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청정생산공정기술

Man-Machine Interface Device for Dismantling Factory

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Abstract

In dismantling factories for recycling, it is important to input actual working data to a personal computer (PC) in order to monitor the work results and related recycling rate of the inputs. This should be performed with a keyboard, a mouse, or other devices. But when a worker is working in the factory, it could be bothersome or time consuming to go to the PC. Especially, workers who works at dismantling factories have a generally low education level are scared to use a PC, which could be used as a pretext for not using the PC. In some cases, data input is performed by a worker after the day's job. In this case, it could take additional time, the worker can make more mistakes, and the data could be unreliable. In this study, we developed a man-machine interface (MMI) device using a safety helmet. A joystick-like device, pushbuttons, and a radio frequency (RF) device for wireless communication is equipped in a safety helmet. This MMI device has functions similar to a PC mouse, and it has a long communication distance. RF is used because it consumes less battery power than Bluetooth. With this MMI device, workers need not go to a PC to input data or to control the PC, and they can control the PC from a long distance. The efficiency of PCs in a factory could be increased by using the developed MMI system, and workers at the dismantling factories could have less reluctance in using the PC.

Keywords : User interface, Dismantling, Safety helmet, SME (small- and medium-sized enterprise), Wireless communication

1. Introduction

The recycling of used products is very important for the efficient use of resources. The European Union (EU) Directive 2000/53/EC [1] and Commission Decision 2005/293/EC [2] have imposed basic guidelines for end-of-life vehicle (ELV) recycle monitoring and the recycling rate. Also, the need for a higher recycling rate is growing. Accordingly, many European and Asian countries have investigated and assessed their ELV treatment process to improve material recovery techniques, including Italy [3], the Netherlands [4], Germany [5], Denmark [6], Japan and Taiwan [7,8].

The dismantling of used products is mandatory to improve the recyclability rate of the products [9,10]. The model factory for this work is an auto recycling center, where a higher recycling rate is necessary to comply with the ELV directive. The main task of the factory is to harvest reusable parts and recyclable materials.

Personal computers (PCs) are necessary devices to generate working instructions for efficient dismantling work and documenting the maintenance inventory of harvested parts and materials. However, at some mid- to small-range workplaces and especially dismantling factories engaged in resource recycling, PCs for work and stock management are rarely used or inefficiently used. Instead, a worker manually inscribes a worksheet and hands it to a PC operator in the office. It is very important to utilize PCs for accurate management of work and stock [11]: direct input of work data not only facilitates accurate data gathering, but also eliminates unnecessary typesetting and cost.

However, it can be very difficult for a worker to interact with a workplace PC via a keyboard or a mouse due to his/her work environment. Radio controlled mice and keyboards are commercially available, but it is not easy to adopt such products because of poor portability at a workplace [11,12]. In this study, a wireless

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input device was developed in order to overcome such difficulties. The proposed device enables a worker to interact with a PC efficiently and remotely.

Section 2 describes user requirements and our functional analysis. Device components and the overall system are explained in Sections 3 and 4. Operational testing results are given in Section 5, and our conclusions are given in Section 6.

2. Requirements and Functional Analysis

2.1. Requirements and features for the device

We desire a device that satisfies user requirements, facilitates easier operation, and enhances work efficiency. It is essential to determine the required system features when designing a new system. Operating a PC at a real workplace may reduce work efficiency since it is not easy for a working laborer to use an ordinary keyboard and mouse.

Portability is a key requirement for a worker to effectively use a wireless input device. It is required for the worker to carry a light pack of input devices such as mouse and keyboard, and to use the device conveniently. Therefore, the input device should be designed such that a worker can put it on his/her helmet or apparel, which facilitates easy operation.

Proper packaging is necessary for the system to be protected from physical impact that may be caused by surrounding metal tools and the facility. Weight, sufficient communicating distance (radio link coverage), portability, and electrical noise at the workplace are important factors to consider. In addition, a power supply (rechargeable battery) is required that can last at least eight hours. The requirements are summarized in Table 1.

