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FPGA DESIGN OF FAULT TOLERANT STEPPER MOTOR AND DC MOTOR CONTROLLER USING TMR FOR SPACE ROBOTIC APPLICATIONS

NAVEEN RAJ [1], SUNIL JACOB [2]
[1]M.Tech, VLSI and Embedded Systems, [2] Associate Professor, Electronics and Communication
, [1 2]SCMS School of Engineering & Technology, Karukutty, Ernakulam
[1]naveenmercedes@gmail.com, [2]suniljacob01@gmail.com

ABSTRACT

In this paper, a fault tolerant stepper motor and DC motor controller using Triple Modular Redundancy is presented and the concept is applied to generate a PWM signal.For the stepper motor controller, a new design is proposed using microcontroller, DAC and amplifiers. The output of DAC will be a sine wave and a cosine wave. Then these waves are given to the next stage where the controlling signals for the stepper motor are produced and given to the motor. In my work, the stage up to the sine and cosine generation is implemented in FPGA and TMR is applied to improve the fault tolerance. Also the sine wave generated after applying TMR is used to generate a PWM signal so that DC motors also can be controlled.

Keywords: DAC, PWM

[1].INTRODUCTION

For facilitating various controlled movements, space robots use stepper motors, BLDC (Brushless DC) motors and DC motors. Space robotics deals with the design and development of semiautonomous machines that have the capability to explore unknown, unstructured, dynamic and hostile environment of outer Space. Space robots are preferred since they can perform tasks less expensively in an accelerated schedule with less risk and improved performance as compared to humans. They can operate for long duration and can also be sent into situations that are so risky for humans. Due to these reasons robots are been widely used for recent space explorations. Stepper motors have found more attention in recent years due to the low cost and accurate controlling properties. Trends have been towards developing micro steps and better accuracy. Stepper motors can be used whenever controlled movements are required. One of the most significant advantages of a stepper motor is its ability to be controlled accurately in steps. DC brush motors rotate continuously when voltage is applied to their terminals. Stepper motors, on the other hand, have multiple toothed electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control or driver circuit. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. So when the next electromagnet is given power and the first is turned off, the gear rotates slightly to align with the next one. The process repeats so that the motor can be turned to the required position. Each of those rotations is called a step, with an integer number of steps making a full rotation. So a stepper motor can be precisely controlled by rotating in steps. [2]

DC or direct current motor works on the principal, when a current carrying conductor is placed in a magnetic field; it experiences a torque and has a tendency to move. If the direction of electric current in the wire is reversed, the direction of rotation also reverses. When magnetic field and electric field interact they produce a mechanical force, and based on that the working principle of dc motor established. This paper discusses digital pulse width modulation control for a DC motor.

In this design Triple Modular Redundancy is used for fault tolerance. Fault tolerance becomes substantial design criteria for the applications where the reliability of hardware is crucial. In space applications, where the fault tolerance of hardware becomes a key issue, TMR comes in handy. Faults affecting the system can be of permanent nature resulting from decay in materials or transient nature resulting from extreme working condition such as heavy electromagnetic disturbance or temporary due to sudden spikes of noise. Triple Modular Redundancy (TMR) is the most applied fault masking technique for fault tolerance of software or hardware systems. TMR technique uses three implementation of the same function (redundant modules) and outputs of these modules are voted by a voting mechanism. The most basic voting algorithm is majority voting, where voter algorithm selects the most common output. TMR masks effect of faults before spreading through the rest of system. Thus TMR helps in preventing noise to be propagated if used properly.

[2].MICRO CONTROLLER DESIGN

The design includes a 16F877A microcontroller, two DACs and associated circuitry which is amplifier circuits using operational amplifiers. One DAC produces sine wave and the other produces cosine wave. Then these are

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amplified to meet the power specifications of the motor. The portion up to the sine and cosine generation is simulated for FPGA and TMR is applied.

