Paper ID: AM-270

Continuous Rotation Control of Robotic Arm using Slip Rings for Mars Rover

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Abstract

This paper presents Continuous Rotation Control (CRC) of Robotic arm in order to reduce time consumption of an arm of a mars rover. Arms are limited to some rotation angle due to the wires connected with arm can be twisted and disconnected from controller. When the arm reaches to its maximum limit it has to rotate backward in a larger angular path than the forward direction due to this rotation angle limitation. We propose an enhanced model for free rotation without losing significant performance. To do so, we consider a robotic arm model including Servo Motors (SMs) and Slip Ring Mechanism (SLM). The SLM allows us to control the rotation of robotic arm from different positions. We also make sure servo motor torque effort is within allowable limits. The results show the significant time saving due to the use of CRC method when arm is already rotated 360 degree in a specific direction to perform a task and the next task is to perform in the same direction of rotation few degrees apart.

Keywords: Mars Rover, Robotic Arm Rotation (RAR), Microcontroller, Slip Ring, Servo Motor.

1. Introduction

Mars rovers are automated motor vehicles including advanced robotics which can propel itself across the surface of the planet Mars. Statistics show that, there have been four successful robotically operated Mars rovers. The motive of these rovers is to search for evidence of ancient life, including the environmental observations [1]. They fall under certain categories based on the nature of their controlling such as fully automatic, semi-automatic and manually controlled [2]. The control of mechanical systems and particularly of robotic arm is an active applied research area. After the era of rigid robotics, major research activity was devoted to improve dynamic performances [3]. The last successful mars rover Curiosity was sent on November 26, 2011; whose arm rotation angle was bounded to 350 degree [4].

The rotation can be improved by using slip rings ensuring continuous rotation as well as reduced time consumption. Reducing time consumption is a great concern to increase performance. Feedback from the robotic arm can be analyzed and processed for stability and the precision movements of the arm [5]. Slip ring consists of a stationary graphite or metal contact (brush) which rubs on the outside diameter of a rotating metal ring. The slip ring allows unlimited rotation of the connected object, whereas a slack cable can only be twisted a few times before it will fail [6]. The starting conditions are not severe but the desire for speed variation makes it necessary to use slip rings [7].

In this paper, we focus on the continuous 360 degree rotation of the arm which will eliminate several difficulties and will save significant amount of time in several specific conditions. We also focus on the data communication and data encryption and decryption in both sides of the servo motor and controller.

2. Arm Architecture

This section is mainly divided into two portions. Fig.1 shows representation of the robotic arm, able to rotate around the vertical axis we have designed by solidworks 2013 edition. The arrangement consists of SMs and at the base section SLM will be added. In both, upper and lower section of the slip ring (shown below), there will be two bearings which support the arm from bending or fracture at the slip ring section. The shaft is coupled with the slip rings which ensures a continuous 360 degree the rotation of robotic arm along vertical axis.

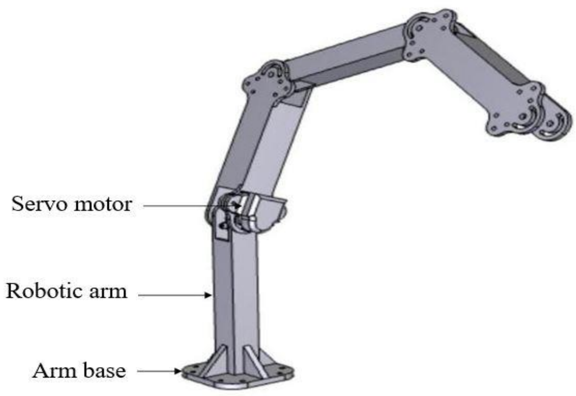

Fig. 1. Model of a Simplified robotic arm

3. Slip Ring Mechanism

Three slip rings are introduced and every slip ring is touched by two brushes counting total of six brushes. Slip rings are the connectors of three individual lines which are ground, vcc and signal. There will be two microcontrollers in both rotating and steady part. Data will be sent through the signal line where vcc and ground will be powering the arm servo motor and microcontroller on the arm.

