MICROCONTROLLER BASED FATIGUE SENSING DEVICES

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Abstract: An aircraft when airborne has to maneuver depending on weather conditions and various other reasons. In a straight or level flight there is only vertical component acting on the aircraft. In extreme conditions, such as mountains terrains, the plane may have to take 180-degree turn. During this maneuver, the vertical component increase that is the aircraft experiences a higher value of acceleration due to gravity, say 2g, 3g or even up to 8g to 10g. During the lifetime of an aircraft, it experiences many such increased values of 'g' and each time a stress is developed on the aircraft wings which is built over a period of time and converts into fatigue. The fatigue starts as a crack on the wings which keeps spreading throughout, thus leading to the breakdown of the aircraft. It is to measure this fatigue that a fatigue meter is used. The fatigue in case of aircraft is sensed by the accelerometer in terms of vertical acceleration. When the aircraft is continuously flying and maneuvering, then depending on the design of the aircraft and the structure of aircraft, certain parameters like vertical 'g' are more prone for inducing fatigue. The vertical 'g' of interest is loaded in a look up table. The sensed 'g' is compared with the stored 'g' and the number of times the aircraft encountering the difference in 'g' is recorded. This recorded 'g' is milked out and can be analyzed off-line to calculate the remaining life of aircraft. The paper aims at developing a portion of fatigue meter, which uses accelerometer to sense the G-force and determine number of G level crossings during a single flight. We are using a 16-bit PIC microcontroller which has a 10-bit internal ADC. G crossing detection algorithm is programmed into microcontroller, based on this algorithm g values are calculated. The microcontroller based system is interfaced with an LCD, and UART which are used to display g crossing, g value with corresponding time stamps. Real time clock is used for time stamping f the G level crossings. Eight switches are provided to display corresponding g counters on the LCD display. This recorded g crossing data are used for further processing, to estimate remaining life of aircraft.

Index Terms–**Airborne, maneuver, fatigue, look up table, g level crossings, g- force, g crossing detection algorithm.**

I. INTRODUCTION

Aircraft machine parts are made up of high quality ductile metals. Because of the various g values experienced by an aircraft, stress accumulates within the parts of an aircraft. Later on, it was found that the machine parts which were under stress resulted into fractures. These fractures took place after a certain period of operations of the aircraft[1]. It was observed that the metal was degenerated and caused fatigue under the action of many stresses and thus its ductile structure turned brittle. The process of progressive localized permanent structural change occurring in materials subjected to conditions which produces fluctuating stresses and strains at some point or points which may culminate in cracks or complete fracture is defined as fatigue. A fatigue crack initiates at a free surface and grows in two stages. During the first stage it propagates at approximately 45º to the direction of applied load following the line of maximum shear stress. After traversing a number of grains it changes direction to propagate at approximately 90º to the direction of the applied load. Cracks growing through these stages are often referred to as Stage I and Stage II cracks respectively[2].

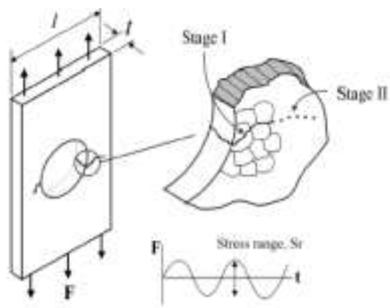

Figure.1: Illustration of Stage I and Stage II Crack Growth

A high proportion of the structure weight of an aircraft is in its wing. In flight, the bending movement in the wing is linearly proportional to the acceleration measured at the center of gravity of the aircraft for a given weight distribution [3]. The unit of acceleration is 'g' m/s2. For an aircraft it is the ratio of lift to weight [21]. The lift vector is broken into horizontal component that balances the centrifugal force created by the turn and the vertical component balances the component of weight which is shown below.

