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Development of Health Monitoring System for Highway Bridges

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***Abstract*—Monitoring and detection of highway bridge structures health status has gained great attention for decades. Many attempts were made to introduce sensors to bridge structures to monitor and assess its status. The main idea of this project is to design and implement a system that is capable of sensing, monitoring and detecting flexural strength of a Pratt truss bridge. The work uses flex sensors with Arduino microcontroller to measure bridge bending at different angles and send these readings remotely through Bluetooth technology to a remote ground station. Two thresholds are considered here to determine the level of risk into three different levels. A buzzer is added to the proposed system to alarm the user that the bridge status is at emergency of imminent bridge collapse. A new powerful Graphic User Interface (GUI) is developed using visual studio programming to read user settings, and display and draw data of bridge flexural strength in a convenient way.**

Keywords—collapse detection; sensing and detection system; highway bridges; arduino; and GUI

I. INTRODUCTION

Collapse detection of civil infrastructures has gained great attention for decades. It is natural that attempts to introduce sensors to structures to gain physical quantity and detect damage before the structure collapse [1]. Structural Health Monitoring (SHM) does a diagnosis of the state of the constituent materials of the different parts of a civil structure, at any instant during its life. Due to environment, usage and aging, and accidental events, the structure may be altered than its normal state. However, the structure state must remain as specified in the design for appropriate use [2]. SHM system uses information acquired from contact and/or wireless sensors, images, etc. for decision making to determine condition and the state of the structure [3].

The process comprises structure observation over a defined period. The observation and damage extraction is done by periodically sampling state to create dynamic response using array of sensors [4]. Accordingly from statically features analysis, the current state of system health is determined. Thereby allows to distinguish between the undamaged and damaged structures.

Several sensing mechanisms are currently available that may be classified such as analog or digital operation and direct or indirect sensing. Also, it can be classified by operation medium, such as electrical, optical, etc. Proximity sensors such as optical proximity sensors that operate by breaking a light sensitive device such as a photocell. Electrical proximity sensors operate by making the sensor and the component complete an electrical circuit (contact type). Moreover, force sensing is an analog operation and sensitive to the direction, which they act. A number of techniques as load cells devices operate under compressing loads. Heat sensing such as Bi-metallic strips, thermocouples, electrical resistance thermometers, etc. can be also deployed.

Acoustic sensing can be used to detect between different sounds. The most common acoustic sensor is microphone. There are many other types of sensing such as gas sensing (smell) and Robot vision (sight) [5]. Radars can be also used for bridges deflections measurement including torsional movements and bending. The extraction of radar signal parameters can be found in [6-7]. Structural Health Monitoring evaluation tests for steel highway bridge include short-term and long-term tests to monitor the structural behavior. For instance, short-term evaluation may involve a special car of different velocities deployed to cross the bridge to measure dynamic strain characteristics of the bridge. On the other hand, long-term monitoring may involve recording strain displacements versus temperature for long period of time [8]. Temperature can be measured using Negative Temperature coefficient (NTC) device, positive Temperature Coefficient (PTC) device or Resistance Temp. Detector (RTD). A typical NTC & PTC device is made from special material that behaves as a thermostat [9]. They are made from ceramic materials whose electrical conduction depends sensitively on temperature. for a constant current applied a cross the device, special circuitry is used to linearism the voltage output with respect to temperature Relative humidity is measured using a capacitor whose dielectric permittivity changes with the presence of water vapor.

In this work, the paper addresses the development of a Pratt Truss bridge health monitoring system using flex sensors and arduino controller to acquire, measure, monitor and analyze the bridge status. A GUI is also developed for a remote ground station that is used to acquire data through Wi-Fi, allow performing additional calculations and effectively present received data for a remote user.

II. SYSTEM LAYOUT

Bridge flexure occurs mainly due to effect of loadings, which act on bridge elements as external forces, live loads, that causes deflection of bridge if it exceeds the design loadings and accordingly bridge collapse may occur. The work only considers Pratt truss bridge. A bridge model is designed and constructed. Two flex sensors were attached to each side bars of the bridge. The flex Sensor is selected because it is considered as a good option for measuring a repetitive bending at high speed. A Flex

Sensor represents a thin strip that determines the bend degree precisely.

