Proposal of the Detection System for Safety Equipment-Wearing Using IBC

Masaki Fujikawa and Masakatsu Nishigaki

***Abstract*— For operating machine tools, safety is an essential requirement. The electronics and information technologies enable us to build a safety device into gloves and helmets to stop machine tools when these safety equipments enter a dangerous area. In this detection system, it is important to prevent errors where the operator forgets or neglects wearing above equipments. According to our investigation, an adequate equipment-wearing detection system does not. In this paper, we propose an equipment-wearing detection system. The aim of this system is to stop a starter and motor/engine installed vehicles and machine tools when a person intends to operate them without wearing safety equipments. We also carried out experimental tests of a laboratory prototype of a system described above.**

***Index Terms*—Application of intra-body communication (IBC) technology, industry, sensor systems, safety system.**

I. Introduction

With the progress in electronics and information technology, a safety system that ensures the safety of machine tool and vehicle operators has been developed. For example, in the case of press-forming machines, a system is equipped that prevents the operator's hand from being caught in the machine [1]. With such a system, several devices generate and receive light beams, and if the light beam cannot be detected when the stamping die begins to descend, the system stops the machine automatically, assuming that the light beam is interrupted by the presence of the operator's hand.

The operator of the press-forming machine usually waits until the machine finishes the stroke holding the blank to be processed in the next cycle to increase operating efficiency, and sometimes, the light beam may be blocked by the blank held by the operator. Furthermore, the light beam may be blocked by the towel the operator uses to wipe sweat or by the bottom of the work uniform. Although the press-forming machine stops automatically for safety, some operators do not like the unintended shutdown of the machine and may knowingly operate the press with the safety system disabled [2]. This is not good for safety, but such a problem may also be due to a safety system that responds to any movement. Accordingly, such a safety system must be equipped with a function to detect whether a part of the human body is actually within the hazard range.

The safety system based on such a concept is incorporated into garbage trucks [3]. In that system, RFID tags are installed in the gloves worn by the operator, and RFID readers are installed on the garbage inlet opening. When the distance between the RFID tag and the reader drops below the prescribed value (i.e., the glove is within the hazard range), the loading plate that takes in garbage stops. However, such a system detects the presence of the glove only and not the hand wearing the glove, and it cannot handle a situation where the worker forgets or neglects to wear the glove. So, the safety system must be able to detect the hand (a part of the human body) wearing the glove (wearing safety equipment) within the hazard range.

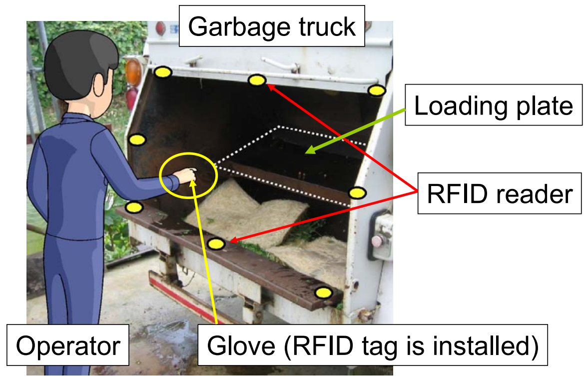

Fig. 1. Grove detection system is installed in garbage truck. This system uses RFID tags and readers to detect operator's glove.

The authors focused on existing safety systems that detect when the article used is within the hazard range for protection from injury and investigated whether such system had a function to reliably detect whether such equipment was worn or removed, but as far as it was investigated, such a function was not considered. In this paper, we propose a system that will detect whether equipment is worn or removed using IBC technology. We also carried out experimental tests of a laboratory prototype of a system.

II. Investigations and Requirements

A. Detection System for Hardhat-Wearing

A system that detects whether a hardhat is worn or not is incorporated in the hand-held type laser beam machine [4]. A pressure sensing switch and IR sensor are installed inside the hardhat in the forehead section, and a micro-switch is installed on the face shield that protects the operator's face. When the following detections are made; i.e., (1) the pressure sensing switch is pressed by the operator's forehead, (2) the IR sensor detects the operator's body temperature, and (3) the

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face shield is in the down position (the micro-switch is pressed), the system determines that the operator is properly wearing the hardhat and allows the laser beam to oscillate.

