Warning System and Storing Method of Perilous environment for a Teleoperated Robot Operator

Hitoshi Kono
The University of Tokyo
Department of Precision Engineering
7-3-1 Hongo, Bunkyo-ku, Tokyo
JAPAN
kono@robot.t.u-tokyo.ac.jp

Abstract: - This study provides a description of the warning system for the operation of a teleoperated mobile rescue robot and the storing method of perilous environmental information when the operator experiences mistakes. Teleoperated robot systems were recently deployed in disaster-stricken areas. In situations involving mistakes, it is important to utilize failed operational information when the operator undergoes training related to teleoperation skills. In this study, a storing and warning method of perilous environment is proposed. Further, it is confirmed that the proposed method can detect the perilousness of the current environment based on the previous perilous environment as measured from the training phase and indicates the same to the operator of the rescue robot.

Key–Words: - Support system of teleoperation; Teleoperated Robot; Rescue robot; Perilous environment

1 Introduction

Recently, various robot systems as opposed to human beings were deployed in disaster-stricken areas to gather information because gathering information in these regions is dangerous. Additionally, information gathering activity involves the possibility of secondary disaster risks [1, 2]. However, robot systems involve certain disadvantages such as disconnection of communication cables, tumbling, and robots becoming stuck. These failures could lead to the failure of a mission and to incomplete missions as well as to the inability to salvage robots involved in a mishap. Thus, the development of a robust robot system and improvements in operability are important issues to avoid the fore-mentioned problems. Several extant studies focused on the same [3, 4, 5] and involved requisite systems for teleoperation. Additionally, the decision making process of teleoperated robot behavior is controlled by a human operator. The operator considers numerous sources of information while controlling a robot. Therefore, teleoperation assisting technology using semi-autonomous control is important in determining the behavior of a robot based on a certain amount of information.

Teleoperation training systems [6, 7] and operator assisting systems [8, 9] were investigated by previous studies. However, it is difficult to anticipate problems and issues in real operation situations. Furthermore, when an operator obtains information from the rescue robot sensors, the operator experiences the disadvantage of processing information simultaneously. Conversely, a perfectly autonomous rescue robot is also subject to the probability of experiencing accidents and subsequently the risk of incomplete missions. Thus, the reliability of a perfectly autonomous rescue robot is below that of human teleoperation.

In response to this problem, in this study, a storage method for the perilous environment was proposed based on the operation failure experienced by the operator. Additionally, a warning system was proposed for the operator based on the stored perilous environment. A simplified overview of the proposed system is shown in Figure 1. Specifically, as per the concept of this study, if the operator experiences an operation mishap and failure, the operator sends a command to the robot via a teleoperation communication infrastructure to store environmental information with respect to the perilous environment using sensors (e.g., Laser range sensor) that are equipped on the robot. In an actual teleoperation situation, if a robot encounters a perilous environment, the robot reminds an operator of the same through a user interface. It should be noted that the proposed system did not form decisions independently, thereby differing from other approaches (e.g., [8, 9]). The robot's behavior was only determined by the operator. The study involved teleoperation assist research involving a semi-autonomous system.

The rest of this paper is organized as follows. Section 2 describes the proposed method. Section 3

