Smart Nudge System Using Autonomous Robots

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***Abstract*— In recent years, people's stress and fatigue have become a growing health hazard as many people spend long hours at their desks or working on computers, or become so absorbed in their work that they put off taking breaks[1][2]. In response, nudge systems that improve decision-making and behaviour to help people make better choices are now attracting attention and are expected to improve work efficiency, maintain health and reduce fatigue by encouraging people to take breaks at the right time[3]. However, current nudge systems nudge through notifications via wearable devices, etc., which tends to make people disregard the notifications and put off taking breaks. In this study, a mobile robot was introduced to the nudge system to address these problems. By encouraging people to take a break with a physical mobile robot, people are more likely to take a break at the right time, which is expected to improve work efficiency and help people recover from fatigue. This study proposes three methods regarding the design of pathways for mobile robots to nudge people, and pursues ways in which people can be nudged more effectively.**

I. Introduction

In recent years, people's health problems due to stress and fatigue have become more serious[4]. This can be attributed to the fact that many people spend long hours at their desks or working on computers, or are so immersed in their work that they put off taking breaks. Nudge systems are currently attracting attention as a solution to this problem. Nudges[5][6] are about improving decision-making and behaviour to help people make better choices, rather than limiting their options. Examples include placing healthy food products in front of cash registers and displaying the number of steps pedestrians have taken near stairs and escalators. The use of nudge systems that measure human bio-metric data in real time and help people to take breaks when necessary is expected not only to make people work more efficiently, but also to maintain people's health and reduce fatigue[7].

A significant challenge with nudge systems is the problem that people are so absorbed in their work that they tend to ignore or put off notifications that remind them to take a break. Current nudge systems[8] nudge by measuring people's bio-metric data in real time via wearable devices and sending notifications to remind people to take a break when necessary. This tends to make people disregard nudges by mere notifications.

In contrast to previous research where nudging is performed by notifications from wearable devices, this research introduces mobile robot technology and considers a nudge system where a mobile robot goes to people and encourages them to take a break. The advantages of this research include the fact that nudge notifications are more difficult to ignore because a physical mobile robot is used to encourage people to take a break, the fact that engagement can be improved because the mobile robot brings coffee and other items, and the fact that in today's society where humans and robots are expected to coexist, it is possible to expect the development of interaction between both parties[9]. The development of interaction between humans and robots can be expected.

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II. Case study

A. Overall picture of the nudge system

The overall picture of the nudge system dealt with in this study is explained by comparing it with previous studies.

The overall picture of the nudge system in the previous study is shown in Fig. 1. First, bio-metric information is acquired by a sensor worn by a human. The acquired human bio-metric information is then transmitted from the sensor to the PC. Alternatively, the acquired human bio-metric information is transmitted from the sensor to the cloud and then the data is transmitted from the cloud to the PC. The PC analyses the acquired human bio-metric information and estimates the level of fatigue of each person. The PC sends the analysis results from the PC to the sensor, as it is necessary to nudge those who are estimated to be highly fatigued to encourage them to take a break and reduce their level of fatigue. The sensor then sends a notification to the person who is estimated to be highly fatigued, urging them to take a break and nudge them.

Meanwhile, an overall view of the nudge system in this study is shown in Fig. 2. The main difference from the previous study is the introduction of a mobile robot in the nudge system. As in the previous study, after analysing the human bio-metric information acquired by sensors using a PC, the PC calculates the shortest route to patrol the humans who need to be nudged and designs the route in this study. The results of the route design are then sent to the robot, which visits the human and performs the nudge.

B. Structure of the room

The structure of the rooms dealt with in this study is shown in Fig. 3. There are eight rooms in total and the number of people in the rooms is set at different levels. The fatigue level of the students is represented by blue, yellow and red, with blue representing normal, yellow slightly fatigued and red very fatigued. The robot nudges the student on arrival in the square next to the student (right or left). The robot nudges the 'red' student first, then the 'yellow' student, but when nudging the 'red' student, the 'yellow' student in the same room nudges the 'red' student as well. Once the 'Red'

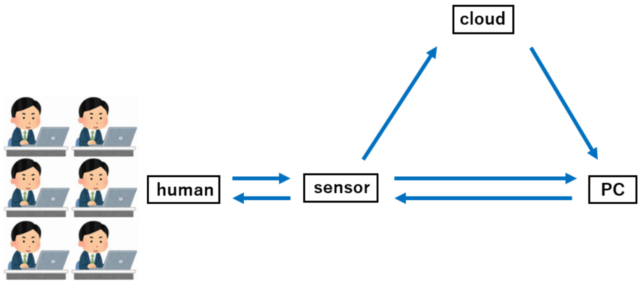

Fig. 1. Overall view of nudge systems (previous research)