An Arduino microcontroller is used to acquire sensed data as two analog voltage values with a resolution of 1024 levels for each analog channel. Next, the microcontroller sends the data collected using Bluetooth technology to a remote ground station that equipped and paired with another Bluetooth. The used Bluetooth modules allows remote two-way communication and pairing with a distance up to 50m. After that the raw is converted to amount of deflected angle.

Many components were used to develop Collapse Detection in Highway Bridges as listed below. Overall connections among the used components in the proposed system are shown in Figure 1. Figure 2 presents the Overall developed system implementation.

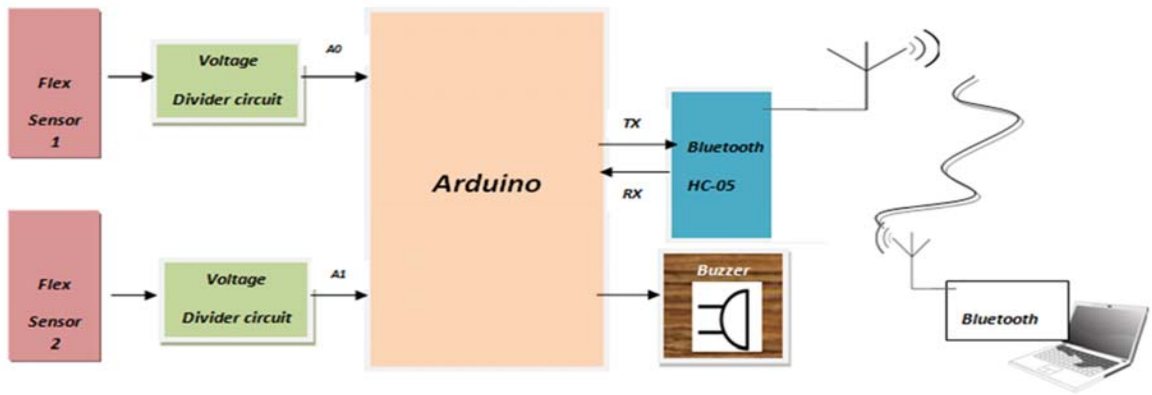


FIGURE I. SYSTEM DESIGN LAYOUT

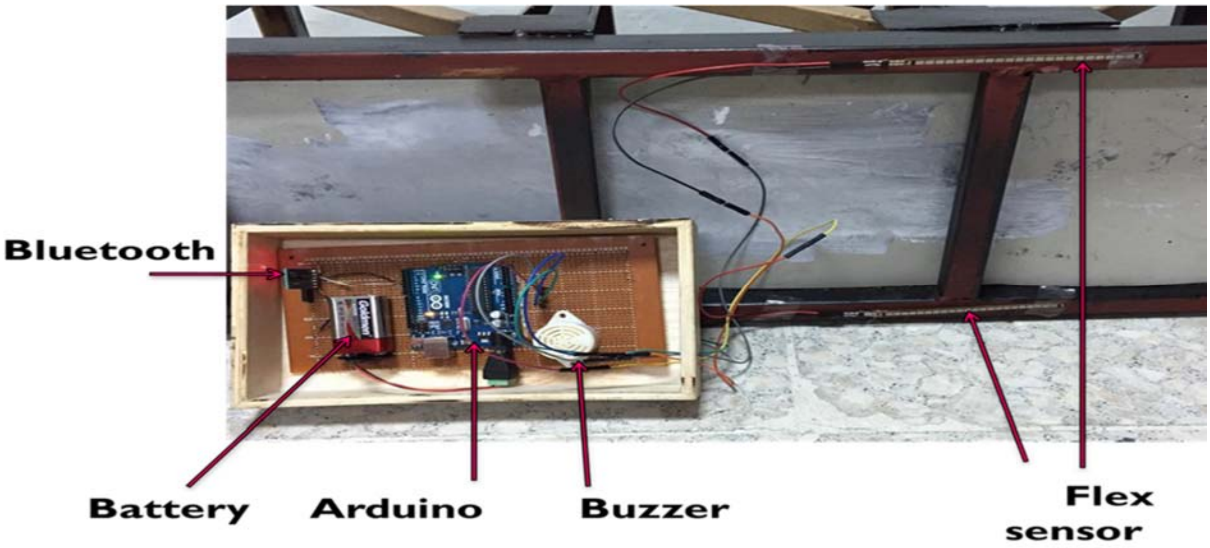
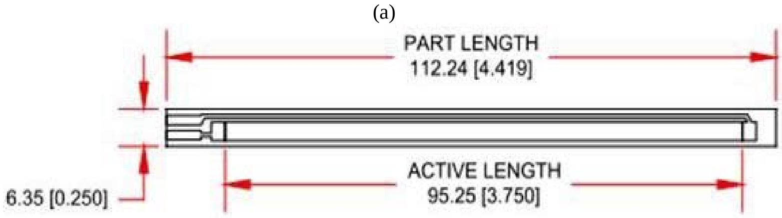


