

Teleoperation System for Quadruped Robots with HAM – Support Functions to Reduce Misrecognition –

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Abstract: Human Adaptive Mechatronics (HAM), which is a system concept to adapt human characteristics, has been proposed. As the HAM application, this paper addresses an information emphasis scheme to alert some hazards which are undetectable by a human operator. The emphasis scheme employs cognitive psychological approach to human discrimination characteristics because excess or deficient emphasis may disturb the operation. One of advantages of teleoperation system is able to include human valuable abilities as global environment recognition, planning, prediction and so on. To implement these abilities to mechanical system is difficult because of not enough intelligence. Proposed teleoperation system is designed to progress the human abilities, and moreover, to not disturb the abilities. In this paper, we consider that the discrimination characteristics depend on window positions on GUI display and operator’s individuality. Finally, the efficiency of the alert scheme is verified by some experiments.

Keywords: teleoperation, console design, cognitive psychology

1. Introduction

The purpose of this research is to realize teleoperation system for multiple mobile robots as shown in Fig. 1. This paper addresses an alert scheme to operator in the teleoperation system. The scheme employs cognitive psychological approach in order to adapt human characteristic variations and individuality. In this research, we especially focus on a sensitivity of displayed information for suitable emphasis.

Researches on human-machine interactions include interdisciplinary problems. ISO13407, titled “Human-Centered Design Processes for Interactive Systems”, was established in 1999[1]. The standard introduces a concept of usability, that is, interfaces should be easy to understand and have maneuverability. Therefore, interdisciplinary collaboration, especially engineering and human science, is necessary to achieve human-machine interaction with usability. However, the standard didn’t make mention that each human had variable operation characteristics and individuality.

Therefore, Human Adaptive Mechatronics: HAM, which is a system concept for mechanical systems which have adaptive functions to human being, has been proposed[2]. The HAM system should be considered not only mechanical system control but also human characteristics with the potential of variety. Humans are complicated because they may adapt to the situation with some learning process, in other words, human characteristics are not constant. However, if a system evaluated human characteristics and adapt them with the HAM concept, high efficiency and/or safety operation results would be expected.

We attempt, with the HAM concept, to improve the potential problems of teleoperation system, that is, not enough quality and quantity of feedback information. The problems may bring about misrecognitions, e.g. obstacle collision in

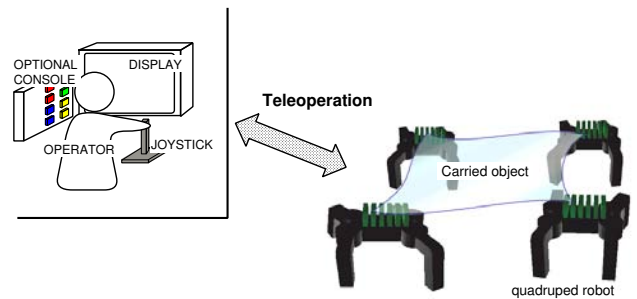


Fig. 1. Teleoperation system for multiple mobile robots

blind corner. Although a lot of master-slave type teleoperation scheme with transparency were proposed[4], such kind of misrecognitions would not occurred frequently because a workspace of the slave robot is limited.

In mobile robot teleoperation, specially in unknown environment, the limited information may disturb the human valuable abilities by misrecognitions. To reduce these mistakes, some researchers have been studied on GUI which includes functions to emphasize important information[5].

However, most of them did not note the varying operators characteristics includes individuality. In other words, the required information by operators, especially in complicated task, is not constant. For instance, a beginner for the robot operation may be confused by too much information and be easy to cause some mistakes. The other way, enough information for the expert operator brings about higher performance than autonomous locomotion of the robots. How information is required and effective for the operator should be considered in order to realize human adaptive system.

In this paper, we focus on collision avoidance between an operated robot and obstacles because the collision is easy to occur in blind side of a robot camera view. The robot of our teleoperation system installed a range finder can also

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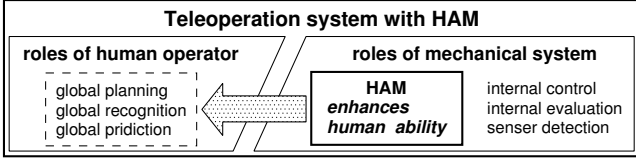


Fig. 2. Roles of operator and mechanical system in proposed teleoperation system

detect the surrounding obstacle information in blind side of the camera view. If the robot made the operator take notice of a risk of collision, the operator could avoid the collision. The purpose of our research is to realize a human adaptive robot teleoperation system with the HAM concept. Therefore, we discuss a suitable scheme for information emphasis depends on human sensitivity with cognitive psychological approach. Then, efficiency of the scheme is experimented and verified.

