Proposal for “Anshin Stop Switch” based on behavior analysis

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ABSTRACT

In the current, generally accepted machine safety, safety is ensured by reducing the risk to an acceptable risk level in the three-step risk reduction process, from the first step of ensuring intrinsic safety to the second step of safety protection by machines. On the other hand, the third step, ensuring safety by machine users, is dependent on uncertain human behavior, and therefore, in principle, it should only be used after the risk has been reduced below the acceptable risk level. In contrast, the concept of human-machine collaborative safety has been newly proposed in recent years, whereby safety is further ensured when humans and machines work together and cooperate with each other by having humans take safer actions. In addition, various studies have begun to consider the possibility of using information technology, AI, and sensors to promote safe human behavior as an effective way to achieve this.
In this paper, we discuss the possibility of human-machine collaborative safety using an emergency stop switch that stops a robot when a human recognizes an abnormality. As a comparison, in the case of the conventional power-off type emergency stop switch based on machine safety, even if danger is avoided by pressing the switch, it generally takes time to restart the robot system after stopping and shutting off the power, and as a result, the operator tends to hesitate to press the emergency stop switch. On the other hand, if there is a function that allows the robot to pause its operation while energized, workers would press the switch without hesitation, which would promote the use of the pause function and ensure greater safety. In this paper, we define an emergency stop function that takes into account the principles of human behavior as an "Anshin Stop Switch," and propose it as an example of human-machine collaborative safety.
The definition of the safety function of the "Anshin Stop Switch" should satisfy the following three points.

(i) A stop function for safety to be used in a human-in-the-loop.
(ii) A device that lowers the psychological and physical hurdles to use.
(iii) It shall be designed to minimize deviation from normal operation based on the assumption of frequent use.

In order to confirm this, we conducted a questionnaire survey of workers in a robot restaurant that is actually in operation. Specifically, when a worker presses the power-off emergency stop switch or the "Anshin Stop Switch" equipped with a function to temporarily stop the robot while it is energized when he or she recognizes an abnormality, the effect of each on danger avoidance and the effect on his or her future behavior were confirmed. The results were modelled and analysed together with our proposed "Safety Behavior Design Diagram" based on “Applied Behavior Analysis”. As a result, we were able to confirm the basic effects of the "Anshin Stop Switch".

1 INTRODUCTION

Conventional machine safety has been based on the principle that safety is ensured by machines alone and does not depend on uncertain human actions. On the other hand, the concept of human-machine collaborative safety has been proposed in recent years, and discussions have begun on the possibility of further ensuring safety when humans and machines work together and cooperate by having humans take safer actions, and on the possible realization of such methods using information technology, AI, sensors, etc. [1].
In the case of conventional power-off emergency stop switches based on machine safety, which are considered in this study, restarting the switch after it has stopped is generally time-consuming, and people tend to hesitate to press the switch. On the other hand, if there is a function that allows a temporary stop while the power is still on, people will press the switch without hesitation, promoting the use of the temporary stop function and ensuring greater safety. In this paper, we define a stop function that takes into account the principle of human behavior as a "Anshin Stop Switch," and propose it as an example of human-machine collaborative safety.

2 HUMAN-MACHINE COLLABORATIVE SAFETY

2.1 Conventional safety of machinery

According to international standards, safety of industrial robots and service robots is reduced in three steps based on the principles of safety of machinery in accordance with ISO 12100. Specifically, step 1 is "intrinsic safety" to eliminate the source of danger, step 2 is "safety protection" by various safety devices, etc., and step 3 is "information on use" by the user.

Here, emergency stop switches installed in dangerous machines and robots are described in IEC 60204-1 "Safety of machinery - Electrical equipment of machines - Part 1: General requirements" and ISO 13850 "Safety of machinery - Emergency stop functions - Design principles". Safety of machinery - Emergency stop functions - Design principles" and ISO 13850 "Safety of machinery - Emergency stop functions - Design principles" specify design and implementation methods for stop functions and power disconnection. Here, the emergency stop switch is considered to be a safety device but is positioned in the information for use in Step 3 because it stops when a person presses the button and safety is ensured, making it a little special. In addition, since the emergency stop switch is a safety function installed in a machine, it is not intended to be carried by a person and operated remotely, as the proposed “Anshin Stop Switch” is, and it is not necessarily easy to use for a robot that moves or operates in a wide range of areas.