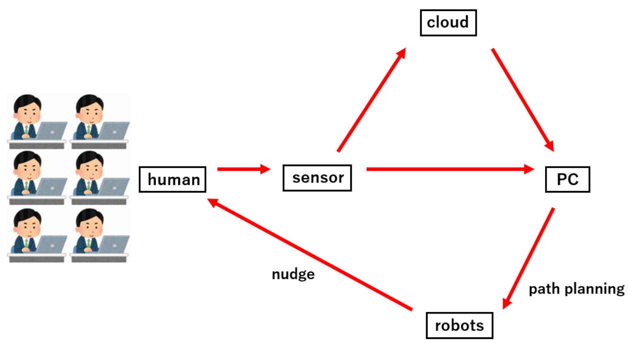

Fig. 2. Overall view of nudge systems (this study)

and 'Yellow' students are gone, the robot returns to the upper waiting area.

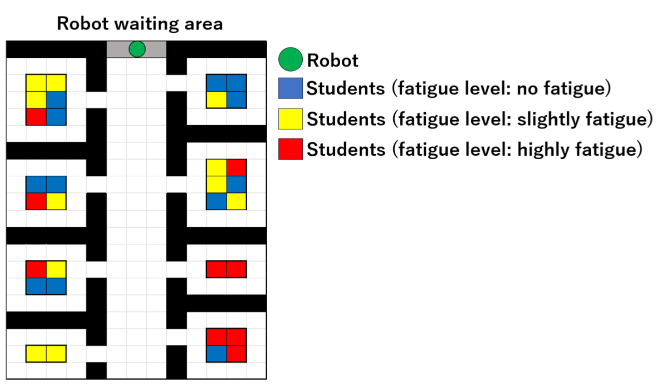

Fig. 3. Warehouse

C. *Human fatigue levels*

Human fatigue levels are explained in detail. There are a total of three human fatigue levels, with blue representing normal, yellow representing slightly fatigued and red representing very fatigued. The transitions of human fatigue are α_1 and α_2, and the transitions of human recovery are β_1, β_2 and β_3(Fig. 4). β_1, β_2 and β_3 are transitions that only occur when the robot nudges. Both β_2 and β_3 are transitions out of a state of high fatigue, so that the sum does not exceed 1.

As the degree of human fatigue and recovery varies from person to person, the parameters α and β were set to different values for each person. Specifically, the method used was to set an average value (reference value) for each parameter, and then to vary the values from person to person according to the standard deviation centred on that average value. The standard deviation in this study was set at 0.04.

And since human fatigue levels fluctuate in a timely manner, the parameter $maxtransition$ is used to define when the human fatigue level is updated. In this study, the definition of time is managed by the number of robot transitions, and it is assumed that when the number of transitions the robot took to move exceeds the value of $maxtransition$, new human biometric data arrives and the human fatigue level is updated.

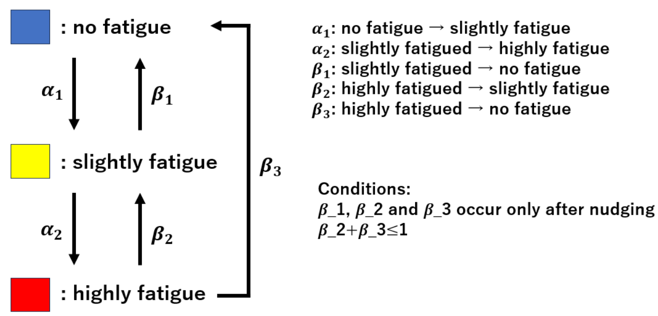

Fig. 4. Human fatigue level

III. Proposed Method

This study presents three proposed methods for determining the order in which robots patrol tasks.

