FPGA Based Navigation Platform for Fixed Path Navigation With Distance Estimation Using Rotation Encoder

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Abstract-**Navigation ability is an important factor for any mobile device. To traverse a particular environment a device needs to know its destination and also avoid dangerous situations like obstacles and collisions. The purpose of this paper is to design an FPGA based navigation platform using a rotation encoder to guide any navigation device through set distances in both forward and reverse directions and to control the directions. The device should utilize the parameters from the rotation encoder and effectively traverse a given location by following predetermined paths loaded in the controller. The rotation encoder calculates number of pulses per rotation which can be used to calculate distance travelled in a given time, provided speed is known. To design a rotation encoder we have used an optical detector IC MOC7811.This helps to move the device forward and backward according to the number of pulses which gets translated into distance. In case of directions during the course of the project it was found that the same properties of the rotation encoder which enables a device to move forward and backward can also be used to make turns. With continuous trials recorded accuracy was also fairly high.**

Keywords—Rotation Encoder, Fixed Path Navigation, FPGA, Distance Estimation, MOC7811

I. Introduction

Autonavigation is no longer just a concept. Various systems both in Indoor and Outdoor Navigation have utilized Autonavigation concepts to some degree. Some of the more commonly used systems include Position Mapping via GPS. In GPS systems the current position of any device with a GPS receiver is mapped with the help of Satellites, and then we use this data to navigate the device to any other location. The GPS satellites transmit signals to a GPS receiver attached to any device. These receivers passively receive satellite signals but cannot transmit any signals. Moreover these require an unobstructed view of the sky, so they can only be used effectively outdoors and also suffer from higher power losses in indoor systems due to noise. Moving on to Indoor Navigation systems which is the area that we focus on, again there are a lot of technologies involved like Wi-Fi based positioning systems (WPS), Bluetooth, Magnetic positioning etc. But all of these systems suffer from one or more disadvantages like high installation charges, prone to interferences, high power loss etc.

The design in this paper follows fixed Navigation protocols. So the end result would be an Automated Navigation Platform which can guide itself to a given location by following pre-programmed paths. This is the best case of navigation since the error percentage of fixed path navigation is much lower. The design also aims to create a platform which is cost effective, consumes less power and be durable. To achieve this, primary component used is an FPGA (Field Programmable Gate Arrays). There are many advantages in using an FPGA as opposed to a processor or controller, but the most important one would be its ability of parallel processing. This would effectively reduce any delays in execution and hence increase the overall efficiency of the system. Since logic cells in the FPGA are programmable, it gives the device a higher degree of versatility in terms of user accessibility. Additionally it can process larger blocks of data in fewer clock cycles and hence would be an ideal solution. Also optimization levels of FPGA are much higher. The final product can be easily enhanced to Application Specific Integrated Circuit (ASIC) designs which are high performance embedded systems.

In the following sections we discuss the design in detail. Section II discusses the basic motivation behind the design and its applicability to the real world. Section III lists the related developments regarding the mentioned design. In section IV, we explain the implementation of hardware and software sections of our design. Section V records the observations made during our experiments and finally we conclude our paper in section VI.

II. Motivation

In this paper we attempt to design a low cost, efficient and durable Indoor Navigation system for a small scale device like wheelchair. The motivation behind this being that most physically challenged individuals who suffer from higher degrees of disability will probably have to use a wheelchair which can assist them to navigate. Thus irrespective of social or economic status the wheelchair becomes their only means of navigation. Hence transforming such devices to be much handier by incorporating autonavigation features where the inputs could be tactile, eye movements, sound based etc would

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not be a wasted effort. There are various means of navigating wheelchair available nowadays such as Wi-Fi, Bluetooth based, IR rays, RFID based etc. for indoor navigation and GPS based methods for outdoor navigation purposes. As the GPS signal strength is feeble at the indoor environments and is prone to interference, we cannot use such methods for indoor navigation. Moreover even GPS and other systems mentioned above require higher initial setup charges and lot of calibrations hence it becomes difficult for the economically challenged to afford high-end wheelchairs.

