Simulation Study on Intelligent Bolt Monitoring System Based on Cloud Service

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Abstract. As a common connector in the industrial field, bolts play a key role in many fields. However, it is hard to obtain the stress value of a bolt directly in traditional ways. In order to achieve that, an intelligent bolt monitoring system based on Cloud Service was studied in this paper. An ultrasonic measurement technology based on the Sono-elasticity Principle was presented first, which laid a foundation for measuring the displacement of a bolt when it was stressed. Then, we did some experiments on emulating the whole process of the system through software simulation. Finally, Cloud Service was introduced to restore simulated data of a bolt, which made it possible for professionals to monitor online. The result shows that the system can work well. In conclusion, an intelligent bolt monitoring system based on Cloud Service can greatly improve work efficiency and bring many benefits to related fields and industries.

Keywords: Intelligent bolt; Cloud service; Monitoring system; Ultrasonic.

1. Introduction

As a common connector in the industrial field, bolts play a key role in bridge construction, aerospace, new energy and other fields. [1] The axial stress of a bolt, which is a principal factor affecting the performance of a bolt, has gradually attracted people's attention. Specifically speaking, once the stress of a bolt is too large, it will increase the load of bolts and lead to bolt fracture. In more serious cases, it may induce structural instability. If the stress of a bolt is too small, it will result in vibration relaxation, structural sliding and other phenomena, which will affect the normal operation of the equipment [2]. As it is very difficult to detect the looseness of a bolt, it may lead to equipment damage and even casualties. Therefore, the necessity of bolt stress control in engineering is self-evident. However, many unpredictable factors affect the accuracy of bolt stress control directly or indirectly, so how to accurately monitor the stress of in-service bolts has always been a problem to be solved.

2. Ultrasonic Measurement Technology Based on the Sono-elasticity Principle

The ultrasonic stress detection method is based on the Sono-elasticity Principle that the velocity of ultrasonic changes with the variation of stress value. Thus, the variation of stress can be detected by ultrasonic and some parameters of ultrasonic can be used to reflect the stress value. In the engineering application of ultrasonic stress detection, ultrasonic longitudinal wave and ultrasonic shear wave are generally used for detecting [3,4], mainly including the longitudinal wave method and two-wave method. In this study, the longitudinal wave method is used to measure the stress value of a bolt. We assume that the stress state of a bolt is under unidirectional stress condition. $V_0$ is used to represent the velocity of ultrasonic when the stress value of a bolt is zero. $V_2$ is used to represent the velocity of ultrasonic when the stress value of a bolt is larger than zero. According to the Sono-elasticity Principle, we can get the following formula.
Where \( A \) is a correlation coefficient determined by the parameters of a bolt and \( \sigma \) represents the stress value of a bolt. At the same time, the length of a bolt will also alter with the change of stress value. If \( L_0 \) and \( L_\sigma \) are used to represent the length of a bolt when the stress value of a bolt is zero and larger than zero respectively, the following equation can be deduced.

\[
\frac{L_\sigma - L_0}{L_0} = \frac{1}{E} \sigma
\]  

(2)

Where \( E \) is a correlation coefficient determined by the parameters of a bolt. Based on the above equations, the stress value of a bolt to be detected can be achieved in three steps. First, it is assumed that the initial length of a bolt is \( L_0 \) and the stress value of a bolt is zero \((\sigma = 0)\) at this time. Then, during the process of calibration, it is assumed that the length of a bolt is \( L_1 \) and the stress value of a bolt is \( \sigma_1 \). Thus, a formula for calculating stress value can be deduced if the length of a bolt is \( L_2 \) which can be measured by ultrasonic.

\[
\sigma_2 = \frac{l_2 - l_0}{l_1 - l_0} \cdot \sigma_1
\]  

(3)

3. Temperature Compensation of Ultrasonic

According to the basic hypothesis of elasticity, a bolt can be considered as an ideal elastic body when its axial stress is smaller than the yield limit of bolt materials. Then, the second-order elastic constant and the third-order elastic constant of bolt materials will not change with the increase of axial stress value at room temperature. As a result, the length of a bolt and measuring temperature are the only two factors affecting the measurement of the axial stress of a bolt.

In this paper, a reflection detection method is adopted. Specifically speaking, an ultrasonic sensor transmits an ultrasonic wave toward a certain direction. The time begins when the ultrasonic is transmitted in the air. The ultrasonic will go back once it touches the obstacle during the transmission. The time stops when the ultrasonic receiver gets the reflection wave. The whole process can be shown in Figure 1.

