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# THE FIRST PHASE OF RESEARCH AND MANUFACTURING OF BRIDGE DEFORMATION MONITORING EQUIPMENT USING POSITION SENSOR: CASE STUDY IN VIETNAM

*This paper is the first result of an experimental study of manufacturing deformation monitoring equipment using a position sensor, an efficient solution for contractors in bridge monitoring during either process of construction or operation in the context of the increasing number of large bridges. The object of the research is bridgework. And the work is aimed at achieving two tasks, which include meeting the need of the surveyors in real-time monitoring and warning during the construction process with a suitable price and reducing the reliance on manufacturers in supplying and operating monitoring systems.*

*The study used a KTR position sensor, a Linear Variable Differential Transformer, and an Arduino board for embedded coding. Data from the KTR sensor are acquired, processed, and controlled by a program written in Python. The results of the study are compared to the true observations from a Mitutoyo Palmer which has 0.01 mm accuracy in a laboratory.*

*The initial results from the laboratory show prospects for applications in reality, and accuracy is suitable for technical measurements. This is also a good choice for surveyors in acquiring continuously monitoring data at high accuracy for bridge monitoring in general and structure in particular. The study is fundamental to expanding the number of channels from 1 to 8 or 16 for monitoring a full cross-section. At the same time, cable connection mode will be developed to Wi-Fi or Bluetooth mode for online observation. The results of the study confirm the scientificity, and feasibility of the solution. This solution can be applied for either bridge monitoring or other monitoring fields and can be produced by contractors. The cost of monitoring projects will be significantly reduced and there will be no more disruption of monitoring projects after suppliers leave as a new system will be quickly added or replaced.*

**Keywords:** *bridge monitoring, Arduino board, potentiometer sensor, amplifier, real-time monitoring, displacement.*

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## 1. Introduction

In recent years, the number of big bridges with complex scales is increasing rapidly including My Thuan, Kien, Can Tho, Binh, Bai Chay, Phu My, Rach Mieu, Tran Thi Ly, Nhat Tan, Cao Lanh, and Thuan Phuoc. Structural health monitoring systems were deployed for many of them. In terms of principle, these systems have the same structure and operating procedures. Equipment systems and their installation can be referred to in [1–3]. Suppliers are reliant on terms of deployment and operation of monitoring systems. Some of the existing monitoring systems do not work after the construction phase. In [4] show that controlling the evolution of impacts on the work during the construction, operation, and maintenance stage is an obligated task of investors, contractors, and management units. For cable-stayed bridges only, by 2015, there were 12 bridges put into operation. Besides normal incidents, some big ones happened such as Rao, Binh, and Bai Chay bridge [4]. Human and economic losses would be significantly reduced if these works were continuously monitored and warned. The reasons for this are below. Firstly, contractors are not proactive about equipment and technologies. Secondly, the expense for this task is exorbitant. In terms of research, an overview of the monitoring systems for bridge work in Vietnam can be seen in [5, 6] in which monitoring systems were mainly imported.

The development of the latest techniques including fiber optic sensors; smart material, communication, wireless network, and data processing has a huge contribution to monitoring systems [7]. The advancement of the Internet of Things (IoT) allows connecting anything, anyone at any time [8–10]. And their structure can be referred to [11, 12]. A wireless sensor network (WSN) can be deployed in various environments and applied to collect data on the different structures [13–15].

As a result, many studies have used sensors in structural condition monitoring systems [15–17]. In doing so, they combined classical surveillance and sensors [18, 19], UAVs combining IoT [20]. Or they combined optimizing sensor placement for structural condition monitoring [21–23].

Five recent years, the number of researches on applying IoT and sensors for bridge monitoring was increasing rapidly, and all is for providing continuous, real-time data, ensuring accuracy and reliability, and warning.

Therefore, it can be seen that research is completely suitable with study trends and the need for monitoring tasks in Vietnam. *The object of the research* is bridgework, and *this article aims* to confirm the feasibility, scientificity, and accuracy of the solution.

## 2. Research methodology

For bridge girders, behavior is shown in Fig. 1.

