Design and Development of Novel Two Axis Servo Control Mechanism

Shailaja Kurode, Chinmay Dharmadhikari, Mrinmay Atre, Aniruddha Katti, Shubham Shambharkar

Abstract

This paper presents design and development of a novel two axis servo-control mechanism. A sphere is used to which a a panel is coupled which is to be driven about two axes mutually perpendicular to each other. The two axis control applicable for the solar panel is sought. A prototype is developed. Two limited angle servomotors are used to drive the wheels which generate the necessary friction torque for the spherical ball to rotate about the two mutually perpendicular axes. A control algorithm is developed and verified in simulations using Proteus software. The complete setup is developed. The controller is validated experimentally using micro-controller.

Keywords: Servomechanism, Two axis control, Spherical ball drive.

1 Introduction

Precise tracking and positioning finds applications in many areas such as robots, missile, spacecraft, radar, automated industries. Solar panel used in spacecraft need to track sun so as to generate maximum power. Even the solar panel used to generate power at ground station need to rotate about east-west axis and about north-south axis. Different mechanisms have been reported, see for example [1, 2, 3] and the references therein. Herein we introduce a novel model for precise two axis control along the axes in horizontal plane which can be used for solar panel control. Due to fast depleting conventional resources the interest in using solar energy is increasing. However the sun's position with respect ro earth does not remain constant. Therefore maximum amount of energy cannot be obtained with fixed solar panels in a particular direction. Also earth's axis gets shifted towards north and south during 'summer solstice' and 'winter solstice' respectively. Hence it is needed to control the panel along both axes that is 'Azimuthal axis' and 'polar axis'. In [1] stepper motors have been used to achieve two axis control. Sun's position is tracked by using sensor and feedback loop

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in [2, 3]. Although there are many approaches for two axis control, most of them include the design that emphasize a control along vertical axis and one of the horizontal axes. Moreover one motor changes position of the other motor, therefore one drive loads the other. This motivated us to develop a design in which control is along both horizontal axes avoiding loading of one drive by the other. The proposed model aims at fixing the motors on the particular base simplifying the design. Further the systems reported in literature use sensors that detect the sun position. Use of sensors increases the cost. Studies concerning the sun's apparent movement concluded that it is possible to predict the relative position of the earth and the sun every day and every hour with accuracy. Using the micro-controllers with programmed values of the angle of the panel and defining the time between two successive positions, it is possible to control the angular position of electric motors to drive the shaft.

This paper is organized as follows: The design of the mechanical assembly, design and development of mechanical model is discussed in Section 2. Section 3 covers building of logic of the control algorithm to achieve two axis servo control. Section 4 presents simulation and experimental results. Section 5 concludes the findings of the work.

2 Design of Two Axis Servomechanism

Two servo drives equipped with control leads for two axis servo control [4]. The two axis servo drive necessary for solar panel is considered here. To capture maximum amount of energy, solar panel has to be moved in both the directions that is east-west and north south. The two axis servo control is employed by using two servo motors placed orthogonally to get controlled movement along both the axis.

2.1 Idea of novel mechanism

In case of ball-wheel mechanism used in a mouse of a computer, when the ball moves, two wheels touching the ball rotate due to friction. Thus any motion of a ball is sensed by the wheels as a trajectory which is mapped into the two axes X and Y due to their orthogonal placement. We explored this idea in a reverse manner by changing the mechanical structure. The decoupled wheels touching to the sphere can be rotated by using two DC servo motors to get independent two axis control. These wheels will make the sphere to move. Thus any X-Y trajectory can be decoupled into X and Y axes and the command can be given to servo motors corresponding to X and Y axes values. The solar panel or any radar system can be mounted on the sphere. This will give two decoupled axis control in upper hemisphere.