2. Teleoperation System for Mobile Robot

2.1. Teleoperation system

One of advantages of a teleoperation is able to include valuable human abilities which are global recognition, planning, prediction, and so on. To implement these abilities to an autonomous robot is difficult because of not enough intelligence and experience. Whereas, to obtain internal condition of the robots (e.g. motor condition, joint angles, etc.) by human operator is impossible.

In our teleoperation system, roles of human operator and robots are divided to improve aforementioned exclusive relationship as shown Fig. 2. In other words, a human operator takes a major role in global recognition, planing, and prediction, then the robots concentrate internal control, evaluation of internal condition as the robot posture and detected sensor information. Furthermore, effective cooperation between humans and robots is an important issue. Our approach is, therefore, to implement some support functions to progress the valuable human abilities without disturbing them.

One of potential problems of teleoperation system is that quality and quantity of feedback information to the operator are limited due to a communication constraints. Display functions to the operator, e.g. monitors, have limitations potentially. In our system, since the robot installed a range finder, the surrounding distance information, which the robot retains, is more than human obtained information. Fig. 3 indicates a concept of recognizable information range. The human adaptive support function, in this paper, is to discriminate the robot detectable hazard, which human cannot get, to human operator without disturb the human abilities.

2.2. Effective support function

Effective support functions are discussed here. There are possibilities to occur some troubles by overlooking some important information. To solve them, the some troubles should be discriminated to human operator previously. We focus on window size changing to take the operator notice the trouble on an alert level. Because width of operator

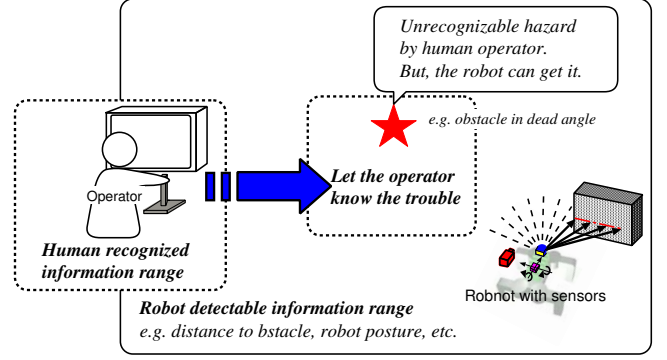


Fig. 3. Differences of recognizable region between an operator and robots.

display is limited, an efficient display size adjustment is required. Furthermore, excessive information emphasis turns out disturbances, in other words, the information operator already noticed does not need emphasis.

Therefore, we are interested in the minimum difference of window size to by a human operator and the difference can be adapted as the emphasis in a unit step of alert level. For such appropriate support, we apply the human characteristics of discrimination by psychological approach as follows.

3. Sensitivity Evaluation by Weber's Law

3.1. Weber's law

In cognitive psychological field, Weber introduced a ratio of a stimulation to the differential threshold was approximately constant, called Weber's law[6]. Where, the differential threshold is defined as minimum stimulation which the human can discriminate. According to Weber's law, the geometrical differential threshold on GUI, discriminated by a human operator, is determined by current geometrical information with a constant ratio. Therefore, the ratio W is defined as follows;

$$W = \frac{\Delta I}{I}, \quad (1)$$

where, ΔI and I denote the stimulation and the differential threshold, respectively. We represent $\Delta I = dI/dr$ with unit steps for discrimination r . The stimulation I can be display window size, joystick feedback force, alert sound and so on. Eq. (1) is therefore transformed as;

$$\frac{dI}{dr} = WI \quad (2)$$

$$I = e^{Wr+C_0} \quad (3)$$

$$C_0 := \log I_0, \quad (4)$$

where, I_0 denotes the initial stimulation and C_0 represents the constant for initialization. Teghtsoonian introduced the Weber's ratio for detection of line length difference W is 0.029[6] as shown in Fig. 4. In other words, humans can not detect the difference of line length less than about 3% on the current length, namely, that is not enough to emphasize the length information. He also said the ratio for force and loudness of sound are 0.143 and 0.048, respectively. The ratio is employed for information emphasis in our teleoperation GUI.