However, in this system, oscillation of the laser beam may be allowed if the operator holds the hardhat in the hand with the face shield down pressing the inside of the hardhat accidentally fulfilling conditions (1) through (3), leading to the risk of injury to the operator. In order to prevent such accidents, a function to detect erroneous wear of the protective gear is required.

B. *Detection System for Seatbelt-Fastening*

In reference [5], a seatbelt-fasening detection system is proposed using the buckle and the resonant tag. In this system, wearing of the seatbelt is determined by detecting (1) whether the strap is connected to the buckle and (2) whether a magnetic field generated by the loop coil installed in the seat assembly is disturbed by the resonant tag sewn in the shoulder strap (a belt that extends obliquely from the shoulder to the waist of the occupant). The intensity of the magnetic field is adjusted so that it will not penetrate the human body. So when the strap is connected to the buckle after the occupant is properly seated, the resonant tag is outside the range of the magnetic field, and the field is not disturbed by the resonant tag. When proper wearing of the seatbelt is neglected, for example, the occupant is seated on the strap connected to the buckle, the magnetic field is disturbed by the resonant tag because the human body is not between the shoulder strap and the seat assembly.

However, if the resonant tag fails, the magnetic field is not disturbed, and the system determines that the seat belt is properly worn even when it is not worn. This means that the system is not based on a design philosophy of prohibiting the operator from starting the engine when the system fails (i.e., not failsafe [6]). Furthermore, disturbance of the magnetic field may be induced by the presence of a metal piece placed closely to the seat assembly, such a system is difficult to use in vehicles where metal tools or parts are frequently carried, as in power shovels or trucks. Because a safety system is intended to ensure safety in the event of an accident, the system must be robust and not affected by disturbances, such as noise, and the use environment must not restrict the system.

C. *Requirements for Detection System*

The authors established the following requirements for the detection system to be incorporated in the safety system based on the considerations explained above.

Requirement 1 (Capable of avoiding false detection): While capable of detecting whether a person is wearing safety equipment, the system must avoid false detection (i.e., to determine that the equipment is worn when it is not actually worn.)

Requirement 2 (Failsafe design): The safety system must be failsafe in principle [7]. This means if the detection system fails, starting the vehicle or machine tool must be impossible.

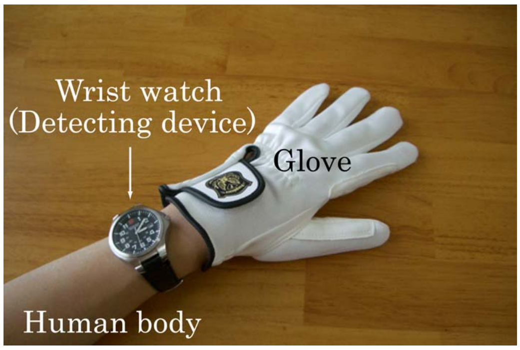
Requirement 3 (Must be capable of detection of encoded signal only): The detection system for the wearing of safety equipment must not be affected by disturbances or changes in environmental conditions.

III. Proposed Detection System

A. *Concept of System Design*

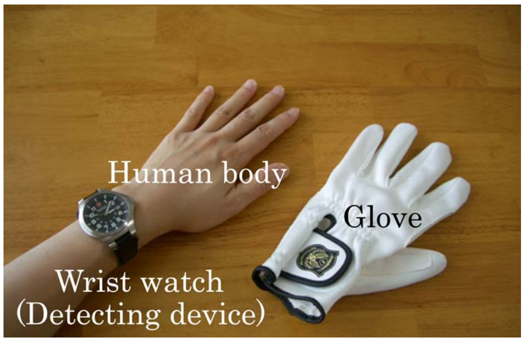
When the relative location between the equipment and the human body is considered, if the target equipment is worn, then the article is in contact or in close proximity to the human body. If the article is not worn, then the article is not in contact or in close proximity to the human body. Accordingly, the authors decided to design a system based on the concept of linking the wearing of the article and the detection device via the human body. This concept is explained using a glove and a wristwatch as follows (see Fig. 2 and Fig. 3). A detection device is incorporated into the wristwatch beforehand. When the glove is worn on a hand as shown in Fig. 2, the glove and a hand are in close contact. In this case, it can be considered that the glove and the detection device are linked via the human body.

Conversely, when the glove is removed as shown in Fig. 3 and the glove and the hand are no longer in close contact, they are considered not linked. In order to materialize the above concept, the authors physically linked the worn article and the detection device using IBC technology.