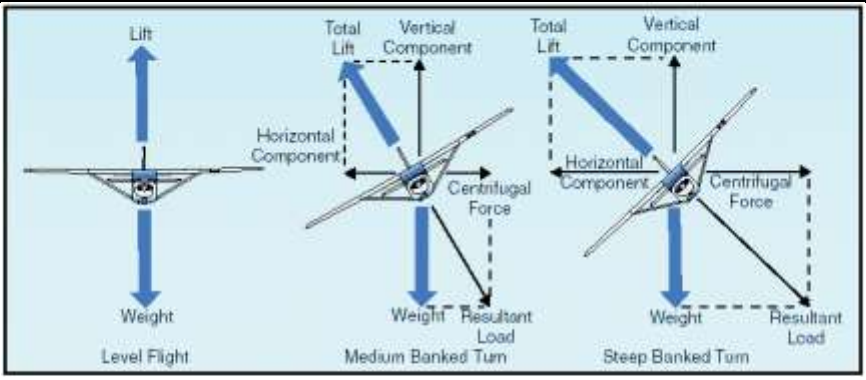

Figure.2: Balancing Components for Different Turns

In a straight or level flight, lift is considered equal to weight. In other words the Up forces are equal to the Down forces. When the aircraft runs into turbulent air[4][5][6], the plane will slow down to find smoother air by changing its altitude. In extreme conditions, such as mountainous terrains, the plane may have to take 180 degrees turn. In such cases, the Up forces[7][8][9] are not equal to the Down forces. In turn, the lift has to be made higher to have its vertical component balance the weight of the aircraft. The four main forces acting on it are thrust, drag lift and weight as shown in the figure below.

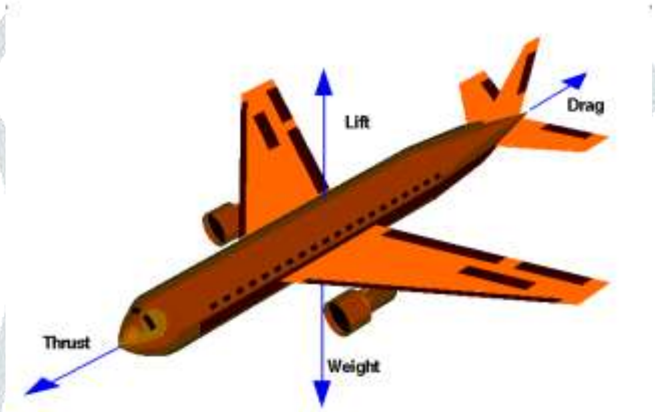

Figure.3: Forces Acting on an Aircraft

Each fatigue cycle is made up of one tension and one compression cycle. When a material is subjected to certain number of these cycles (which is constant for a given material), it breaks down and collapses. It has been discovered that different g-levels induce fatigue cycles of various magnitudes[10]. The cycle starts at particular g-level and ends at different (not necessarily higher) g-level. The levels where the fatigue cycle starts are called the Lock levels and the g-levels where the fatigue cycle [11] ends, is called an Unlock level. If and only if both the lock and the corresponding unlock level is crossed, only then will a fatigue cycle complete. Fatigue meters and counting accelerometers were designed to monitor acceleration of structural life consumed during flight. The fatigue meter stores the G level counts for each individual flight and for the total flights. The unit contains an internal clock/calendar set by the Ground Support Equipment for recording the time of each G level crossings. The fatigue meter[12] design features a solid state micro-machined accelerometer that provides reliable and accurate information to the system. The signal is fed into a digital signal conditioning circuit containing A/D converter and a microcontroller programmed for producing the average stress value and the number of G-Level crossings[13][14][15] of an aircraft. Knowing the load history; the crack initiation and crack propagation time is predicted. The load history is the number of cycles and the dynamic responses of the structure [16][17][18] over its intended service life. Knowing the load history, we can predict if a structure or component will meet its design service life [19] [20].

