Digitization of Palpation for Remote Inspection

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Abstract

There are growing concerns over worker shortages in the machinery and equipment maintenance sector, and remote inspection and checking work is being considered as a means of overcoming such concerns. Yet there have been almost no cases of remote inspection and checking work performed using tactile information. In light of this, we are proposing a remote sensing technique tailored to checking looseness of equipment, where tactile information acquired by junior Field Engineers (FEs) at work sites is digitized, and then determined by senior FEs at a remote location. We developed a prototype sensor glove for use by junior FEs at work sites, and a preliminary assessment algorithm to make it easier for senior FEs to determine conditions—evaluation experiments revealed that these delivered ample performance for preliminary assessments. In addition to being used for remote inspection and checking work, this technology is also anticipated to be applied for a range of applications such as remote medical procedures via palpation.

1. Introduction

Appropriate maintenance is essential for the various types of machinery and equipment underpinning our day-to-day lives. Annual inspections conducted by skilled workers are mandated for machinery and equipment that are particularly important, which are checked to ensure that maintenance is being performed under the conditions stipulated by law. Concerns over worker shortages in the maintenance sector have led to calls to implement remote operations based on digital technology as a way of boosting the efficiency of inspections.

Compared to methods based on visual or aural information, there have not been any methods of remote technology established for inspection items based on the use of workers' tactile information (palpation). Given that the travel time to work sites for conducting annual inspections cannot be reduced unless all inspection items can be performed remotely, we decided to focus on digitalizing palpation. Note that there have been cases of remote palpation being considered from the perspective of remote medical procedures.(1)

We turned our attention to inspections that check the state of looseness of equipment using tactile information, and examined the feasibility of a system based on sensors that acquire the force and movement of hands when vibrating equipment located at work sites—this data is then delivered to senior FEs stationed at a remote location. Given that numerous items need to be inspected in a continuous process to acquire data, we opted for an approach where unskilled junior FEs wear sensor gloves and vibrate the equipment, instead of attaching sensors to the equipment. To assess the feasibility of this system, we developed and tested a prototype sensor glove for use by junior FEs at work sites, and an algorithm for preliminary assessments conducted at work sites. After a preliminary assessment, senior FEs stationed at a remote location are able to check the sensor data and make a final determination based on their overall viewpoint leveraging their past experience—we thought that we would be able to achieve efficient and reliable inspection work by taking this approach (Fig. 1).

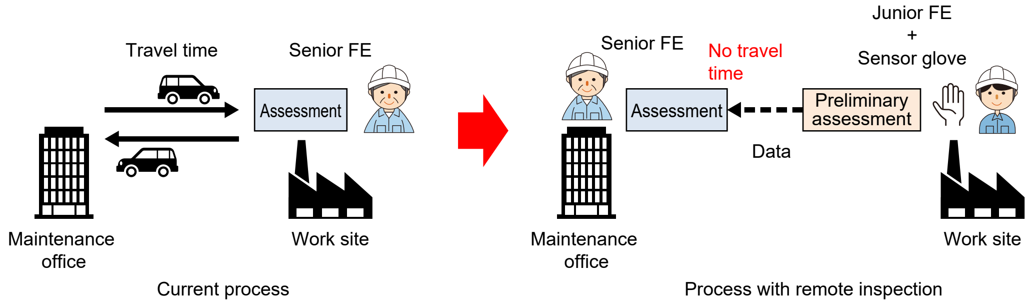


Fig. 1 Operational improvements through the introduction of remote inspection

2. Prototype Sensor Glove for Acquiring Work Site Data

To verify the feasibility of the proposed method, the first step was to develop a prototype sensor glove worn by junior FEs at work sites.(2)

2.1 Examples of target inspection items

Before developing the prototype sensor glove, we studied the specific items being targeted. Given that items being inspected with the use of tactile information often include sensors and covers, we assessed an inspection method of holding target inspection items secured with bolts by grasping them with the thumb and index finger, and vibrating them as shown in Fig. 2.