Table 1. User requirements

Elements	Requirements
Weight	Light (200 g or so)
Radio link coverage	Long distance (100 m or so)
Duration time	One day (8 hours or more)
Response time	Fast (1 ms or less)
Portability	Convenient

2.2. Functions for data handling of the system

Input/output requirements for a dedicated software system were developed, and interaction elements between the interface and a PC are listed in Table 2. Each work process is performed by the predefined interaction elements, in which there can be some data modification or data input operation.

The predefined worksheet provides work operations that minimize keyboard input, and facilitates the selection of work completion. A proper size of monitor screen with enhanced readability, cursor movement, selection, and cancelation is required for the use of a PC via the developed wireless MMI device.

To fulfill the required functions of the MMI, the system should have a wireless communication system to the PC and battery operated internal command input devices (Figure 1).

Table 2. System interaction elements

PC	Output for operator	- Display the list of parts to dismantle - Display command buttons
	Return to server	- List of dismantled reuse parts - Barcode number of the dismantled parts
Input device	Output for PC	- Selection of part to work - Confirmation of each work - Cancelling the selection
	Input from Operator	- Cursor movement to select part for work - Push button to select part for work or confirm the working result

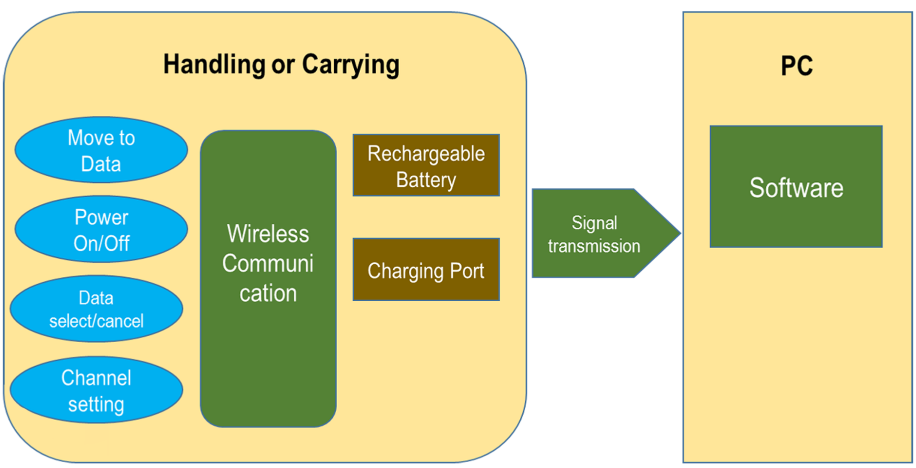


Figure 1. Structure of an MMI system.

2.3. Comparison of wireless systems

Wireless fidelity (Wi-Fi) has been adopted for wireless local area network (WLAN) products based on the IEEE 802.11 standard, which can reduce network wiring costs. Wi-Fi facilitates wireless communication in the open air or in an area where cable wiring is not permitted. Wireless network adaptors are equipped in most notebook computers. In addition, the chipset price has been lowered, which enables digital equipment makers to use WLAN adaptors. It can be said that Wi-Fi is now used globally as a standard. A typical wireless router with either the 802.11b or 802.11g standard can have radio link coverage of 32 m (indoors) to 95 m (outdoors). Compared with other wireless standards, Wi-Fi consumes a fairly high amount of electric power, which restricts its use [13].

Bluetooth wireless communication systems use the frequency range of 2,400 to 2,483.5 MHz, which is part of the industrial scientific and medical (ISM) band. Specifically, 79 channels from 2,402 to 2,480 MHz are used in order to prevent radio interference between wireless devices at the band fringes. ISM is a frequency band for industrial, scientific, and medical devices that generates low radio output but also requires no radio regulation. Some examples include amateur radio (ham bands), WLAN, and Bluetooth devices. Bluetooth originated from "Harald Bluetooth Gormsson," a King of Denmark and Norway in the 10^{th} century, which represents the unification of wireless interface standards as King Harald did.

Bluetooth is a communication standard designed for short range and low power consuming devices based on low price transceiver microchips. It enables Bluetooth devices to communicate with each other as follows:

1) Wireless headset: a phone call or mp3 music listening is possible with the phone in a pocket or briefcase.
2) Wireless file transfer: electronic file transfer is possible between phones, or between a PC and a phone.

