Ethernet based Industry Automation using FPGA

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***Abstract*—The aim of this work is to develop an embedded system directed at automating appliances in an industry via Ethernet. The system employs server/client architecture; switching commands for the appliances which are connected to the client, can be received and displayed at either end. The data containing information about the control commands are transferred between the end points of communication using Transmission Control Protocol (TCP). The remote host processes the commands received and translates them into actions of switching particular appliances ON or OFF. This type of control system gives the liberty for control of appliances from remote locations connected through Ethernet. A novel embedded system has been designed, implemented on Field Programmable Gate Arrays (FPGAs) and a small-scale prototype is developed.**

***Keywords*—Ethernet, Appliance Automation, Field Programmable Gate Array (FPGA), Transmission Control Protocol(TCP), Embedded System.**

I. Introduction

With appliance automation being embedded into every field in today's era, technology which had been merely a tool in various industries and manufacturing units has now become a necessity and thereby removing the need for human presence in the site for monitoring purposes. This opens up a whole new dimension in the process of appliance status monitoring and data acquisition providing better speed, accuracy and reliability. One such technology is automation which enables the control of any industrial equipment and acquisition of data from a remote location via Ethernet.

Earlier, Ethernet was used solely to exchange messages, but now is widely being used in various applications as it is easy to establish and more importantly, it is highly user friendly once a proper communication is established. When cost factor is considered, establishing an ethernet connection is affordable and involves less maintenance cost when compared to any other means of communication. Added to these, Ethernet offers a variety of protocols each with its own benefits such as speed, reliability etc. In [1], a system that establishes an ethernet communication link between a personal Computer (PC) and FPGA using UDP/IP protocol is developed. This system is dependent on a PC for establishment of communication and cannot be used for a standalone application. Moreover, the User Datagram Protocol (UDP) protocol used in [1] is not reliable as it is not connection-oriented and the delivery of packets is not always guaranteed. The design and development of an automation system based on GSM is mentioned in [2], as GSM based networking is rapidly growing and has got huge potential for its appliation in the field of automation. Even though networking through GSM is rapidly growing, it is completely dependent on the service provider thus making it prone to network failures very often. Ethernet communication is an independent network and highly reliable. According to the objective and application of a system, a suitable protocol is wisely chosen and utilized in the establishment of communication and data transfer. The proposed system demands a reliable and fast means of communication, which is provided by TCP protocol.

Embedded Systems are generally classified under computer systems but they are very much application specific. Any embedded system thus developed performs tasks to execute only specific real time objectives. It is embedded into a complete device. Though embedded systems possess numerous advantages, based on their objectives, various real time performance constraints must also be taken into consideration and designed with utmost care. Thus a meticulous and organized design results in a much simpler and robust system, also proving to be cost effective. Reference model is one of the architectural tools used to describe the major elements present within an embedded system design which is commonly referred to as Embedded Systems Model. As per the Embedded Systems Model, the physical components which fall on an embedded board are contained in the hardware layer and the application software layer contains the software and its associated resources.

The use of Field Programmable Gate Arrays (FPGAs) in high performance and low volume applications is very significant. The inherent feature of FPGAs to execute many instructions in parallel has classified them to be very powerful. The design of hardware using FPGAs is highly flexible and can be easily reconfigured without much change in external circuitry, to suit the requirements at a particular time. FPGAs allow customizable bit-widths and massive instruction-level parallelism. Consequently the level of optimization in FPGAs is much higher than that provided in microcontrollers or Digital Signal Processors (DSPs).

Keeping these factors in mind, the primary objective of this paper is focused on setting up of one to one connection between two FPGA hosts boards were one act as the server and other as the client using TCP protocol. This enables easy supervisory and control of appliances situated in remote location.

II. Design of the System

A. Ethernet Communication

Ethernet is a common name given to various closely related network standards. As a network standard, each version of Ethernet employs specifications for the physical network layer to organize and control the transfer of data. Protocols like Internet Protocol (IP) define communications without reference to the physical transport medium. Thus a TCP protocol is employed along with IP. TCP establishes connections, sequences and acknowledges packets sent, and recovers packets lost during transmission, thereby making it extremely reliable for communication [3].

TCP breaks down the data into several packets at sending machine and assemble the packets at the machine where it is received. Packets are chunk of data grouped into one or more wrappers that identifies the particular chunk of data and route them to the appropriate destination. The wrappers consist of chunk of data along with few additional bits at the beginning and end which are called the headers and trailers respectively. The placement of these headers and trailers in each type of required information is decided by Network Protocols.