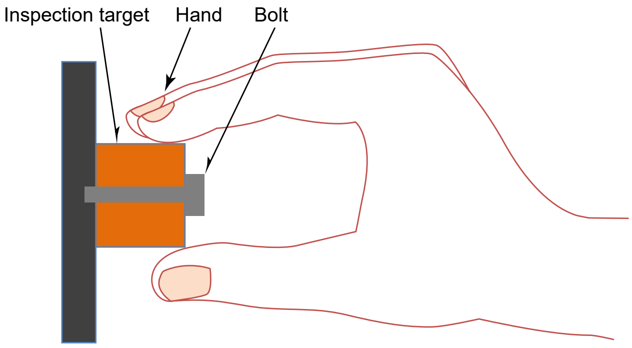
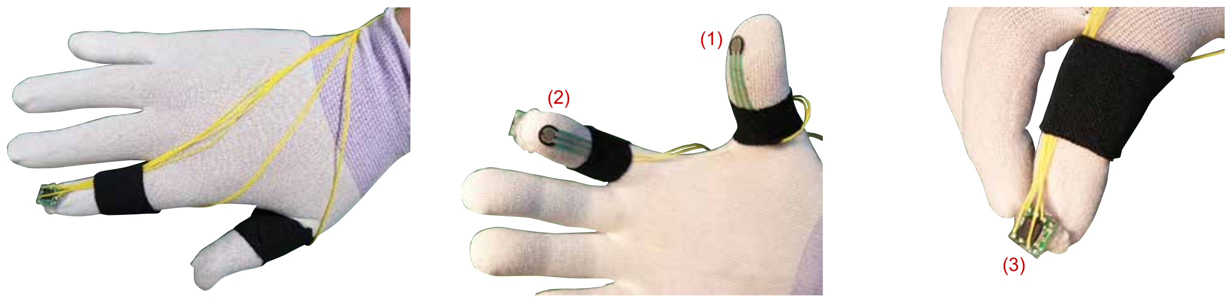


Fig. 2 Examples of target inspection items

2.2 Selection of sensors and development of prototype sensor glove

A prototype sensor glove was then developed to be used for collecting data during vibration.

Sensor data required for determining looseness include movement while vibrating the vibration target as well as the strength and direction of the force from the finger causing that movement. We decided to use sensors mounted on FE's hands, based on the perspective of the ease of installing and mounting the sensors. Given that only the FE's fingertips maintain contact with inspection target during vibration, we decided to focus on acquiring "contact force" and "acceleration" information at their fingertips. After taking these mounting restrictions and the ease of making the system into consideration, we decided to mount pressure sensors (1) and (2) at the tips of the FE's thumb and index fingers that form the contact surfaces with the target inspection item, and acceleration sensor (3) at the tip of the FE's index finger (Fig. 3).



Whole view Pressure sensor Acceleration sensor

Fig. 3 3 Sensors on prototype glove

We thought that mounting these sensors into the FE's work gloves would help alleviate the impact of wearing them without affecting operations, so we developed the prototype shown in Fig. 3. To prevent wiring from restricting the movement of FEs, we also made use of Bluetooth[*1] for connecting to PCs and other devices.

*1 Bluetooth is a registered trademark of Bluetooth SIG, Inc.

3. Preliminary Assessment Algorithm

Together with the prototype sensor glove, a prototype algorithm for preliminary assessment of looseness conditions was also developed. This algorithm comprises two stages: determining vibration quality (Section 3.1) and determining looseness conditions (Section 3.2), with looseness conditions only determined after vibrations are determined to be appropriate. The final determination after the preliminary assessment is conducted by senior FEs from their overall viewpoint based on their experience.

3.1 Determining vibration quality

Vibration quality is determined in two ways: whether or not the item is being "grasped" appropriately, and whether or not the direction and strength of the force "applying vibration" are appropriate.

The evaluation of "grasping" uses pressure sensor values at the tip of the thumb and index finger, and determines it to be appropriate if they both exceed the threshold values.

The evaluation of "applying vibration" uses the phase difference between changes in the pressure sensors of those two fingers, and is determined to be an appropriate vibration if it exceeds a preset phase difference threshold. This is based on the fact that the two waveforms are in the opposite phase when applying vibration is applied at the appropriate time and direction, but are not in the opposite phase when the direction of vibration is different or grasping is not tight enough. Figure 4 shows the waveforms when the opposite phase is present, and when only the fingers are being opened or closed. The phase difference is calculated by applying a bandpass filter (1 to 5 Hz) to the two waveforms to extract the AC component, then fitting a single-frequency sinusoidal wave to identify the frequency.