This section describes the Travelling Salesman Problem (TSP)[10], which is important for the three methods presented below. The TSP is the problem of finding the shortest route that visits each task only once and returns to the starting point, and requires a circuitous route that minimises the overall travel cost. In solving the TSP, the all-search method, which tries all combinations, provides an accurate solution but is computationally explosive, so the 2opt method, which is an approximate solution method for the TSP, was adopted in this study. A comparison of the computational complexity of the total search method and the 2opt method is shown below. The computational complexity of the total search method is $O(n!)$, whereas that of the 2opt method is $O(n^3)$. Therefore, it can be seen that the larger n, the number of tasks, the more effective the 2opt method is compared to the all-search method.

a) The total search method: All city orders (combinations) are evaluated. The computational complexity of the total search method is therefore $O(n!)$[11].

b) The 2opt method: Start with a random route (order of cities); try to see if the route improves by choosing two edges and swapping them. This is tried for every pair of edges. The computational complexity of this part is $O(n^2)$. This operation is then repeated as long as the route continues to improve. This loop may be executed n times before the root becomes optimal. Thus, the computational complexity of the 2opt method is $O(n^3)$[12][13].

A. Method 1: TSP (1 use)

The first method is the TSP (1 use). The TSP is used only once for all tasks, and the robot cycles through the tasks according to their order. In this method, the TSP is solved for the whole task without distinguishing between rooms, so the robot may not be able to nudge humans on a room-by-room basis; after using the TSP only once and determining the order of the tasks, the A^* algorithm is used to calculate the shortest path for the robot A^* algorithm.

B. Method 2: BASE line

The second method is the BASE line. The BASE line is defined as the case where the robot simply goes around the room once. The robot's movement is fixed to an anti-clockwise direction and it is assumed to go round once it has passed the halfway point in its path in the room(Fig. 5). However, the order in which the robot circles the room is determined by the TSP. The structure of the code is as follows: first, the tasks are rearranged in an anti-clockwise round-the-room order, and then the room that the robot should go round is determined. Finally, the path between each task is determined. The robot's path is designed by using the path that circles the room counterclockwise once and the path that is determined by the A^* algorithm.

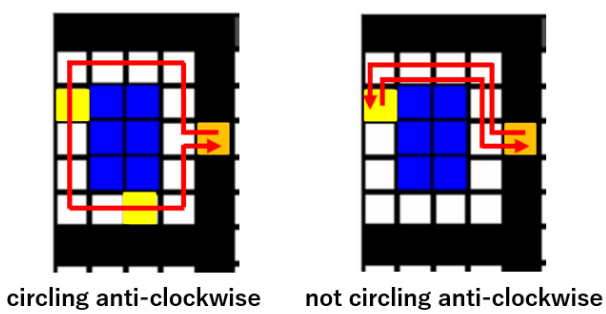

Fig. 5. Baseline

C. Method 3: TSP (2 use)

The third method is TSP (2 use). TSP is used twice for all tasks. Specifically, the order in which the robots patrol the room and the order in which the robots patrol the room are each calculated using TSP. After using TSP twice and determining the order of the tasks, the A^* algorithm is used to calculate the shortest path for the robot.

IV. Comparison experiments

Comparative experiments were conducted focusing on two aspects: 'path planning' and 'nudging'. In the comparison in terms of 'path planning', the three proposed methods are compared according to the number of robot transitions. In terms of 'nudges', the three proposed methods are compared according to the degree of recovery of the human fatigue level, and then the previous study and the present study are also compared according to the degree of recovery of the human fatigue level.

A. Experiment 1: Path planning

Here, the three methods are evaluated in terms of how optimised the path planning is. The evaluation criterion is the total number of transitions travelled by the robot.

1) Comparison of methods 1, 2 and 3:

a) Initial configuration: For the three methods, the total number of transitions moved by the robot was measured. The number of robots was set to one, and the experiment was conducted such that the total number of transitions was measured for each of the four different parameter values, for a total of 10 transitions for each. In order to compare the differences between the methods more clearly, ten patterns of human fatigue levels were created and the three methods were used equally for the same task position. The human fatigue levels were updated only once, and are shown in Fig. 6 for four different parameter values: the first(Fig. 7) is $\alpha_1 = 0.2, maxtransition = 120$, the second(Fig. 8) is $\alpha_1 = 0.2, maxtransition = 160$ and the third(Fig. 9) is $alpha_1 = 0.4, maxtransition = 120$ and the fourth(Fig. 10) is experimented as $\alpha_1 = 0.4, maxtransition = 160$. However, $\alpha_2 = 0.7, \beta_1 = 1, \beta_2 = 0, \beta_3 = 1$ are fixed.