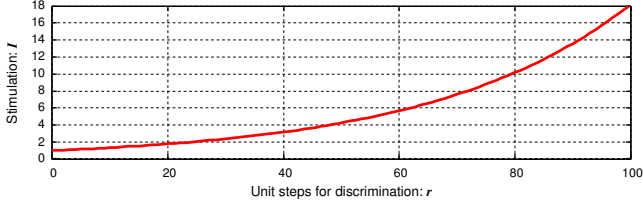


Fig. 4. Example of the stimulation I by unit step r in $W = 0.029$

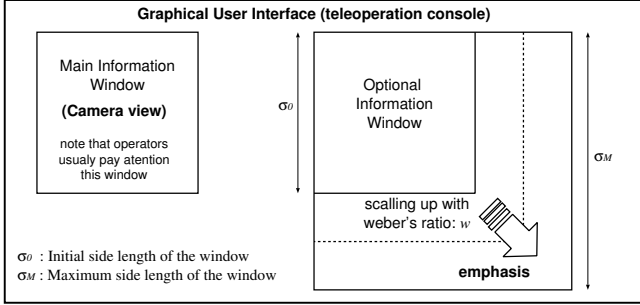


Fig. 5. Definitions of stimulation on GUI

4. Prior Experiments for Weber's ratio

We had two prior basic experiments. Motivations of the experiments are to measure the Weber's ratio on multiple windows display because teleoperation system has multiple information which operator should grasp. Furthermore, these information has different importance or criticality depended on circumstances. Consequently, information alert level to let the operator notice should be selected in compliance with the window position or circumstances.

In this paper, side length of squared information window σ is focused on as the emphasis stimulation (see Fig. 5). Our teleoperation GUI consists of camera viewing window, called main window, and some optional information windows. Although the optional windows, in usual, are not so important, they have possibility to include human undetectable important information. At that time, the window is emphasized to alert with scaling up.

An initial side length of the window is σ_0 and the maximum σ_M is defined due to GUI console size limitation. According to Eq. (4), the side length σ is as follows;

$$\sigma = e^{w_s r + \log \sigma_0}, \quad (5)$$

where, w_s denotes Weber's ratio for side length of the squared information window.

Note that the ratio w_s may not correspond to line length because the target is plane and also human operator should usually note the main camera view. The prior experiments to measure w_s are described in follows.

4.1. Weber's ratio with two information windows

First, the Weber's ratio for an optional information window is measured with a simple application as shown in Fig. ???. The application is consist of two windows, namely, the left one is main window corresponds to robot camera view, and the right is an optional window scales up at random. First, an initial size of the optional window σ_0 is selected randomly.

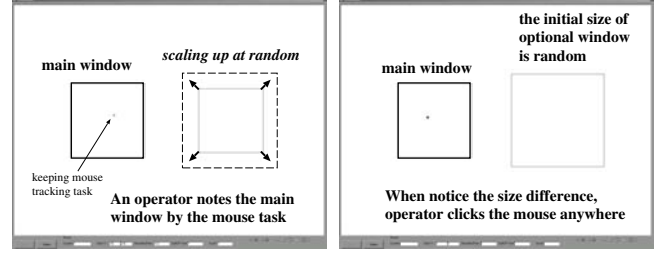


Fig. 6. Simple application for measure the Weber's ratio for optional window size

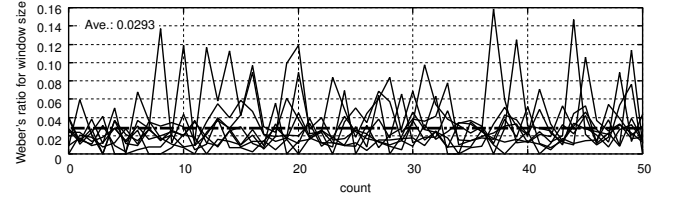


Fig. 7. Result of Weber's ratio measuring for optional window size

Subjects are instructed to do a mouse tracking task in main window to keep the subjects mind to the main window, and also to click the mouse when the operator discriminates a scale change of the optional window. The weber's ratio is determined with the optional window sizes at the clicked, σ_c , and the initial size σ_0 . The Weber's ratio in the first prior basic experiment w_s^p is;