Here in this paper an economically efficient, accurate method of fixed path navigation designed in an FPGA platform is discussed which uses very few components as opposed to other existing systems. Coding in FPGA mainly involves HDL coding which is flexible and can be used to include future enhancements such as bigger algorithms which helps in variable path navigation.

III. Related Works

There are various types of navigation platforms for outdoors as well as indoors nowadays. These platforms include RFID tag based, Wi-Fi based, Bluetooth based systems etc. RFID based navigation can be used for indoor as well as outdoor. In [1] RFID tags based localization and navigation for outdoor environment is described. Here the RFID reader reads the tags located at the grid of nodes where each node has a particular RFID tag which represents a specific location inside the area of interest. The RFID tags give the information such as location inside the area and orientation of the vehicle. The error correction and obstacle detection capabilities are also included in FPGA platform. But the drawback of this system is that the number of RFID tags used is much higher even for smaller areas which make the system costlier. Also the system is unmanned material handling system which cannot be used for medical applications where precise navigation is a must.

Some other implementations[2] shows the implementation of fuzzy logic control for the wheelchair manipulation done in FPGA platform. The fuzzy system produces feedback signals to guide the wheelchair removing misalignment of wheel motion in accordance with the input from joystick. In robotic control applications[3] multi robotic navigation system designed in FPGA platform where there is a start point and a goal point designed with IR Beacon system are discussed, within this two points a number of robots will follow the leader robot on a behavioral basis. The human friendly wheelchairs [4] which are guided with the visual information from the patients such as facial expressions or eye movements are also on the rise. The system gets the information for controlling the wheelchair by extracting ten feature points around nose, mouth and eyes on the same plane taking sum of absolute difference in real time (30frames/second).But this requires large amount of data base and calculations which makes the system tedious to implement.

Voice detection based motion control [5] can also be used if degree of disability of individuals is to the point where hand movement is not possible. The system uses FPGA platform and Labview is used here to train, capture and process the voice signals and control the high power dc motors in wheelchair. The system is integrated with IR signals for path finding and Ultrasound sensor for obstacle detection. This system also needs large amount of databases and calculations.

IV. Design and Implementation

Our design utilizes a BASYS 2 Spartan 3E FPGA board for overall control of the system, a rotation encoder, motors and corresponding motor drivers. The FPGA controls the actions of the motor driver with inputs from the rotation encoder. The rotation encoder is fitted to the motor shaft to record the number of rotations completed by the motor. The motor drivers control the direction of rotation of the motors. The overall architecture of the design is shown in the block diagram in Fig. The arrangement can be fitted to any small scale indoor navigation device. Herein we use a normal wheelchair, replacing the back wheels with 320W, 24V motor driven wheels with a speed of 4600RPM. These motors are controlled by Pololu 24V, 23A motor drivers.

A. FPGA Board

In this design we use a Digilent Basys 2 Spartan 3E board as the overall controller. The board is shown in Fig 2. The FPGA features 18-bit multipliers, 72 Kbits of dual port block RAM and can operate at frequencies even higher than 500MHz. Use of external supplies in the range of 3.5V to 5.5V is possible. User I/Os can be provided with the four 6-pin headers, 8 LEDs, 4 pushbuttons, 8 slide switches. The FPGA receives signals from the Rotation Encoder, from which it calculates the required distance to be travelled. Once the distance is calculated the FPGA provides corresponding signals to the Pololu motor drivers which in turn control the rotation of the wheelchair motors.

B. Rotation Encoder

The Rotation encoder is used to estimate the distance travelled from the number of pulses obtained. The MOC7811 has two sections, an LED section and a detector section. When properly biased the emitter emits continuous radiations in the direction of the detector. To obtain the number of pulses we fix a patterned metal disc on the motor shaft. The leaves of this disc are placed in such a way that it rotates in between the emitter and detector sections of the encoder IC as shown in Fig 3. The circuit arrangement of MOC7811 is shown in Fig 4.