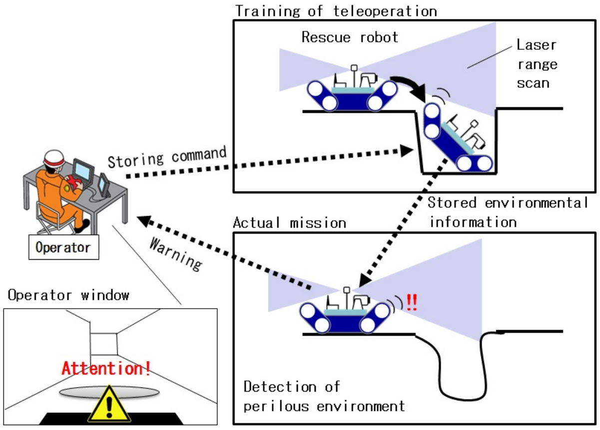

Figure 1: Simplified overview of proposed method

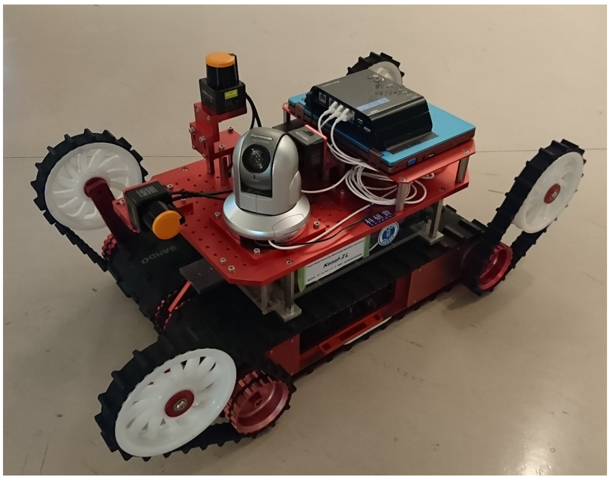

Figure 2: Rescue robot Kenaf–Ⅱ

provides details on the experimental condition and environment. Section 4 details the evaluation of the proposed method based on experimental results. Section 5 presents the concluding remarks.

2 Proposed Method

In this study, it is assumed that the teleoperated rescue robot corresponds to Kenaf–Ⅱ as shown in Figure 2. Kenaf–Ⅱ is developed for a disaster response. This corresponded to a prototype robot of the Quince robot that is deployed in the Fukushima-daiichi nuclear plant [10, 11]. The robot is a crawler type robot with four flippers that support climbing obstacles and steps. The robot can be controlled by a laptop computer with a joystick via a wireless LAN connection. In the study setup, this robot possesses a networked camera and a laser range sensor. The data of the laser range sensor is obtained from a laptop computer equipped on the robot using ROS (Robot operating system).

Figure 1 indicates the proposed method and the flow, and the flow is described as follows:

1) In the training phase of the teleoperation of the robot, the operator controls the robot with a trial-and-error approach.
2) If the operator makes mistakes during the operation or encounters a perilous environment as shown in Figure 1, then the operator sends a storing command to the robot via a wireless teleoperation communication infrastructure.
3) After the robot receives the storing command, the robot stores external environment information, such as the perilous environment encountered, using equipped sensors such as laser range sensor.
4) Subsequently, the robot continues to retain information related to the perilous environment.
5) In other situations involving actual teleoperations (and also including other training phases) in disaster sites, the operator repeats the teleoperation with respect to the perilous environment, and the robot detects the same prior to reaching the perilous environment.
6) Simultaneously with the detection of the perilous environment, the robot also sends a warning signal to the operator's user interface, and the user interface indicates marks or messages in the teleoperation window.

The aim of this method includes avoiding failure and missed operations as well as accelerating improvements in the teleoperation skill of operators utilizing experiences.

2.1 Storing of Perilous Environment

In this study, the distance information between the robot and artifacts in the indoor environment is adopted as perilous environment information. For example, with respect to the distance between the robot and wall and the ceiling, the distance information is measured by adopting the laser range sensor (Laser range finder: LRF) that is equipped on the robot body. The data from the LRF corresponds to S, and it is defined as follows:

$$S = (s_1, s_2, \cdots, s_n), \tag{1}$$

Where each s_n denotes a distance data of the LRF, and S of the perilous environment is described as S_p. S_p is defined as follows:

$$S_p = (s^p_1, s^p_2, \cdots, s^p_n). \tag{2}$$

As mentioned above, if the robot encounters a perilous environment as judged by the operator, then the operator sends commands to the robot to store the S_p via the teleoperation communication infrastructure.

The data from the LRF is a large number that resembles a point cloud. Hence, the computing system involves high computing cost to process all the LRF data. Additionally, if all the LRF data is stored as an environmental feature, then the stored data is over fitted to the environment, and it is difficult to utilize. Conversely, detection of the perilous environment based on stored data is difficult if the environmental features consist of few LRF data points. That is, there is a tradeoff between the number of data points that correspond to the environmental feature and the performance of LRF data and perilous environment.