$$w_s^p = \frac{\sigma_c - \sigma_0}{\sigma_0}. \quad (6)$$

Fig. 7 indicates the result of the experiment with eight subjects. Each subject carried out fifty trials and an average of the ratio is 0.0293. This is close to aforementioned the ratio for line length. The measured ratio, however, has wide variability of not only the trial but also individuality. This means the emphasized information determined by constant the ratio, even if it takes the average, is not appropriate for any operators.

4.2. Weber's ratio with four information windows

Secondly, the GUI with three optional windows is experimented (see Fig. 8). The instructions to a subject are almost same as the first experiment, namely, fifty trials with the mouse tracking task. However, only one optional window selected randomly for scaling up in a trial. Then, the operator should indicate the scale changed window.

The result of the experiment are shown in Fig. 9 and Fig. ??. The results indicate that the multiple optional window task brings about increasing the Weber's ratio. And, the position of the window influences the Weber's ratio. Especially, window 2 and window 3 have a pronounced tendency to increase the Weber's ratio. Also the results tends wide variability of the trial and individuality.

4.3. Discussions of the prior experiments

The Weber's ratio for the teleoperation GUI is discussed here. Above prior experiments indicate as follows.

- Many optional windows tend to increase the ratio and different each window.

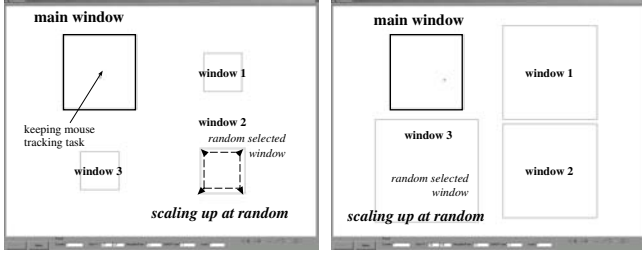


Fig. 8. Simple application for measure the Weber's ratio for optional window size (three optional windows)

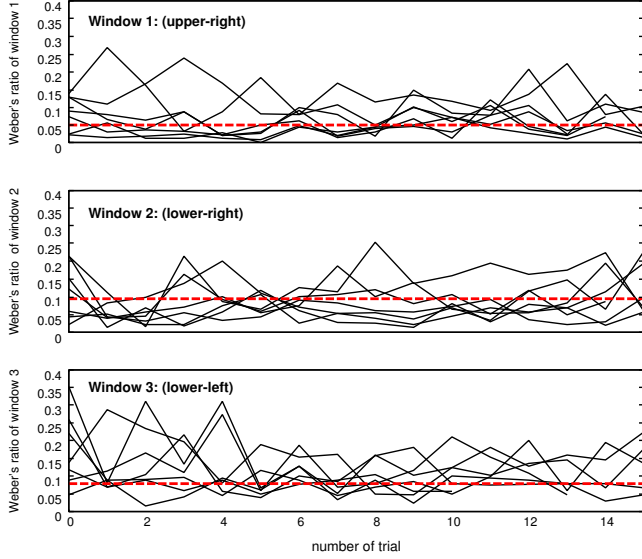


Fig. 9. Results of prior experiment 2: Weber's ratio w_s^λ for each window

- The ratio depends on the trial and individuality.

The first point is caused by limited human attention resource. Therefore, information should be hidden or increase the ratio to be excluded by human attention. According to second prior experiment, the window 2, which is the most far from main window, take the largest most Weber's ratio. Namely, unimportant information window moves to the point far from main window. In the future, disposition of multiple information windows with considering a joystick and sound information will be experimented (see Fig. 11). By the second point, the average of Weber's ratio is not appropriate the information emphasis. Consequently, we im-

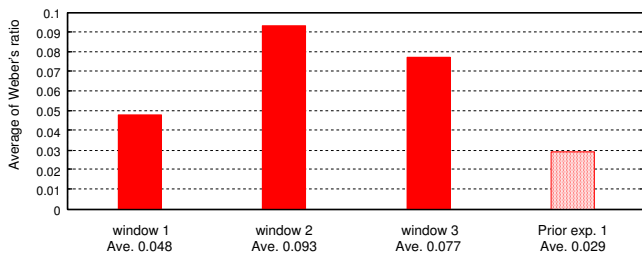


Fig. 10. Results of prior experiment 2: comparison of averages of w_s^{λ} for each window and prior experiment