FIGURE II. DEVELOPED HARDWARE SYSTEM IMPLEMENTATION

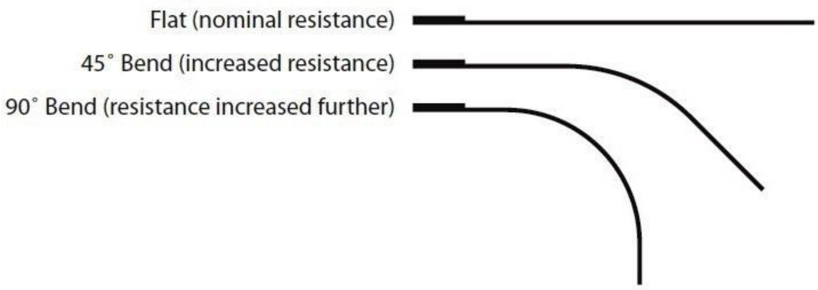
Three status levels are defined to describe bridge risk condition. The three levels are specified by limits set though the operator that defines the high/low-level thresholds. The data is then presented and plotted to the operator in a convenient and powerful way. Finally, the data can be saved for further off-line detailed analysis. To ensure that the bridge is healthy, we connected the buzzer with Arduino to alarm operator of emergency cases were the acquired signals exceed high threshold level.

Two flex sensors are used in this project, each has 4.5” length. The resistance across the flex increases as the bending of the flex sensor increases. When the metal pads of the flex are on the outside of the bend, its resistance increases. Connector is 0.1” spaced and bread board friendly. Figures (3.a and 3.b) show the external image of the sensor and its dimensional diagram respectively. The change in resistance of flex sensor is demonstrated in Figure (3.c).

(a)



(b)



(c)

FIGURE III. A. EXTERNAL IMAGE OF THE FLEX B. FLEX DIMENSIONAL CHARACTERISTIC C. ILLUSTRATES FLEX RESISTANCE CHANGE

III. Proposed System Development

Two flex sensors were attached to each side bars of the developed bridge model (See Figures 4 and 5). The flex Sensor is selected because it is considered as a good option for measuring a repetitive bending at high speed. A Flex Sensor is a thin strip that measures bend degree forced upon it. Then these two flex sensors connected to two analog voltages in an Arduino. An Arduino microcontroller is used to acquire sensed data as two analog voltage values with a resolution of 1024 levels for each analog channel.

FIGURE IV. FINAL DEVELOPED PRATT TRUSS BRIDGE MODEL

FIGURE V. TWO FLEX SENSORS ATTACHED TO EACH SIDE BARS OF THE BRIDGE.