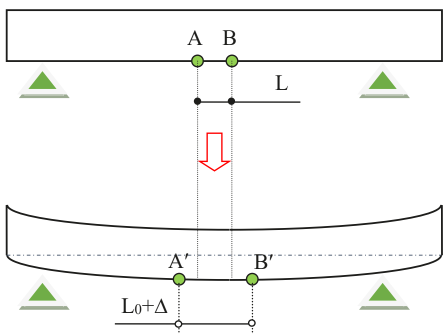


**Fig. 1.** Bridge girder status with loading and unloading

The stress-strain relationship is linear:

$$\sigma = E \cdot \varepsilon, \tag{1}$$

where $\sigma$ – stress of measured point, MPa; $E$ – elastic modulus of the material, MPa; $\varepsilon$ – unit strain, mm/mm.

The distance between points $A$ and $B$ without the impact of loading and underloading is $L_0$ and $L_0+\Delta$ respectively, and $\varepsilon$ is determined:

$$\varepsilon = \frac{\Delta}{L_0}. \tag{2}$$

Suppose that $L_0$ and $\Delta$ can be measured, combined with a modulus of the material, and equation 1, $\sigma$ can be determined:

$$\sigma = E \cdot \varepsilon = E \cdot \frac{\Delta}{L_0}. \tag{3}$$

In case $E$ is unknown, $\Delta$, $L_0$ can be used for other technical purposes.

*Arduino board and Amplifier*

The Arduino board is an embedded system with a brain that is hidden from the end-user [24]. The Arduino board can be used for coding with different languages [25, 26], and is built to control a range of functions as well [27]. An adapter is integrated into the Arduino board (Fig. 2). The following analysis shows that this integrated circuit is not suitable for the required accuracy.

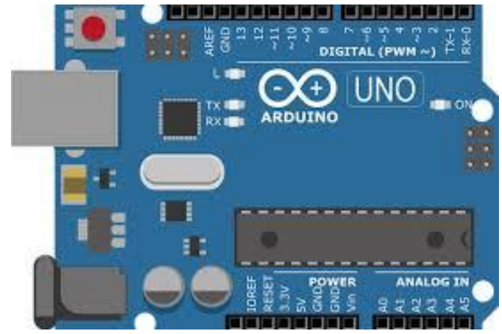


**Fig. 2.** Arduino board

For technical observation, the accuracy of stress measurement is about 0.01 MPa. The modulus of concrete grade 30 MPa is about 28.100 MPa, and unit strain needs to be measured as follows:

$$\Delta\varepsilon_{yc} = \frac{\Delta\sigma}{E_c} = 3.558 \cdot 10^{-7} = 0.356 \mu\varepsilon.$$

The travel of a common position sensor is $\Delta = 12.7$ mm, integrated ADC has a 10-bit solution, and the maximum number of states is $\rho_{10bits} = 2^{10}$. The solution of real displacement following the travel of the sensor will be:

$$\delta_{10bits} = \Delta / \rho_{10bits} = 12.7/2^{10} = 0.0124 \text{ mm}.$$

For basic length $L_0 = 200$ mm, the solution of unit strain is as follows:

$$\Delta_{\varepsilon 10bits} = \delta_{10bits} / L_0 = 0.0124/200 = 62.011 \mu\varepsilon.$$

The ratio between the real and required solution is as follows:

$$\Delta_{\varepsilon 10bits} / \Delta_{\varepsilon yc} = 174 \gg 1.$$

This means that the accuracy does not meet the required technical accuracy. The analysis shows that if data is collected directly via integrated ADC on the Arduino, it will not be used for assessment and analyzing structure. Based on the above analysis, an HX-711 (Fig. 3) amplifier will be used.

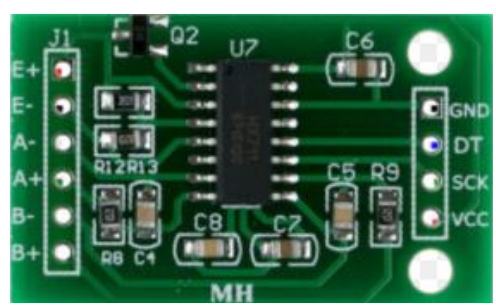


**Fig. 3.** Amplify circuit and ADC

HX-711 has a 24-bit solution (01 bit for positive or negative signs). The maximum number of states is $\rho_{24bits} = 2^{24-1}$. And the solution of real displacement is as follows:

$$\delta_{24bits} = \Delta / \rho_{24bits} = 12.7/2^{23} = 1.51 \cdot 10^{-6} \text{ mm}.$$

The solution of unit strain is as follows:

$$\Delta_{\varepsilon 24bits} = \delta_{24bits}/L_0 = 7.56 \cdot 10^{-9} = 0.00757\mu\varepsilon.$$

The ratio between the real and required solution is as follows:

$$\Delta_{\varepsilon 24bits}/\Delta_{\varepsilon yc} = 0.0212 \ll 1.$$

In conclusion, HX-711 allows enhancing the accuracy of data measurement and meets the requirements of the civil engineering sector.

