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A BLUETOOTH BASED STEPPER MOTOR CONTROL SYSTEM

S.Kanimozhi[*1] and G.Senthil Kumar[2]
[*1]Associate. Professor, Dept. of Electronics, SNR Sons College, Coimbatore-641006, India.
[2]Head of the Department, Dept. of Electronics, SNR Sons College, Coimbatore-641006, India.

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ABSTRACT
Networking technology for the Internet of Things (IOT) is widely used in Wireless systems. Although they can be used to exchange control commands and data between machines, they were initially designed for voice communication systems. In this paper, we present the Blue Steps system which gives a user wireless control over stepper motors. The Blue Steps hardware incorporates a Field Programmable Gate Array (FPGA) coupled to a Bluetooth module and a custom build driver circuit. The FPGA hosts a micro-controller and the control logic for the stepper motors. The Bluetooth module establishes a wireless connection between a mobile device and the micro-controller. Apart from the general systems design, we also conceived the User Interface (UI) software and a driver circuit for the stepper motors.

INTRODUCTION
The Internet of Things (IOT) is the result of a recent idea where objects become smart or indeed smarter through micro processing and networking [1]. Such smart objects take measurements, do processing and communicate the resulting data through the network [2,3]. It is up to either a central instance or a distributed processing system to make sense of that data [4]. One of the goals of that technology is to remove human decision making almost completely [5]. For mature IOT systems, human interaction happens only on a very high level, where machine based decision making is incapable of resolving a choice. However, such a scenario implies that routinely choices are resolved and actions need to be executed. Actuators are devices which translate decisions into physical actions.

Stepper motors are a special type of actuators: they translate electronic commands into precise rotary motion. These electro-mechanical devices are widely used for motion control, because of their low cost and their ability to manipulate a connected electromechanical system [6]. The motor shaft moves in discrete step increments when electrical pulses are applied to it. Stepper motor technology is advantageous in applications where we need to control rotation angles, speed, steps and position. They can work in open loop control, i.e. no feedback channel is necessary. Furthermore, these motors are known for their high reliability and low maintenance. Using stepper motors for IOT applications implies that the dedicated control circuit is networked.

The Blue Steps system addresses the need for networked stepper motor control. The system offers remote control for up to two stepper motors. The remote control channel is established, via a Bluetooth link between a user centric device, such as smart-phone, tablet or PC, and dedicated control hardware. A user controls direction, speed and the number of steps with a User Interface (UI) on the Bluetooth terminal. To establish that functionality, we designed and manufactured a circuit which boosts the control signals from a dedicated embedded control system and interfaces to a Bluetooth module. We configured Field Programmable Gate Array (FPGA) logic as an embedded control system. To be specific, we instantiated a standard microcontroller with peripherals and a custom built stepper motor driver module in the FPGA. The microcontroller runs custom software which generates the UI and at the same time interfaces to the dedicated stepper motor driver module. To integrate these ideas, we prepared software which enabled communication between these components. The Blue Steps system links stepper motors and mobile devices. Such a link is very important for turning the decisions of an IOT system into actions. The material of the paper is organized as follows. Section II details the individual components used to establish the Blue Steps system. That section presents a block diagram which provides a system overview and it structures the module description. The discussion section details specific design decisions and it sets the Blue Steps system into a wider context of IOT systems.

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MATERIALS & METHODS

This project is an integrated system which includes components and blocks as highlighted in Figure 1 and Figure2. Figure1 shows the physical setup of the Blue Steps system. Its upper half shows two connected stepper motors. One motor sits at the base and turns a shaft. The second motor is mounted on the turning shaft and it moves a pointing arm in an angular motion. The stepper motors receive control signals from a driver circuit. The driver circuit boosts the control signals, such that they deliver enough power to drive the stepper motors. That driver circuit is shown in the middle of Printed Circuit Board (PCB). The Darlington driver components are arranged in two distinct columns. The lower portion of the Figure shows the Spartan FPGA LX9 micro board mounted on the PCB. The Bluetooth module is plugged in on the left side of the PCB. That module ensures the up-link between the FPGA logic and a user centric Bluetooth enabled device.