2.2 Design of mechanism

The schematic of the proposed model is shown in Fig.1. The motors are equipped with the wheels which are in touch with the sphere. To have proper friction between sphere and rollers both are coated with rubber. Due to friction between the surfaces coated with rubber, a friction torque is produced which drives the sphere. The sphere is comparatively big so that solar panel can be mounted on it and the center of gravity of sphere and panel assembly does not shift significantly during motion. Also it is designed to be hollow to reduce weight. The sphere is made to rest on cup like structure made up of ball bearings (caster wheels) to avoid loading of roller (wheels) with dead weight of the system so that load on motor will be reduced and the sphere will rotate freely about two axis without slipping out.

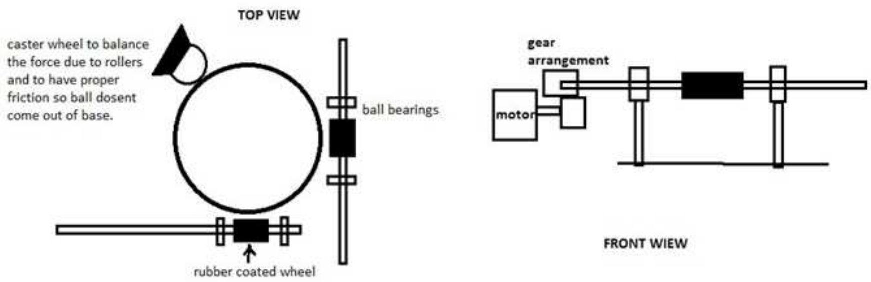


Figure 1: Schematic of the proposed model

2.3 Development of assembly

Development of the assembly includes actual building of mechanical model in steps. A wooden base of dimensions of $500 \times 400 \times 28$ mm is cut into a shape of circle of diameter 230 mm with thickness 28 mm. By turning process on lathe machine, a slanted bore is made at an angle of 35 degrees measured from upper surface to inner side of the wood. Six caster wheels are fitted on slanted cup shaped structure at equal distances. These castor wheels provide platform for resting and free movement of a rubber coated sphere. A hollow steal coated cast iron sphere of diameter 150 mm and weight 500gm is considered. The sphere is processed by sand blasting and is coated with natural rubber in rubber lining workshop. The coating is 10 mm thick making the diameter of coated sphere 170 mm. Sandering is done by sandering machine to reduce the thickness and making spherical surface less rough and more even. This coated and sandered sphere is of 160 mm diameter and rests on the caster wheels of base assembly. Now for driving assembly, two mild steel rods are of diameter 6 mm and length 220 mm are taken. The inner diameter (ID) of the ball bearings was same as that of diameter of rod. Ball bearings are fitted at precise distances from the both ends. The ball bearings are fitted in acrylic plate of the dimensions as shown in Fig. (2).

2.4 Design of drive mechanism

The drive mechanism consists of wheels, shaft, ball bearings, and couplers. The top view of driving system is as shown in Fig.1. The wheel is to be fitted in rod. Two ball bearings are fitted tight on either side of wheel. The ball bearing are fitted in an acrylic frame such that the assembly consisting of the shaft and the wheel can be mounted

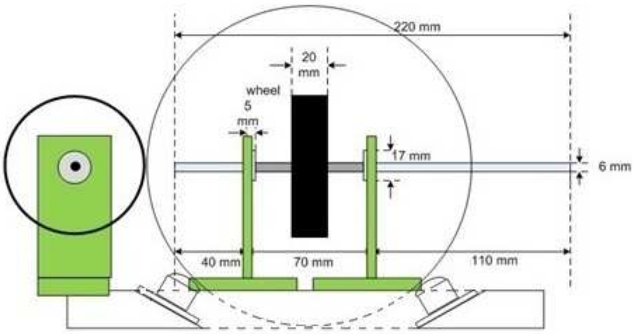


Figure 2: Model assembly

and the height of the frame is chosen so that the wheel touches exactly at the center of the sphere. The motors are connected to the shaft by couplers. The shaft assembly is so mounted such that wheels touch the sphere with appropriate pressure and creates enough friction between sphere and wheel. A caster wheel should be mounted in such a way so as to balance the resultant force by wheels as shown in Fig.1. The diameter of wheels is so chosen that the panel mounted is not obstructed by the wheels and the sphere to wheel ratio is at least 1:2. Also they should be large enough to sustain the torque as torque is product of force and radial length. The parameters are:

$$\begin{aligned}
\text{Radius of sphere, } R &= 80mm \\
\text{Distance between top of panel and center of sphere, } d &= 80mm \\
\text{Weight of solar panel} &= 0.5Kg \\
\text{Weight of rod} &= 0.1Kg \\
\text{Weight of coated sphere, } W &= 0.7Kg \\
\text{Total weight of assembly} &= 1.3kg \\
\text{Coefficient of friction, } k_f &= 0.44 \\
\text{Acceleration due to gravity} &= 9.81m/s^2 \\
\text{Torque to drive sphere, } T_s &= WgR = 1.020Nm \\
\text{Torque required for motor} &= \frac{T_s}{k_f} = 2.316Nm.
\end{aligned}$$

Servomotors from robokits india having torque specification 3.5 Nm are chosen. Servo Motors are DC motors equipped with a servo mechanism for precise control of angular position. The RC servo motors usually have a rotation limit from -90^0 to 90^0. The chosen servomotors are DC motor connected with a gear mechanism which provides feedback to a position sensor essentially a potentiometer. as shown in Fig.(3). Motor 2 is used to achieve East-west motion. Motor 1 is used to get north-south motion. From the gear box, the output of the motor is delivered via servo spline to the servo arm. The potentiometer changes position corresponding to the current position of the motor. So the change in resistance produces an equivalent change in voltage from

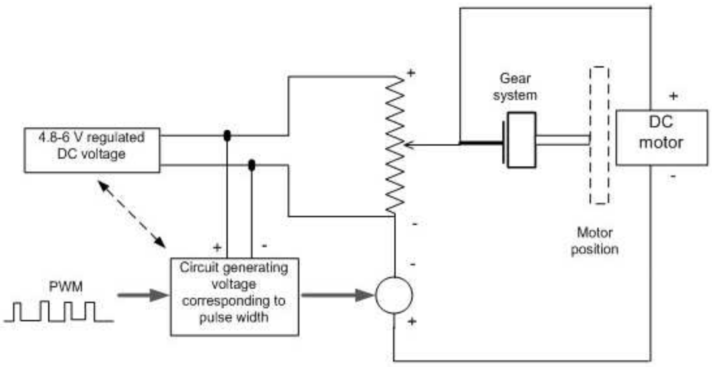


Figure 3: Servomotor with feedback

the potentiometer. A PWM signal is fed through the control wire. The pulse width is converted into an equivalent voltage that is compared with that of signal from the potentiometer in an error amplifier. A sequence of such pulses (50 in one second) is required to be passed to the servo to sustain a particular angular position. It has been found for a chosen servo with a pulse range between 0.6 to 2.4 milliseconds for 0 to 180 degrees, a pulse width of 1 milliseconds gives an angular position of 40 degrees.

3 Development of Control Algorithm

The main objective is to develop control algorithm for replication of actual solar tracking. A control algorithm should yield the desired position control of a panel which is to be mounted on the vertical axis of the sphere. ATmega 16 microcontroller is used for the algorithm implementation and the code is developed using winAVR software. The C code is used to program the microcontroller. RS232 interface is used to establish user interface. A micro-controller is used to generate necessary control in terms of PWM pulses. The pulse width is controlled by controlling delay routine. It has been found that the servo motor takes angles between -90^0 to $+90^0$ for PWM signals of 600 μsec to 2400 μsec width respectively. So we have range of 1800 μsec for 180^0. Thus the delay required to maintain the panel at center without tilt is $1500\mu sec$. Fig. (4) illustrates the computation of delay which is used for generating the necessary PWM signal for both the motors. To achieve position P_1, motor 1 should attain 'b' and motor 2 should attain 'a'. The required delays are

$$\begin{aligned}\text{Delay for 'a'} &= 1500 + 900\cos 35 = 2237.23\mu sec \\ \text{Delay for 'b'} &= 1500 - 900\sin 35 = 983.78\mu sec.\end{aligned}$$