There are different kinds of potentiometers and their specifications and applications are in [28]. For this experiment, a Linear Variable Differential Transformer (LVDT) will be used (Fig. 4).

**Fig. 4.** KTR potentiometer sensor

When there is a movement, the output voltage will change linearly with the displacement of the probe (Fig. 5). Based on the parameters of those devices, a completed circuit was set as (Fig. 6).

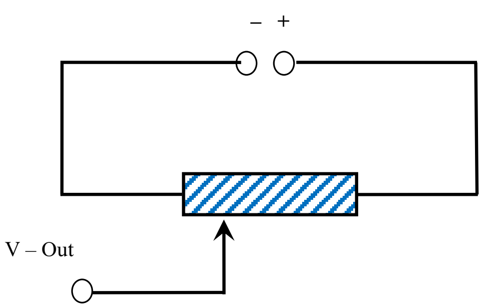


**Fig. 5.** Illustration of the circuit

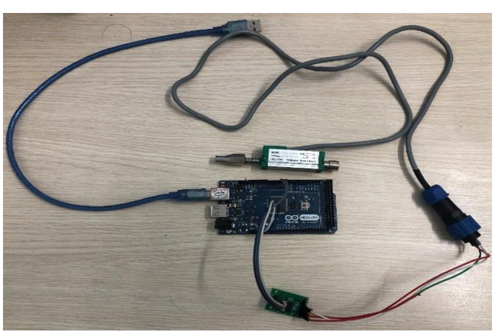

**Fig. 6.** A completed circuit

For this experiment, the C# language was used for embed coding on the Arduino Board to control the sensor to get data, transfer, and process. Visual Basic was used to code for displaying, analyzing, and storing data. Data is transferred to a computer via a cable and stored on hard disks. Program interface can be referred to in Fig. 7.

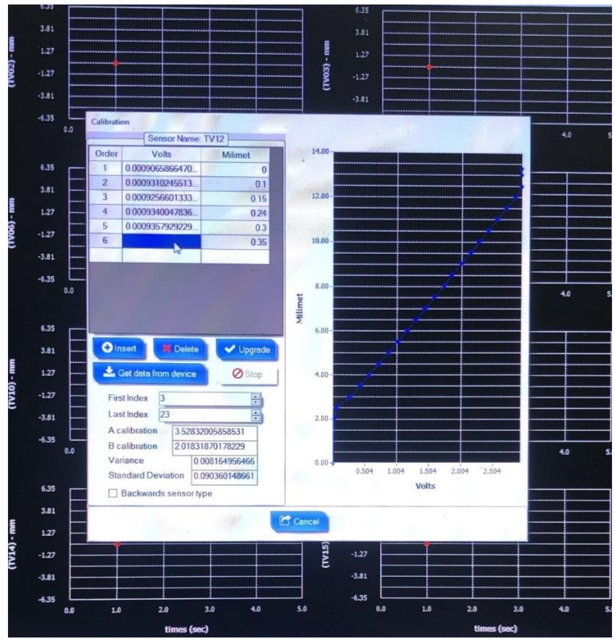


**Fig. 7.** Program interface

In this program, the volts readings and the displacements in mm can be observed in the two first columns, and *A*, *B* coefficients for calibrating can be input as well as variance and standard deviation can be calculated.

## 3. Research results and discussion

After manufacturing and adjusting the device, the experiment was performed in a Lab. The results were compared to a Mitutoyo Palmer that has 0.01 mm accuracy. The results are in Table 1.

For calculating regression coefficients, the values of $Y^*$ and $(Y - Y^*)^2$ are in Table 2.

Calculating regression coefficients:

$$b = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\Sigma(x-\bar{x})^2} = 12.37782556;\ a = -2.121381478,$$

where $a$ and $b$ are regression coefficients; $x$ – reading of volts; $\bar{x}$ – the average value of readings of volts; $y$ – displacement; $\bar{y}$ – the average value of displacement.

Variance:

$$\sigma^2 = \frac{\Sigma(y-y^*)^2}{n-1} = 0.018984,$$

where $y^*$ – calculated displacement.

