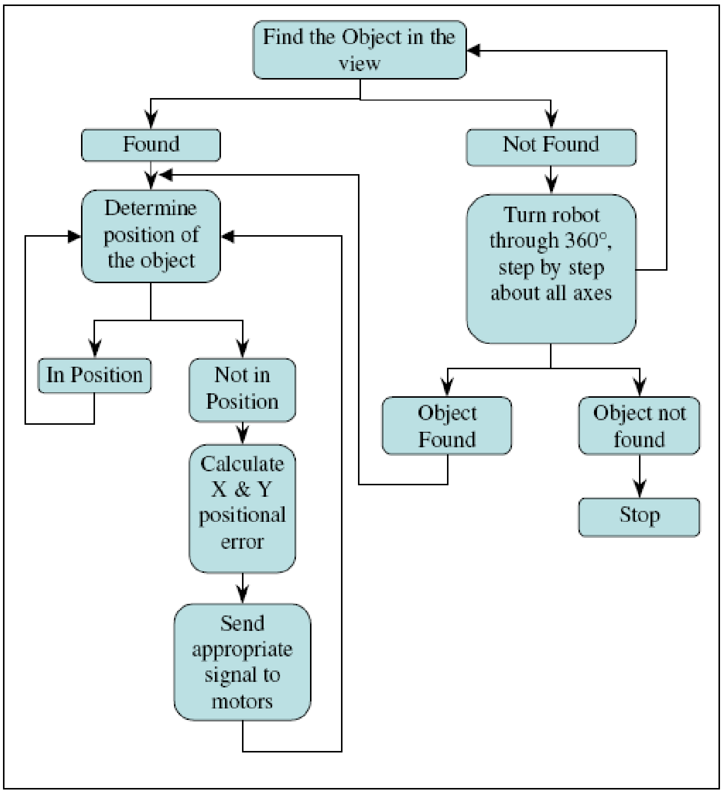

Fig. 4 Flowchart for program of robot

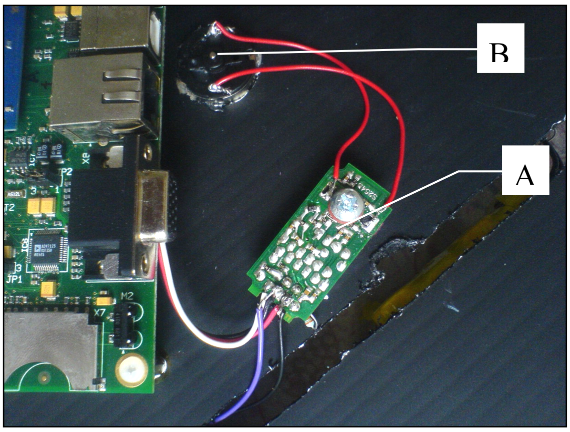

Fig. 5 Modified servo motor card and normal DC motor attached to it, whole assembly mounted on the robot
A: Modified Servo control card; B: Normal DC motor attached to the servo card

yellow colour blob of the ball, the robot turned towards the ball. The working of the robot was tested by holding the ball at various positions and distances. This was recorded with the help of a video camera, shown in figures 6 and 7.

The output of the vision software was satisfactory wherein the camera detected the colour in the picture and could easily point out its location on the screen. It placed a red cross on the blob of the colour.

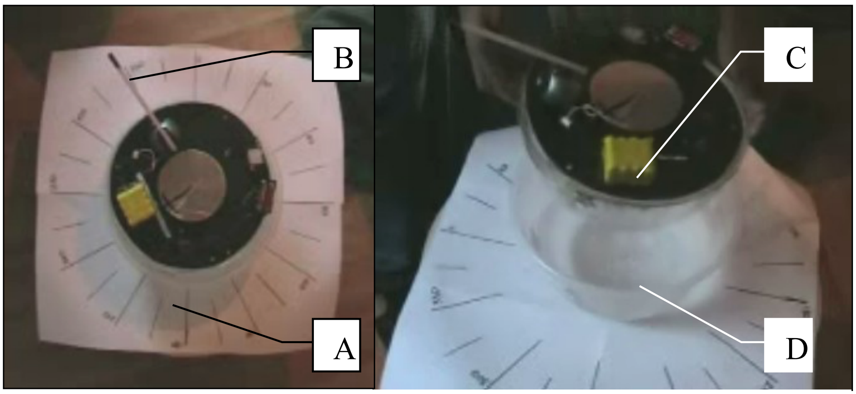

Fig. 6 Test setup for the robot with circular scale
A: Circular scale, B: Pointer attached on the camera
C: Floating robot body D: Water tub

Even though reversing of the rotation of the robot was done, its speed in reverse direction was not as high as that in forward direction. This limited the testing of performance of the robot in one direction only, i.e. on the right side of the robot. When ball was held at left side of the robot, the motor rotated very slowly in reverse direction, making a very slow movement of the robot body and unable to reach the ball.