Thus corresponding to the commanded position the delay is set in a delay routine to generate the necessary PWM for driving the servomotor. For replicating the Sun tracker, the reference position which is the axis of the sphere on which the panel is mounted need to acquire East-most position, and further move in West direction in 8

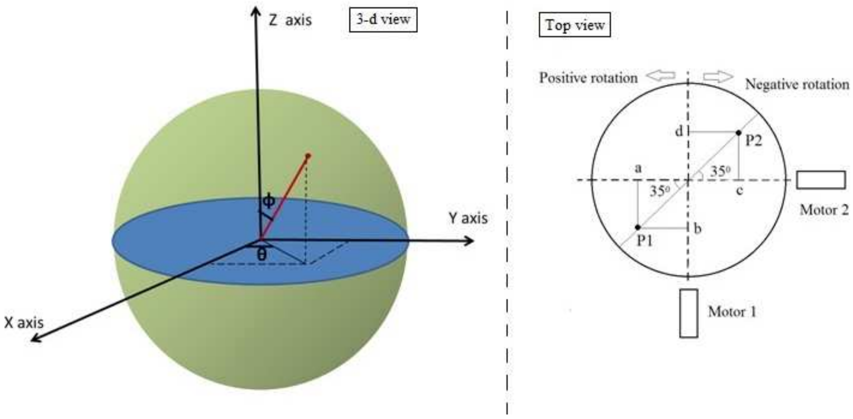


Figure 4: Computation of delay

equal steps to acquire West-most position. Number of steps and the rate can be adjusted by controlling the delays in the control algorithm. The information from solar table can be used to decide the no. of steps and and the rate. Once West-most position is attained, panel takes East-most position. The axis is shifted 30^0 in North from reference axis(i.e. replicating summer solstice). Then it acquires West-most position in 7 steps. Now, the panel is made to move in same manner on the axis shifted 30^0 on South side (i.e. replicating winter solstice).

4 Simulation and Experimental Results

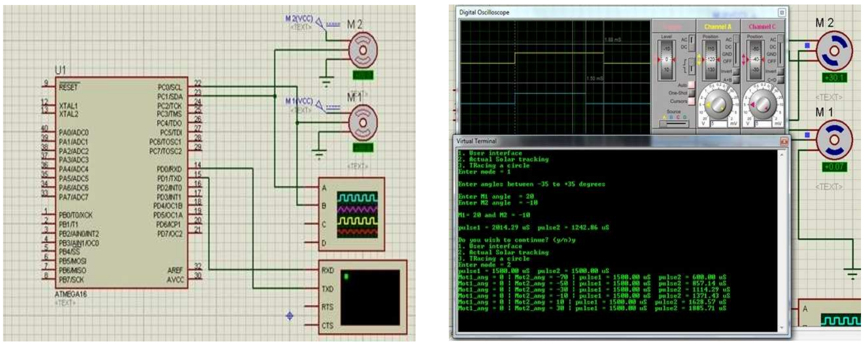
The control algorithm was tested in simulations which follows two decoupled Servo motor control by using Proteus software. Both servo motors are powered by 6 volts DC source and are controlled by PWM signals generated by micro-controller ATmega16. Fig (5) shows the simulation model and the resultant pulses on the scope.