2.2 Detection of Perilous Environment

Following the storage of information related to the perilous environment S_p, it is necessary for the robot to detect the perilous environment prior to encountering the same because S_p explains the perilous environment and it is necessary for the robot to avoid the perilous environment. Wherein, the calculation of potential field is adopted for the estimation method of approaching the perilous environment [13, 12]. The current measured data of the environment by the robot S_c is defined as follows:

$$S_c = (s_1^c, s_2^c, \cdots, s_n^c), \tag{3}$$

and the potential field between S_c and S_p based on euclidean distance is defined as follows:

$$U(S_c, S_p) = w \cdot \exp\Big\{-\frac{d^2(S_c, S_p)}{\sigma^2}\Big\}. \tag{4}$$

Here, w denotes the weight parameter of the potential. σ denotes the controlling parameter of potential spread. $d^2(\cdot)$ denotes the euclidean square distance between S_c and S_p, and it is defined as follows:

$$d^2(S_c, S_p) = \sum_i (s_i^c - s_i^p)^2. \tag{5}$$

Equation (4) indicates an increase in the risk of approaching the perilous environment by calculating the potential between S_c and S_p. With respect to the implementation, Equation (4) is always calculated and indicated to the operator.

2.3 Attention Distance from Perilous Environment

Prior to the collision of a robot with the perilous environment, it is necessary to define the evaluation indicator as a deadline for detecting the approaching of the perilous environment. The distance D_a from the perilous environment is proposed as the distance that must be detected prior to encountering the perilous environment, and it is defined as follows:

$$D_a = 2T_d \cdot V_r \cdot F_s, \tag{6}$$

Here, T_d denotes the time delay in communication, and the unit corresponds to [s]. V_r denotes the maximum moving velocity of the robot, and unit corresponds to [m/s]. F_s denotes the safety factor.

Equation (6) considers a communication delay that includes the commands sent from the operator and the information sent from the robot. Normally, time delay is involved in the communication environment. It is necessary to consider the time delay for the teleoperation flow as follows:

1) The robot observes and measures the environmental information (e.g., camera image and LRF data).
2) The observed and measured data is transmitted to the operator via the communication infrastructure.
3) The operator determines the next action based on the received data and sends a command to the robot.
4) After receiving a command from the operator, the robot executes the action that corresponds to the command.

A time delay exists between each of the above processes. Equation (6) considered only the time delay with respect to the communication because it corresponds to the longest delay. The time of decision of the operator is not considered in this system. According to Equation (6), it is possible to account for the distance from the perilous environment due to the communication delay that prevents the detection of the perilous environment.

3 Experiment with Simplified Environment

An experiment is performed using the actual rescue robot system to confirm the increasing value of potential when the robot moves near the perilous environment. Additionally, the experiment is performed in

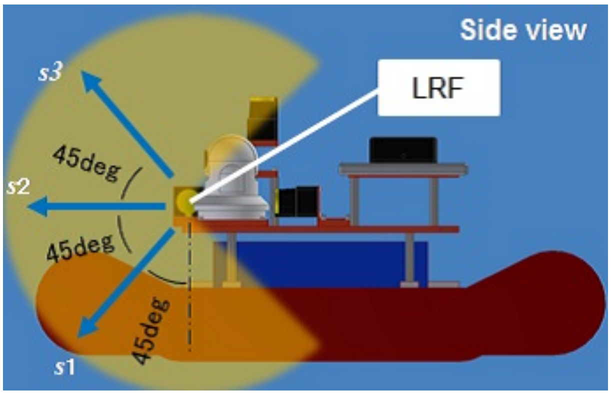

Figure 3: Scanning range of a LRF (side view)

two similar environments including the perilous environment. Thus, it is confirmed that the proposed system presents an “attention” warning to the operator when the robot encounters environments similar to the perilous environment as well as environments that are slightly different from the perilous environment. The environmental setup and experimental conditions adopted are detailed in the next section.

3.1 Environment and setup

As mentioned above, the robot shown in Figure 2 is adopted in this experiment. This robot includes the UST-10LX as LRF that is manufactured by HOKUYO AUTOMATIC CO., LTD., and it is implemented at a height of 250 mm from the ground. The UST-10LX can measure ambient distance information within a maximum range of 270 deg. The scan step of UST-10LX corresponds to 0.25 deg. The robot can obtain 1080 data points from the UST-10LX. In the experiment, an LRF is used on the robot, and three data points corresponding to distance information are used as shown in Figure 3 to decrease the number of data points.

Maximum velocity of the robot is set as 1 m/s, and therefore, the V_r of Equation (6) is set as 1. The communication delay of the transmission of camera image approximately corresponds to 0.5 s, T_d is set as 0.5, and F_s is set as 1.2. Therefore, in this setup, D_a is calculated as 1.2.