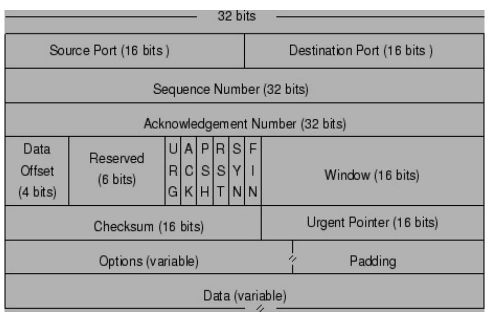

Fig. 1. TCP data format

From Fig. 1, it can be seen that TCP contains source port which is a 16 bit port number of the process that originated the TCP segment on the source device. Similarly, it also contains the destination port which is also a 16 bit port number of the process that is the intended recipient of the message. Added to these there are few other bits such as acknowledgement bit, synchronizing bit, finish bit etc. for the proper synchronization, establishment of connection and transfer of data.

B. Industry Appliance Automation

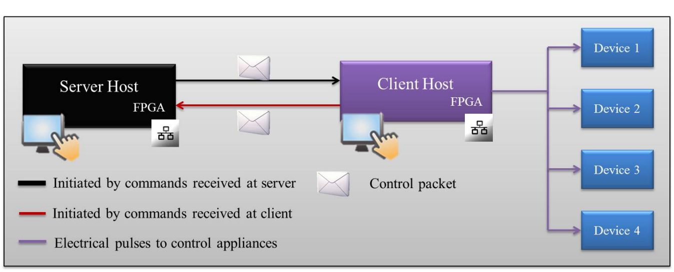

Fig. 2. Block Diagram of the entire system

The system consists of two FPGA host boards, out of which one acts as server and the other as client. The two hosts are connected via Ethernet interface and appliances are connected at the client end. Touchscreen is used as an input device on both the host machines. Control commands can be received both at the server and at the client. When input is received at the server, a control packet is sent to the client where the appliances are accordingly switched ON/OFF. When input is received at the client, the appliances are controlled according to the input and a packet is sent to the server to update the status of the appliances.

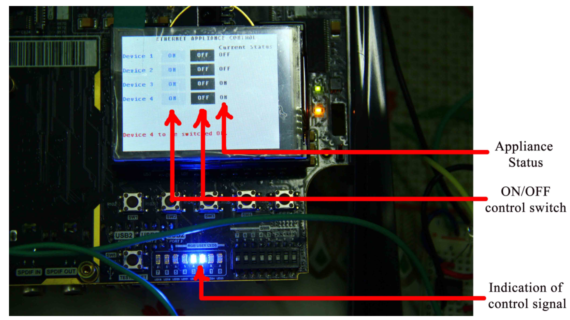

Fig. 3. Menu driven User Interface

A small-scale prototype is designed to support four devices i.e. user can control and monitor the status of four appliances from a remote location. A user interface is developed to facilitate the user to switch ON/OFF any appliance independently and also to monitor the current status of all the appliances. Fig. 3 is an instance in the prototype when appliances 1 and 2 are turned OFF, whereas the appliances 3 and 4 are turned ON. The status of appliances is displayed beside the ON/OFF options. To indicate the control signals of appliances 3 and 4, LEDs 2 and 3 are turned ON where in the LEDs 0,1,2,3 corresponds to the control signals of appliances 1,2,3,4 respectively in the developed prototype.

This menu driven user interface is used to execute the extensive algorithm employed to implement automation with the desired features. When an either ON or OFF option is selected on any one of the FPGA host board (client/server), a control packet which consists of data of the control pulse for that particular appliance to be controlled along with the previous status of other appliances is generated. The control packet thus being created is disintegrated into packets with proper headers and trailers added based on the TCP protocol. The packets thus created are sent from source FPGA host board socket to the destination FPGA host board. At the destination, the data packets are assembled together to form the original control packet which consists of the control signal and status of appliances. Based on the control signal, a control pulse toggles the state of the desired appliance. The status information of other appliances is updated in the TFT panel.

C. Implementation using FPGA

The hardware blocks used in the design of the embedded system is shown in Fig. 4. The design is developed for Altium Nanoboard (NB3000) FPGA host board which employs a TSK3000A (32-bit soft core). The processor is interfaced with many peripherals such as Random Access Memory (RAM), Ethernet port, SPI master controller, TFT display, touchscreen pointer context and I/O port. The TSK3000A is a RISC