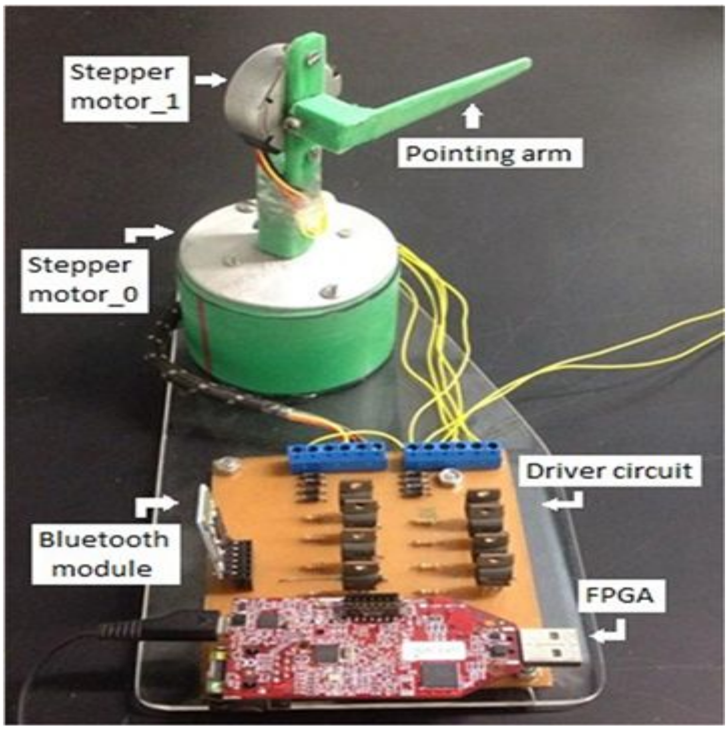

Figure 1. Physical setup of the Blue Steps system

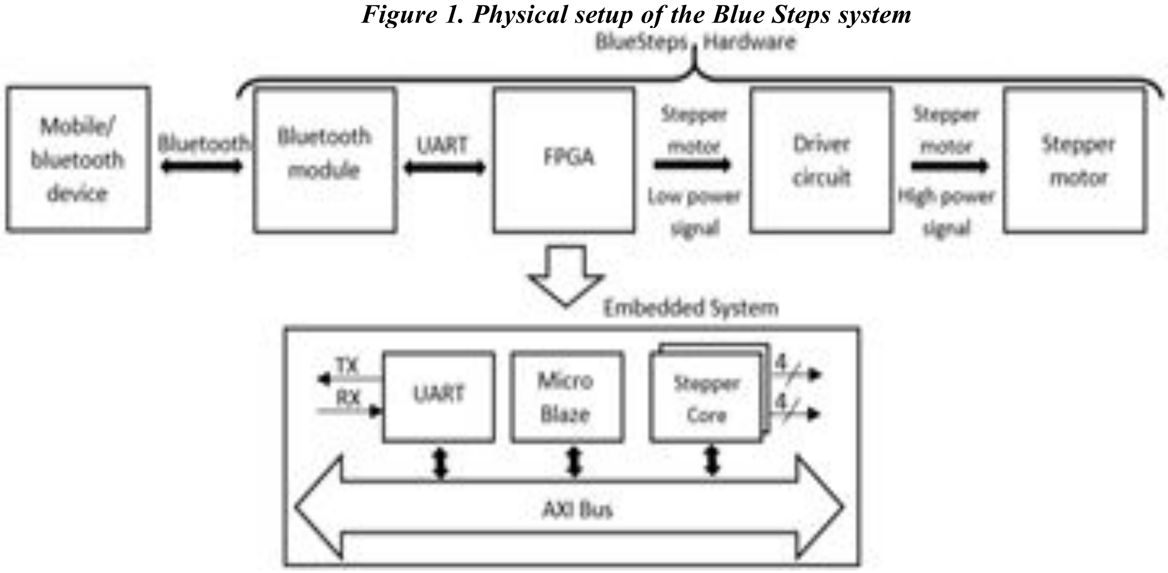

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Figure 2. Block Diagram of the Blue Steps system

Figure 2 shows the block diagram of the Blue Steps system. The diagram details both the blocks which establish the module functionality and the communication links between them. The mobile device is connected to the Blue Steps hardware via Bluetooth. The Bluetooth module translates the wireless communication to wire bound Universal Asynchronous Receiver/Transmitter (UART) signals. These wire bound signals are transmitted and received by the embedded system, implemented in FPGA logic. That logic establishes the Blue Steps core functionality by instantiating a Micro Blaze (MB) microcontroller with peripherals as well as a custom stepper Intellectual Property (IP) core. Section II-A describes the functionality of these components in greater detail. Actuator control is exercised when the stepper IP core sends low power control signals to the driver circuit on the PCB. That circuit boosts the control signals such that high power signals are sent to the stepper motors in order to ensure proper operation of such a demanding load.

The Well-Known HC-05 Bluetooth Module Was Used To Establish A Host Control Interface (HCI) Bluetooth Link Between The Blue steps Hardware And The Handheld Mobile Device. The HCI Uses The UART Protocol.