HC05 Bluetooth module is used to allow remote two-way communication and pairing with a distance up to 30m. The HC05 Bluetooth Module has transmission rate of 9600Kbps. The TX of the Arduino is connected to RX of the Bluetooth and vice versa. Also, at the remote ground station, the station is equipped and paired with another Bluetooth that was connected to HC05 Bluetooth, and connected the buzzer with Arduino to alarm operator of emergency cases were the acquired signals exceed high threshold level. Figure 6 depicts the proposed system prototype implementation.

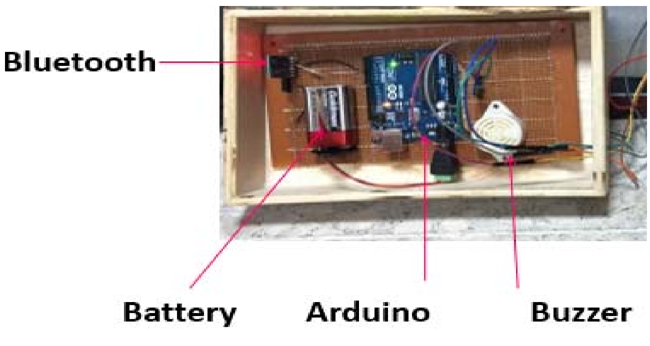


FIGURE VI. PROPOSED PROTOTYPE IMPLEMENTATION

IV. DEVELOPED ALGORITHM WITH ITS GUI

A new powerful Graphic User Interface (GUI) is developed using visual studio programming to read user settings, and display and draw data of bridge flexural strength in a convenient way. The Processing steps of the overall System is listed below. The overall algorithm of the developed prototype is presented in Figure 7.

Step1: Two flex sensors were attached to each side bars of the bridge. Sensing a repetitive bending at high speed.

Step2: An Arduino microcontroller is used to acquire sensed data as two analog voltage values with a resolution of 1024 levels for each analog channel,

Step 3: initialization the Bluetooth.

Step4: in GUI Interface the user enters thresholds (th1 and th2) then Read user defined these thresholds and send the two value to Arduino.

Step 5: When no enquiring event return to Step 4, else the Arduino sends the data collected from two flex sensors by using Bluetooth technology to a remote ground station that equipped with another Bluetooth.

Step 6: in GUI interface Read flex1 and flex2 (A1 and A2)

Step 7: Draw line connecting previous and current point.

Step 8: Check the values of sensing sensors (if) the analog values of two flex sensors was equal or greater than threshold two the buzzer is (ON) and display emergency to alarm the user that the bridge was collapse. (else if) the analog value from flex one was (equal or greater than threshold on and less than from threshold two) or the analog value from flex two was (equal or greater than threshold on and less than from threshold two) buzzer (of) and display critical to alarm user that the bridge was in critical condition and necessary drills were done. Else display normal that means the bridge was in health status.

Step 9: While not stop return to step 4 else save the event and saving the bridge data