Bluetooth can be used with low power consumption (100 mW) at a low price. It is also a comparatively safe wireless communicating method because of frequency division transmission. The signal can reach other Bluetooth devices over obstacles, but does not have directivity so that angular positioning of each device is not necessary. Finally, Bluetooth is a global standard that enables unrestricted data communications between Bluetooth devices.

ZigBee is a mesh-type wireless network standard with low cost and low electric power consumption. Its low cost feature enables ZigBee to be widely used in wireless control and monitoring. Low power consumption facilitates a long duration time with a small battery. The mesh-type network provides a wide range of communications and high security. ZigBee is operated on the ISM frequency band: 868 MHz in Europe, 915 MHz in the USA and Australia, and 2.4 GHz in other regions. It has been designed, compared to other wireless personal area networks (WPANs) such as Bluetooth, to be used conveniently and inexpensively. ZigBee's activation time from sleep mode is less than 15 ms, and it shows excellent device response. Therefore, it requires very low electric power since it can stay in sleep mode most of the time, which enables its long duration time.

ZigBee protocols have been designed for applications with low electric power and a low data transfer rate. The goal is to construct a general purpose, low cost, and self-constructing mesh network that can be applied to industrial control, imbedded sensors, medical data gathering, monitoring of smoke and intrusion, building and home automation, etc. Among the radio frequency (RF) technologies, it is advantageous to use non-contact communication technology utilizing the 2.4 GHz ISM frequency band with a next-generation local area communication chip based on an ultra-low power design, with high runtime performance and low price. It is similar to existing WPANs, but the need for a device setting is not necessary.

The general specifications of RF communication can be summarized as follows: direct current (DC) 1.9 to 3.6 V power supply, a low power wireless chip (15 mA in transmission and

Table 3. Comparison of wireless communication methods

	Wi-Fi	Bluetooth	ZigBee	nRF2401
Distance (m)	50-100	10-100	10-100	10-100
Network topology	Point-to-hub	ad hoc, very small network	ad hoc, star, mesh peer-to-peer	
Operation frequency	2.4 and 5 GHz	2.4 GHz	868 MHz (Europe), 900 to 928 MHz (N. America), 2.4 GHz (worldwide)	2.4 to 2.5 GHz ISM
Device and application impact	High	High	Low	Low
Battery option and Runtime	High	Medium	Very low	Very low
Device setting	manual	manual	automatic	automatic
Security		64 and 128 bit encryption	128 bit AES	AES
Application field	WLAN, broadband internet	Wireless connection between devices	Industrial control and monitoring, sensor network, building and home automation	Wireless connection between devices

18 mA in receiving), high stability, and SHOCKBURST communication mode (developed by NORDIC). The communication distance can be more than 50 m in the case of line of sight, which may depend on the specific situation inside a building. It can run by a coin cell battery and provides a very long duration time due its ultra-low power design [14,15].

Various wireless systems are compared in Table 3. The data transfer distances do not differ in magnitude because most of the systems adopt similar operation frequencies. An RF communication system with a general purpose and low power nRF2401 chip was adopted in this research.

2.4. Input devices

Many input devices have been developed for the PC (Table 4).

The keyboard can be categorized into two types: electronic and mechanical, based on how current flow is activated. The electronic method detects a depressed key by measuring electric charge, while the mechanical method utilizes metal switching under each key. The mouse is an input device that controls the cursor on a computer monitor. Various operations and program activations are possible by mouse clicking.

The joystick is a cursor control device using a lever system, which facilitates swift cursor movement compared to a keyboard. It can be classified as a switch type or volume type. The switch type uses electronic switching by a lever movement, while the volume type adopts an angular encoder that enables more precise control. In addition, buttons can be attached to the joystick lever in order to input various signals.

2.5. Carrying the MMI device

A worker cannot carry an MMI device by hand during typical dismantling work. The most comfortable way of carrying an MMI device could be by using working clothes or accessories.

