# Design of Human-Interface for Situation Awareness

Makoto Itoh and Toshiyuki Inagaki

September 11, 1996

ISE-TR-96-139

This paper will be presented at the 5th IEEE International Workshop on Robot and Human Communication, November 11-14, 1996, Tsukuba.

# Design of Human-Interface for Situation Awareness

M. Itoh and T. Inagaki
Institute of Information Sciences and Electronics
and the Center for TARA
University of Tsukuba, Tsukuba 305 Japan
mako@aleph. is. tsukuba. ac. jp, inagaki@is. tsukuba. ac. jp

**Abstract**

*In this paper, we discuss an issue how human-interface of a large complex system affects situation awareness. Through some experiments for controlling a simulated fluid circulation plant, we show that poor situation awareness is due to various factors, such as automation, mental models on the system, workload, human-interface design. We also show how we can improve the human-interface for aiding situation awareness.*

## 1 Introduction

A modern semi-autonomous system can be described by a human supervisory control model [11]. As a supervisor, a human operator can interact with a system at different levels of automation. How can the human operator share functions with automatic systems?

It has been said that human-centered automation must be realized and that "a human locus of control is required," where a human operator bears full responsibility for his or her actions. However, it is not clear whether humans have to bear responsibility at any time in any case. For example, the situation-adaptive autonomy concept is proposed by Inagaki [3]. This concept allows the machine to share authority and responsibility positively in some situation.

In a situation where a human has authority and responsibility for operation, he must identify causes of a trouble immediately for taking countermeasures against the trouble. As has been seen in various accidents or incidents, however, it is not an easy task for the human operator to identify the operating condition of a large complex system correctly.

The difficulty of identifying the operating condition may be due to inherent complexity of the system, time pressure for the identification, poor design of human-machine interface, and complacency or mistrust on automatic controllers, etc. These are factors contributing to the lack of situation awareness.

This paper investigates how human operators can be provided with some help for acquiring situation awareness in the human supervisory control configuration, where human operators are supposed to have responsibility for the operation.

Some experiments are conducted to investigate (a) how situation awareness is related to various factors, such as automation, mental models on the plant, workload, human-interface design, (b) how design of human-interface can improve or degrade human's situation awareness.

## 2 Situation Awareness

Situation awareness (SA) has gained considerable attention as a performance-related psychological concept. SA is defined as (1) the *perception* of the elements of the environment within a volume of time and space, (2) the *comprehension* of their meaning, and (3) the *projection* of their status in the near future [2].

As has been seen in various accidents, poor SA can cause catastrophic accidents [6]. SA is an essential prerequisite for safe operation of a dynamic and large complex system. However, acquiring and maintaining SA becomes difficult as the complexity of the system increases.

It is said that poor SA of the current state of an automated aircraft can result from three circumstances, such as (1) complacency or boredom, (2) deficient display design, and (3) deficiencies of the pilot's mental model [13].

## 3 The Simulated Plant

We investigate process control of a simulated fluid circulation plant in Fig. 1. The plant consists of three subsystems, A, B, and C. The purpose of the plant is to supply fluid which is required at subsystem B. Subsystem A is for adjusting the quality of the 'product fluid' for subsystem B. Both the temperature and the flow rate of the fluid into subsystem B should be bound in some region. Coming out from subsystem B, the used fluid goes back to subsystem A for renewal. While passing through subsystem C, a portion of the flow quantity is disposed of as waste.

Control elements for adjusting the flow are: (1) the main pump for refilling a suitable amount of fresh fluid into the pipeline, (2) the emergency pump for compensating the loss of the flow quantity into subsystem B, (3) the bypass line leading to the emergency waste for discarding fluid in excess.

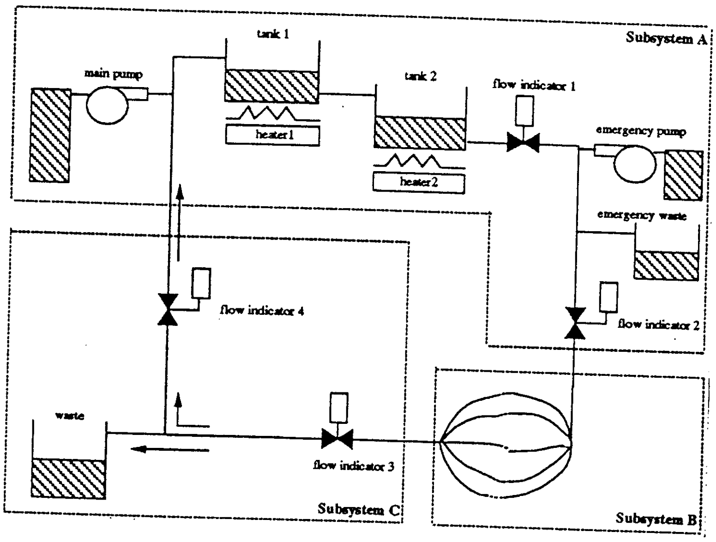



**Figure 1: The simulated plant**

# 4 Experiment

## 4. 1 Possible malfunctions

Some malfunctions can occur in the plant.