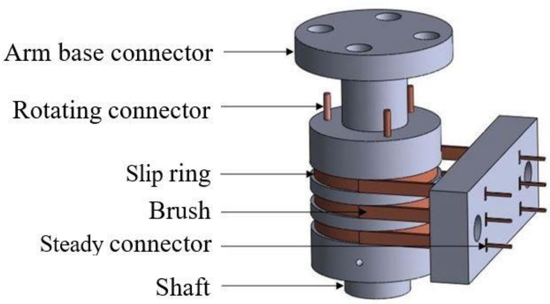

Fig. 2. Slip ring mechanism

As the metal ring turns, the electric current or signal is conducted through the stationary brush to the metal ring making the connection. Either the brushes or the rings are stationary and the other component rotates [6].

3. Methodology

Numerous methods exist for manipulating robotic arms- position controlled manipulators, joystick based controllers [8], speech and gesture based controller [9], and sensor based interfaces [10] to name a few. This section focuses on the data communication process on the two sides of the setup. We used two MCUs both Atmel Atmega8A and running at16 MHz [11]. The master MCU (steady side) which commands the slave MCU (arm side). General servo motors use 50Hz constant frequency while varying duty cycle from 1ms to 2ms. Thus on the slave side only variable is duty cycle. So, data to be sent is only duty cycle. We will first convert the data from decimal to binary, then generate PWM (pulse width modulation) according to the data. We used timer 1 as compare mode and PWM frequency is 4 kHz. For example, if we want to send number 20 as duty cycle then the number is converted into equivalent binary number 10100. We added a start bit which is 50% duty cycle of the PWM indicating that data transmission starts. 10% and 90% duty cycle represents binary 0 and 1 respectively.