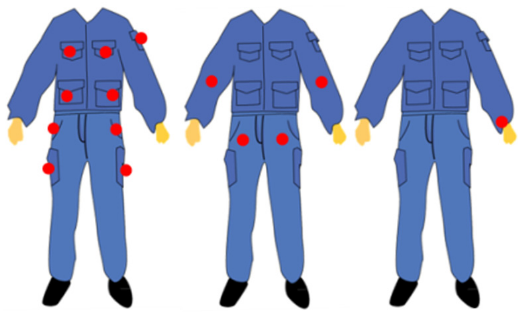


Figure 2. Possible carrying positions of MMI device.

The device could be carried in the pockets of working clothes, with a wrist strap, or in a safety helmet (Figure 2).

Generally, working clothes have many pockets. It is possible to carry a small input device such as a wireless mouse in a pocket. However, it is difficult to operate a mouse, which requires a mouse pad. A working uniform is equipped with various-sized pockets for carrying tools, and is tightly designed. An interfacing device attached in the cloth could be designed like a wearable computer. It could be made to be removable, or fixed (but this is not a good idea considering the frequent washing of the cloth).

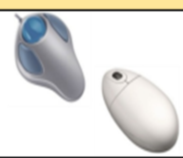
A wrist-strapped input device could be designed like a wrist watch. But such equipment can lower work efficiency due to workers' objections. It is mandatory that a worker should wear his/her protective helmet. Also, an MMI device built into a helmet can be protected. Therefore, the helmet is a practical solution for carrying the proposed MMI device.

3. System Components

3.1. RF wireless system

The nRF2401 board used in this study is suitable for PC

Table 4. Input devices for the PC

	Keyboard	Mouse, Trackball	Digitizer(Touchpad)	Joystick
Shape				
Characteristic	Arrangement of many key buttons	Use of a ball or laser sensor	Touch pad, touch pen	2 dimensional D.O.F., XY directional pitching
Type	Mechanical, Electrical	Mechanical, Encoder	Impact adhesive, Capacitive	Mechanical, Encoder
Feature	Character typing, Cursor moving, Data selection or deselection	Pointing, Cursor moving, Data selection or deselection	Commonly used pointing device, able to sense absolute position	Usually used to control video game, Cursor moving

interfacing applications with devices such as a frequency synthesizer, power amplifier, crystal oscillator, demodulator, or modulator. Also, it needs very low power: the current flow is 9.0 mA when the output power is -6 dBm (12.3 mA in RX mode), with power-down and standby modes.

For ZigBee, an 8 ms communication cycle is required, and the real duty cycle is much larger than that of an nRF24xx chip for a 1.772 ms run time (mainly because the ZigBee requires eight times the transmission time). The average current flow of the ZigBee during the communication cycle is 4 mA. It can continuously run for 500 hours with an AA battery (2,000 mAh), which would correspond to a 2.5 month run time for mouse operation, on average [14].

The average current flow for Bluetooth operation is 4 mA, and it consumes roughly 8 mA for synchronization even in idle mode. (Note that the current consumption of an nRF40xx chip is 10.2 uA in idle mode, and 351 uA for a ZigBee chip.) The practical battery life of a Bluetooth mouse is typically one month at most.

Provided that the general communication cycle is 8 ms and the nRF24xx-based device operates for 559 us, the real duty cycle becomes 1:14.3, which means that the average current consumption is 855 uA. Its continuous run time can be 2,350 hr for one AA battery (2,000 mAh), which corresponds to roughly one year of mouse operation, on average [12,14,15].

3.2. Power supply

The developed MMI device requires 8 hr of continuous run time, and it has been designed to run for 20 hr by considering some special cases. A rechargeable 3.7 V lithium-polymer battery of 400 mAh capacity was chosen for this study.

3.3. Control buttons

The MMI device is designed to be equipped with push buttons that are similar to those of a mouse. There are only two buttons in the device because it is not required to input characters or numeric data at the workplace (partly for security reasons).

3.4. Joystick

Cursor movement control on the monitor screen is enabled by a volume-type joystick containing an encoder. It is required that the joystick parts can be equipped inside of the helmet. A commercial joystick for a game controller satisfies the requirements (see Figure 3). Note that such a device facilitates directional control as well as signal input by pushing down on the whole joystick to press down a tact switch.