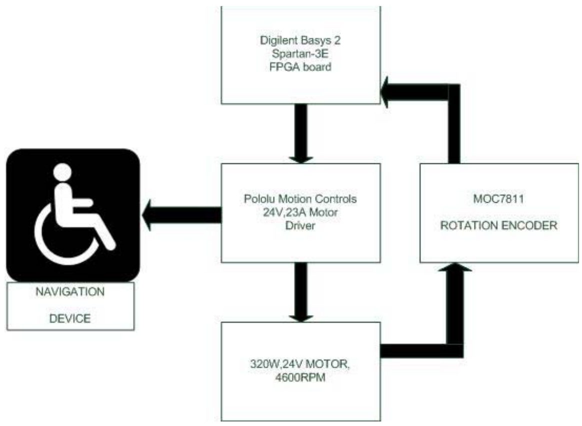

Fig. 1. Block diagram

Fig. 2.Digilent Basys 2 FPGA board

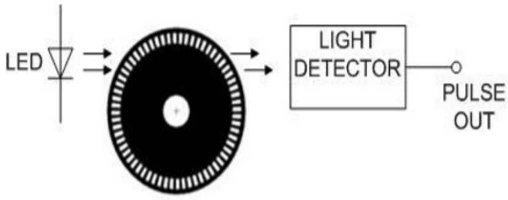

Fig. 3. Working principle of Rotation Encoder

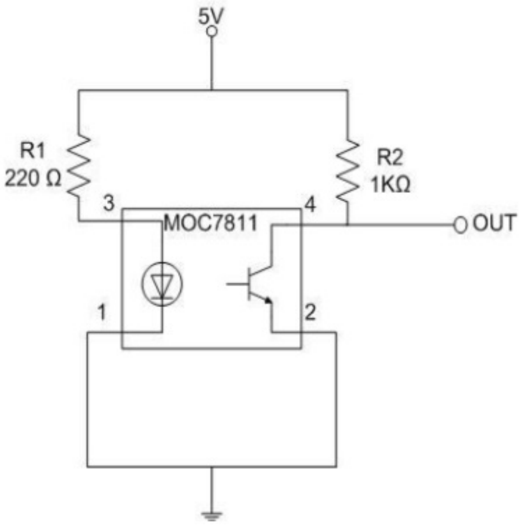

Fig. 4. Circuit Diagram of Rotation Encoder

This results in a pattern of alternate light and dark at the detector section. This pattern is converted into a pulse waveform with the light and dark sections represented by ON and OFF of the pulse. Hence the output of the rotation encoder is a pulse waveform. Now from the number of pulses we can calibrate distance using the following formula.

$$Distance = \frac{Wheel\ Circumference\ \times Counts}{Counts\ per\ Revolution} \quad (1)$$

C. Motor Drivers

To drive the wheelchair motors we use two Pololu 24V, 23A motor drivers. These MOSFET H-bridge motor drivers enable bidirectional control of high-power DC motors. The H-bridge is made up of N-channel MOSFETs which determine the performance of the drivers. The maximum frequency allowable for PWM is 40KHz. The port connections between the FPGA and the motor driver and also between the driver and motor are shown in Fig 5.

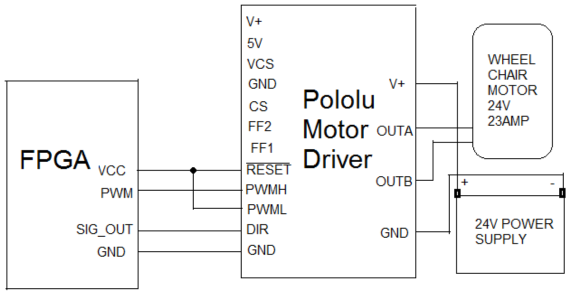

Fig. 5. Port Connections between FPGA, Motor Driver and Motor

V. Experiment Results

Test runs were conducted using a Rotation Encoder with four leaves with diameter 6.5cm. We found that as the number of leaves increased so did the accuracy. But for this particular application the encoder with four leaves provided high levels of accuracy. The motors used were 24V, 320W wheelchair motors, which were driven by 24V, 23A Pololu motor drivers. The FPGA used is a Digilent Spartan 3E, Basys 2 board. The experimental setup is shown in Fig 6.