Fig. 3. Data in terms of duty cycle

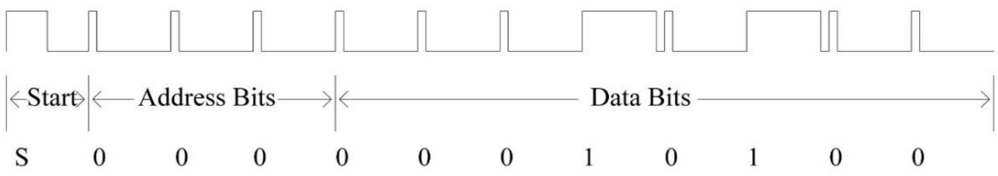

Fig. 4. Sequence of single data with start and address bits

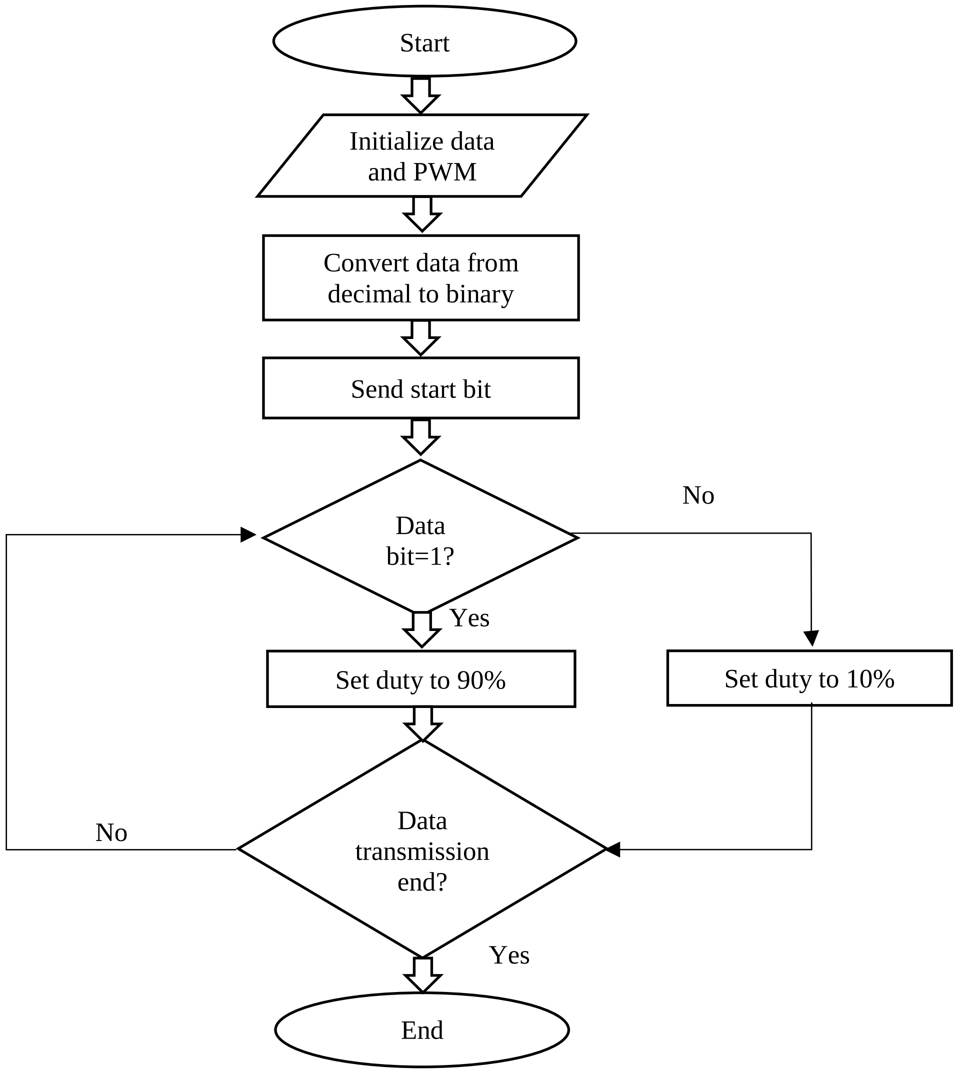

Fig. 5. Single data encryption by master MCU

In the slave MCU the signal wire is connected to the INT0 (PD2) pin. When any pulse comes, corresponding interrupt triggers and MCU executes corresponding interrupt service routine known as ISR. Now, duty cycle can be measured by starting a timer in rising edge and stopping the timer at falling edge [11]. As the data sending frequency 4 kHz is fixed then the time period will be 1/4000=0.25ms . So, the duty cycle is given by,

$$Duty\ cycle = \frac{timer\ value\ in\ miliseconds}{0.25} * 100 \tag{1}$$

Slave MCU will generate PWM according to the data and this PWM will go to the servo motor. For multiple servo motors, the additional PWM channel is required. For example, 3 address bits can command 8 (2^3) individual servo motors. Thus requiring 8 channel PWM, but Atmega8A has only 3 PWM channels. Here, we can use higher PWM channel MCUs like Atmega2560 which has maximum 12 PWM channels [12].