2.2 Collaboration between human and machine

For the emergency stop, it is assumed that the risk has been reduced to an acceptable risk level and safety has been ensured by measures up to the second step before this function is required. In addition, since the safety function includes an element of inappropriate human behavior to ensure its operation, making it a so-called human-in-the-loop, there has not been much discussion on what kind of specifications from the human point of view should be used to make the system safer, as in the case of the “Anshin Stop Switch”. In contrast, the recent rapid progress of information technology has made it possible to develop a new type of safety system.

In contrast, in recent years, human-machine collaborative safety, in which people and machines share a space and work together for the same purpose, utilizing information technology, generative AI, and various safety sensors, which have made remarkable progress, has attracted attention [2]. In such cases, human-in-the-loop is a common structure in human-machine coordination, and how to achieve safe human behavior in the design of the system thereby has become a major issue, and one method is “Applied Behavior Analysis” studies.

2.3 Safety based on behavior analysis

Behavior analysis studies have shown that the mere presentation of "information on use" and general safety education and training, which have been required in the machine safety framework to date, are not sufficient, and that in order for people to behave correctly and safely and not engage in unsafe behavior, the environment as a antecedent stimulus and the accompanying behavior when people actually act are important to control. control the environment that serves as the antecedent stimulus, as well as the concomitant nature of a person's actual behavior. In the emergency stop function, which is the subject of this paper, if it is safe to stop, it means that it is important to design the environment, equipment settings, and systems that promote greater use of the stop function and ensure that stopping the system does not cause disadvantages to users. This is what we propose in this “Anshin Stop Switch”.

3 PROPSAL FOR “ANSHIN STOP SWITCH”

3.1 Definition of “Anshin Stop Switch”

The concept of the “Anshin Stop Switch” is a safety function that users can use with confidence, that they will want to use frequently, and that they can use at any time. The functional specifications for this are not only that the switch has a shape that is easy to push and easy to handle, but also that the system will pause (stop category 2) for reasons that will be described later, and that the user can carry the switch and press it remotely at any time. It is also important to design the system so that it can be easily restored after a stop and immediately return to normal operation. In summary, the definition of safety functions of the “Anshin Stop Switch” should satisfy the following three points.

(i) A stop function for safety to be used in a human-in-the-loop

(ii) A device that lowers the psychological and physical hurdles to use.

(iii) It shall be designed to minimize deviation from normal operation based on the assumption of frequent use. In addition, it is also important to verify through experiments, based on behavior analysis, whether the design and implementation of a system that meets these requirements actually promotes the safe behavior of using the stop function and whether it changes behavior.

3.2 Problems of conventional safety switches

Looking back at the case of pressing a conventional emergency stop switch as a comparison for the proposed “Anshin Stop Switch”, for example, in the case of stop category 0, the power supply is immediately cut off, and without an electromagnetic brake, the robot may move unintentionally due to its own weight or inertia, causing property damage due to interference with surrounding objects. Even in stop category 1, safety is the highest priority, and the robot only stops as fast as possible without going off track, and no other conveniences are considered. As a result, even if safety is ensured by pressing the emergency stop switch, if the power supply is cut off, the entire system will be treated as an abnormal process, and it is certain that some time or property damage will be caused. Such actions that are detrimental to the user have a negative learning effect, and the user's behavior is inhibited. In other words, through experience, the user learns not to press the stop switch even if he/she senses danger, which is unsafe. Since this is based on actual experience, it cannot be solved by general safety education or learning.

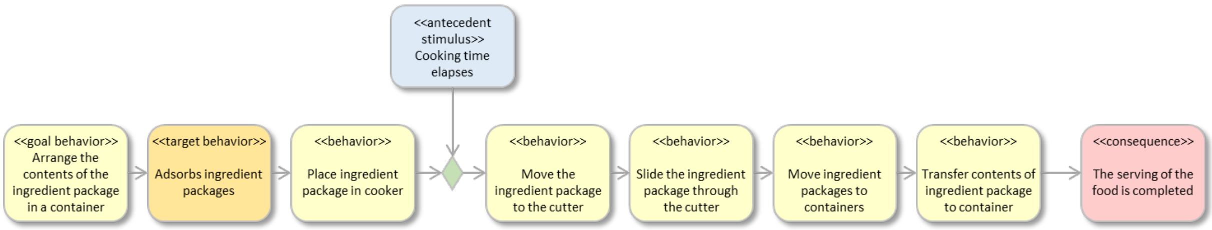

Figure 1. *Series of behavior chains that correctly transfer the contents of the ingredient package to the container by a robot*