4.1 Experimental results

The complete prototype is shown in Fig (6). The angular steps to replicate sun tracking were predefined in micro-controller program. DC Power Supplies (6 V, 5A) are used to drive servo motors. The control signals are generated on PC_0 and PC_1 output pins and connected to control inputs of servo motors M_1 and M_2 respectively.

4.2 Validation of exact positioning

After commanding a particular position as a reference through RS232, a control is executed. The observed position was measured using the calibrated stand. It has been found that the desired position is achieved with the accuracy of the order $90 - 95\%$.



(a) Model simulated (b) Generated Pulses.

Figure 5: Simulation results

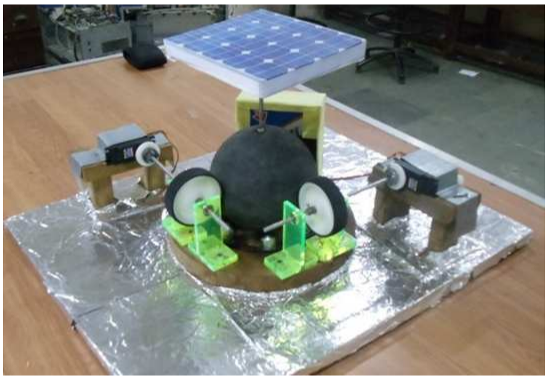


Figure 6: Prototype of two axis servo-control mechanism

Table (1) depicts the commanded position sequence and the experimental control signal that generates necessary PWM for servomotor. The θ_1 is position command for motor M_1 which drives the sphere along North-South. The corresponding control gets available at PC_0. Similarly θ_2 is position command for motor M_2 which drives the sphere along East-West and the corresponding control gets available at PC_1. It has been found that the commanded position sequence is achieved with the accuracy of $90 - 95\%$. Effect of adding the disturbance was also studied. It has been found that, the desired position is achieved even in the presence of the disturbance. This is valid as long as there is no slippery motion between sphere surface and wheels. When a disturbance is applied, the motor shaft moves to change the position of the potentiometer. This changes potentiometer resistance and so the voltage creating a voltage difference between reference voltage generated due to pulses and potentiometer voltage causing motor to run and obtain the desired position. This makes voltage difference zero and accurate position is obtained even after applying disturbance.

Table 1: Experimental results

(a) Motion along East-west with $\theta_1 = 0$ and $PC_0 = 1500$

θ_2	PC_1
0	1500
-70	600
-50	857.14
-30	1114.29
-10	1371.43
10	1628.57
30	2085.71
50	2142.86
70	2400

(b) Motion along East-west with $\theta_1 = 30^0$ and $PC_0 = 1731.43$

θ_2	PC_1
0	1500
-66	651.43
-44	934.29
-22	1217.14
0	1500
22	1782.86
44	2065.71
66	2348.57
0	1500

(c) Motion along East-west with $\theta_1 = -30^0$ and $PC_0 = 1268.57$

θ_2	PC_1
0	1500
-66	651.43
-44	934.29
-22	1217.14
0	1500
22	1782.86
44	2065.71
66	2348.57
0	1500

5 Conclusions and Discussions

The prototype to achieve the two axis control using novel servomechanism has been developed and validated experimentally. In the proposed mechanism, both the motors remain fixed at their position without loading each other. It has been observed that actual angular positions taken by the sphere and those obtained in the simulations were matching. Two axis control over a hemispherical region of diameter 700 mm has been obtained. Though feedback of panel is not used, accurate control of panel position is obtained due to servo mechanism of the servomotors. Use of micro-controller supports flexibility in control. User interface has been provided to enhance computer utility.

The proposed mechanism is based on friction drive mechanism, which demands more torque. However, since loading of one motor on the other is eliminated it reduces the torque requirement. Due care need to be taken while developing the sphere surface to avoid wheel slippage from the sphere surface. Regular maintenance like oiling is required for the smooth operation of the bearings. Advanced control strategies can be investigated to improve the performance further.

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