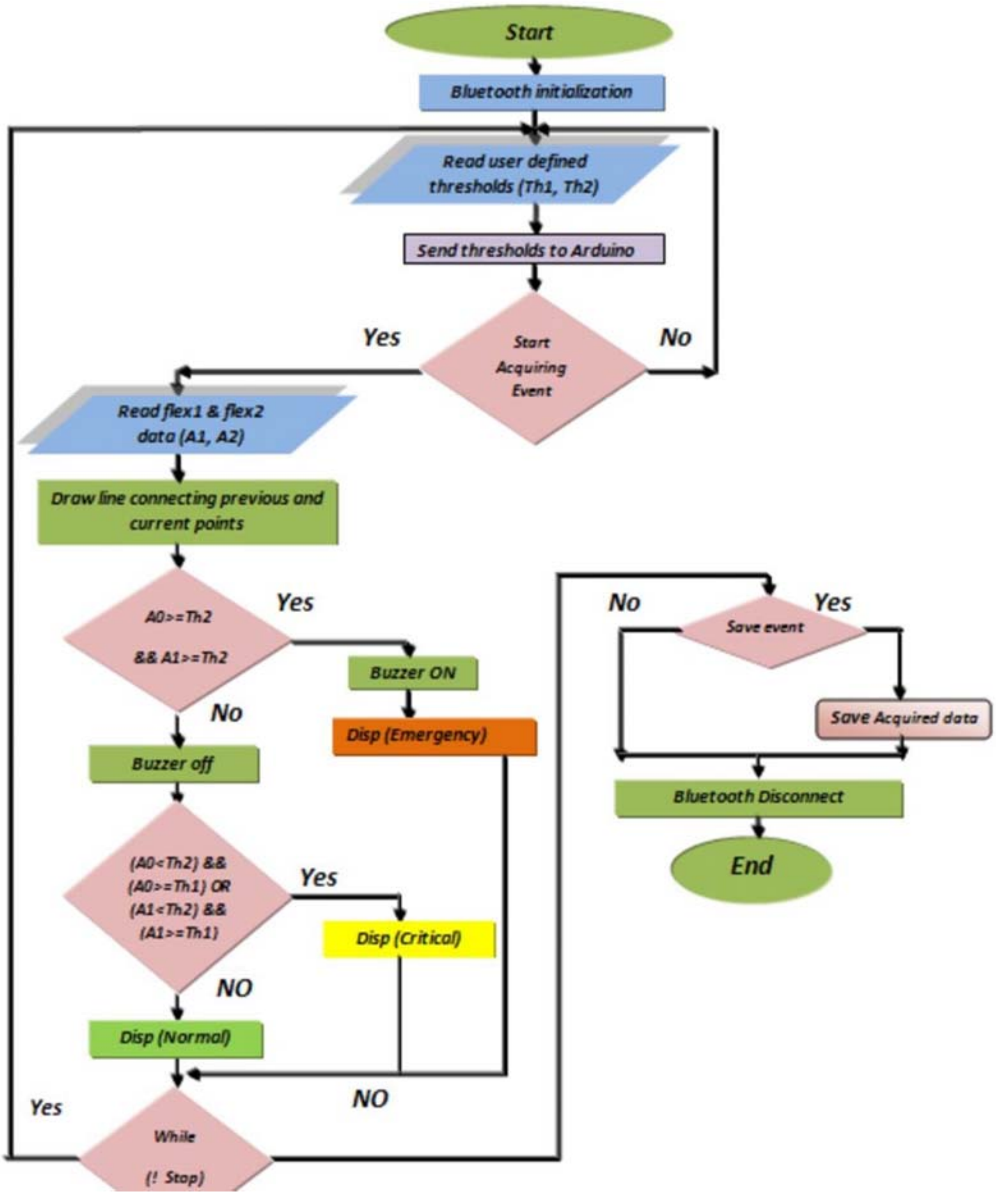


FIGURE VII. DEVELOPED ALGORITHM

V. EXPERIMENTAL RESULTS

Several problems were encountered during the development of the proposed system such as lose contacts with flex bending, connection lost, developed GUI program interrupted, etc. Fortunately, we managed to settle these problems and develop a robust program that can sense the presence of flex bend effectively and send the acquired data using Bluetooth link to a remotely ground station that receives the data and process it. Two threshold levels were set to allocate bridge health situation. The threshold levels allow system to identify bridge health status into three decision categories: Normal, critical and risk. Each category depends mainly on the predefined threshold values. The results are shown in Figures (8 and 9). The acquired data is presented and plotted for each flex sensor. The system has an option to store the acquired data for further processing.