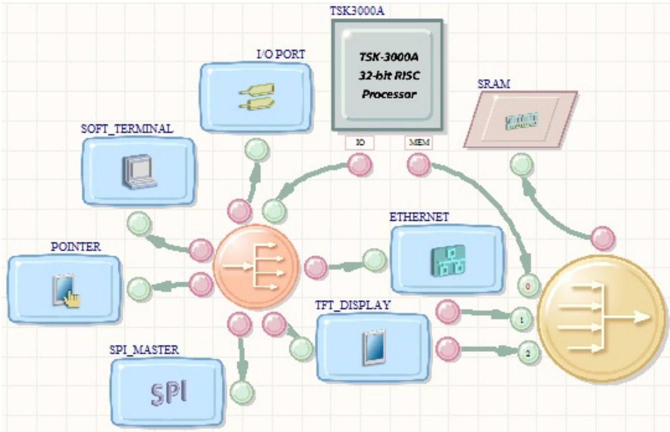

Fig. 4. Schematic of Hardware Implementation in FPGA

processor compatible with the Wishbone bus system. The Ethernet family of peripheral devices provide an interface between a processor and a physical layer device through the support of the IEEE802.3 Media Independent Interface (MII). Communication with multiple slave SPI peripherals are controlled by the SPI master controller. The TFT display unit provides a 32-bit interface between a host processor and a TFT LCD module. The controller supports the native module screen resolution of 240x320 and 320x240 and has a timing unit which is capable of generating all required control and timing signals. The pointer component detects the touchscreen pen input and feeds it to the processor. The I/O port block is a Wishbone-compliant, configurable parallel port unit, providing a simple register interface for storing data to be transferred to/from other device in a design.

D. Algorithm

Fig. 5 and Fig. 6 describe the flowchart of algorithms designed for the server and client respectively. Initially, the server FPGA creates a socket and waits for the client to connect to it, after the which the client initializes and pings the server thereby attempting to connect to it. Once a connection is successfully established, a menu driven user interface is displayed in both FPGA host board's TFT panel following which the receive buffer is checked for data, and if a control packet is received, the status of appliance is changed based on the command obtained from the control packet. When a user switches ON/OFF an appliance, the control packet is generated accordingly and sent to the remote FPGA host board using TCP protocol after which the menu is updated in the local FPGA host board.

The algorithm is designed in such a way that communication is not confined to one direction, but it is bi-directional, i.e. the changes in the client FPGA is also sent to the server FPGA and is updated in the display. Thus bi-directional communication is established between the FPGAs implementing the data acquisition and supervisory operation, the most required features for any appliance automation. When the status of an appliance is changed at the server, the status is updated locally on the display and the control signal is sent to the client. In the case when it is controlled from the client, the state of the appliance is toggled and its present status is sent to the server