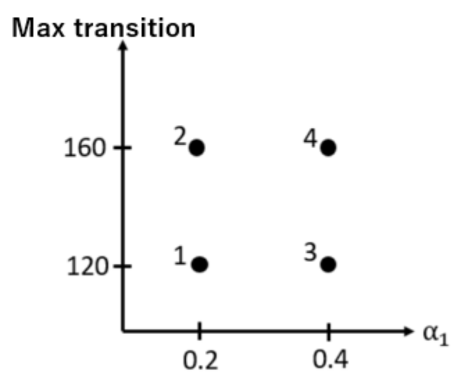

Fig. 6. parameter

b) Experimental results: For the three methods, the parameter values were changed in four steps, as shown in Fig. 6, and the total number of transitions moved by the robot was measured. The graphs are shown below (Fig. 7, 8, 9, 10).

c) Discussion: TSP (2 use) was found to be clearly superior to the other two methods. The advantages and disadvantages of the TSP (1 use) and the BASE line, which are described below, are considered to have resulted in the two methods having almost the same values.

Advantages of TSP (1 use): no need to waste time circling the room.

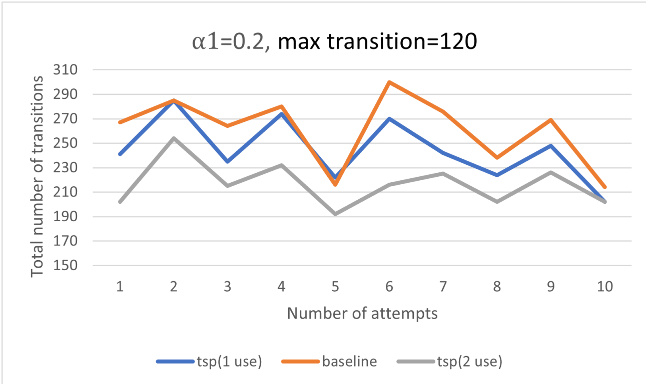

Fig. 7. Experiment 1-1-1

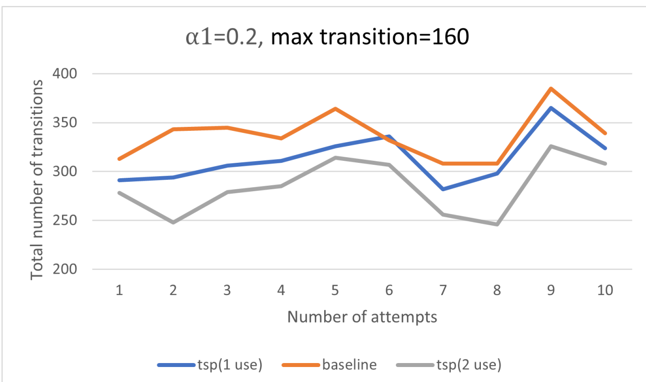

Fig. 8. Experiment 1-1-2

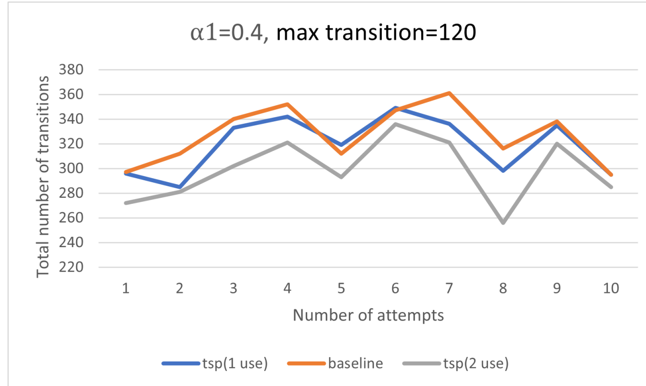

Fig. 9. Experiment 1-1-3

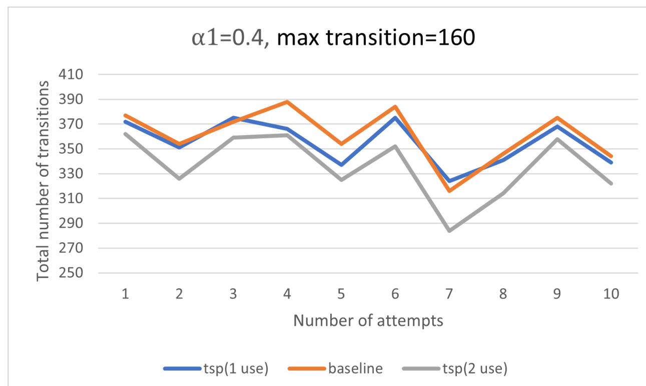

Fig. 10. Experiment 1-1-4

Disadvantage of TSP (1 use): tasks are not differentiated on a room-by-room basis, which leads to inefficiency when tasks are not processed on a room-by-room basis.
Advantages of the BASE line: tasks are differentiated on a room-by-room basis, so tasks can be processed on a room-by-room basis.
Disadvantages of the BASE line: efficiency is reduced because a roundabout may be wasted in a room.