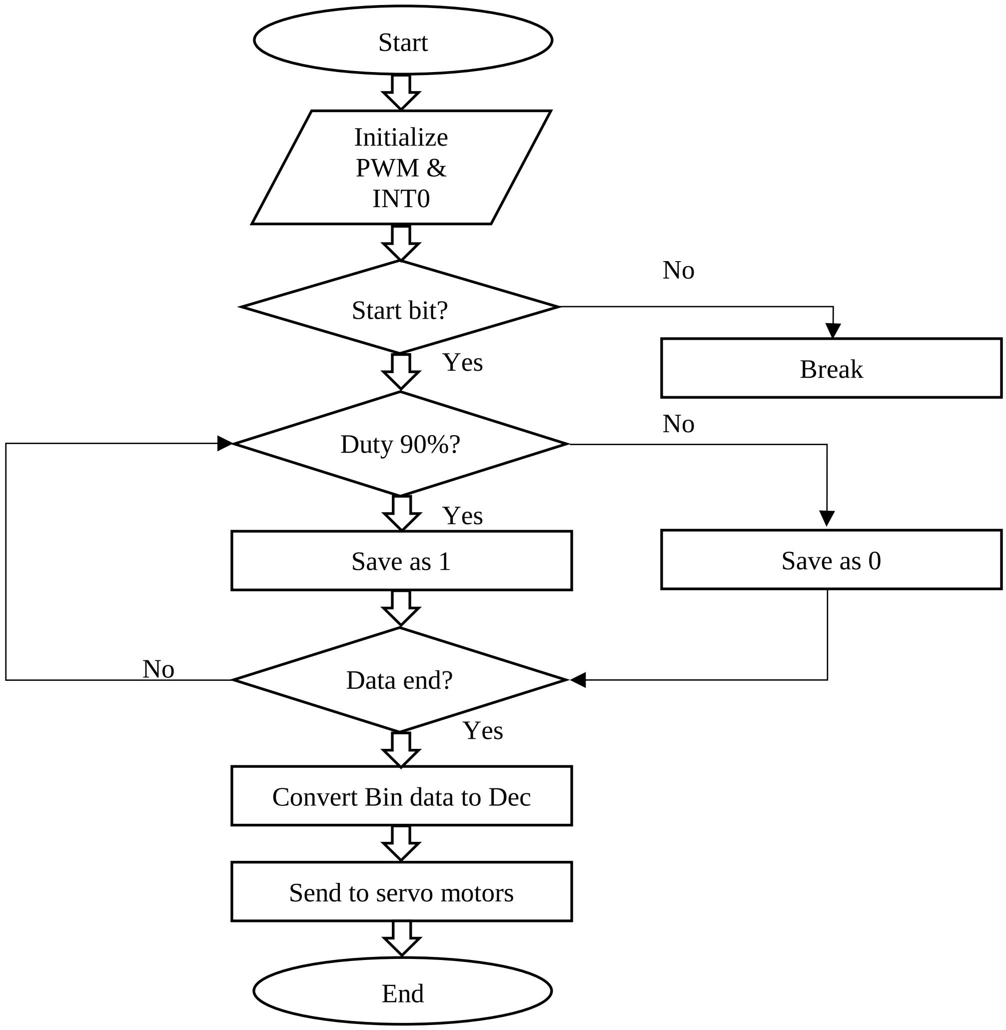

Fig. 6. Single data decryption by salve MCU

By this two flowchart we represent the data transmission process during a certain task. Master MCU commands the slave through the one wire data bus. Considering single servo motor in slave MCU section, the additional address bits are discarded in both flowcharts. For multiple servo motors, every motor will have an identity number. Data will be sent with identity numbers (address bits). If identity number of the data matches with a servo motor identity number, the slave MCU will decode and send the data to the particular servo motor.

4. Results

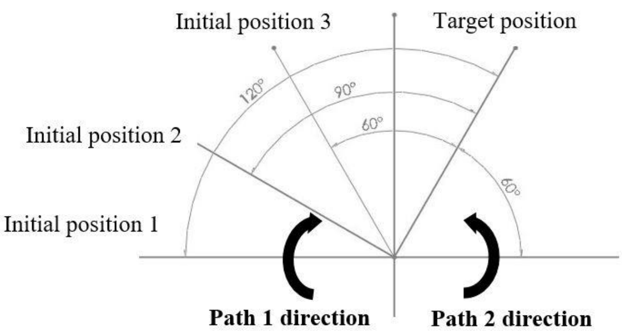

Fig. 7. Robotic arm at different positions performing a sample task

Fig. 7 indicates that a robotic arm is already rotated to a position from positive vertical axis. This position may be initial position 1, 2 or 3. Since our model is capable of crossing the 360 degree boundary, therefore it follows the path 1 direction to reach in the target position ensuring less time consumption. To do this we have created a schematic with microcontroller shown in fig. 8 and ultimate time saving data have shown in table 1.