II. PROJECT OVERVIEW

Here a brief introduction to the analysis of the system in its entirety with comparison between existing electromechanical fatigue meter and the proposed microcontroller based g-level recorder is provided. In the existing system, the electromechnaical fatigue meters implemented in the aircrafts processes the data from servo accelerometer which translates the vertical acceleration of the aircraft to equivalent electrical signal. Electro mechanical counters are used to record the number of times the vertical acceleration of the aircraft varies between to specified ‘g’ levels called lock and unlock. The comparator along with transistors, diodes and resistor are used to process the vertical acceleration data. The display is on eight counters in each level the electromechanical fatigue meters are prone to errors due to mechanical vibrations and they consume more power. Whereas in the proposed system, the microcontroller based g-level recorder proposes to utilize 16 bit PIC24FJ128GB106 microcontroller. This controller has the required analog to digital converter unit to convert the analog output of the accelerometer to digital value to be processed by the controller for ‘g’ computations. The unit is provided with a nonvolatile memory to record all g-level crossings. It has suitable type of display unit to display the selected g-levels. The g-level recorder is capable of working into two modes. In first mode the unit senses the g-levels and records the ‘g’ crossings. In the second mode, the display unit displays the recorded ‘g’ levels. This is offline when the aircraft is on ground.

III. IMPLEMENTATION

In the implementation we included a system design and system development. The system design consists of the following steps. Firstly the hardware design that is designing of the circuit, testing individual hardware components which form the integral part of the circuit., hardware design simulation using proteus and implementing the hardware. Secondly the software design that is, coding using embedded c and compiling and inking the code in MPLAB IDE. The system development consists of implementation of the g-crossing algorithm.

‘g’ crossing algorithm updates the counters for each ‘g’ level depending upon its lock and unlock status. Here the algorithm is explained and also shows fixed g-levels for jaguar plane and its lock and unlock voltages.

IV. OVERVIEW OF COMPONENTS

To develop a microcontroller based system which can be used to sense the variation of g-force acting on aircraft and to update the necessary g-counters the following block diagram is used is shown in the diagram below.

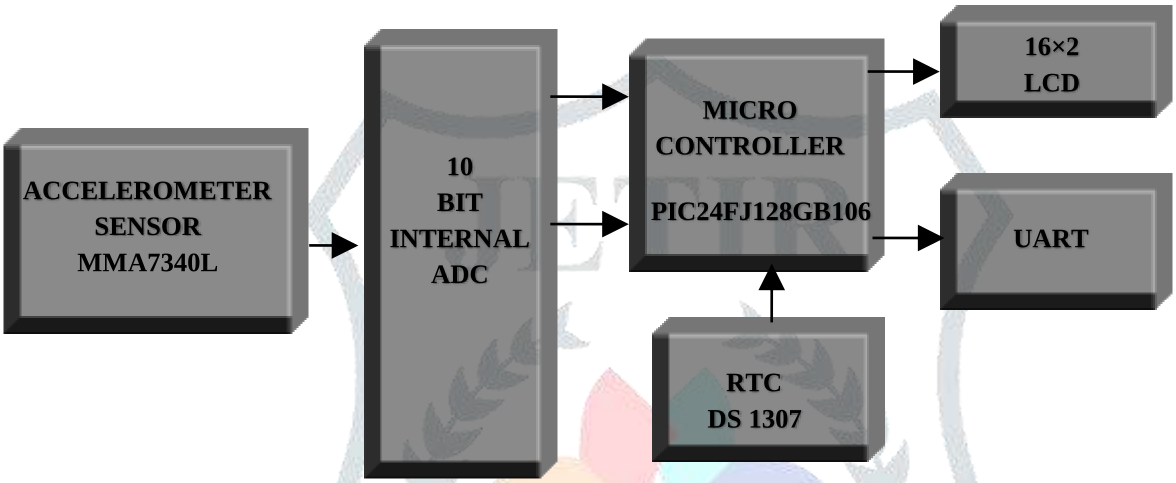

Figure.4: Block diagram of microcontroller based fatigue sensing device

The above block diagram shows an accelerometer sensor (MMA7340L) which produces voltage based on variation of g-force which is feed to PIC24FJ128GB106 microcontroller. The algorithm is calculated and results such as g crossings and g value are displayed on UART and LCD with time stamps using DS1307.

