ERGONOMICS AND USABILITY OF PENDANT TERMINALS FOR IMPROVED SAFETY

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Abstract

Highly advanced, automated production systems have recently been developed, however, humans still operate machines directly in many environments, especially in teaching operations where operators program robots using pendant terminals. Teaching operations are in most cases performed in hazardous areas, thus ensuring operator's safety is of primary importance. Various standards such as ANSI/RIA R15.06, IEC60204-1, ANSI B11.19, and ISO10218 (Manipulating industrial robots – Safety) which is currently being revised, describe the requirement of pendant terminals with 3-position enabling switches [1-4]. Accordingly, the usage of such devices has dramatically increased in the last few years. This paper reports the evolutionary improvement in pendant terminals, safety components for installing on the pendant terminals, both of which have been developed from the viewpoints of ergonomics and usability, based on thorough analysis of human behaviors on the operation of machinery.

Introduction

Highly automated production systems as shown in figure 1 still involve many situations where humans directly operate machineries, such as setting, teaching, process changeover, trouble-shooting, repairing, cleaning and maintenance. These human-attended operations are performed in extremely hazardous areas, thus operators must be provided with reliable safety measures, for instance carrying a mobile pendant terminal as an enabling device, to protect themselves from possible accidents [5-9]. After presenting the safety of ergonomically-designed pendant terminals at the 2nd SIAS conference in 2001, we have further pursued enhancement in ergonomic and usability aspects, and conducted researches on operator's usability of pendant terminals in actual working environments. Concurrently, the requirement of pendant terminals that ensure operator's safety has greatly increased, and the urgent development of such devices is highly expected.

Requirement of Ergonomic Usability on Pendant Operation

ANSI/RIA R15.06 stipulates that a teaching operator must hold a pendant, which can be controlled only by the operator, and the pendant must have an enabling device using an "OFF-ON-OFF" 3-position enabling switch [1]. The usability of a 3-position enabling switch depends on how the switch is installed in the mobile pendant. The designer has to take into consideration the operational characteristics of a 3-position enabling switch on a pendant, such as the load on the pressing finger. Various ergonomically- designed teaching pendants have been developed for various applications [5-9].