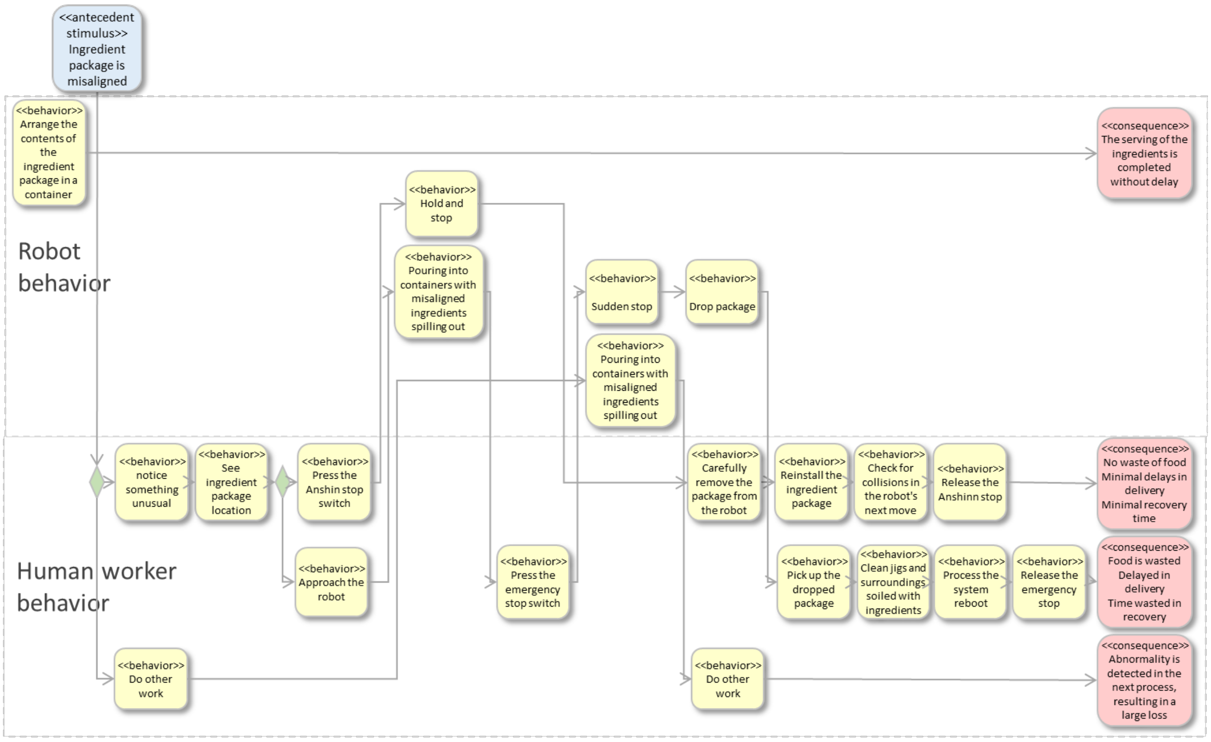

Figure 2. *Safety behavior design diagram related to the use of Anshin Stop Switch and emergency stop switch*

4 VERIFICATIONS OF “ANSHIN STOP SWITCH”

4.1 Verification of the effectiveness of the “Anshin Stop Switch”

The results of the actual use of the “Anshin Stop Switch” in the field were verified. The various robots (service robots operating in human coexistence areas and industrial robots operating in off-limits areas) that Kawasaki operates in the Future Lab Haneda [3] restaurant is equipped with “Anshin Stop Switch” designed according to the aforementioned definition and the operators are initially properly trained based on the risk assessment and the safety management [4,5]. In addition, an emergency stop switch in accordance with conventional machine safety based on the results of risk assessment is also implemented. This makes it possible to collect and compare the experiences and results of the emergency stop switch and the “Anshin Stop Switch” when either one or both of them are used by the operational staff of several restaurants that use the robots, through questionnaires or other means.
The results of the two individuals were collected in this study, and the results of those actions are illustrated using the Safe Behavior Design Diagram shown in Figure 1 and 2.
The top row of the figure 2 shows the prior stimuli of behavior analytics. The bottom row also describes the behavior of the operational staff, with cases at branches, and the subsequent behavior is described in parallel. If the staff does not notice that the package of ingredients handled by the cooking robot is out of alignment, the robot will spill the ingredients, resulting in a big loss.
On the other hand, when an emergency stop is applied after noticing the misalignment, the worker must rush to the location of the emergency stop switch and press the button, and the robot's sudden stop is equally damaging. If the operator has such an experience, the next time he encounters a similar situation, he will try to find a way to deal with it without pressing the emergency stop. Also, if it is not clear whether the package is out of alignment or not, the operator is likely to make a decision not to stop until it is clear that the package is indeed out of alignment and will cause damage if it is left in place.
In the case of pressing the proposed “Anshin Stop Switch”, the system can be paused remotely, allowing the operator to stop it immediately and check the situation at ease. Even if there is an actual misalignment, it can be handled (it is designed in such a way) without fear of dropping the ingredients while the machine is paused, so there is no waste of ingredients. Thus, by pressing the reassuring stop switch, only good results are obtained, and the system learns to press the switch immediately the next time something happens.