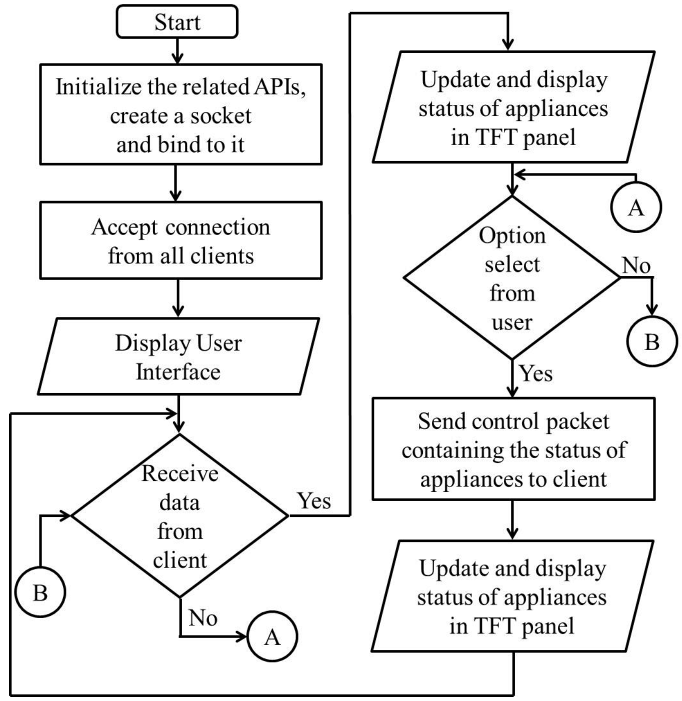

Fig. 5. Flowchart of Algorithm running on Server

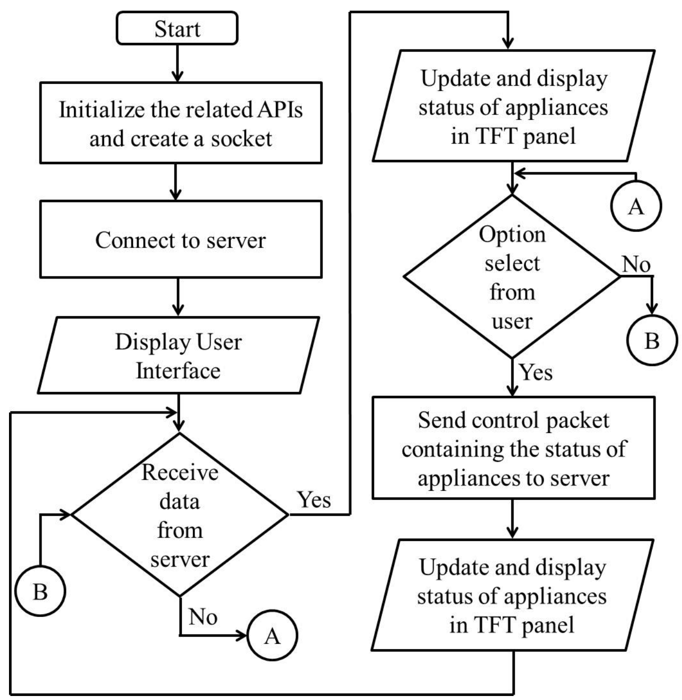

Fig. 6. Flowchart of Algorithm running on Client

where the display is updated.

III. Hardware Implementation and Field Test

A small-scale prototype was developed with two FPGA host boards which are designated each with distinct IP and MAC addresses and connected together via a network switch. Network switch is used to facilitate full-duplex transmission.

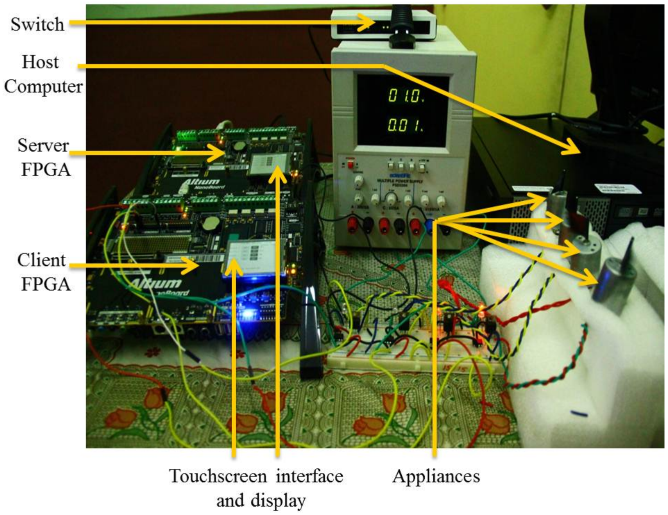

Fig. 7. Photograph of the entire hardware setup

The control signal generated by FPGA cannot directly drive an appliance, thus an appliance driver circuit is designed and developed. The external driver circuitry consists of an IGBT which drives the appliance whenever a gate pulse is applied, generated based on the user input on the server menu or on the client menu. To represent industrial appliances, four DC motors are interfaced at the client side FPGA and are operated according to corresponding control signals.

IV. Design Summary

The design was synthesized using Altium Designer and the generated device summary is shown in Fig. 8 and the power consumed by the design was generated by Xilinx XPower Analyzer is shown in Fig. 9.

Device Resources - Usage Summary	
4-Input LUTs - Logic	5,692 / 22,528 25%
Average Fan/Non-Clock Nets	3.63
BUFGMUXs	5 / 24 20%
I/O Pins	162 / 502 32%
over-mapped for a non-slice resource or if Placem	
RAMB16BWEs	6 / 32 18%
Slice Flip Flops	2,604 / 22,528 11%
Slices with only related logic	3,645 / 3,645 100%
Slices with unrelated logic	0 / 3,645 0%
Slices	3,645 / 11,264 32%
Total 4-Input LUTs - Logic	6,013 / 22,528 26%

Fig. 8. Device Summary Generated upon Synthesis

V. Conclusion

Thus, Automation via Ethernet allows appliances to be controlled from remote location and in the process allowing replacement of human operators, performing tasks beyond speeds of human capability and significant reduction in operation time.Based on this, the system was developed which provides a superior and user friendly interface (TFT touchscreen and display) reducing the complexity in operation to control the appliance. Thus, a necessity for a person to be present near any Industrial machine or appliance for constant

On-Chip	Power (W)	Used	Available	Utilization (%)
Clocks	0.054	6	---	---
Logic	0.020	6873	22528	30.5
Signals	0.017	8174	---	---
IOs	0.031	154	502	30.7
BRAMs	0.006	10	32	31.3
MULTs	0.000	2	32	6.3
Leakage	0.064			
Total	0.193			

Fig. 9. Power Report Generated by Xpower Analyzer

monitoring of it's operation is not required. This system will prove beneficial in the areas where the risk factor in the manual operation of high power machines is very high.

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