A complete Design and Implementation of a low cost Remote Controlled Flying Machine with FPGA based Control System

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***Abstract*— The paper presents the outlines of a low cost design and implementation of Remote Controlled Flying Machine and the Field Programmable Gate Array (FPGA) implementation of Control System. Several criteria have been taken under consideration for keeping the cost as low as possible. The wind tunnel test of the flying machine proves its stability and effectiveness. On the other hand, the electronic controller based on FPGA presented in this paper is a very efficient implementation with error checking and attack countervailing capability.**

Keywords-Remote controlled model airplane, FPGA, Aeronautical Design, flying machine

I. INTRODUCTION

A remote controlled flying machine can find a variegated utilization in today's world. In regions where natural calamites are very common the airplane is of especial significance. To predict the amount of destruction caused by these calamities like flood, earthquake or cyclone it is necessary to have pictures of the area which is sometimes done by capturing pictures from helicopter. But it is very costly. So to minimize the cost the low cost remote controlled flying machine can be used. One more instance where the airplane can find its utilization is scientific research. Various information like humidity or temperature data of various heights are sometimes necessary for scientific research. So using such kind of flying machine, research could be conducted efficiently. For the purpose of journalism it can also be used to capture pictures where it is unsafe to go.

For developing a flying machine of high performance yet of low price several criteria has been taken under consideration including using low cost material for implementing the airframe and designing a cost effective FPGA based controller. The airframe is completely made of local material. Another specialty of this airplane is its auto take off capability.

In search for a suitable hardware platform a lot of commercially available options were considered such as the platform based on microcontrollers as PIC or Atmel 89 series, the platform based on other microprocessors, DSP processors and FPGA-based hardware. In recent years, FPGA-based hardware implementation technology has been used for control system field successfully due to the advantages of their programmable hard-wired feature, fast time to market and reusable IP (Intellectual Property) cores [1]. Besides, the FPGA based system can get a very high speed level, since it can carry out parallel processing by means of hardware mode. Moreover FPGA implementation can enable us reducing the production cost significantly lower and lead us to low cost chip development. Considering all the facts FPGA-based hardware implementation technology has been used in this implementation.

This paper is organized as follows. In section II, the overview of both aeronautical design and FPGA-based control system design is presented. The detailed aeronautic design of the proposed low cost remote controlled flying machine is described in section III. In section IV, the detailed architectural design of the FPGA-based controller of the proposed low cost remote controlled flying machine is presented. In section V, contains the experimental results. The concluding remarks are in section VI, followed by the references.

II. OVERVIEW

Broadly speaking, the paper describes two fronts of research: The aeronautical design and implementation of a low cost flying machine and the FPGA based electronic control unit design.

Fig.1 shows a model of the remote controlled flying machine which has been made in this research.

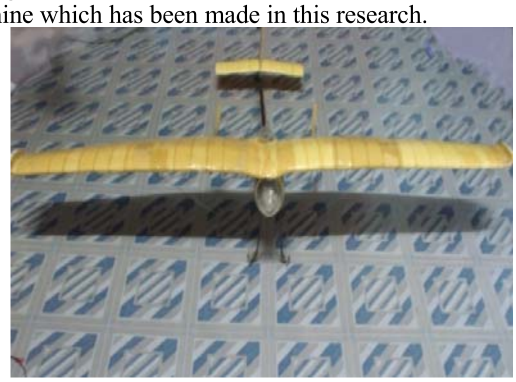

Figure 1. The Model of the Flying Machine

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The airplane can be controlled by wireless communication devices and is designed to send digital data which can be gathered from any kind of transducer set in the airplane (for example camera for Pictures or Video). The control system is designed by Field programmable gate array (FPGA). The FPGA based control system is special for two purposes. Firstly for it's error checking capability and secondly for it's ability for preventing any attack like hijacking or sniffing. The sophisticated control system ensures that no other intruder can hijack the control of the airplane or sniffs the information sent by the airplane. To prevent attack like sniffing and hijacking RSA encryption\decryption is used. So it becomes almost impossible for the attackers to either sniff or hijack the airplane. Moreover an improved error checking method is also implemented in this control system which enables it for detecting any error. The medium of wireless is especially prone to error originated from collision and interruption. Cyclic Redundancy Check (CRC) is used to countervail the problem.