Standard deviation:

$$s = \sqrt{\sigma^2} = 0.137784.$$

The average value of observations:

$$y_{tb} = 7.297272727 \text{ mm}.$$

**Table 1**

Readings of volts and displacement

| Readings of volts $x$ (Volt) | Displacement $Y$ (mm) |
|---|---|
| 5.021621240 | 0.00 |
| 5.021621240 | 0.59 |
| 5.021621240 | 1.00 |
| 5.021621240 | 1.53 |
| 5.021621240 | 2.01 |
| 4.746249436 | 2.59 |
| 4.440280764 | 3.08 |
| 4.093516270 | 3.62 |
| 3.889537156 | 4.04 |
| 3.644762219 | 4.52 |
| 3.399987282 | 5.07 |
| 3.134814434 | 5.53 |
| 2.910437408 | 6.04 |
| 2.696259338 | 6.55 |
| 2.461683357 | 7.01 |
| 2.216908420 | 7.56 |
| 2.002730350 | 8.06 |
| 1.819149147 | 8.51 |
| 1.564175254 | 9.10 |
| 1.380594052 | 9.55 |
| 1.125620159 | 10.04 |
| 0.850248355 | 10.52 |
| 0.625871329 | 11.04 |
| 0.452489082 | 11.52 |
| 0.197515189 | 12.05 |
| 0.013933986 | 12.53 |
| 0.013933986 | 13.13 |

**Table 2**

Readings of volts and Displacement

| $Y^*=a{\cdot}X+b$ | $(Y-Y^*)^2$ |
|---|---|
| 1.725051 | 0.081196 |
| 2.309220 | 0.078837 |
| 2.958296 | 0.014812 |
| 3.693916 | 0.005464 |
| 4.126633 | 0.007505 |
| 4.645895 | 0.015849 |
| 5.165156 | 0.009055 |
| 5.727688 | 0.039081 |
| 6.203678 | 0.026790 |
| 6.658031 | 0.011671 |
| 7.155656 | 0.021216 |
| 7.674917 | 0.013206 |
| 8.129270 | 0.004798 |
| 8.518716 | 0.000076 |
| 9.059613 | 0.001631 |
| 9.449059 | 0.010189 |
| 9.989956 | 0.002504 |
| 10.574120 | 0.002929 |
| 11.050110 | 0.000102 |
| 11.417920 | 0.010420 |
| 11.958820 | 0.008314 |
| 12.348270 | 0.033027 |
| $\Sigma$ | 0.3986725 |

The error of observation:

$$\frac{s}{y_{tb}}=0.018881561=1.89\ \%.$$

The relationship between the reading of volts and displacement is in Fig. 8.

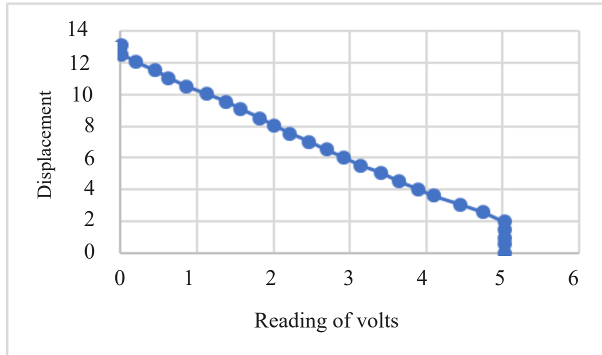


**Fig. 8.** Relationship between the reading of volts and displacement

The research and development of displacement equipment based on position sensors provide the surveying field with a useful tool for continuously obtaining high-accuracy data for monitoring structures in general and bridge works in particular during construction and exploitation, particularly for inspection tasks.

Based on the initial experimental results, the application of the equipment is feasible, and the accuracy is smaller than mm.

The study's first phase was conducted with only one channel to confirm the scientificity and feasibility. Therefore, it is recommended to increase the number of channels from 1 to 8 or 16 channels to monitor the state of the bridge girder span cross-section and for a comprehensive assessment of the span structure.

Transferring data via USB cable should be replaced by Bluetooth or Wi-Fi for the convenience of users.

The results of the study can be applied to other fields in construction.

## 4. Conclusions

The research is successful to manufacture a monitoring system using a KTR position sensor. The novelty of the research is getting data from the sensor with no requirement of a data logger; data can be transferred into a computer.

In the research, a controlling program is successfully obtained to automatically get data from the sensor using Python, a real-time processing algorithm, and display data on the screen.

The accuracy of the solution is smaller than 1 mm and can be applied in the reality of real-time bridge monitoring.

## Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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