(a)

Fig. 2. The concept of the detection system (a): The IBC is established between the wrist watch and the glove.



(b)

Fig. 3. The concept of the detection system (b): The IBC is not established between the wrist watch and the glove.

B. *IBC (Intra-Body Communication) Technology*

IBC technology uses the human body as the communication path to transmit information. Several methods have been introduced, however, the classification of these methods is different depending on the interpretation of the communication mechanism [8]-[11]. In order to enable straightforward discussions, the authors reorganized the classification of the methods from the following viewpoints: (1) loop configuration (Table I), (2) electrode connection method (Table II), and (3) signal sensing method (Table III).

TABLE I: GENERAL CLASSIFICATION BASED ON THE LOOP CONFIGURATION

Name of the Method and Characteristics
Common grounding method: IBC is established by the closed loop: Grounding wire -> Transmitting device -> Human body -> Receiving device -> Grounding wire
Earth grounding method: IBC is established by the closed loop: Earth -> Transmitting device -> Human body -> Receiving device -> Earth
Circuit separation method: IBC is established when the closed loop of the receiving device receives electromagnetic wave generated by the closed loop of the transmitting device.

TABLE II: GENERAL CLASSIFICATION BASED ON THE ELECTRODE CONNECTION METHOD

Name of the Method and the Characteristics
Contact-type connection method: The electrode must be in contact with the human body. Alternating or direct current can be transmitted.
Noncontact-type connection method: The electrode need not be in contact with the human body. AC component of the signal can be transmitted through capacitance.

TABLE III: GENERAL CLASSIFICATION BASED ON THE SIGNAL SENSING METHOD

Name of the Method and the Characteristics
Electric signal sensing method: Change in the electric current or voltage is detected as a signal. This is not suitable for the transmission and receiving of high speed signals.
Photonic sensing method: Change in electrical charge is detected as a signal. This is suitable for the transmission and receiving of high speed signals.

According to the authors' classification, the method described in [9] is classified as the *earth grounding*, *noncontact-type connection*, and *photonic sensing method*, the method described in [10] is classified as the *earth grounding*, *noncontact-type connection*, and *electric signal sensing method*, and the method described in [11] is classified as the *common grounding*, *non-contact type connection*, and *electric signal sensing method*.

C. Detection Mechanism

In this subsection, the detection method using IBC is explained. In Fig. 2 and Fig. 3, a signal-generating device is incorporated into the equipment (a glove) and a signal-receiving device is incorporated in the detection device (a wristwatch). The signal-generating device generates a "peculiar signal" that links the worn article and the detection device and transmits the signal to the signal-receiving device via the human body. The detection device determines whether an article is worn or not based on the status of whether or not the peculiar signal is received (i.e., whether the worn article and the detection device are linked). Furthermore, when the signal-generating device and signal-receiving device are incorporated into the same worn article as shown in Fig. 4, whether the article is worn or not can be determined by the article alone. As such, IBC technology can be used as a measure to determine whether linkage between the worn article and the detection device is established (i.e., whether the article is worn or not).

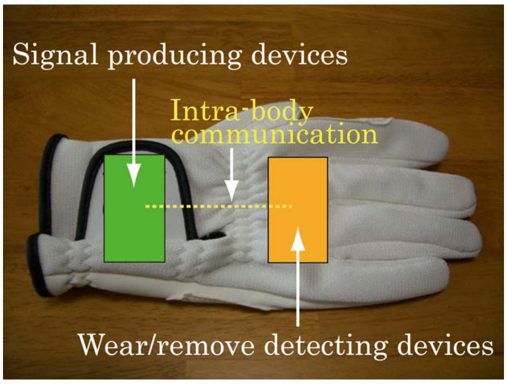


Fig. 4. Detection mechanism using IBC. The IBC is established between signal producing devices and wear/remove detecting devices via the surface of the human body (hand).

D. Prototype Fablication

The authors fabricated the prototype of the article equipped with the detecting function. The common grounding, noncontact-type connection, and electric signal sensing method has employed because it was relatively easy to implement. A glove was used as the worn article because gloves are considered most commonly used for protection from injury.