[3].STEPPER MOTOR DRIVERS USING FPGA

Field Programmable Gate Arrays (FPGAs) offer significant advantages in high performance and low volume applications. They also offer high flexibility in hardware programming and can be easily reconfigured as per the requirements at a Single particular point of time without much change in the external circuitry. The level of optimization in FPGAs is very high in comparison to microprocessors or Digital Signal Processors. A continued rotation of the motor is obtained as long as the sine and cosine waves are applied to the motor. The speed of shaft rotation depends upon the frequency of applied signals. The quicker the signals are applied to the windings of the motor, quicker the rotor tends to respond to the signals by aligning itself to the corresponding stator poles. The sine and cosine signals obtained from the motor are then given to amplifiers which is then given to the motor. [1],[5]

[3.1]. Microstepping

Stepping, or turning a stepper motor at its rated step size, results in jerky movement. Microstepping is a technique used to smooth the motors movement between full steps and to improve the step resolution of the motor. Microstepping also improves the efficiency of the system because the current in the windings of the motor is manipulated in a controlled manner rather than being turned on and off abruptly.

[3.2].Current Limiting

Current limiting is used when a stepping motor is driven at a voltage that is higher than the motors rated voltage. There are several advantages to driving a motor at high voltage, namely, the torque and speed characteristics of the motor are improved. These parameters are improved because the current in the motor windings is more responsive to changes made by the controller. When running a motor at a voltage that is higher than its rated voltage, current limiting considerations must be made. The current in the windings of the motor cannot exceed the maximum current rating of the motor or motor life will be severely affected. One of the most effective ways to limit current is through the use of a chopper circuit.

[4]. NEED FOR FAULT TOLERANCE

Nowadays, the trends in production of integrated circuits, is to fit the greatest number of devices into small chip area, which leads into high power density. Thus, the manufacturers get into situations where for example, transistor structure is only a few atoms wide. Reduction in size of devices and isolation gaps leads to undesirable phenomena of transient fault, because much less energy is required to flip transistor from one to another state. Therefore, increasing of the reliability of devices is necessary, whether with the appropriate hardware or software modification.

[5].SINE & COSINE GENERATION AND FAULT TOLERANCE USING TMR IMPLEMENTED IN FPGA

The steps involved in the generation of sine and cosine waves are illustrated in Fig 1. For better accuracy 512 discrete points are taken for a single sine wave. Using the two equations below 512 values corresponding to 512 points of sine wave can be produced using Matlab.

1. t=0:pi/256:2*pi;
2. Int32(sin(t)*10000/256)

Due to this increased number of points used, the sine wave produced will be finer than that produced by the microcontroller and DAC. A controlling input is provided for controlling the frequency of the sine wave so produced. Thus by the use of the controlling input, the speed of the motor can be varied. For some time it has been known that the reliability of digital systems can be improved through the use of redundant components, if these additional components are properly employed. The use of redundancy is proposed not as a replacement, but rather as a supplement to the two cardinal principles of reliable design: 1) use the most reliable components and 2) use the least possible complexity consistent with required system performance. This is not just a matter of using every available means. The analysis shows that the effectiveness of redundancy as a tool for obtaining digital system reliability is much more pronounced in a system composed of basically reliable components than in a system of unreliable components. Put another way, while redundancy can be used as a lever to greatly enhance the reliability of an already reliable system, it is of little use-and can even have a detrimental effect-if the nonredundant system is unreliable in the first place. Fault tolerance becomes substantial design criteria for the applications where the reliability of hardware is crucial.[4],[6]

The sine and cosine waves obtained as shown in Fig 1 are then given to the necessary amplifying circuitry can be used to control a stepper motor. The circuitry for amplification consists of simple Op Amps.