3.5. Helmet

The proposed MMI device is attached in a helmet that is comprised of three different parts, as shown in Figure 4: a hard-hat, an impact absorber, and a wearing strap. The EN397 is a safety standard for a helmet in Europe, and the Korean ministry of employment and labor provides such a standard in Korea [16]. The safety helmets are classified in three different types (A, B, and E), as described in Table 5.

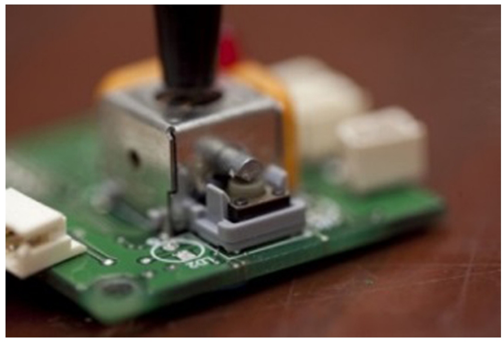


Figure 3. Joystick tact switch.

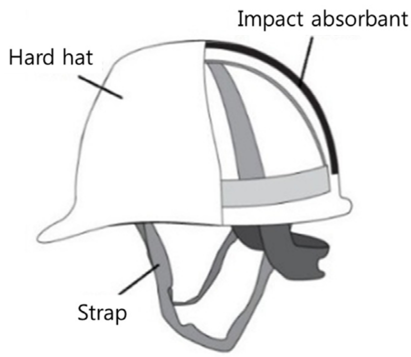


Figure 4. Helmet structure.

Table 5. Helmet classifications

Type	Purpose of use	Note
AB	To prevent or decrease injury from falling, flying, and crashing objects.	
AE	To prevent and decrease injury from falling or flying objects, and to protect the human head from electrical shock.	Dielectric withstands voltage
ABE	To prevent or decrease injury from falling or flying objects, and to protect the human head from electrical shock.	Dielectric withstands voltage

The switches and joystick components are designed to be attached to each type of helmet, while the other components are located inside of the helmet (between the shell and strap).

4. System Overview

4.1. MMI system

The hardware components of the system were assembled in

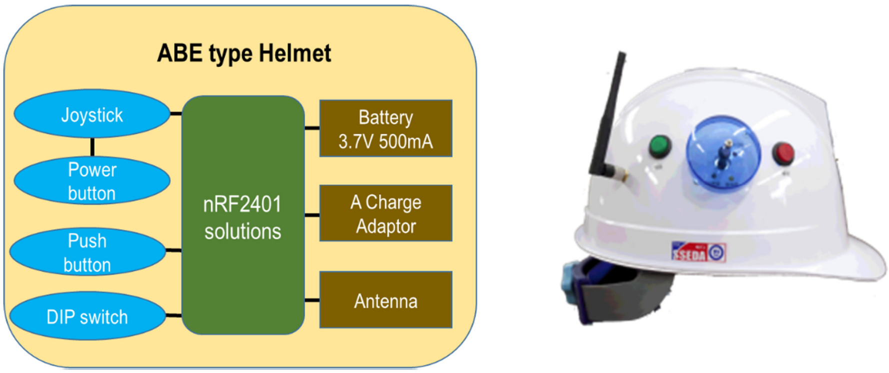


Figure 5. Helmet MMI system structure.

the helmet: the nRF2401 board, joystick, two push buttons, battery, and charger. Six signal addresses of the board are used for an operator to control cursor movements, selection, and cancelation. A power ON/OFF control is facilitated by pressing the joystick switch for over 3 s, along with two push buttons, to enable selection and cancelation.

A DIP switch is used to select six different channels in order to avoid interference with other PCs at the workplace. Also, each workstation can distinguish its own MMI device by a channel address value. The overall system structure is shown in Figure 5.

4.2. Software

Dedicated software was developed to control the MMI device, which also generates worksheet data by selecting process items, and stores data in a server computer. The software is divided into two modules: a module in the MMI device and a module in the PC.