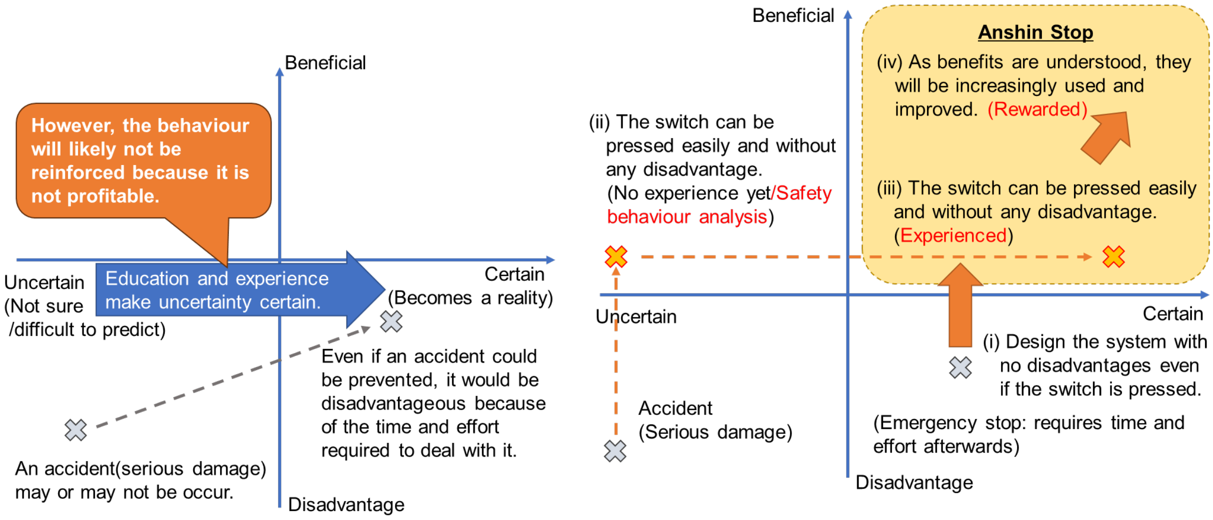

Figure 3. Model of the effect of “Anshin Stop Switch”(right) and emergency stop switch(left).

4.2 Modelling of the impact of using the “Anshin Stop Switch”

The effect of the “Anshin Stop Switch”, as described thus far and confirmed by the questionnaire, and its comparison with the emergency stop switch, is modelled and shown in Figure 3. The figure is divided into four quadrants, with the left quadrant representing uncertainty and the right quadrant representing certainty for the user. The upper quadrant represents a benefit and the lower quadrant represents a detriment.
Here, the occurrence of an accident is in the lower quadrant because it is a major negative, but in reality, such a situation does not occur very often, so it is uncertain and is located in the lower left quadrant, the third quadrant of the figure. If the emergency stop switch is pressed here, even if the accident is avoided, there will still be a detrimental result. Therefore, we are in the fourth quadrant because there is definitely a disadvantage. In this case, neither education nor experience will lead to a change in behavior to use it. Furthermore, the risk increases when users do not press the emergency stop switch.

On the other hand, safe stops are designed and implemented so that there is minimal or almost no operational or property damage. If the user has never pressed it, there is uncertainty and it will be located in the first quadrant, but if there are positive results from actually having the user press the safety stop, it will encourage a change in behavior to press it more frequently (second quadrant). This will avoid the danger of not pushing and further increase the safety of the operation.

5 CONCLUSIONS

We defined and proposed the "Anshin Stop Switch" as an example of human-machine collaborative safety. We also conducted a questionnaire survey to confirm whether the switch was effective in the situations in which it was actually used. We would like to collect more data in the future, and to elaborate on the specifications of the "Anshin Stop Switch".

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