Graph in fig. 8 shows the result of the test carried out and how robot oscillates about the position of the ball and then eventually comes to the required position.

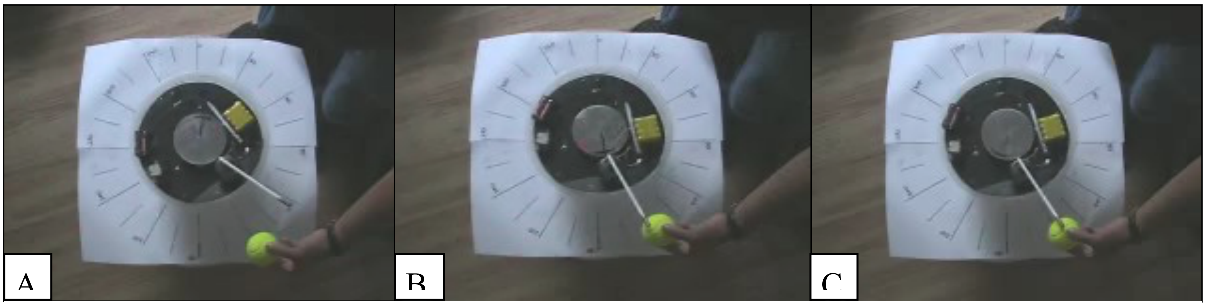

Fig. 7 Testing of Robot
A: Starting position of robot and ball; B: Maximum over travelled position; C: Final position of the robot

6. Conclusion

In this robot optical sensing and use of reaction torque of an electric motor are the new techniques used. After looking at the results got from the testing of the robot it can be concluded that the robot can work using these two techniques. Though at this stage this robot is not very precise and accurate, it can be made so using still high standard components and writing codes especially for this robot. But overall results of the project are positive suggesting that further development in the project can be very useful.

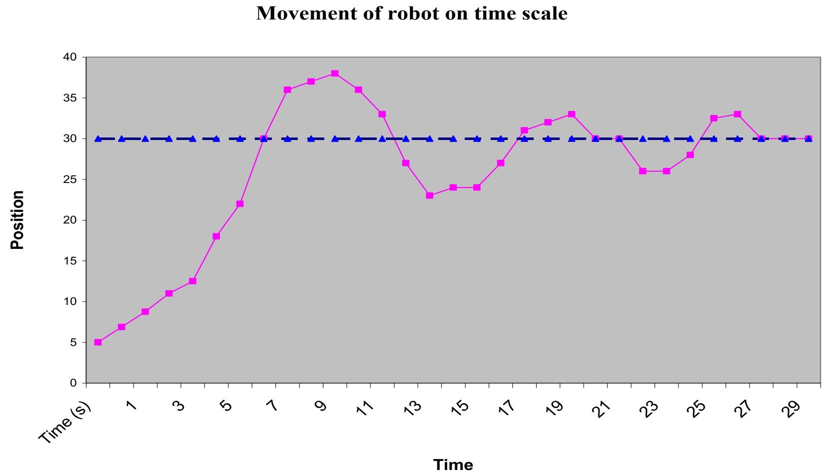

Fig. 8 Graph showing movement of the robot on time scale

Position of the ball

Position of the Robot

References

AP - MCSTA (2007), http://www.apmcsta.org/File/doc/Conferences/6th%20meeting/He%20 Ping.doc, (19/09/2007)

Atkins E.M., Lennon J.A., Peasco R.S., (2002), 'Vision-based Following for Cooperative Astronaut-Robot Operations' *IEEE, Aerospace Conference Proceedings,* (1): 215-224

Dallas Personal Robotics Group (2002) http://www.dprg.org/tutorials/1998-04a/, (19/06/07)

Hannah J., Hiller M. J. (1999), *Mechanical Engineering Science,* Longman, Singapore

Logitech (2007), http://www.logitech.com/index.cfm/webcam_communications/Webcams/ devices/243&cl=gb,en , (27/06/2007)

Mars rover exploration mission (2/03/2005), http://marsrovers.nasa.gov/technology/is_autonomous_mobility.html, (25/06/2007)

NASA (10/07/07), http://www.sti.nasa.gov/tto/spinoff1997/t2.html, (18/09/07)

Ranchbots (2007), http://www.ranchbots.com/club/papers/Modifying%20Hobby%20Servo %20Motors%20for%20Continuous%20Rotation.pdf, (26/06/07)

Searle D. G. (2002), *Guide to European Electric Motors – Drives and Controls,* Professional Engineering Publishing, Great Britain

Thro E., (2003), *Robotics: Intelligent Machines for the New Century,* Facts on file science library, USA

Toradex (26/04/2007), http://www.toradex.com/downloads/Colibri%20PXA270%20 Datasheet.pdf, (01/03/2007)

Wang H., Marks R.L., Lee M., Rock S., (1994), 'Automatic Visual Station Keeping of an Underwater Robot' *IEEE, In: Oceans' 94.'Oceans Engineering,* (2): II/137 – II/ 142