The robot is deployed in the indoor environment as shown in Figure 4. In the basic environment, it consists of a flat surface floor and a vertical wall that is constructed in the front of the robot.

In the initial state of the experiment, the robot is set 2 m away from the wall as shown in Figure 4. The robot is teleoperated by an operator via a wireless LAN connection, and the operator can manually send the command that stores the perilous information on the robot. If the robot receives a command that corresponds to storing the perilous environment, then the sensor data from the LRF is stored in the laptop computer attached to the robot. The computation of Equation (4) and (6) is also executed on the laptop computer attached to the robot.

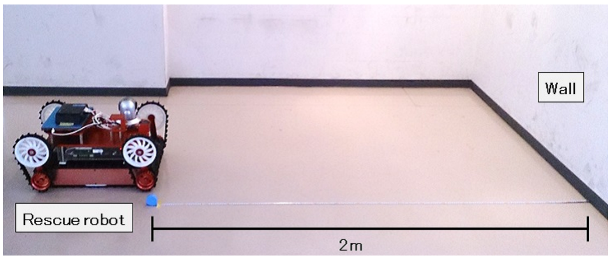

Figure 4: Example of the environmental setup

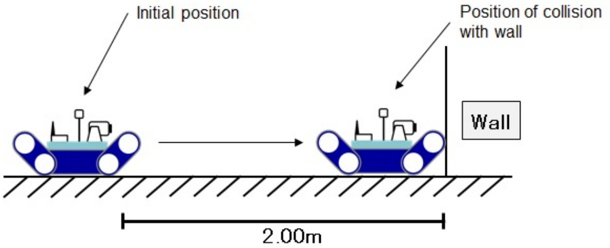

Figure 5: Initial position of the robot and storing position of the perilous environment.

3.2 Storing Information of Perilous Environment

In the experiment, three sensor data (distance) points are used to store the perilous environment as shown in Figure 3. Based on Figure 3, the perilous environment S_p is re-defined as follows:

$$S_p = (s_1^p, s_2^p, s_3^p). \tag{7}$$

Similarly, S_c is re-defined as follows:

$$S_c = (s_1^c, s_2^c, s_3^c). \tag{8}$$

As mentioned above, the initial state of the robot is shown in Figure 4. In the experiment, it is considered that the perilous environment collides with the wall. Hence, at the beginning of the experiment, the operator operates the robot that moves to collide with the wall as shown in Figure 5. The robot reaches the wall, and the operator sends the signal to the robot to store the sensor data as corresponding to the perilous environment.

After the storing the perilous environment, three different environment related tasks are performed to detect the perilous environment. First, in order to detect the perilous environment, the robot calculates Equation (4) and w in Equation (4) is set as 1.

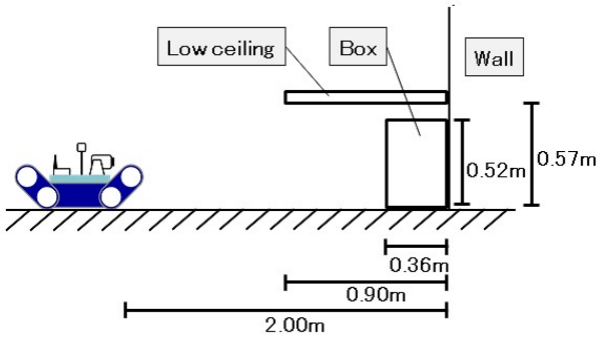

Figure 6: Placement of the obstacle in the experimental environment.

3.3 Condition 1: Wall

Second, in order to confirm the estimation of the perilous environment, the experimental condition uses only the wall in the environment as shown in Figure 6. This experimental condition is termed as *Condition 1*. Condition 1 corresponds to the same environmental state as the stored perilous environment.

As per the aim of this experiment specified in condition 1, it is confirmed that the robot estimates the approaching perilous environment using the stored environment information.

3.4 Condition 2: Wall and Box

In this condition, the environment consisted of the *Wall* and a *Box*, and this is termed as *Condition 2*. This is similar to the environment in condition 1 and the perilous environment. The box is placed in the position nearest to the wall with the placement corresponding to the front direction from the robot as shown in Figure 6. The condition is simulated such that obstacles existed in the environment that changes from the perilous environment experienced in the past.