B. *Experiment 2: Nudges*

In this section, the three methods are evaluated against each other, this study and previous studies, focusing on the extent to which nudging by the robot helped humans to recover from fatigue. The evaluation criteria are the proportion of fatigued humans (sum of slightly fatigued and very fatigued humans) to all humans (henceforth 'red proportion') and the proportion of very fatigued humans to all humans (henceforth 'red and yellow proportion').

1) Comparison of methods 1, 2 and 3:

a) Initial configuration: The time course of human fatigue levels was measured for the three methods. The number of robots was one, the parameter values were fixed, and the experiment was conducted such that the fatigue level was measured for 10 updates of the human fatigue level. In order to compare the differences between the methods more clearly, the initial settings for the human fatigue level were kept the same, so that the three methods were used equally for the same task position. Parameter values were set fixed as $\alpha_1 = 0.4, \alpha_2 = 0.7, \beta_1 = 1, \beta_2 = 0, \beta_3 = 1, maxtransition = 110$.

b) Experimental results: For the three methods, we measured the 'percentage of red' and the 'percentage of red and yellow' when the human fatigue level was updated for 10 times. The graphs are presented below (Fig. 11, 12).

c) Discussion: Compared to the other two methods, TSP (2 use) shows lower values for both the 'percentage of red'(Fig. 11) and the 'percentage of red and yellow'(Fig. 12), and is therefore an excellent method for keeping human fatigue at a lower level. The results for TSP (1 use) and baseline are almost the same, as both have advantages and disadvantages.

2) Comparison with previous studies: Experiments have been conducted on the three proposed methods, focusing on the 'path planning' and 'nudge' perspectives, and two experiments confirm that TSP(2 use) is superior to TSP(1 use) and the BASE line in terms of 'path planning' and

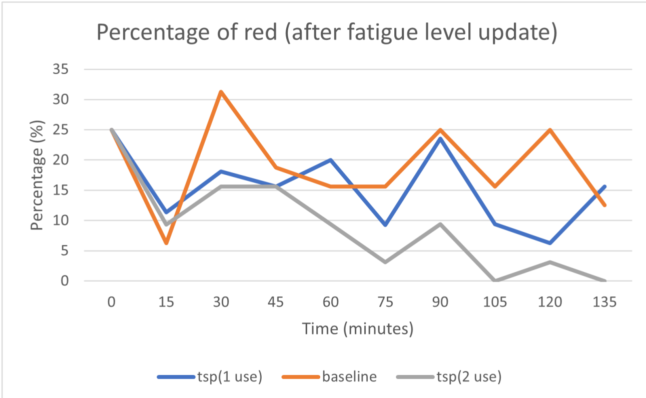

Fig. 11. Experiment 2-1-1

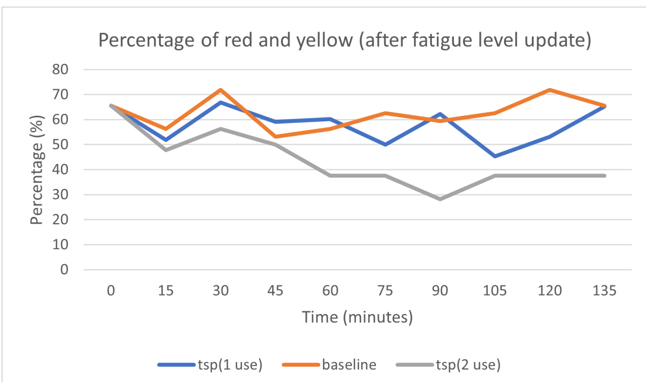

Fig. 12. Experiment 2-1-2

'nudge'. Therefore, a comparative experiment is conducted here between the previous study and this study using TSP (2 use), focusing on the nudge perspective.

In the previous study, nudges are not performed by the mobile robot, but nudges are sent to humans to encourage them to take a break, using only notifications via wearable devices or other means. This has the advantage that nudge notifications can be sent to all humans at once, but the disadvantage is that notification-only nudges tend to be disregarded by humans, so they continue to work without taking a break, resulting in fatigue. In this research, a mobile robot nudges humans by going to them and encouraging them to take a break, which has the advantage of creating an environment where humans can easily take a break and tend to recover from fatigue, but the disadvantage is that it takes a lot of time to nudge all humans, as the robot moves to each individual human and nudges them. The disadvantage is that it takes a lot of time to nudge every human being. The experiment was conducted by reflecting these advantages and disadvantages of both in the parameter values. Fig. 13 shows the advantages and disadvantages of both the above-mentioned methods.