V. G CROSSING ALGORITHM

g-levels	LOCK values (V)	Unlock g Level	UNLOCK values (V)	Equivalent Binary bands	
				Lock	Unlock
-1.5g	1.0625	-0.5	1.1875	1812	2026
-0.5g	1.1875	0.25	1.28125	2026	2186
+0.25g	1.28125	1.0	1.375	2098	2346
+2.5g	1.5625	1.75	1.46875	2666	2506
+3.5g	1.6875	2.50	1.5625	2879	2666
+5.0g	1.875	3.25	1.65625	3199	2825
+7.0g	2.125	4.25	1.78125	3625	3039
+8.0g	2.25	4.75	1.84375	3839	3145

Table.1: g-levels

Steps involved are, check if the ‘g’ value is positive or negative. If ‘g’ value is positive compare currently acquired g-level value with previous value. If current value is more than the previous value compare current value with positive g levels available and set the corresponding lock level of that g level. If current ‘g’ value is less than previous ‘g’ value compares current value with positive g levels, check if the lock value for the particular ‘g’ level is set. If the lock value is set increment the ‘g’ crossing for the particular ‘g’ value and then reset the lock value. If ‘g’ value is negative compare currently acquired g-level value with previous value. If current value is less than the previous value compare current value with positive g levels available and set the corresponding lock level of that g level. If current ‘g’ value is more than previous ‘g’ value compare current value with positive g levels, check if the lock value for the particular ‘g’ level is set. If the lock value is set increment the ‘g’ crossing for the particular ‘g’ value and then reset the lock value. Implement decimal adjust of the g-crossings to convert it from hex to BCD.