Table I shows the difference between actual distance travelled and Expected distance Travelled when we tested the device to move in a straight line to different distances ranging between 1 to 4m. As shown in the table the error percentage lies in the range of 1 to 5 with an average error 2.4 percentage.

Fig. 6. Experimental Setup of the design

TABLE I. DISTANCE ESTIMATION WITH ROTATION ENCODER FOR FPGA

No of Tries	Expected Distance in cms	Obtained Distance in cms	Error percentage
1	100	95	5
2	100	101	1
3	150	148	2
4	150	146	4
5	200	201	1
6	200	199	1
7	250	248	2
8	250	249	1
9	300	301	1
10	300	303	3
11	350	351	1
12	350	348	2
13	400	401	1
14	400	400	0

The device was tested in a plot with a grid size 0.6m as shown in Fig 7a and 7b. The whole plot was divided into three different sections and a fixed path was set to travel from one section to another. Fig 7a and 7b shows the Expected paths and the Actual paths taken by the device for some of the trials conducted.

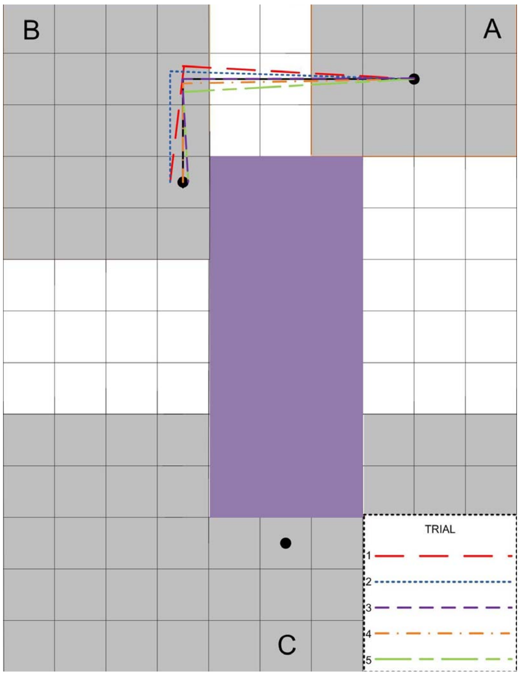

Fig. 7a. Plots showing expected path A to B and different paths obtained for some of the trials

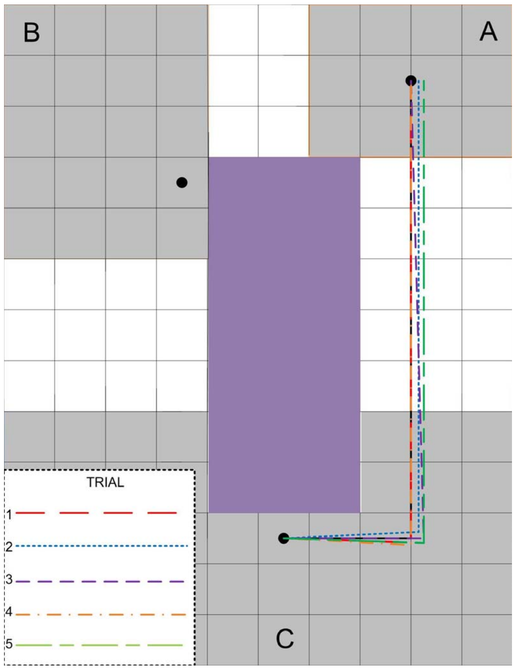

Fig. 7b. Plots showing expected path C to A and different paths obtained for some of the trials

VI. CONCLUSION

An FPGA based Navigation platform for fixed path navigation has been designed. The design was tested on a normal wheelchair with a rotation encoder fixed on one of the motors. The accuracy of rotation encoder readings was found to be fairly high with an average error percentage of 2.4. the device was tested in indoor conditions for different paths as well. This design is versatile and any future enhancements can be easily installed to it. In future applications even variable path navigation can be implemented with some improvements in design.

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