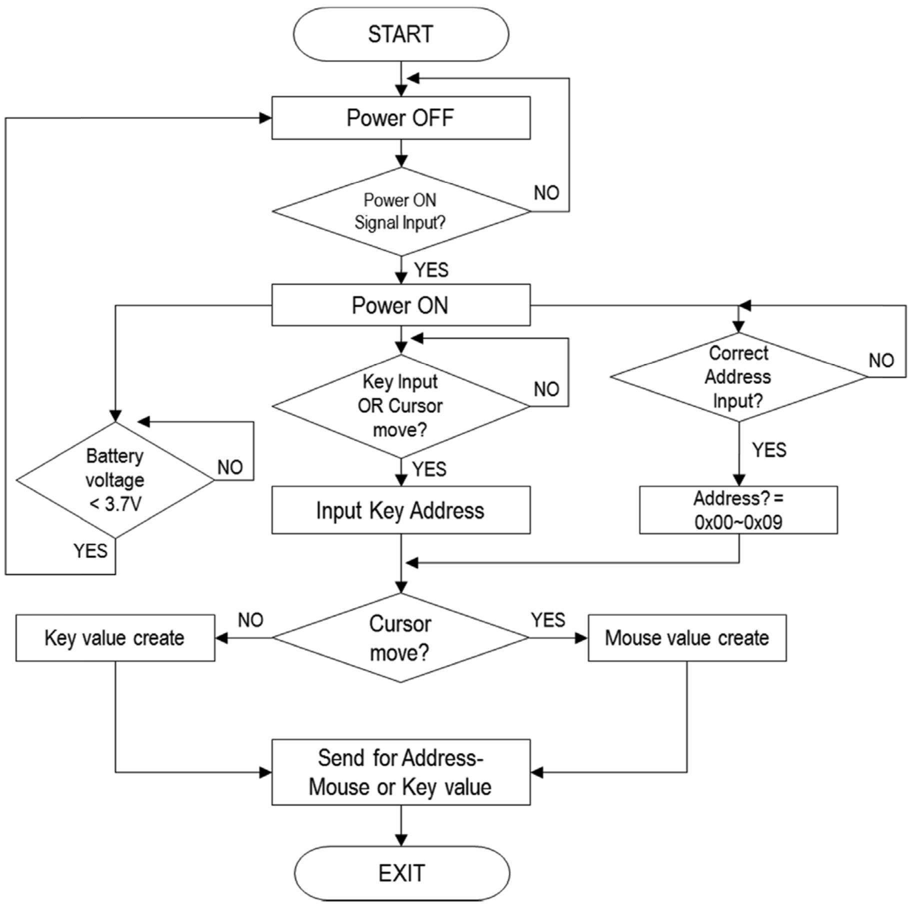


Figure 6. Information flow of MMI device module on helmet.

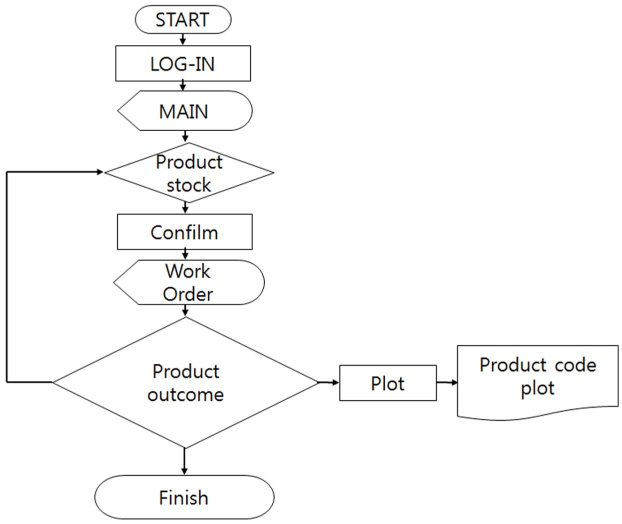


Figure 7. Information flow of module in PC.