III. AERONAUTICAL DESIGN

A. Wing Design

Main plane section is Zhukovsky cambered Aerofoil [2]. In Fig. 2 top and side view of main plane is shown. Its maximum thickness is 12 percent of the chord and camber is 2 percent of the chord. The wing is a tapered wing. Its root chord is 15 cm and tip chord is 10 cm and wing span is 100cm.

So the tapper ratio = $\dfrac{Tipchord}{Rootchord} = \dfrac{10cm}{15cm}$ =0.66

So the Aspect Ratio = $\dfrac{(Span)^2}{Span \times Meanchord} = 8$

So it could be understood from the tapper ratio and high Aspect Ratio that the induce drag force would be minimized. The wing has winglets which have dihedral angle. These winglets serve for reducing induce drag force and ensuring the overall stability. The angle is 5 degree.

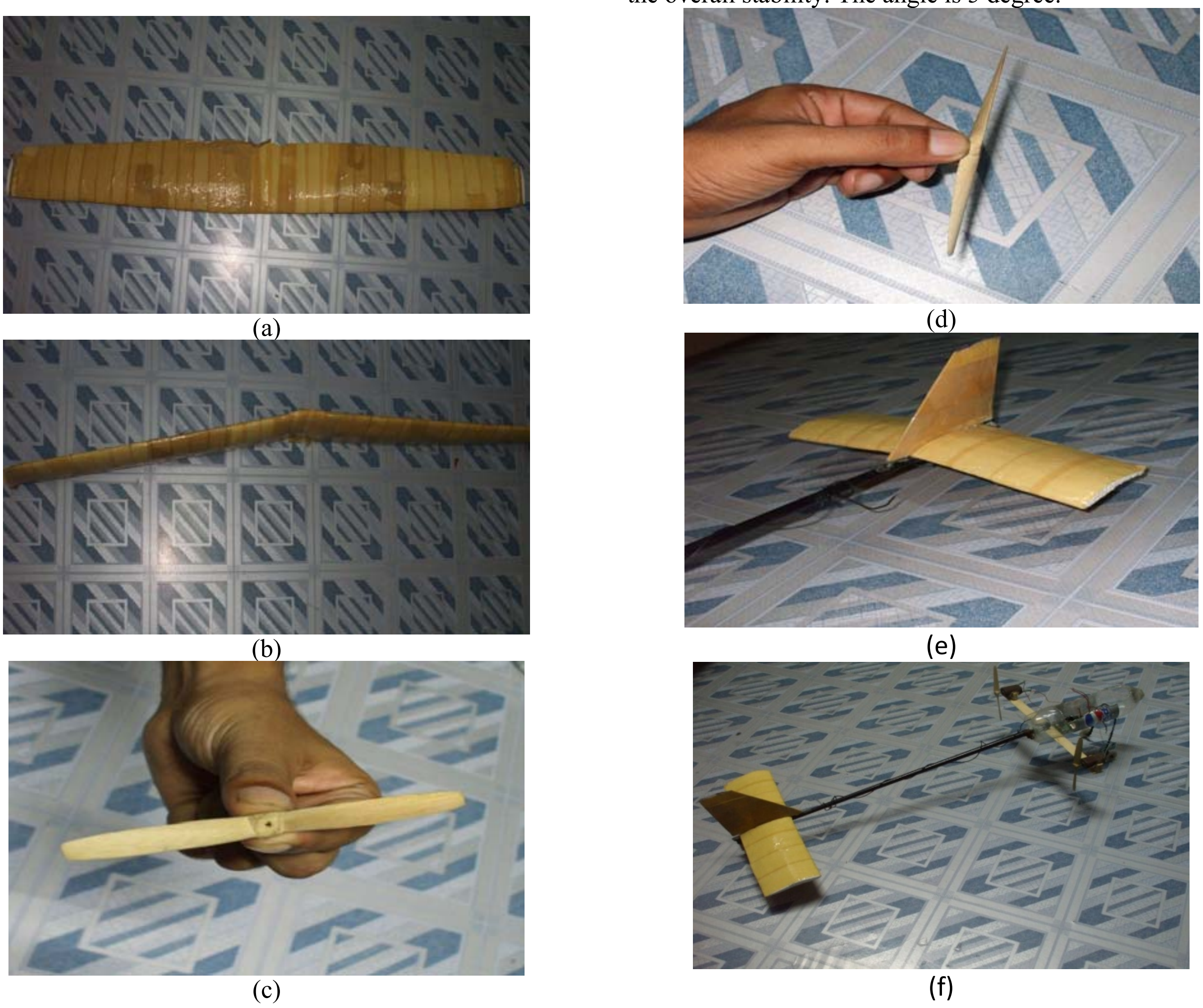

Figure 2. Figure of various part of the Model (a) Top view of Main Plane (b) Front view of Main Plane (c) Front view of propeller (d) Side view of Propeller (e) Tail Plane & Vertical Stabilizer (f) The Model without Wing.