The transmitting electrode (25 mm × 50 mm) and receiving electrode (25 mm × 10 mm) are attached to the inside lining of the glove (see Fig. 5), and the circuit board is attached to the back surface of the glove. In order to prevent the wiring that connects the electrodes and the circuit board to function as an electrode, electromagnetic shielded wire was used. Pieces of copper foil were used as the electrodes and their surface was coated with a thin insulating film (PVC). The glove was made of cowhide (thickness of the skin is about 1.0 mm), which is commonly used when operating machine tools.

Fig. 7 shows a block diagram of the implemented system. In this case, the signal-generating device and the signal-receiving device are incorporated into the single circuit board. The oscillator that generates square wave signals at 100 kHz is connected to the transmitting electrode, and the signal propagates along the hand to the receiving electrode when the hand is in proximity to these two electrodes. The signal received is processed in order to extract the 100 kHz square wave component. When reception of the 100 kHz square wave signal is confirmed, the circuit will illuminate LEDs labeled "Decoding" and "Receiving" as shown in Fig. 8.

Because the circuit and the human body have analogue properties, the signal may be received intermittently even when the glove is worn. Consequently, a timer is used so that the system can determine whether the glove is still worn if the signal is received again within the prescribed interval after momentary interruption of receiving. When the system determines that the equipment is worn, the LED labeled

"Receiving" illuminates, and when system determines that the equipment is not worn, the LED labeled "Remove" illuminates. Because the prototype was used in this experiment, the following specification was used in implementation of the system.

1) The transmitting device and the receiving device are installed on a single circuit board with the transmitting device and the receiving device connected to the common grounding wire.
2) The transmitting device and the receiving device are incorporated into the same glove, and detection is made for the glove.
3) Sensitivity of the receiving electrode is adjusted by the variable resister installed on the circuit board.
4) Timer setting is 7 seconds.
5) Transmitted signal is not encoded.

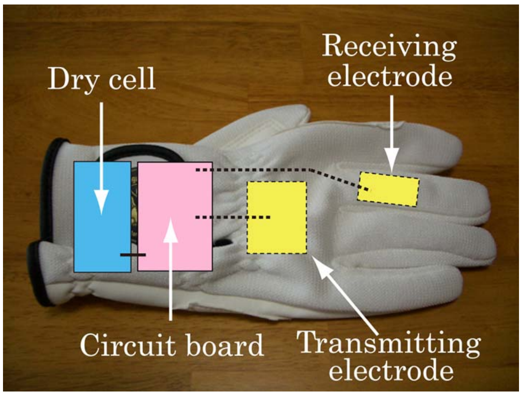


Fig. 5. System implementation image. Both electrodes are attached to the inside lining of the glove.

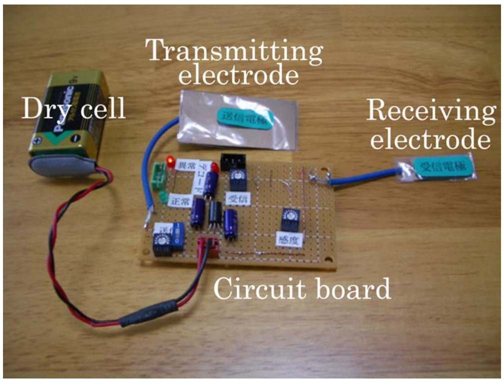


Fig. 6. Fabricated prototype system. Both electrodes are coated with a thin insulating film (PVC: polyvinyl chloride).

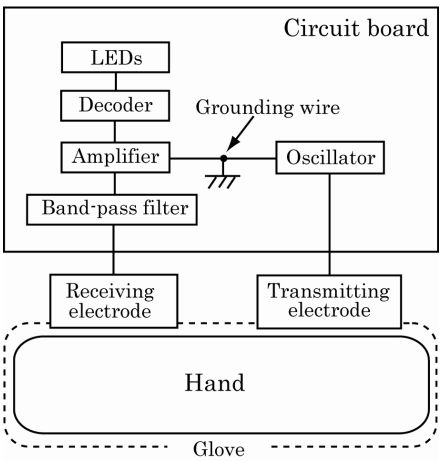


Fig. 7. The block diagram of prototype system. The transmitting device and the receiving device are connected with common grounding wire.