(1) Pipe rupture. Three stages of pipe rupture can occur: (a) the first stage where 10% of flow quantity is lost, (b) the second stage where the flow decreases 9% of the current quantity at each time point, and (c) the third stage where 100% of flow quantity is lost right away. The first stage goes to the second in 60 time units, where one time unit corresponds to 1.3 seconds. The second stage goes to the third in 25 time units.

In the first and second stage, the subject can 'repair' the pipe by pressing the 'repair button.' It is assumed that it takes five time units for completion of the repair. If the rupture is in the second stage, activation of the emergency pump can compensate the loss of flow quantity to subsystem B.

We say that an accident occurs five time units after the transition to the third stage: the flow rate into subsystem B becomes zero at that moment. Once the pipe rupture enters into the third stage, the operator must shut down the whole plant immediately for avoiding an accident.

(2) Level meter failure. Level meter 2 can give an erroneous reading. The level meter fails in two ways: The reading is (a) smaller, or (b) larger than the true value. In either case, reading error grows linearly as time goes on. Immediately when the subject presses the 'reset button,' the level meter becomes normal and the reading error vanishes.

(3) Heater failure. The temperature of the fluid at the main pump is around 30℃. If heater 1 or 2 loses capability to heat the fluid, the temperature of the fluid goes down to 30℃. The failed heater comes back to its normal operating condition immediately when the subject presses the 'restart button.'

## 4. 2 Tasks imposed on the subject

Each subject is requested to perform 'main task' and 'sub-task' simultaneously. Main task is to feed as much proper 'product fluid' as possible to subsystem B. The requirements of the fluid into subsystem B are: (1) The temperature must be kept within 50℃～70℃, and (2) The flow rate must be kept within 14～22, measured in an appropriate dimension.

Two types of sub-tasks are prepared: (1) Transcribing English words or sentences listed on sheets of paper, and (2) solving problems which needs reasoning. The former sub-task is considered skill-based, while the latter rule-based or knowledge-based. The sub-tasks are imposed for preventing the subject from concentrating his attention fully on the main task.

Rating of the subject's performance is done based on the performance in main and sub-tasks. The maximum of the score for a trial is 6000 points in the main task. The score of the main task is determined by the quality of the fluid. The fluid which fails to satisfy either one of conditions is not regarded as the proper product. The maximum of the score for a trial is 4000 points in the sub-task. If an accident occurs in the main task, the total score of the trial is made 0. If a trial is terminated by a shutdown command, the subject is given the score at that time point. Each operator is informed that some monetary bonus will be given if he gets either the highest or the second highest score, which is to make operators 'wise' or 'ambitious' instead of letting them 'lazy.'

## 4. 3 Automatic control systems

There are three automatic controllers which are available for subjects: (1) 'auto-supply' for controlling the main pump, (2) 'auto-compensator' for controlling the emergency pump, (3) 'auto-shutdown' for shutting down the whole plant to prevent an accident. Fig. 2 shows the activation and deactivation thresholds for those controllers. The decision of control for the automatic controllers is made based on the reading of flow meter 1. For example, 'auto-supply' makes the main pump ON when the reading of flow meter 1 goes below 17. On the other hand, 'auto-supply' makes the pump OFF when the reading of the meter exceeds 19. 'Auto-compensator' works in a similar manner. 'Auto-shutdown' shuts down the plant when the reading of flow meter 1 becomes less than 5. These controllers are made 'not so stupid, but not so wise' in order that the automatic systems have 'comparable' capabilities to the humans.