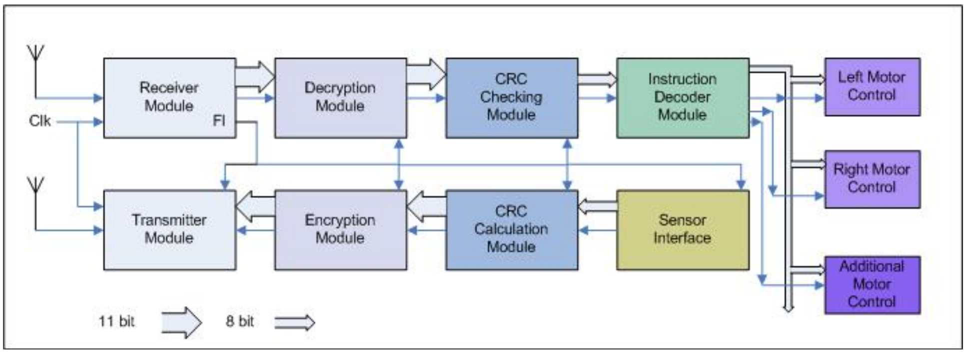

Figure 3. overview of the FPGA-based control system

Polystyrene sheet (Thermocol) has been used as a fundamental material. The rationales behind this are that this material is very easy to shape and also abundant in market. Moreover, it is very cheap. Scotch tape has been covered well around the whole Main Plane.

Tail Plane is also a Zhukovsky aerofoil. Maximum thickness is 9 percent of the chord and camber is 2 percent of the chord. It is a rectangular plane. Its span is 28cm and chord is 8cm.

So the Aspect Ratio = $\frac{(Span)^2}{Span \times Meanchord} = \frac{28}{8} = 3.5$

B. Propeller Design

The Propeller is a two bladed wooden Propeller because of its low cost. If Propellers were made with plastic its cost would have been much higher because of molding and dice costs [3].

TABLE I. SOME PARAMETER OF PROPELLER

Diameter	11 cm
RPM	11000-12000(Tachometer)
Advanced Ratio	0.0098 – 0.0104
Solidity Ratio σ	0.0405
Twisting angle	4 – 40 degree
Static Thrust	.5 lb

C. Vertical Stabilizer(Fin)

It is Symmetrical Aerofoil section. It is also Zhukovsky Aerofoil Section. Maximum Thickness is 4% of the chord.

D. Power Plant

When the motors are fully loaded each of the two motors draw about 2.7 amps current. So the total power of the two motors used is approximately 61 watt. That is, each motor power is 2.75 x 11.1 watt or 30.5 watt. The motors ensure high RPM, optimum torque and high power to weight ratio.

E. Battery

3 cell phone 1020mAh Li-ion rechargeable batteries have been used for its Light weight and reasonable current capacity. Each provides 3.7 volt. Each weighs 25 grams.

Ni-Cd batteries would have been better from some point of view but costlier and heavier.

IV. FPGA BASED CONTROL SYSTEM DESIGN

The FPGA-based control system has some modules including Receiver Module, Decryption Module, CRC Checking Module, Instruction Decoder Module, Motor Control Module, Sensor Interface Module, CRC Calculation Module, Encryption Module and Transmitter Module [5]. In Fig. 3 the overview of the control system is shown. Each of the Modules which are designed for serving a particular purpose is described below.

A. Receiver Module

This module is converts the serially received data into parallel format. After each 8 bits of data it produces the output and sends this to the next module, Decrypt Module. As soon as the valid data is ready at the output of this block a pulse is generated in Fl signaling that valid data is ready in the input bus of the Decrypt Module. Actually this Fl works as a cardinal clock of the whole implementation.