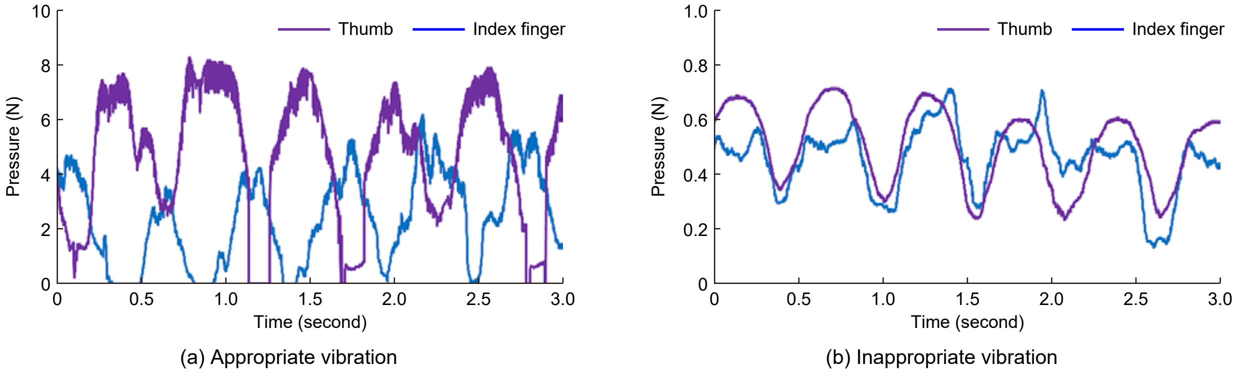


Fig. 4 Relationship between vibration quality and pressure sensor waveforms

If either the "grasping" or "applying vibration" is determined to be inappropriate, an instruction is shown to apply vibration again.(3)

3.2 Determining looseness conditions

Looseness conditions are determined for data that has been determined to have appropriate vibrations when evaluating vibration quality. Looseness conditions are determined using the maximum amplitude from the acceleration waveform at the fingertips. This method uses the fact that there is play between the bolts and the bolt holes of the metal block as shown in Fig. 5, and when it is loose, the block moves with vibrations, thereby generating a pulsating acceleration waveform caused by impacts at the edge of play. More specifically, the measurement period was divided into one-second intervals, with the maximum amplitude of acceleration changes for each interval used as the feature value. The average value of this feature value over the measurement period (10 points) was compared with threshold value (0.5) set experimentally, and when the value exceeded the threshold value, it was determined that there was looseness.

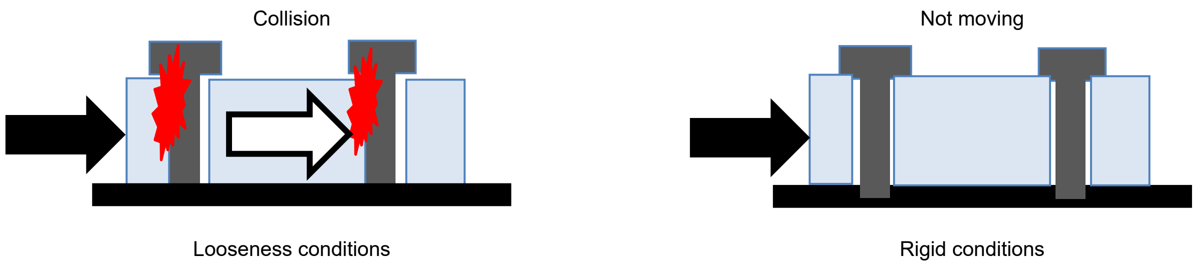


Fig. 5 Pulse generation depending on the presence of looseness

4. Evaluation Experiment

To verify the effectiveness of the sensor glove and preliminary assessment algorithm, a jig was made up to trial the data collection and determination.

4.1 Evaluation experiment conditions

For the evaluation experiment, a jig was made by securing a metal block matching the size of the target inspection item with two bolts (Fig. 6). A coil spring was mounted to each bolt, and the bolts were tightened with a torque wrench to set conditions with and without loosening such that the tightening torque could be reproduced.