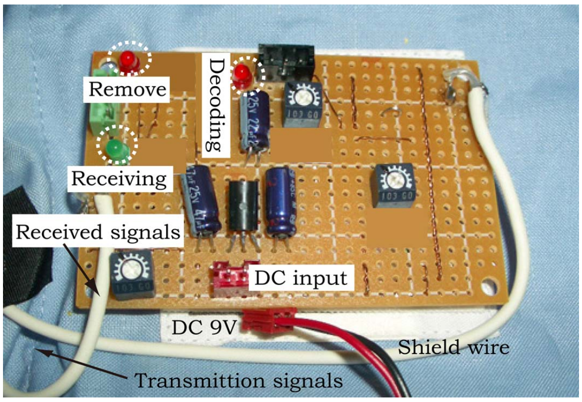


Fig. 8. The circuit board of prototype system. You can see three LEDs laveled "Receiving", "Decording" and "Remove" are incorporated on the curcuit board. The DC input is 9V.

IV. Considerations

The detection system using IBC satisfies the three requirements described in subsection II-C. In this section, the reasons for satisfying the requirements are explained. For easy understanding, the implemented system in Section III is used as a specific example.

A. *The Reason Why Requirement 1 Is Satisfied*

1) When the transmitting electrode and the receiving electrode are very close, the signal may be transmitted inadvertently even when the glove is not worn (see Fig. 9). However, when the noncontact type connection method is used, receiver sensitivity of the electrode can be adjusted by changing the material and thickness of the insulation coating on the receiving electrode, or by changing the applied electric current or voltage. Accordingly, it is possible to avoid communication even if the transmitting electrode and the receiving electrode are close when the article is not worn by designing these factors appropriately.

(a)

(b)

Fig. 9. Envisioned cases of (1). These are common cases.

2) When the noncontact type connection method is employed, communication may be established inadvertently even when the glove is not worn because communication is established when the human body and the electrodes are close (for example when the gloves removed are held by the hand). However, in this method, the receiving sensitivity of the electrode can be adjusted by changing the material and thickness of the worn article. Accordingly, it is possible to avoid communication even if the human body and the electrodes are close when the article is not worn by designing these factors appropriately.

B. The Reason Why Requirement 2 Is Satisfied

1) When the article is not worn: When either of the transmitting device or receiving device fails, transfer of the signal is impossible even if the transmitting and receiving electrodes are close. This prevents the system from determining that the article is worn when the article is not actually worn, which makes it possible to disable the starting of machine tools etc.
2) When the article is worn: When either of the transmitting device or receiving device fails, transfer of the signal is impossible, and the system determines that the worn article is removed. This makes it possible to stop machine tools in operation

C. The Reason Why Requirement 3 Is Satisfied

1) It may be possible that the receiving device may receive the signal due to electrical noise or environmental noise, even when the transmitting device is not transmitting. This can be avoided by adding a system that properly encodes the signal by the transmitting device and check the encoded signal by the receiving device.
2) When the encoding method changes for each article, one-to-one correspondence can be established between the signal transmitted by the transmitting device and the signal received by the receiving device. Owing to this, if the bodies of operator A and operator B make contact, the receiving device of article A worn by operator A will not process the signal transmitted by the transmitting device of article B worn by operator B (see Fig. 10).
3) The possibility that a change in the environment within the human body may affect IBC cannot be denied. Stable IBC can be maintained by incorporating a mechanism that feeds back changes in the conductivity of the human body by detecting it in real time as described in [12].

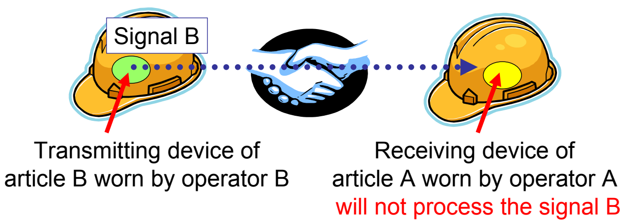


Fig. 10. Image of one-to-one correspondence. The Receiving device of article A processes singal A only.

V. Conclusion

In this paper, it was demonstrated that the security of the safety system can be enhanced by detection of the worn article using IBC technology. The authors identified three requirements of the detection system of the worn article by scrutinizing the problems associated with existing safety systems and demonstrated that the safety system using IBC technology can satisfy all three requirements. The laboratory prototype system based on the common grounding, non-contact type connection, and electric signal sensing method was fabricated, and the effectiveness of the system was confirmed through evaluation and review in pilot studies.

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