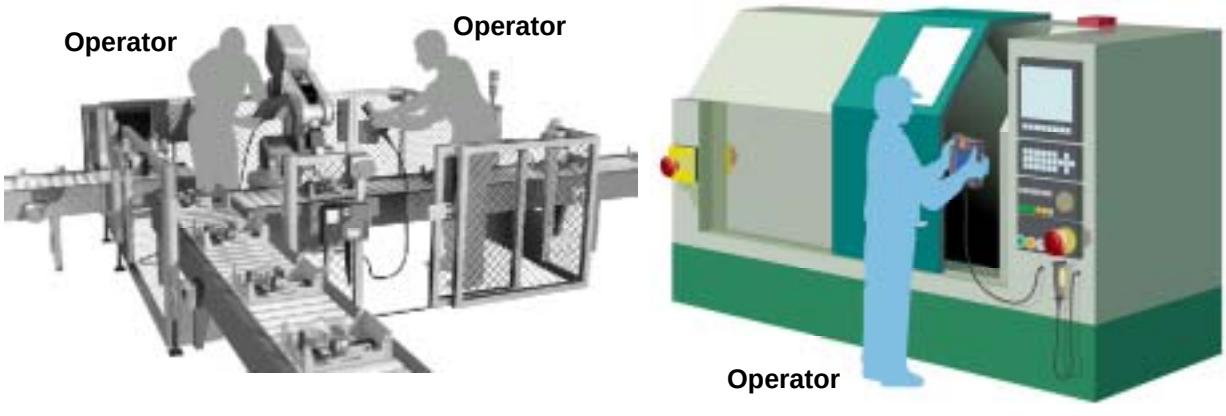


Figure 1. Production System Examples

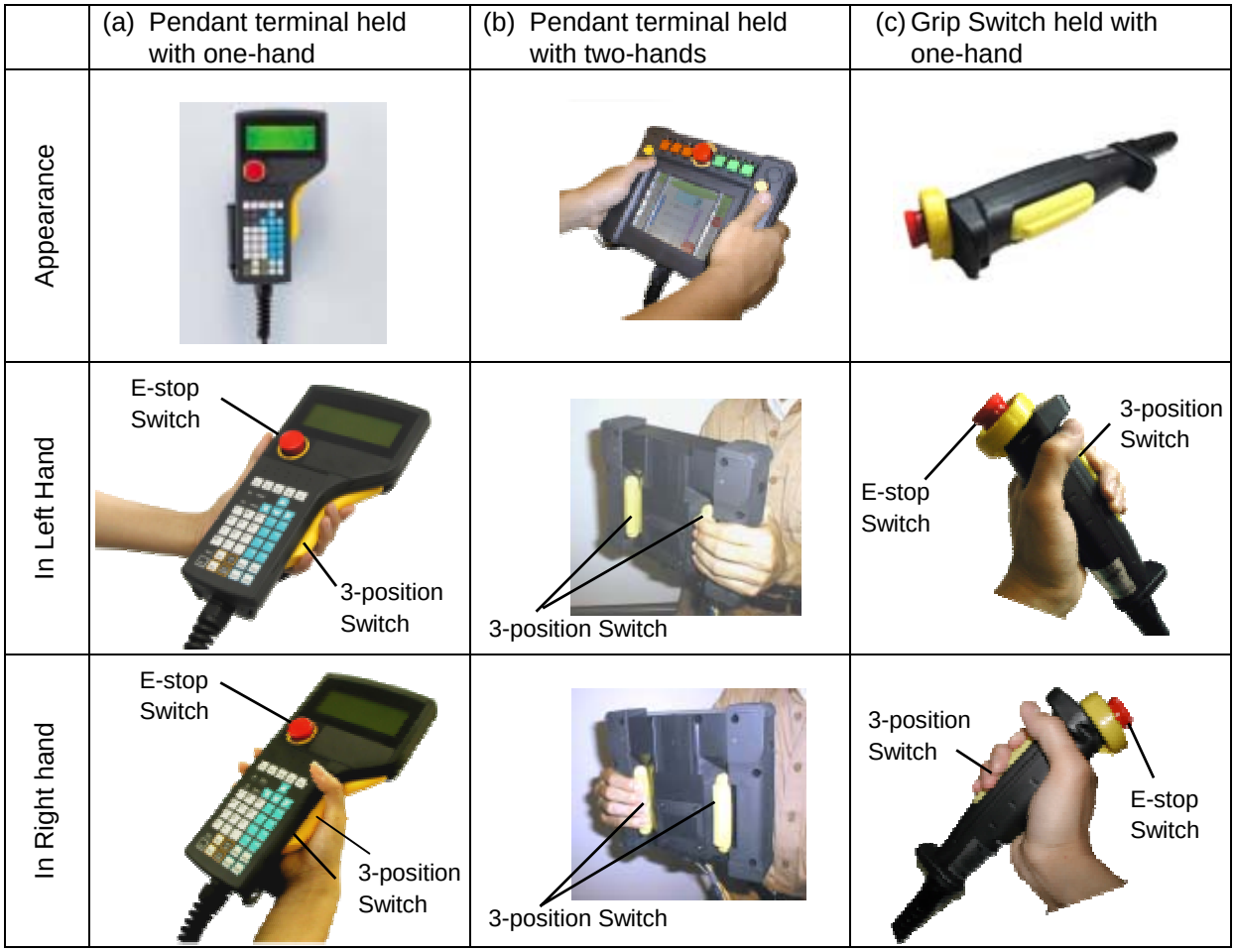
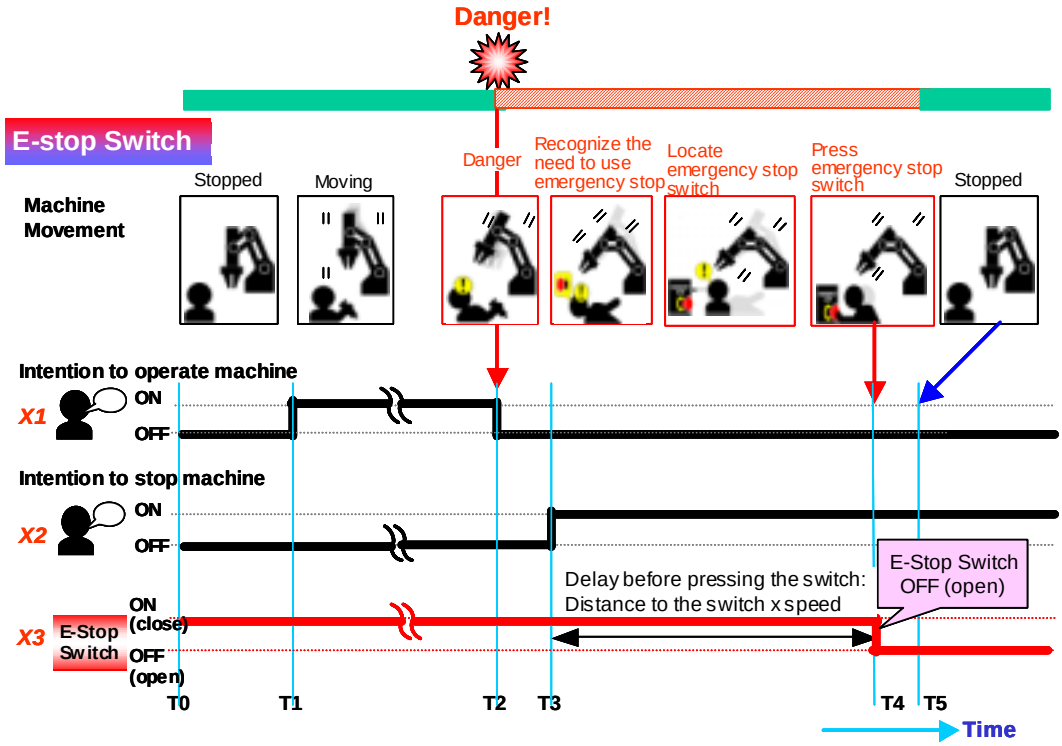