VI. FLOW CHART FOR ‘G’ COMPUTATION AND MAIN FOW CHART

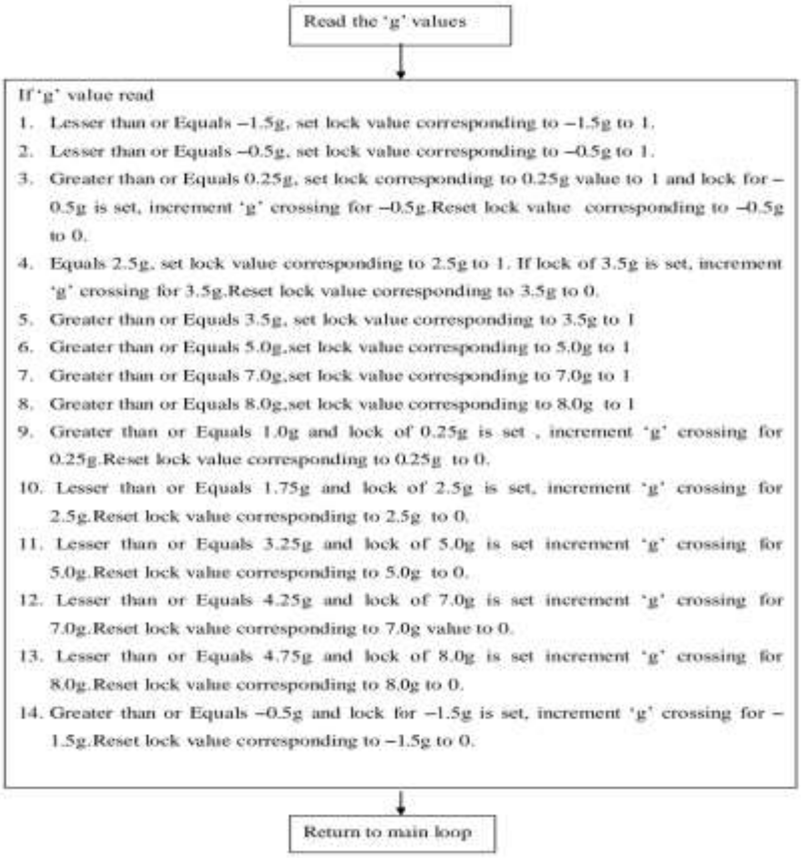

Figure.5: Flow chart for g crossing algorithm

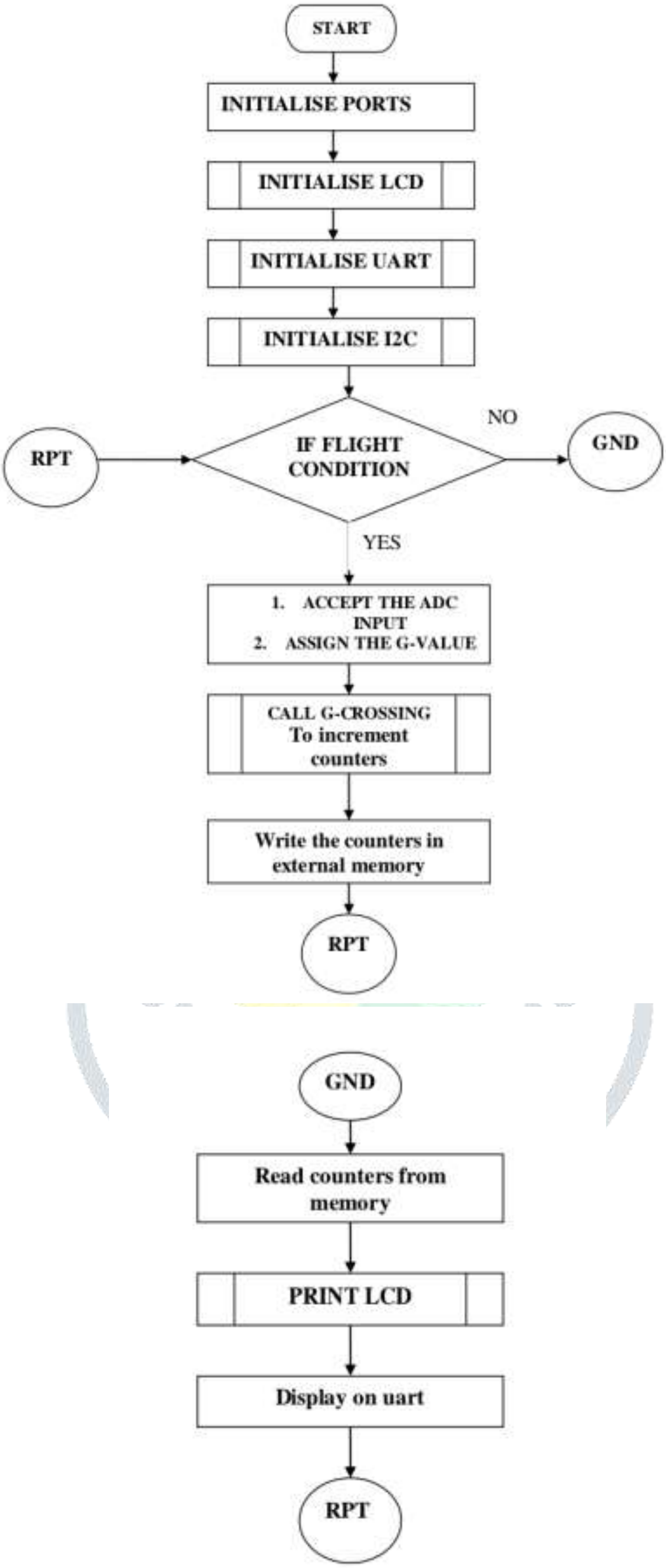

Figure.6: Main flow chart

VII. DEVELOPMENT SOFTWARE

We have used MPLAB C30 for code compiling and proteus simulator for real time simulation of hardware and proteus VSM provides debugging facility for both assembly code and high level language source. The PICkit2 development programmer which is used to download the hex-file on the microcontroller. This is connected to the PC using a serial cable.