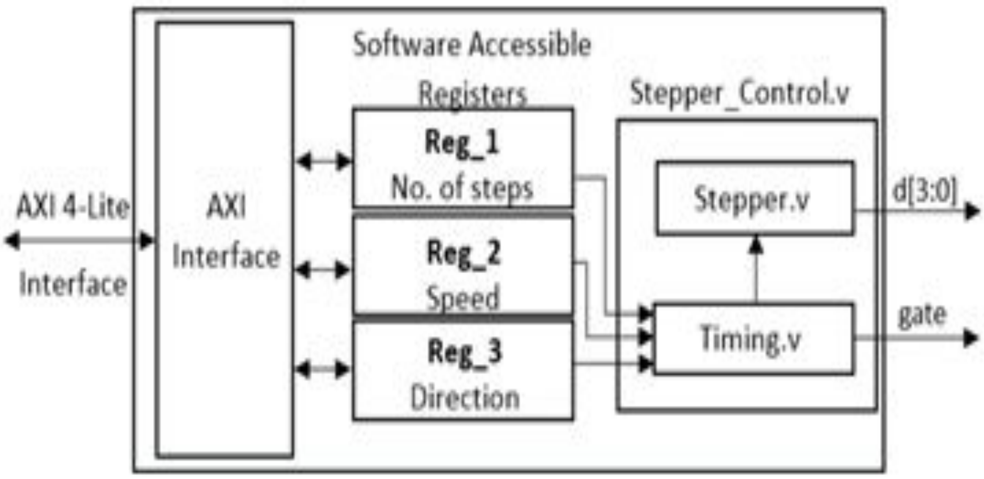

Figure 3. Block Diagram of the User_Logic.v

Figure 3 shows the block diagram of the User_Logic.v module, which resides in every Stepper IP core. That module contains three sub-blocks. The XPS tool creates a Hardware Description Language (HDL) template file. In our case, that template file was called User_Logic.v. We have extended that template file to define our peripheral. Software Acces- sible Registers and Stepper Control.v in figure 3 are these extensions. The sub-blocks are described as:

- AXI Interface: This block implements the AXI 4-Lite slave interface for register access and data transfer.

- Software Accessible Registers: Three Software Accessible Registers are instantiated: they are implemented in the slave mode of User_Logic.v. The content of these registers is referred to as one buffer. The MB is a 32 bit processor, hence each of the register holds 32 bits. We can read and write to the Software Accessible Registers. So, the communication link, between AXI interface and Soft- ware Accessible Registers, is bi-directional. The reading and writing of registers provide adequate functionality. When the peripheral is instantiated, we can access the register by reading and writing to the base address+offset. The base address is unique for each peripheral on the AXI bus. Out of three registers, one is specified for “Direction of the motor” with offset “0” [1], second is for “No. of steps” with offset “4” and third is for specifying the “Speed of the motor” with offset “8”.
- Stepper_Control.v: That module contains the func- tional components of the stepper core. The Timing.v module receives the signals from the Software Accessible Registers and processes the user input. The user input is the number of steps, the time duration for one step and the direction. As soon as the command for direction is received by the Timing.v module, the motor starts to move. The movement is initiated through an output com- mand named “gate”, which is input to User_Logic.v. The stepper motors can process only one user command at

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a time. If the motor/motors are already in motion then it cannot process a new instruction before the current task is accomplished. Hence, the "gate" signal takes care of that issue. The Stepper.v module receives information from Timing.v. It is responsible for generating the half step control signals for the stepper motor. The four bit wide "dout" register drives these four signals and sends them to the User_Logic.v module. These signals are generated according to the movement, speed and direction of each motor. The information for movement, speed and direction is being provided to it from the Timing.v module. Stepper_Control.v is the top-level module for the components discussed above. The top-level module sends all input and output signals to the User_Logic module.

CONCLUSION

In this paper, we present Blue Steps, a Bluetooth based remote control system for stepper motors. The system consists of the Blue Steps hardware and software. The hardware establishes a Bluetooth link between a mobile, user centric, device and an embedded system, instantiated in FPGA logic. Using that link, the embedded system provides the UI, which facilitates user control. To be specific, a user can set speed, number of steps and direction for each of the two stepper motors. Within the embedded system, two custom IP cores translate the commands into stepper motor signals. These signals are boosted by a driver circuit on a custom made PCB before they cause the stepper motors to move.

Our achievement was the completion of a whole cycle of control between a remote device and the actuator. To establish that control we designed and developed both the Blue Steps hardware and software. That design was challenging, because it involved custom IP cores and custom PCB circuits. Furthermore, the software setup was also developed without supporting frameworks. Hence, the Blue Steps system is an example of hardware software co-design which generates control signals with a precision of 10 ns. As a consequence, our system facilitates the development of innovative actuator control strategies for state of the art IOT applications.

Remote controlling actuator is becoming one of most important factors which determine the feasibility of introducing an IOT environment to manufacturing companies. The most likely way of interfacing with devices in the future will be IP; it is more flexible, scalable and compatible. One of the biggest issues will be to realize usable and accessible devices, with relevant functionality, for all kinds of users. Since this is an ongoing field of investigation, the results of the Blue Steps project are likely to be worthy of further analysis.

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