Figure 2. Holding Status of Ergonomically-designed Pendant Terminals and Grip Switch

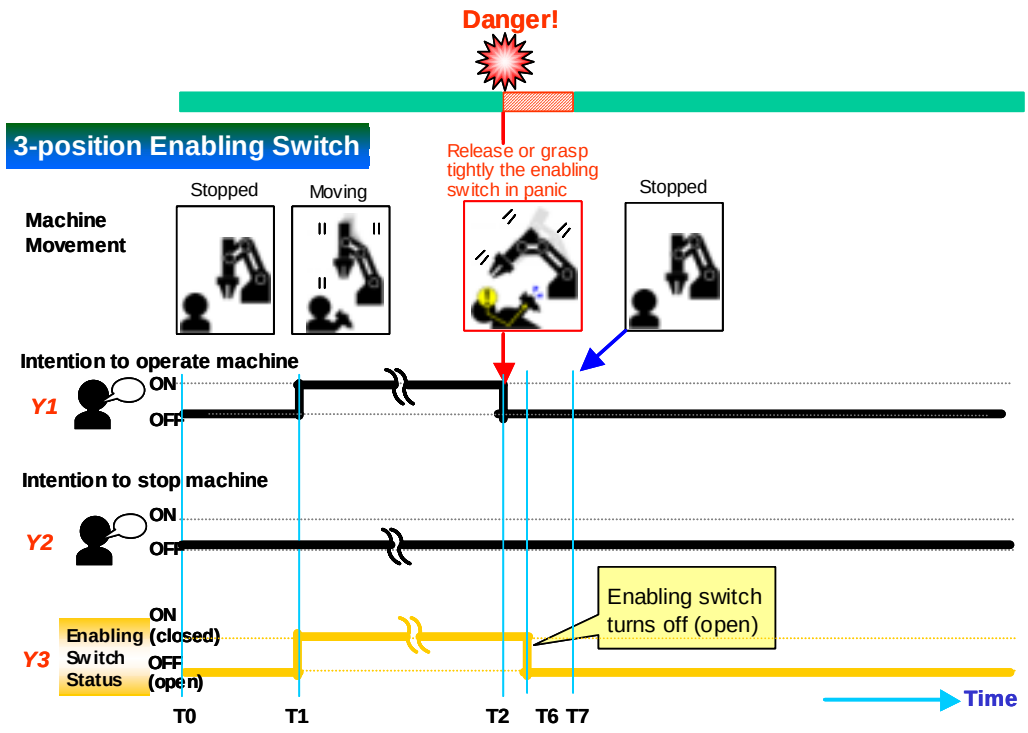
Figure 2 shows the examples mobile pendants and grip switch held in right and left hands. Small-sized robots, such as desktop type, are generally programmed using a one-handed pendant as shown in figures 2 (a). A one-handed pendant must be designed for easy operation for both right and left hands, so that the operator can change the operating hand when feeling tired on one hand. This ergonomic design is extremely important to achieve high-level usability for the operator. Figures 2 (c) shows the examples of grip switch. Because grip switches are generally used in one hand, the grip switch is also ergonomically designed to allow the operator to operate in either hand.