VIII. WORKING AND ITS RESULTS

In this paper we deal with estimating ‘g’ crossing experienced by flights during maneuvering. By the above estimation it is possible to determine the remaining life of aircraft. The accelerometer is mounted at the center of gravity of the aircraft. During the aircraft maneuvering, the aircraft experiences various g-forces. The accelerometer output voltage varies which is a measure of variation of g force that leads to structural damage of the aircraft. Here we have implemented 8’g’ levels as counters and individual counters are incremented when aircraft experiences appropriate fatigue cycles. In general there are two modes of operation fight mode and ground mode. When aircraft is stationary on ground it is said to be in ground mode and when aircraft is flying and maneuvering it is said to be in flight mode. In this paper we deals with both flight and ground mode, in flight mode the g-force variation is acquired which is the accelerometer output which in turn fed to the 10 bit internal ADC of microcontroller which is further processed by the g-crossing algorithm fed into the microcontroller. Based on this algorithm the counters are incremented and the corresponding g-values and time stamps are displayed on UART. In ground mode operation the updated values of counters are displayed on the UART which can be displayed on the screen of the desktop monitor. There are 8 DIP switches provided for user friendly operation that is switching on individual switches appropriate counter can be displayed on LCD.

Before implementing on hardware the system was simulated on real time simulations software called proteus and with the help of virtual instruments provided by proteus the program debugging was made easier.

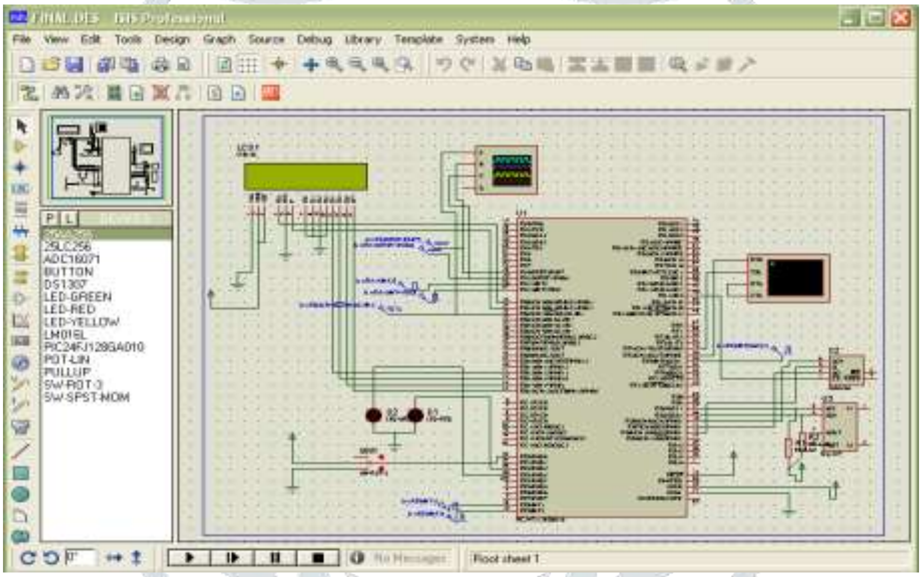

Figure.7: Schematic of microcontroller based fatigue sensing device

The above figure shows the schematic of the system designed in proteus simulator, some of the additional features like signal generator through which signal like square, rectangular pulse and many other waveforms of different frequency is given and digital oscilloscope is also provided, through which analyzing the input signals become easy. Analog analysis graph plots the graphs of input signal given through which details of frequency, amplitude can be seen.