As per the aim of this experiment specified in condition 2, it is confirmed that that the proposed system estimates the approaching perilous environment using an environment similar to the perilous environment.

3.5 Condition 3: Wall and Low Ceiling

In this condition, the environment consists of the *Low ceiling* and *Wall*, and this is termed as *Condition3*. This is also an environment similar to that in condition 1 and the perilous environment. The low ceiling is realized by the table that is placed in the position nearest to the wall and the upper side of the robot. This condition simulates a situation where an obstacle is encountered or a material (e.g., ceiling of indoors) falls and changes the environment from the perilous environment experienced in the past.

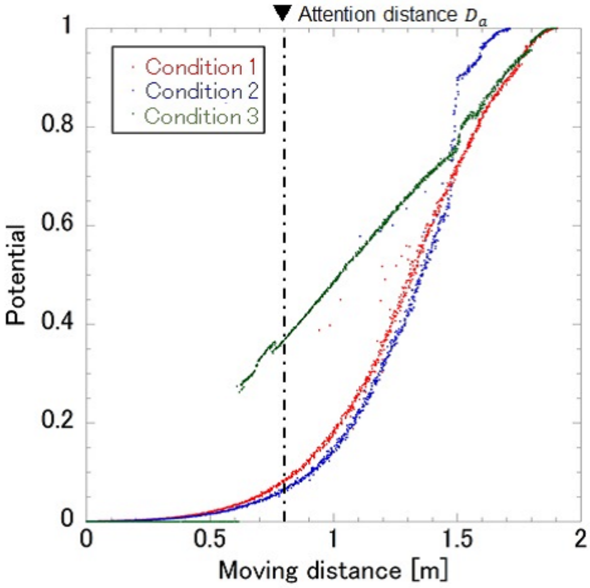

Figure 7: Change in potentials

As per the aim of this experiment specified in condition 3, it is confirmed that that the proposed system estimates the approaching perilous environment using an environment similar to the perilous environment that is different from that in condition 2.

4 Results and Discussion

4.1 Value of Potentials

Figure 7 shows the results for the change in potentials in each experimental conditions. Condition 1 and condition 2 in the Figure 7 shows the increase in the potential value in the form of a Gaussian distribution as the wall approaches. Conversely, the change in the potentials of condition 3 increases at the moving distance corresponding to 0.6 m. The change in potentials of all the conditions increases prior to the attention distance corresponding to D_a. Therefore, the robot can estimate the approaching perilous environment prior to when the robot enters the area that involves the possibility of encountering a perilous environment. This implies that the robot warns the operator of the potential value of encountering a perilous environment prior to colliding with the wall even in a teleoperation environment in which the operation command from the operator is delayed by the communication delay and transmitted to the robot. Thus, it is suggested that it is possible to sufficiently avoid the perilous environment even if the operator sends a stop command to the rescue robot.

As a result of condition 2 and condition 3, the change in potentials indicates the same increase to the high value. The transition of S_c is indicated in the next section to discuss this phenomenon.

4.2 Change in Measured LRF Data

Figure 8 to Figure 10 shows the results for the change in the measured data form the LRF and the potential value that was calculated by Equation (4. In these figures, *position of collision with wall* denotes the S_p.

As shown in Figure 8 and Figure 9, s_1^c is nearly unchanged until immediately prior to when the S_c experiences a close encounter to S_p. Following the small changes in s_2^c and s_3^c, s_1^c decreased rapidly. The main cause of this phenomenon is that the value of s_1^c corresponds to the distance between sensor and flour surface, and the s_1^c exhibited a constant value until robot approached the wall. Only in condition 2, the potentials of 7 exhibited an increase near the wall. However, it is difficult to observe this phenomenon in Figure 9. This implies that the LRF measured the distance to the box, and three data points of the S_c

Conversely, as shown in Figure 10, s_3^c decreased to an extreme row from the start position in an early stage. Following the decrease in the s_3^c value, the behavior of the change in S_c is similar to condition 1 and condition 2. The main cause of the extreme changing in s_3^c is attributed to the low ceiling. Additionally, s_1^c and s_2^c correspond to the same condition as condition 1 and condition 2. The sensor of the robot measured the distance to the ceiling height using s_3^c immediately prior to entering under the low ceiling. Therefore, the S_c value experienced a sudden change, and this phenomenon also exhibited a change in the potential in condition 3.