Middle- and large-sized robots, such as welding and painting machines, need a number of teaching programs and therefore require middle or large, information-terminal type pendants equipped with a Graphical User Interface (GUI) shown in figures 2 (b). Machine users with progressive foresight place a great importance on the inherent safety design of machines, and require the pendants equipped with two enabling switches, both on the right and left. Two enabling switches are necessary because the operator needs to change the operating hand during teaching operation, and either right-handed or left-handed operators must be able to use the pendant.

An important mechanism of the pendants equipped with two enabling switches is that while one enabling switch is held depressed in position 3 “OFF”, the other switch must not enable the robot motion. Enabling of robot motion must resume only after both enabling switches have been released and safety has been confirmed. For this purpose, a measure must be provided to detect whether the two enabling devices are “OFF” at position 1 or position 3.



(a) Emergency Stop Switch



(b) 3-position Enabling Switch

Operator's Reaction to Dangerous Situations

In order to ensure safety and usability for the operator, emergency stop switches must be installed on mobile pendants together with 3-position enabling switches, as required by various international standards[1-4]. The operations of emergency stop switch and 3-position enabling switch installed on pendant terminals are described below from the viewpoint of operator's reaction to dangerous situations. The 3-position enabling switch enables machine operation. An enabling device is provided with a function to disable machine operation when the panicked operator either releases or grasps tightly the enabling device. The emergency stop switch, on the other hand, is used for the sole purpose of stopping machine operation in emergency.

While the panicked operator is expected to disable machine operation in danger using the enabling device, emergency stop switches can provide additional protection to the operator, ensuring complete disabling of the machine operation. The use of emergency stop is required as a complementary protective measure in ISO12100 (5.4.2), and ANSI/RIA R15.06 states more specifically the requirement of emergency stop on mobile pendants (4.7.4). Installing both 3-position enabling switch and emergency stop switch on a mobile pendant provides increased safety to the operator.

Emergency Stop Switch Operating Status

Figure 3 (a) shows the operating status of an emergency stop switch. As the chart X1 shows, machine operation starts when the operator intends to operate the machine at T1. When the operator encounters a dangerous situation at T2, X1 turns off. The intention to stop machine X2 turns on at T3 after X1 has turned off. At T3, the operator recognizes the need to stop machine operation by using the emergency stop X3. Because the operator has only recognized the need to stop operation, X3 remains on (closed). The machine remains in operation and the operator is still in dangerous situation. When the emergency stop switch is pressed at T4, the switch turns off, stopping the machine operation at T5 after necessary response time of the machine. As the figure shows, the emergency stop switch is operated only a fraction after the operator intends to stop the machine X2.

3-position Enabling Switch Operating Status

Figure 3 (b) shows the operating status of a 3-position enabling switch. As chart Y1 shows, machine operation starts when the operator intends to operate the machine at T1, by turning on the enabling switch Y3. When the operator encounters a dangerous situation at T2, Y1 turns off, but the panicked operator's intention to stop the machine operation Y2 remains off. Because the panicked operator either releases or grasps tightly the enabling switch, Y3 turns off at T6, thus stopping the machine operation at T7 after necessary response time of the machine. As the figure shows, a 3-position enabling switch can disable machine operation even when the operator's intention to stop machine operation Y2 remains off.