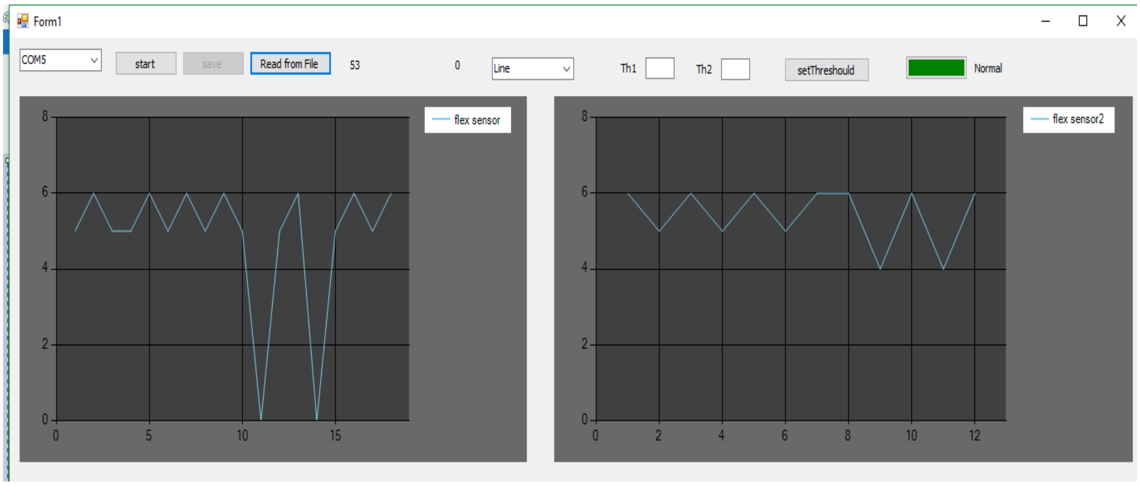


FIGURE VIII. DEVELOPED GUI SHOWING TWO FLEX SENSOR READINGS IN NORMAL BRIDGE HEALTH SCENARIO

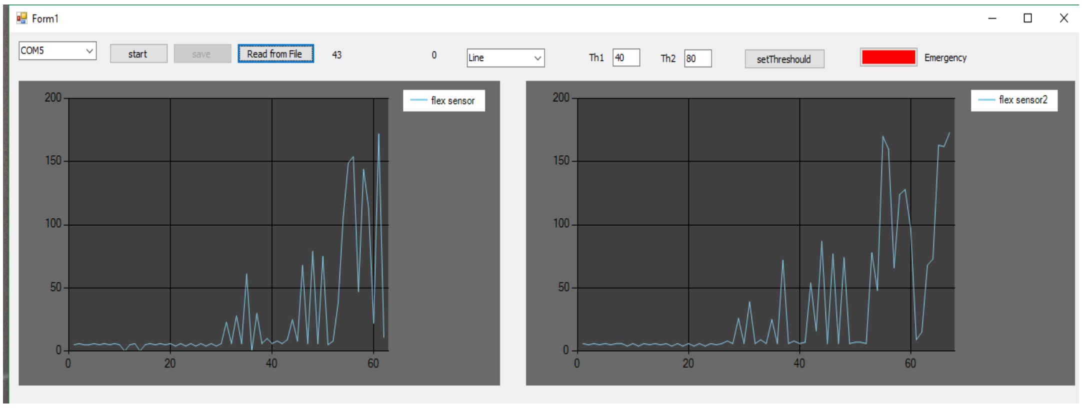


FIGURE IX. DEVELOPED GUI SHOWING TWO FLEX SENSOR READINGS IN EMERGENCY BRIDGE SITUATION.

VI. CONCLUSION

The main idea of this paper was to design and implement a system that is capable of sensing, monitoring and detecting flexural strength of a Pratt truss bridge. The work used flex sensors with Arduino microcontroller to measure bridge bending at different angles and send these readings remotely through Bluetooth technology to a remote ground station. Two thresholds are considered here to determine the level of risk into three different levels. A new powerful Graphic User Interface (GUI) is developed using visual studio programming to read user settings, and display and draw data of bridge flexural strength in a convenient way. Results show that the implemented system accurately detects presence of bridge bending at two different situations when it reach certain predefined threshold levels. As a result, The project provides an effective solution for early pre-collapse detection of Pratt truss bridges. The project can be used as a part in converting conventional bridges of a kind to smart bridges where abnormal flexural strength is measured to predict imminent and critical pre-collapse situations.

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