Hence, the change in S_c can explain approaching the wall of the robot. Additionally, the proposed method confirmed that the robot remained in the state of approaching the perilous environment with respect to the operator.

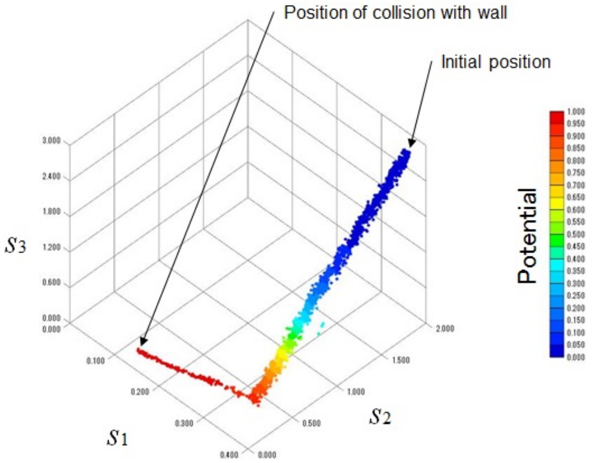

Figure 8: Change in distance data of S_c in condition 1

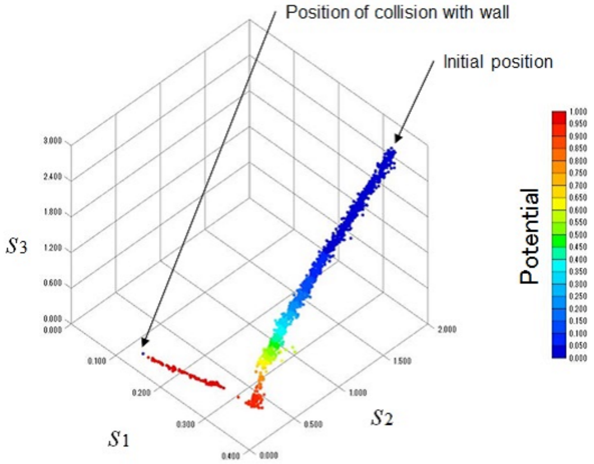

Figure 9: Change in distance data of S_c in condition 2

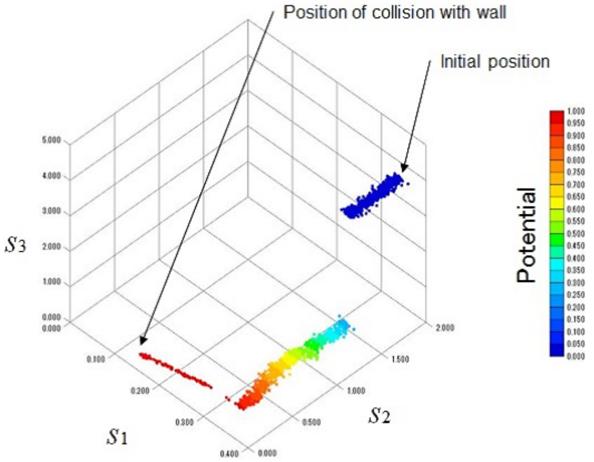

Figure 10: Change in distance data of S_c in condition 3

5 Conclusion

This study involved proposing a storage and estimation method of the perilous environment and the concept of a warning system to inform the operator of a teleoperated robot based on prior operation failures experienced by the operator. Additionally, basic experiments were performed under three conditions, namely a condition consisting of an environment similar to and two environments similar to the perilous environment to confirm that the proposed system can estimate the approaching perilous environment. The experimental results suggested that the proposed system could estimate the approaching perilous environment using the three distance data points that were measured form LRF based on stored environmental data corresponding to the perilous environment.

Future research will involve confirming the number of data points denoting the distance from the LRF to the express perilous environment. Furthermore, the rescue robot Kenaf–II involves three LRF, and it is possible for this robot to obtain more distance data points. Additionally, future work will involve demonstrating the effectiveness of the proposed method in the other situations (e.g., irregular terrain and a pitfall).

Moreover, it is necessary to discuss the methodology of the warning system on the user interface of robot operator to realize the proposed method with respect to an actual operation system.

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