Table 1: (a) Emergency Stop Switch and (b) Stop Switch

	(a) Emergency-stop switch		**(b) Stop switch**	
Appearance				
	HA1E	XA1E	HA1E	XA1E
Button color	Red	Red	Gray	Gray
Operating force	Approx. 6N	Approx. 10N	Approx. 6N	Approx. 10N
Operation method	Pushlock Turn Reset	Pushlock Pull or Turn Reset	Pushlock Turn Reset	Pushlock Pull or Turn Reset
Safety Lock Mechanism	Yes	Yes	Yes	Yes
Safe Break Action	No	Yes	No	Yes
Direct Opening Action	Yes	Yes	Yes	Yes
Contact Configuration	2NC	4NC	2NC	4NC
Double Circuit	Yes	Yes	Yes	Yes
Double circuit and Monitor circuit	No	Yes	No	Yes

Table 2: 3-position Enabling Switches

		3-Position Enabling Switch			
Ergonomics, Usability & Performance \ Appearance		 HE1B	 HE2B	 HE3B	 HE5B
Operation Style	Thumb type	Yes	No	Yes	Yes
	Hand-held type	No	Yes (four fingers)	Yes (three fingers)	No
Operating Force	To maintain in position 2	Approx. 3N	Approx. 4N	Approx. 4N	Approx. 3N
	To shift from position 2 to position 3	Approx. 15N	Approx. 30N	Approx. 20N	Approx. 17N
Ergonomic Features	Position 2 can be maintained with light pressing force	Yes	Yes	Yes	Yes
	Clicking tactility when pressing into position 2	No	Yes	Yes	Yes
Contact Configuration	3-position switch	1 contact	2 contacts	2 contacts	2 contacts
	Button-returned monitor	No	2 contacts maximum	No	No
	Button-returned monitor	No	2 contacts maximum	No	No
Installation Convenience on Pendants		Good	Good	Excellent (mounting hole ø16)	Excellent (mounting hole ø16)

Requirements for safety components on pendant terminals

As explained above, many factors must be considered in order to ensure safety operation of pendant terminals. Accordingly, many factors such as ergonomic feature, usability, and safety must be achieved on safety components. Table 1 shows (a) emergency stop switches, (b) stop switches, and table 2 shows 3-position enabling switches as the examples of safety components, which have been developed with the latest ergonomic research to provide the advanced safety features.

Emergency stop switch is used with the operator's intention to stop machine operation, to provide the final stop means to the operator. Emergency stop switch needs to meet many strict structural requirements, and those for installing on pendant terminals, in particular, must be highly shock resistant, because pendant terminals are subjected to the possibility of inadvertent drops by operators. Table 1 (a) shows the features of small sized emergency stop switch, all of which are highly shock resistant to possible drops, when installed on pendant terminals. The Safe Break Action structure, which maintains the open status of contacts when the contact block is removed, is an extremely effective safety structure for emergency stop switches. The emergency stop switches are installed with four NC contacts which provide safety and convenience to the operators. When using the emergency stop switch to stop robot operation, four NC contacts can be configured into double circuits, increasing the safety level. When using the emergency stop switch to stop the robot operation and also the related system connected to the robot, each set of two NC contacts can be connected to the robot and the related system.

Table 1 (b) shows the examples of stop switches. The usage of wireless communication is expected to increase with battery-powered pendant terminals, and the usage of pendant terminals as detachable mobile device is also expected to increase to allow connection to many different equipment. Accordingly, the stop switches on such pendant terminals must be colored differently from red-colored emergency stop switches, which are installed on the pendant terminals that are constantly connected to the system. The requirement for gray-colored stop switch, for instance, is expected to be an important factor in the future pendant applications [2-4].

Table 2 shows the examples of 3-position enabling switches [9-12]. Achieving the high level of usability to suit each application of pendant terminals is extremely important, and many different types of 3-position enabling switches have been developed to suit actual applications. The required usability includes several factors such as the ease of holding and pressing the switch, ease of maintaining the

switch in position 2, suitable design for operating fingers, and required operation load. Since many types of pendant terminals have been developed, special attention must be paid to the achievement of excellent ergonomic design of 3-position enabling switches [9-12].

The above components and pendant terminals have widely been utilized in universal industrial applications. The combination of safety components, which have been developed reflecting the intensive ergonomic research, provides pendant terminals that achieve the inherent safety of machinery.

Conclusion

This paper reported the evolutional improvement in pendant terminals and the necessity of the next-generation pendant terminals from the viewpoints of safety, ergonomics, and usability. Even in highly advanced and automated production systems, humans still operate machines directly in many environments, thus the usage of such devices has dramatically increased in recent years. The features and functions of safety components on the pendant terminals have also progressed, in the reflection of advancing standards and the demands from the industry to achieve high level of safety. To achieve the inherent safety of machinery, we will further commit ourselves to the research and development on the ergonomics and usability of pendant terminals.

References

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