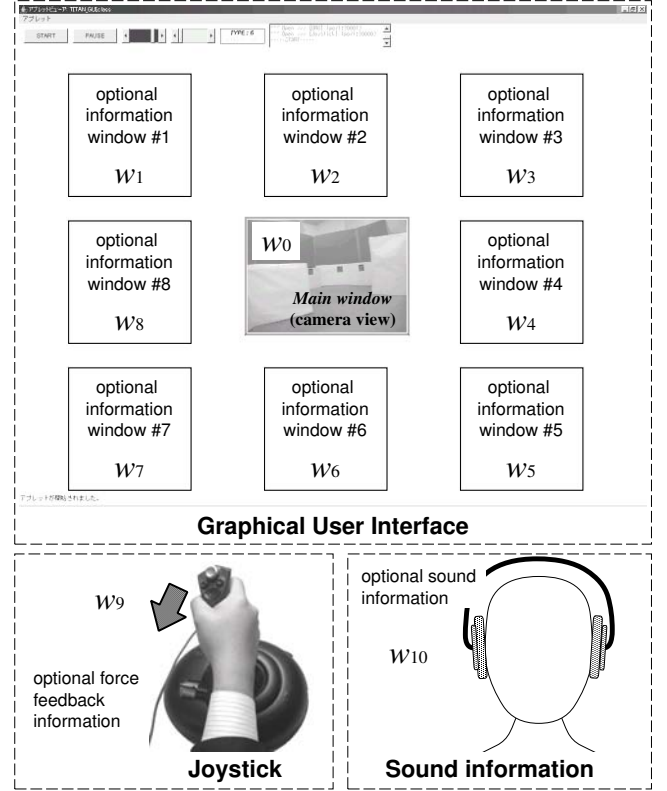


Fig. 11. Weber's ratio on each optional factor

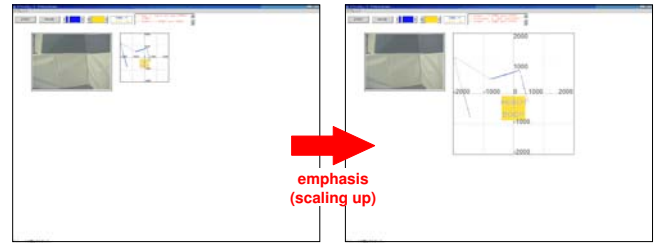


Fig. 12. View of GUI display for the teleoperation system

plement the heuristic adaptive technique with evaluation for a human discrimination. By this technique, the Weber's ratio, in other words, the ratio for emphasis information adapts for each operator. Finally, the Weber's ratio for the window is expected to be typical for the operator. The technique is described in next section.

5. Weber's ratio adjustment on an operator

Because the Weber's ratio w_p for the optional window is not constant and depends on individuality, adaptive scheme for operators with w_p is proposed. In this paper, the GUI consists of a camera view window and a surrounding distance information window as the optional as shown in Fig. 12. A purpose of the adaptation is to reduce the misrecognitions without disturbance of the human operation.

Since display size is limited, Weber's ratio saturated at discrete alert level λ is defined as follows;

$$w_p^{(\lambda)} = \frac{\log\left(\frac{\sigma_M}{\sigma_0}\right)}{\lambda} \quad \{\lambda|1, 2, \dots, 100\}. \quad (7)$$