	Advantages	Disadvantages
Previous research	Nudging possible for all humans	Low human recovery rate
This research	High human recovery rate	May not nudge all humans

Fig. 13. Advantages and disadvantages of previous studies and this study

a) Initial configuration: 'percentage of red' and 'percentage of red and yellow' for the previous study and this study using the TSP (2 use). The parameter values reflected above are presented in Table 1(Fig.). The advantages of the previous study are addressed by not setting $maxtransition$, while the disadvantages of the previous study are addressed by reducing the value of β. The advantages of the present study are addressed by increasing the value of β, while the disadvantages of the present study are addressed by setting the value of $maxtransition$. In order to ensure equality in both experiments, the initial setting of the human fatigue level is the same.

b) Experimental results: For the previous study and the present study using TSP (two levels), we measured the 'percentage of red' and the 'percentage of red and yellow' when the human fatigue level was updated for 10 times. The graphs are presented below (Fig. 14, 15).

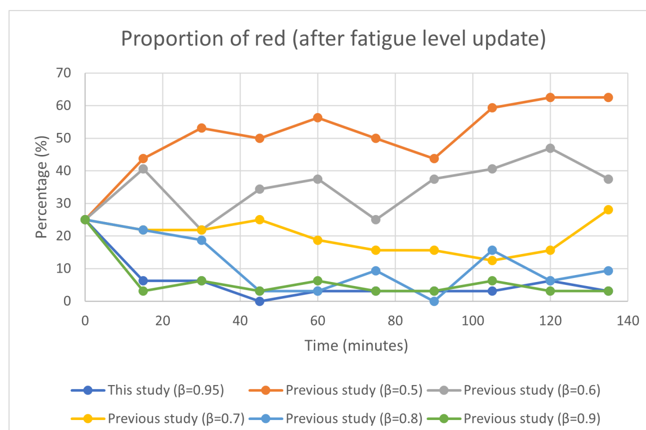

Fig. 14. Experiment 2-2-3

c) Discussion: In the previous study without mobile robots, it was observed that the 'proportion of red'(Fig. 14) and the 'proportion of red and yellow'(Fig. 15) became smaller as the value of β increased. For $\beta = 0.5, 0.6, 0.7, 0.8$, the 'proportion of red' and 'proportion of red and yellow' are smaller in this study using the mobile robot than in the previous study, which means that this study has better task processing efficiency. In the case of $\beta = 0.9$, the 'proportion of red' and 'proportion of red and yellow' for both were almost the same. This suggests that the advantages and disadvantages of both were balanced when $\beta = 0.9$.

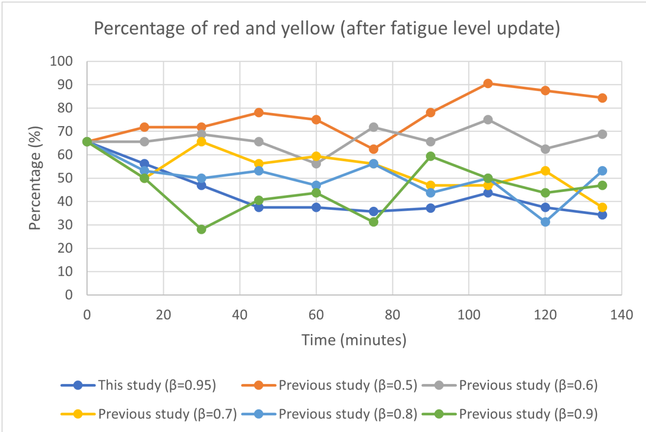

Fig. 15. Experiment 2-2-4

V. Conclusion

A. Summary

A nudge system with a mobile robot was proposed to relieve the stress and fatigue accumulated by long hours of desk and computer work. Comparative experiments were conducted on the three proposed methods from two perspectives - path planning and nudging - and on previous studies and this study, confirming that our method 3 is the best.

B. Future Challenges

Future plans include increasing the number of robots. In order to increase the number of robots, it is necessary to solve problems related to the optimum task allocation for each robot and the avoidance of collisions between robots. It is expected that increasing the number of robots will further maintain human health and reduce fatigue, and that a more upgraded nudge system can be achieved.

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