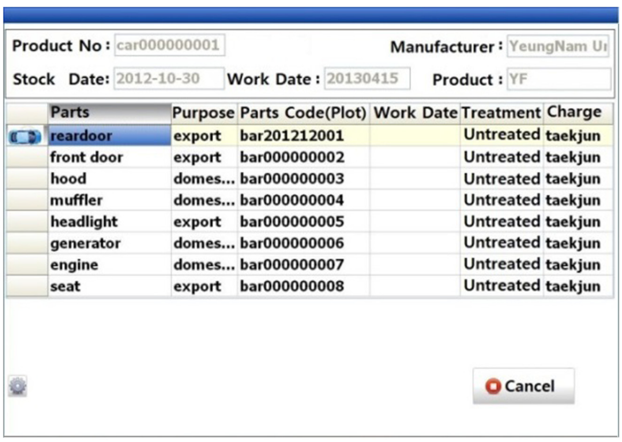


Figure 8. Screenshot of ELV dismantling control software.

The overall information flow of the MMI device module is shown in Figure 6, where the command signal (i.e., the box) is selected and transferred to the computer. The software module in the PC is shown in Figure 7. This module reads the movement of the joystick and the state of the push buttons via the input channel address.

The developed system was applied to the ELV dismantling process. Figure 8 shows the software screen that controls the ELV dismantling process. A list of to-be-dismantled parts is presented; these can be selected by a cursor movement controlled by the MMI device on the helmet. In addition, bar code printing for a dismantled component is enabled by push buttons on the MMI device.

5. Operational Testing

5.1. Distance and obstacle testing

The obstacle test evaluates the communication performance when an obstacle is located between a worker and the PC screen. Most ELV dismantling facilities considered in this study are higher than a normal operator: e.g., a large wall is located between a worker and the PC monitor (this should be avoided because the worker is supposed to look at the PC monitor to control his/her own MMI device without large obstacles). Therefore, the device was tested to determine whether it works from various distances, with and without obstacles.

Table 6. Distance and obstacle testing

Distance (m)	Obstacle exists	No obstacle
1	OK	OK
3	OK	OK
5	OK	OK

The test results are summarized in Table 6, which shows that the developed device works well up to a 5 m distance from the target PC, regardless of the existence of an obstacle. The content of a monitor screen could not be identified at a distance of over 5 m. Also, we note that an additional antenna is necessary for the system to properly work.

5.2. Communication interference avoidance testing

It is important to avoid any radio interference when communicating between an MMI device and the corresponding PC because there are several workstations, each of which is equipped with a set of MMI devices and a PC at the workplace.

Five independent MMI devices were tested to determine whether each PC receives the correct signal sent by the corresponding MMI device when they are working simultaneously. Table 7 shows the test results. Each MMI device sends various signals such as "power on/off," "up/down/left/right," and "cancel/select" to check whether each software function works correctly, and whether the cursor movement is correct.

All of the joystick and push buttons of the five simultaneously working MMI devices operated correctly, and we verified that there was no radio interference between devices.

Table 7. Interference avoidance test

Command	Signal	MMI1	MMI2	MMI3	MMI4	MMI5
ON/OFF	3 s	OK	OK	OK	OK	OK
Up	0x33	OK	OK	OK	OK	OK
Down	0x34	OK	OK	OK	OK	OK
Left	0x35	OK	OK	OK	OK	OK
Right	0x36	OK	OK	OK	OK	OK
Cancel	0x01	OK	OK	OK	OK	OK
Select	0x02	OK	OK	OK	OK	OK

6. Conclusions

It is common that a computer-based network is constructed at the workplace; this facilitates accurate work data gathering and better product quality. Also, more research is required in order for workers to work more efficiently. In this study, a wireless MMI device was developed to enhance accessibility to a PC by workers in the workplace. The features of the proposed device can be summarized as follows:

1) By adopting a low-power wireless chip, battery duration time was prolonged more than fivefold compared with Bluetooth.

2) A synchronization process is not needed; thus, the MMI device can be instantly activated.

3) Work efficiency was maximized by installing the MMI device into the worker's safety helmet.

We note that the overall size of the developed helmet MMI prototype could be made smaller by downsizing a few parts, and by finding the optimum layout of the parts and wiring.

The developed MMI device was tested at an ELV dismantling plant, where work and stock management could be effectively assisted by the system. The system is composed of five MMI device sets run simultaneously via five radio channels without interference.

It is expected that the developed system can facilitate a more efficient management of work and stock via convenient interaction between a worker and a PC in the workplace.

Acknowledgements

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