![Figure 1. Ultrasonic Measurement Technology.](image)

As the propagation velocity of ultrasonic in the air is 340 m/s, the distance \( s \) between the transmitting point and the obstacle can be calculated according to time \( t \) recorded by a timer, which can be shown in the following equation.

\[
s = 340 \times \frac{t}{2}
\]  

(4)

Although the propagation velocity of ultrasonic in the air is 340 m/s under room temperature, it is easily influenced by several factors such as temperature, humidity and pressure. Among these, temperature is the most influential factor. The propagation velocity of ultrasonic will increase by 0.6 m/s once the temperature increases 1°C generally. The propagation velocity of ultrasonic at different temperatures can be shown in the following table.
Table 1. The velocity of ultrasonic at different temperatures.\textsuperscript{[5]}

| $T / \degree C$ | -30  | -20  | -10  | 0    | 10   | 20   | 30   |
|----------------|------|------|------|------|------|------|------|
| $v / m \cdot s^{-1}$ | 313  | 319  | 322  | 331  | 337  | 344  | 350  |

It is obvious from the table that the influence of temperature on ultrasonic ranging cannot be neglected. In order to get accurate measurement results, the temperature compensation of ultrasonic should be taken into account. The empirical model of ultrasonic velocity and temperature can be obtained by experiment.

\[ V = 331.5 + 0.607T \]  

Where $T$ represents the measuring temperature and $V$ represents the actual propagation velocity of ultrasonic.

Thus, equation (4) can be revised as follows:

\[ s = (331.5 + 0.607T) \times t/2 \]  

4. Software Simulation

In this paper, software simulation includes four steps. The first step is to input the displacement detected by an HC-SR04 ultrasonic sensor. The second step is to input the temperature measured by LM35 that is a temperature sensor. The third step is to input the two-dimensional code captured by a camera. The fourth step is to monitor the stress and give off an alert if the stress is not in a reasonable range.

4.1. Input of Displacement

HC-SR04 ultrasonic sensor is used to measure the displacement of a bolt to be tested. The corresponding code is programmed on MATLAB. The result of displacement can be achieved by clicking buttons in GUI, as is shown in Figure 2.

4.2. Input of Temperature

LM35 is used to obtain the measuring temperature. The corresponding code is programmed on MATLAB. The result of temperature can be achieved by clicking buttons in GUI, as is shown in Figure 3.

4.3. Input of Two-dimensional Code

In order to distinguish bolts with different parameters, such as $E$ mentioned above, a two-dimensional code is introduced to record relevant information including initial length $l_0$, measuring displacement $l_1$, temperature and stress. A camera can be used to recognize a two-dimensional code and visit the database of tested bolt, which can be shown in Figure 4.
4.4. Stress Monitoring and Alarming

In order to judge whether the stress of a bolt is too large or too small, an intelligent algorithm is developed which can give off warning message and alert if the stress is larger than or less than a standard value, which can be shown in Figure 5. Otherwise, the output is the stress value of a bolt.

Figure 4. Database of the tested bolt.
5. Cloud Service

In this study, Cloud Service is used to restore data of tested bolt online. With the help of Cloud Service, we can achieve remote monitoring of data. Furthermore, when the database is large enough, files of the database on the cloud can be downloaded and then more information can be obtained by data mining. Here, RDS (Relational Database Service) that is a stable and reliable online database service is utilized. In order to implement communication between the local database and RDS, how to connect is the main concern.

In MATLAB, a function named database is a wise choice to achieve that. Several parameters such as the name of the database, the account of the database, the password of the database, the URL of RDS are needed to input. If the state of AutoCommit is ‘on’, we can get a connection to RDS successfully, as is shown in Figure 6.

![Database Properties](image)

**Figure 6.** Database properties.

Then, data can be downloaded and upload through correlated code. For example, data can be read from RDS by typing the following code that `e=exec(conn, 'SELECT * FROM second')`, which can read data from a table named second. Figure 7 is the downloaded data from RDS.

![Data Table](image)

**Figure 5.** Warning message.
Similarly, data can be uploaded to RDS by typing the following code that insert (conn, ‘second’, {'l0', 'l1', 'Stress', 'T'}, {l0, l1, Stress, T}), which can upload data to a table named second. In addition, the selection of specific data can also be achieved by typing the corresponding SQL code. Therefore, data exchange between the local database and RDS is becoming more convenient through Cloud Service.

6. Conclusion
In this paper, an intelligent bolt monitoring system based on Cloud Service is studied, which mainly includes ultrasonic measurement technology and Cloud Service technology. One of the innovative points is that each intelligent bolt has a unique ID code, such as a two-dimensional code which contains its data tested before. In addition, RDS is used to achieve data remote monitoring and exchange, which makes it convenient for professionals to obtain real-time data. As a result, it can greatly improve work efficiency and bring many benefits to related fields and industries.

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