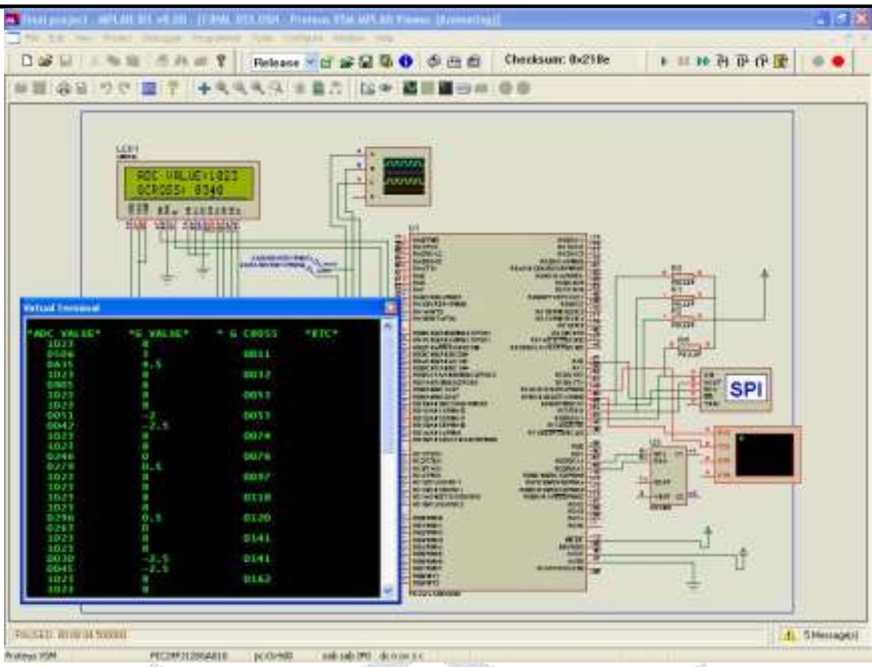

Figure.8: Showing details of g value and g counter on UART

The above figure shows along with the schematic display on the virtual terminal which corresponds to display on UART. Using proteus simulation software a virtual hardware circuit is rigged up and tested before implementing on hardware. Real time simulation is viewed in proteus. It has many options like digital oscilloscope which is used in viewing input waveform. Signal generator which is used to generate signals of desired frequency and so on. The figure 7 shows the result displayed across LCD and digital oscilloscope.

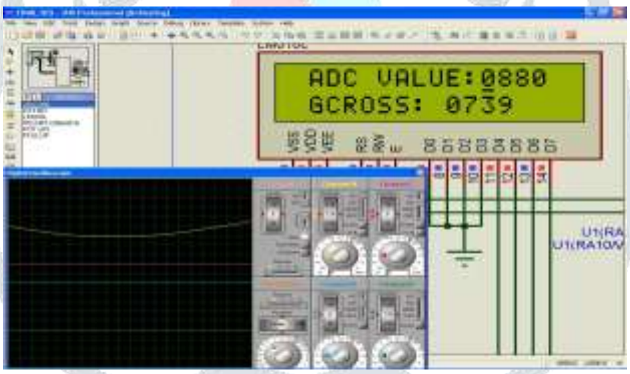

Figure.9: LCD and digital oscilloscope

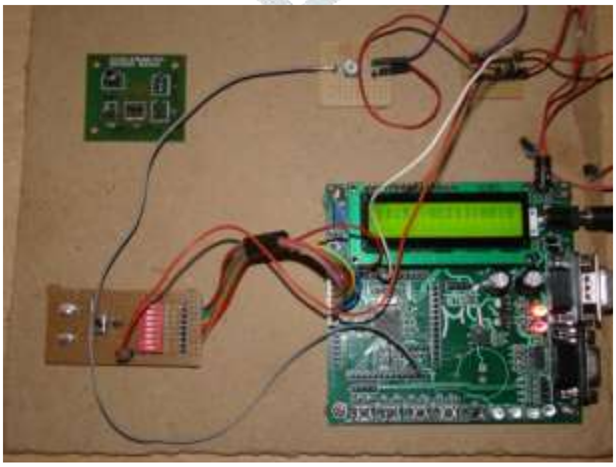

Figure.10: Model of microcontroller based fatigue sensing device

IX. CONCLUSION

The main objective of this paper is of analyzing of fatigue data in order to reduce a spectrum of varying stress into a set of simple stress reversals and to develop an event tracking system has been successfully implemented and demonstrated. There exists various stress cycles algorithm, the algorithm is used here is the g crossing algorithm. The g-level crossing is important in analyzing the stress experienced by an aircraft. The g-level crossing is simulated by means of the DIP switch. The system developed forms an integral part of a fatigue analyzer which includes interfacing of LCD for user interface and real time clock for time stamping.