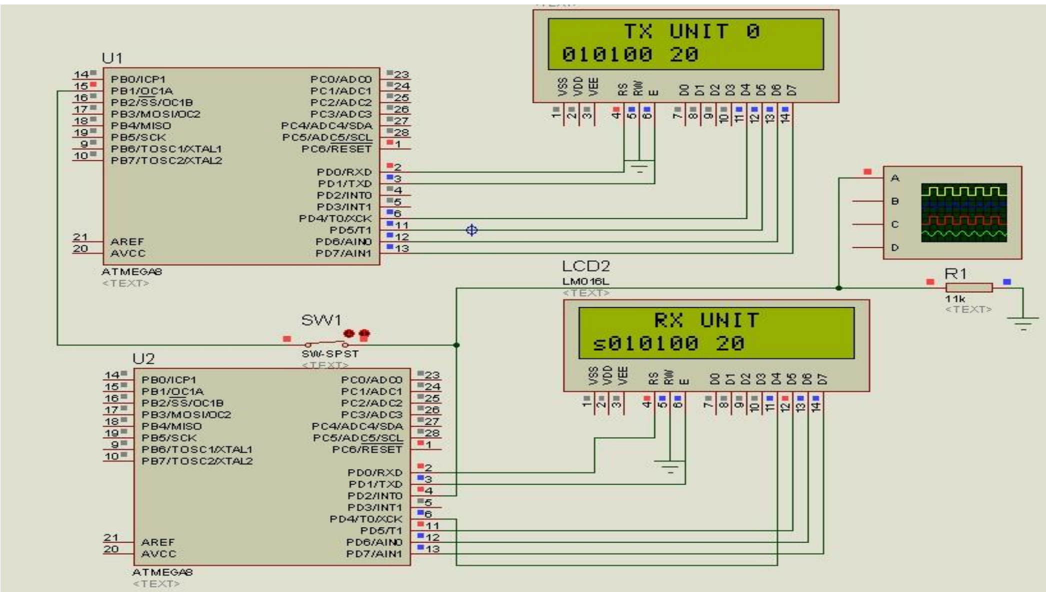

Fig. 8. Simulation result of data encryption and decryption

Figure 8 shows the simulation result of data transmission from master to slave MCU via one wire data bus. The simulation was originally performed in Labcenter Electronics Proteus 7 professional design suite. In the figure TX unit is master and RX is slave. In RX unit, “s” in front of binary data represents the start bit.

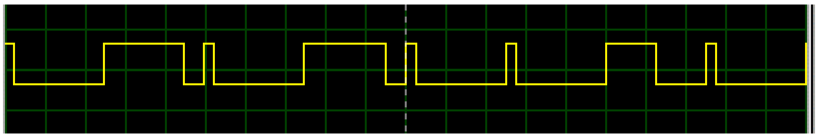

Fig. 9. PWM generated according to the data in simulation software

Figure 9 represents the PWM output signals ensuring the theoretical signal values matched with the simulation output values.

Table 1. Comparison of regular and proposed time requirement

Angular distance	Initial arm position		Path 1 time required		Path 2 time required	Time saving (ms)	
From	Path 1 distance	Path 2 distance	8 bit system (ms)	10 bit system (ms)	Normal system (ms)	Compared to 8 bit	Compared to 10 bit
Position 1	120°	240°	306.17	307.0	600	293.83	292.9
Position 2	90°	270°	229.63	230.0	675	445.37	444.4
Position 3	60°	300°	153.08	153.5	750	596.92	596.5

We have arranged the results of our proposed model as ultimate time saving in milliseconds (ms) shown in Table 1. To do this, we took some initial position of the arm at certain angles shown in figure 7. Table 1 represents the corresponding time required for our proposed model and normal time required calculated on the basis of running microcontroller units at maximum clock frequencies mentioned in the methodology section. The above calculation was done considering MG996R servo motor which can rotate at a rate of approximately 60 degree /150 ms [13].

Table 2. Time delay due to certain work done

Actual time required for 8 bit system (ms)	Actual time required for 10 bit system	Time required from data sheet	8 bit system error (%)	10 bit system error (%)
153.08625	153.50625	150	2.055	2.33

Datasheet [13] shows that for 60 degree rotation time required for servo motor without slip ring system is 150 (ms) where our results show that these values are 153.08625 and 153.50625 for 8 bit and 10 bit data system respectively. On the basis of this calculation 8 bit and 10 bit system error due to work delay shown in table 2.

5. Conclusion

This paper concludes with the confirmation of PWM signal output for continuous rotation of the robotic arm as we proposed. The control algorithm is proposed to ensure the data transmission ending which affects the rotation angle delay of the robotic arm. The simulation results show that the servo motor control system has good performance to control the portal frame. This servo-control system can not only enhance performances of position error and tracking speed, but can also save the time for rotation in the specified case and guarantee a strong robustness for system which is a subject of concern of Mars rovers.

6. References

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