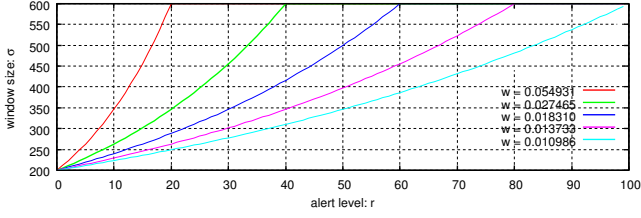


Fig. 13. Plots of optional window size by alert level r on each Weber's ratio

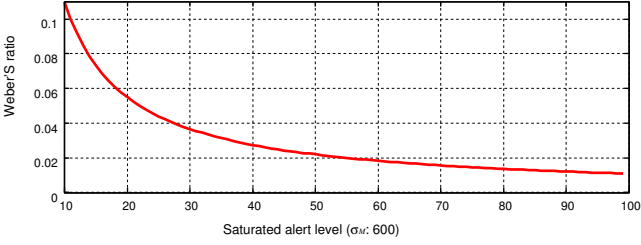


Fig. 14. Plots of Weber's ratio saturated the window size by alert level

Where, the λ corresponds to sensitivity level for the discrimination, and σ_M denotes maximum window size defined in Fig. 5. In this paper, the minimum window size $\sigma_0 = 200$, and the maximum $\sigma_M = 600$. The samples of $w_p^{(\lambda)}$ are shown in Fig. 13, and also $w_p^{(\lambda)}$ by saturated alert level is indicated in Fig. 14.

The alert level r in our teleoperation is discussed here. As shown in Fig. 15, if the minimum distance from obstacle is greater than d_0 , the emphasis functions does not carried out. Therefore, the alert level r , with actual minimum distance d sensed by range finder, is as follows;

$$r = \frac{d_0 - d}{\alpha} \quad \text{if } (d_0 > d), \quad (8)$$

where, α denotes a scaling factor the alert level and actual distance, in this paper, let $\alpha = 10$.

For adjusting the Weber's ratio for operator's characteristics and individuality, whether the operator discriminate the alert is evaluated. As indicated in Fig. 16, the nearest obstacle direction and human joystick input vector \mathbf{m} are detected. By an elevation angle of them ϕ and a magnitude of

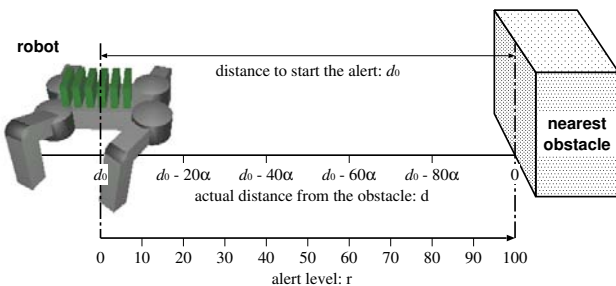


Fig. 15. The definitions for relation of alert level and distance from the nearest obstacle

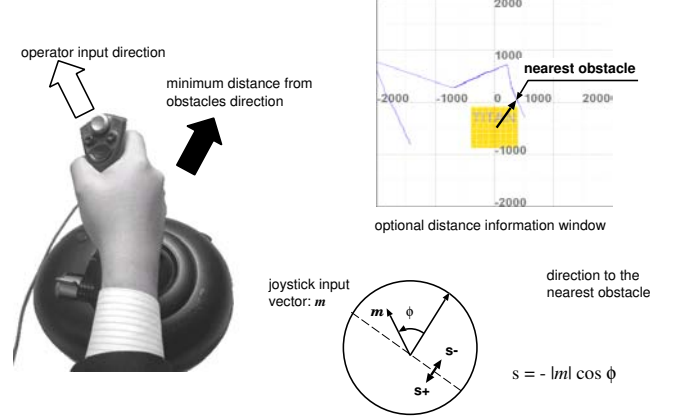


Fig. 16. Evaluation method whether the operator discriminates the obstacle information

joystick input $|\mathbf{m}|$, the evaluated score ξ is determined as;

$$\xi = -|\mathbf{m}| \cos \phi. \quad (9)$$

Thus, we defines the function to adapt the human Weber's ratio with an internal variable x is as follows;

$$k_p x + b_p \dot{x} = \xi, \quad (10)$$

where, b_p and k_p are viscous and stiffness coefficient, respectively. If the internal variable x is over a threshold x_0 , the saturated alert level λ is incremented. Oppositely, x less than $-x_0$ brings about λ reduction. The model works as kind of filter to reduce an oscillation of the level λ .

6. Experiments

Experiments to verify efficiency of the adaptive Weber's ratio adjustment. The experimental environment is shown in Fig. 17. The subjects are instructed to let the robot reach the target position without obstacle collisions. The environment include walls as the obstacle, and two turning motions are required to pass through the passage. This passage is so narrow and easy to make collision in blind corner. In this experiment, two patterns of alert scheme are verified by two subjects. One is by the constant Weber's ratio takes 0.029 which is the average of the first prior experiment. The other is adaptive the ratio by the score ξ .