X. FUTURE WORK

The above system developed can be improved by using an external memory interfaced with the microcontroller, which can be used to store the counters and their corresponding time stamps. That is during flight condition of aircraft counter values along with their time stamps can be written on the memory and later when in ground condition it is read for further analysis. The values obtained from this system is used for further processing to monitor the stress levels continuously and then estimate the remaining life of the structure with the help of other necessary equipments which is not a part of the current model g-level crossing is important in analyzing the stress experienced by an aircraft. The stress cycles can be found by using many algorithms.

XI. ACKNOWLEDGMENT

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REFERENCES

[1] Megson, T. H. G 2007 Aircraft Structures for Engineering Students, 4th edition, Elsevier, USA.
[2] Mansoor M, Ejaz N. 2009 Eng Fail Anal 16(7) 2195.
[3] Venkatesha, B. K., Prashanth, K. P., & Deepak Kumar, T. 2014 Global Journal of Research and Engineering-GJRE-A, 14(1), 13.
[4] Grbovic, A., & Rasuo, B. 2012 Engineering Failure Analysis, 26, 50.
[5] Harris, C. E, Newman, J. C, jr. 1996 NASA Technical Memorandum 110293, Langley Space Centre, USA.
[6] Mitchell, M. R., & Landgraf, R. W. 1996. ASTM 3rd Volume.
[7] McKeighan, P. C., & Ranganathan, N. (2005). ASTM Vol. 1439.
[8] Payne, A. O. 1976 Engineering Fracture Mechanics, 8(1), 157
[9] Barbarino, S., Bilgen, O., Ajaj, R. M., Friswell, M. I., & Inman, D. J. (2011). A review of morphing aircraft. Journal of Intelligent Material Systems and Structures, 22(9), 823-877.
[10] Hileman, J., Spakovszky, Z., Drela, M., Sargeant, M., & Jones, A. (2010). Airframe design for silent fuel-efficient aircraft. Journal of aircraft, 47(3), 956-969.
[11] Immarigeon, J., Holt, R., Koul, A., Zhao, L., Wallace, W., & Beddoes, J. (1995). Lightweight materials for aircraft applications. Materials Characterization, 35(1), 41-67.
[12] Joshi, S. P., Tidwell, Z., Crossley, W. A., & Ramakrishnan, S. (2004). Comparison of morphing wing strategies based upon aircraft performance impacts. sea, 2, 32.
[13] Kechidi, M. (2013). From'aircraft manufacturer'to'architect–integrator': Airbus's industrial organisation model. International Journal of Technology and Globalisation, 7(1), 8-22.
[14] Ko, A., Leifsson, L. T., Schetz, J., Mason, W., Grossman, B., & Haftka, R. T. (2003). MDO of a blended-wing-body transport aircraft with distributed propulsion. AIAA Paper, 6732, 2003.
[15] Kroo, I. (1984). A general approach to multiple lifting surface design and analysis. AIAA Paper, 84- 2507.
[16] Kroo, I. (2005). Nonplanar wing concepts for increased aircraft efficiency. VKI lecture series on innovative configurations and advanced concepts for future civil aircraft.
[17] Kroo, I., Smith, S., & Gallman, J. (1991). Aerodynamic and structural studies of joined-wing aircraft. Journal of aircraft, 28(1), 74-81.
[18] Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C., Lim, L. L., . . . Sausen, R. (2009). Aviation and global climate change in the 21st century. Atmospheric Environment, 43(22), 3520-3537.
[19] Liebeck, R. H. (2004). Design of the blended wing body subsonic transport. Journal of aircraft, 41(1), 10-25.
[20] Lowson, M. V. (1990). Minimum induced drag for wings with spanwise camber. Journal of aircraft, 27(7), 627-631.
[21] Global Journal of Researches in Engineering: B Automotive Engineering Volume 14 Issue 4 Version 1.0 Year 2014