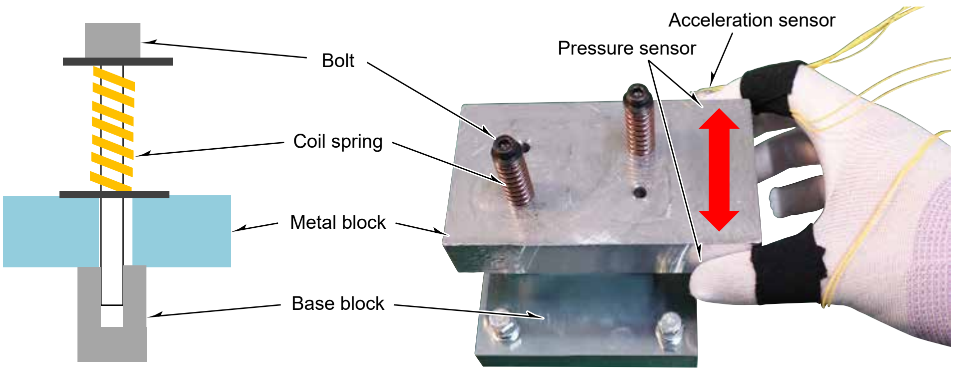


Fig. 6 Fixture for evaluation data acquisition

In the evaluation experiment, a tester wearing a sensor glove applied vibrations to the jig for more than 10 seconds, and only data that was determined to be of an appropriate vibrationquality was collected. Using this method, data for 61 conditions with looseness and 61 conditions without looseness were collected for evaluation.

4.2 Experiment results

The acquired evaluation data were used to assess the determination performance of the preliminary assessment algorithm. As shown in Fig. 7, the evaluation data revealed a tendency for peak acceleration to be larger under looseness conditions, and to be smaller under rigid conditions. Moreover, when calculating the determination feature values for each data, the determination results of all data perfectly matched with the jig settings (100% accuracy), as shown in Fig. 8. If a high level of accuracy is acquired with the preliminary assessment, final determinations made by senior FEs are able to focus on difficult cases, such as those with a low level of looseness. From these results, the preliminary assessment algorithm that we developed was verified as being effective for achieving remote inspections of equipment looseness with greater efficiency.

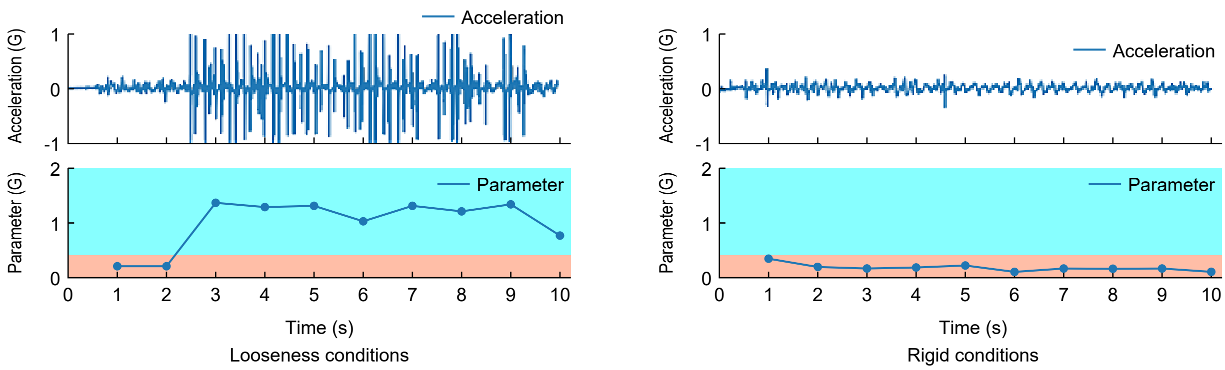


Fig. 7 Waveform data under looseness condition and rigid condition

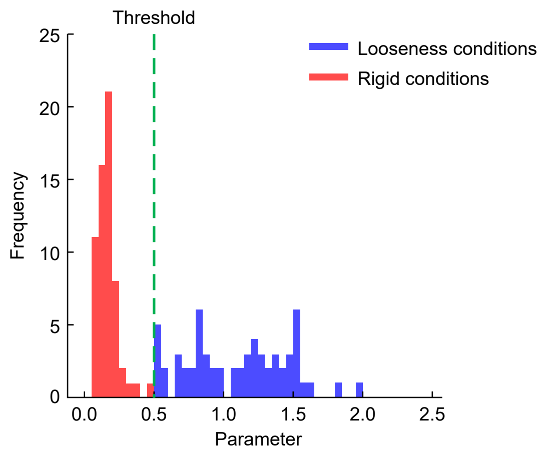


Fig. 8 Extracted parameters from evaluation data (acceleration waveforms during vibration)

5. Conclusion

We developed a prototype sensor glove and preliminary assessment algorithm for digitizing tactile information of junior FEs at work sites for conducting remote inspections utilizing tactile information, which we verified as delivering sufficient performance. Moving forward, we will continue verifying the effectiveness of the system for various target inspection items, ensuring robustness for FEs and the environment, and looking into development of a system for data protection and management. With the development of technology for remote work that involves tactile information, we are seeking to achieve a future where highly reliable services by senior FEs are readily available around the world for the maintenance of machinery and equipment.

References

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