Results of the experiment are shown in Fig. 18. Fig. 18 (a) indicates the sensitive level λ corresponds to the saturated step of Weber's ratio. Because the experiment environment is narrow, the level keeps low. In 100 [s] to 160 [s], the subject 1 takes it higher, that is, inhibit the excessive information alert. Fig. Fig. 18 (b) and (c) show comparisons of each scheme. However, we do not get the significant difference between the fixed and flexible Weber's ratio approach.

Because the GUI employed this experiment has only one optional information display, the human can note the main and optional information without difficulty. Due to narrow experimental environment, the human operation evaluation λ tends to take low score. Future, We attempt to experiments multiple window GUI and another environment, then, compare with these results.

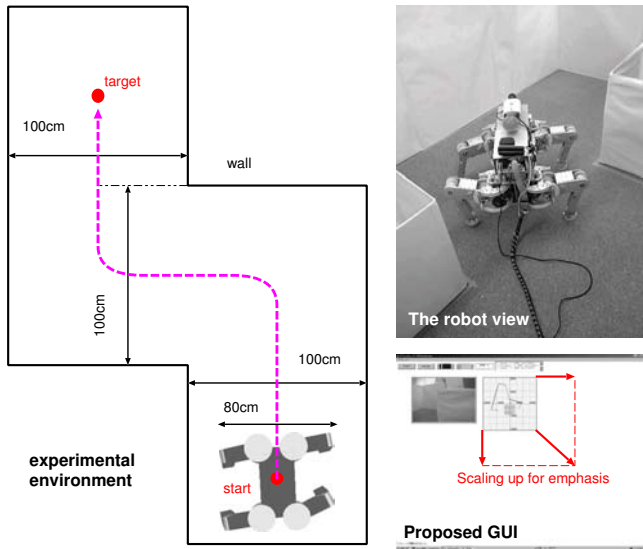


Fig. 17. Environment of experiment for the actual teleoperation system

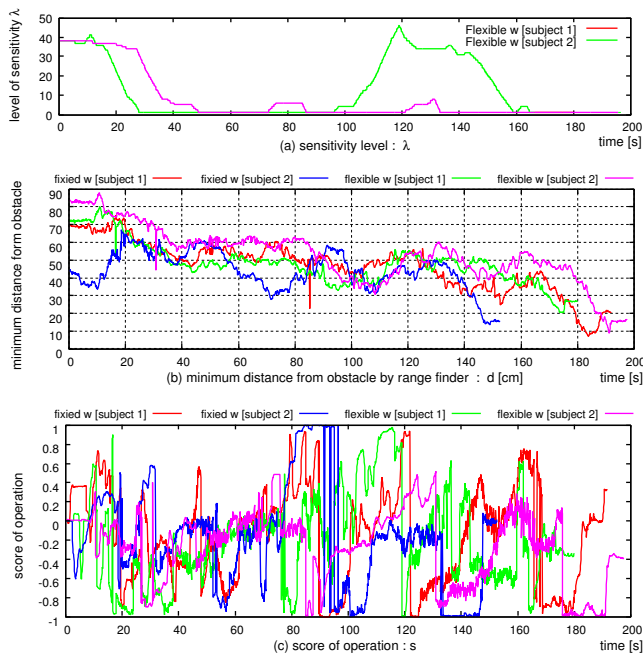


Fig. 18. Results of the teleoperation experiments: (a) plots of sensitive level λ , (b) plots of minimum distance from obstacles d , and (c) plots of the operation score s

7. Conclusions

This paper presents the information emphasis technique for teleoperation system to reduce human misdirection. The technique employs stimulation control because excess or deficient emphasis may disturb human operation. Efficient and appropriate alert by Weber's ratio is discussed. However, the ratio strongly depends on circumstances or individuality. Then, we present adaptive scheme by simple human evaluation determined by human joystick input and the nearest obstacle direction. The scheme would be expected to absorb differences of the individuals and circumstances. However, because the GUI for the experiment is include only one op-

tional window, significant differences are not detected. In future, alert schemes for multiple optional windows are conducted. For this, evaluation technique for detecting human discrimination should be considered.

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