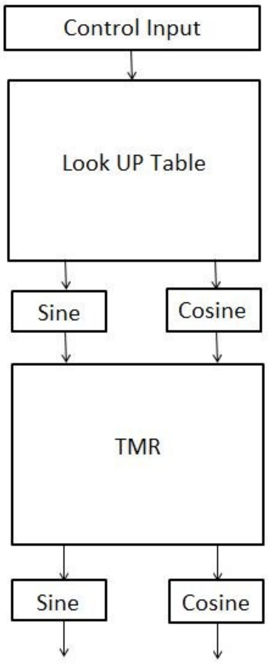

Fig.1. Sine & Cosine generation

[6]. PWM GENERATION AND DC MOTOR CONTROL

The sine wave obtained as the TMR output is given as modulating signal for the PWM wave. Triangular wave is used as the carrier signal. By adjusting the supply voltage, the PWM signal can be varied and thus the speed of the DC motor can be varied. The PWM signal obtained from the sine wave can be used for driving the DC motor at a constant speed by using in conjunction with an H-Bridge.[3]

[7].SIMULATION RESULTS AND OBSERVATIONS

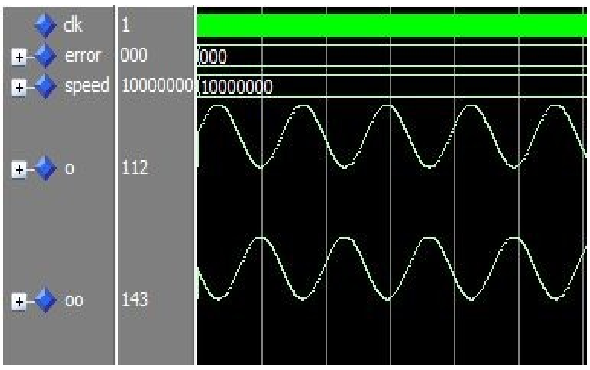

Fig.2. Sine wave obtained from microcontroller and DAC *Fig.3. Sine and cosine waves obtained as TMR output from FPGA*

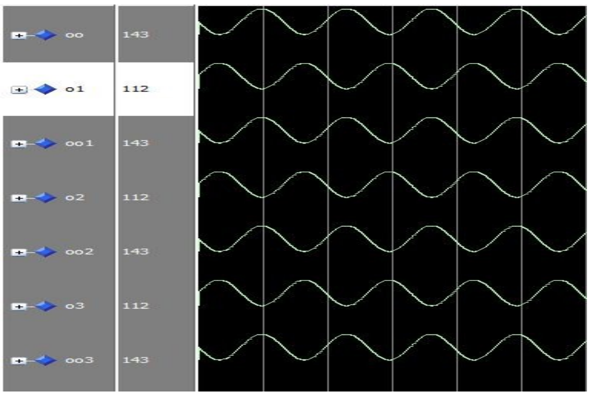

Fig.4. TMR signals for sine and cosine waves *Fig.5. Noise tolerance in final output due to TMR*

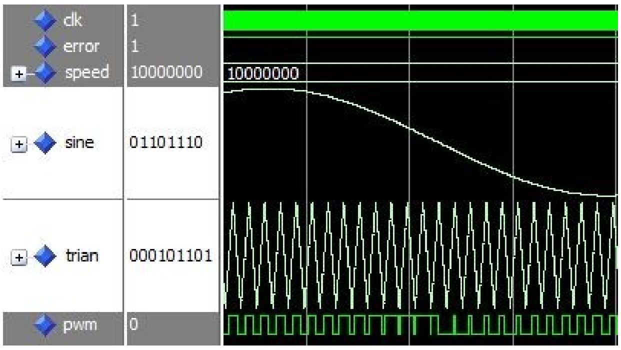

Fig.6. PWM generation using the generated Sine wave

Fig 2 shows the sine wave produced using microcontroller and DAC. Fig 3 shows the final sine and cosine outputs produced by the FPGA. This sine and cosine waves are obtained after the six waves shown in fig 4 are passed through a majority voter thus implementing Triple Modular Redundancy. Fig 5 shows even if there is an error in one of the redundant components, the final output will not be affected, thus making the system fault tolerant. Fig 6 shows the PWM signal generated using the sine wave. This PWM signal can be used to drive brushless DC motors.

CONCLUSION

Motor controllers using microcontrollers are simple and cost efficient. But using FPGA more reliable controllers can be developed. The stepper motor driver and PWM modulator implemented by replacing the microcontroller and DAC with FPGA will be more fault tolerant and less noisy.

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