B. Decryption Module

This Module ensures the reliability and security for controlling this airplane. It takes the input from the output of Receiver Module and Decrypt the Parallel Data using RSA algorithm. The RSA algorithm is one of the best in the area of security and a simplistic approach for implementation in FPGA. Suppose, the remote controlled airplane is being controlled by a valid sender. The authorized sender before sending any command, m (such that $m<n$) would encrypt the command. So the encrypted value, c of the command, m that the sender sends is

$$c = m^e \% n. \quad (1)$$

Now to decrypt the received encrypted command, m The receiver computes

$$m = c^d \% n. \quad (2)$$

So the encryption key is (e,n) and decryption key (d,n) [8].

C. CRC Checking Module

An error-detection technique used widely in the field of computer networks is based on Cyclic Redundancy Check (CRC). After decrypting the command, a cross checking is needed to ensure whether any error has been occurred. As the medium of the command transfer for controlling the airplane is wireless there is always a probability of occurring an error by interference. An error-detection technique used widely in the field of computer networks is based on CRC. In this research this mechanism has been used [8].

D. Instruction Decoder Module

The responsibility of Instruction Decoder Module is chiefly to decode the command sent by the sender. This Module is connected with some Motor Control Module. In this implementation the Instruction Decoder Module takes the error free instruction from the CRC Checking Module and understands which of the three Motor Control Modules should be enabled through the three enable line.

E. Motor Control Module

Motor Control Module is responsible for controlling the motors connected with the propellers and other facilities. There are in total three Motor Control Modules. These Modules takes the instruction available at the bus only if the enable pin of the module is high. This Module can receive only four instruction that is speed up, speed down, start and stop and it can control the motor using pulse amplitude modulation.

F. Sensor Interface

The control system is designed to receive digital data from any kind of transducers or sensors in a serial manner. The sensors include Radar, Photo or Video Camera, IR Scanners, Temperature sensors or ELINT. In this implementation the serial data is converted into eight bit parallel data by this Module and passed to the next.

G. CRC Calculation Module

CRC calculation Module is responsible for protecting from any error which can be occurred in the path between sender and receiver. CRC Calculation Module calculates the bit pattern called remainder on the basis of previously agreed Generator bit pattern. It adds the remainder bit pattern at the end of the data bit received from the Interface Module.

H. Encryption Module

The Encryption Module works the same way the Decryption Module works. It ensures the security of the data of the sensors or transducers by encrypting it using RSA algorithm. Thus sniffing the data can be prevented.

I. Transmitter Module

Transmitter Module is a very important module for this implementation which is responsible for wireless communication. At first the module receives parallel data from Encryption Module. After parallel to serial conversion it sends the serial data into input of the sender of the wireless communication device.

V. Experimental Results

For testing the stability of the model wind tunnel test is a very reliable test. In this research this test has been conducted. From the data of lift and drag force, pitching moment, rolling moment, and yawing moment it could be conceived that the model is a stable model. Initially the angle of attack of wing is about 9^o. At time of level flight the setting angle of attack is about 4^o. In our implementation and research, the airplane can be controlled from a distance about 50 meters, as the range of the wireless device is 50 meters. The simulation of FPGA based control system has done by Quartus II (ver. 7.2 sp3). The controller has been tested in a single chip FPGA (Cyclone II EP2C35F672C6). From the simulation result it can be said that a very successful low cost secured control system of such flying machine is FPGA implementable. This control system would be a much faster, more efficient [7]. This can even be implemented as a low cost controller IC [8].Lastly in Table I the major challenge, cost is shown.

TABLE II. Cost of different parts of the model

Part Name	*Material*	*Price*
Main Plane	Polystyrene sheet & scotch tape	20 BDT
Tail Plane	Polystyrene sheet & scotch tape	2 BDT
Propeller (2 pieces)	Wood	10+10=20 BDT
Fuselage	Plastic bottle & carbon fiber	10 BDT
Landing Strut	Ms rod	2 BDT
Wheel	Plastic	10 BDT
DC motor(2 pieces)	-	40 USD
Battary(3 pieces)	Li-ion battery	3 USD

a. BDT is the currency of Bangladesh (1 USD is about 70 BDT)

VI. Conclusion

In this paper the aeronautical design and implementation of a low cost remote controlled flying machine and a FPGA-based controller is demonstrated. Future works of this research may include IC implementation of such kind of airplane controller, low cost unmanned aerial vehicle design based on similar technology [10].

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