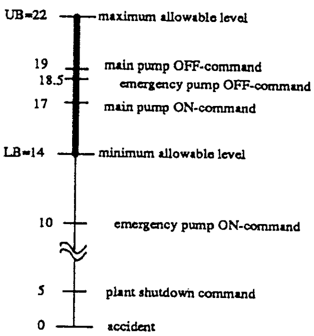



**Figure 2: Activation/deactivation thresholds**

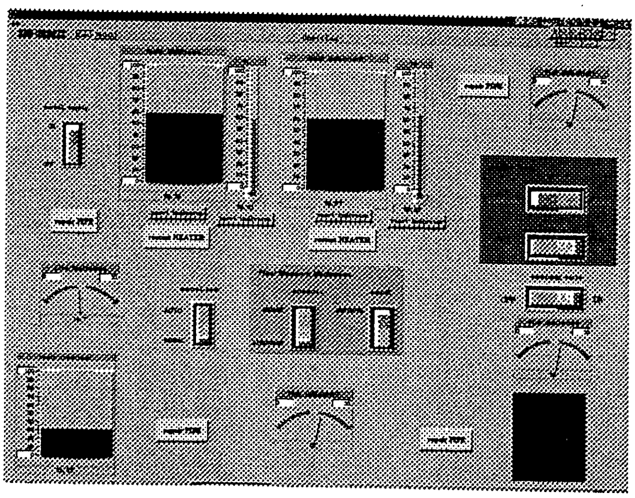


**Figure 3: Human-interface of the control panel**

## 4. 4 Human-interface design

The subject can guess the plant state only through indicators showing parameter values, such as the flow rate, the fluid level and the temperature. Fig. 3 depicts the human-interface of the control panel which is available on the display. The interface has been developed with the Hewlett Packard's VEE for Windows. Some preliminary experiments have been conducted for designing the human-interface.

## 4. 5 Schedule

The experiment which lasts five days is a series of 25 trials. It takes 300 time units for a trial. Malfunctions occur in each trial as shown in Table 1. Subjects are not informed when and how many malfunctions may occur.

Trials are divided into two groups: (1) 'training phase', and (2) 'competition phase'. All trials on Day 1 and Trial 1 on Days 2 to 5 belong to training phase, where subjects do not perform any sub-task, and control the plant manually. The remainder of trials is in competition phase. Purposes of the training phase are to develop and maintain skill of manual control and to learn what happens if a malfunction occurs. Subjects also learn capabilities of automatic control systems at Day 1 Trial 5 by controlling the plant with the automatic systems.

Subjects compete against others in the total score of the main and sub tasks for each trial in competition phase. Subjects are imposed to perform sub-tasks of the transcribing English words in competition phase on Day 2 and Day 4. On Days 3 and 5 are imposed problem solving sub-tasks.

**Table 1: Experimental schedule**

| | #1 | #2 | #3 | #4 | #5 | #6 |
|---|---|---|---|---|---|---|
| Day 1 | n | p(60) | h1(90) | p(60) | p(60) | - |
| Day 2 | p(150) | n | h1(100) | n | p(40) | - |
| Day 3 | h1(250) | p(130) | n | n | h2(180) | l(100) k=+0.2 |
| Day 4 | h1(120), l(200) k=+0.2 | h2(120), p(180) | l(70) k=-0.2, p(100) | n | - | - |
| Day 5 | p stage 2(80), l(150) k=+0.2 | h1(110), p(180) | l(70) k=-0.1, p(110) | n | l(130) k=-0.2, p(150), h2(180) | - |

(Note) (1) n: no malfunction, p: pipe rupture, h*i*: heater *i* failure, l: level meter failure
(2) 'x(y)' denotes the event x occurs at time point y
(3) 'k' denotes coefficient for linear growth of error in the reading of the level me

# 5 Results and Observations

Seven students participated in the experiment. Table 2 shows their scores and ranking.

Through experiments, we have observed some interesting points for a study of SA. The issues are described in the following.

**Table 2: Subjects' scores and ranking**
**('†': accident, '*': accident was prevented by the automatic control system)**

| | ranking | score(name, maintask, subtask) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | trial 2 | | | trial 3 | | | trial 4 | | | trial 5 | | | trial 6 | | |
| Day 2 (subtasks of transcribing words) | 1 | MA | 5404 | 62 | TO | 5071 | 0 | MI | 5096 | 4000 | MA | 5301 | 4000 | | | |
| | 2 | SH | 4960 | 500 | IN | 4866 | 3 | TO | 4680 | 2000 | TO | 5368 | 2000 | | | |
| | 3 | MI | 5367 | 0 | MA | 4560 | 8 | MA | 5389 | 500 | IN | 5139 | 2000 | | | |
| | 4 | KA | 4949 | 0 | SH | 3980 | 500 | IN | 5329 | 125 | KA | 5180 | 250 | | | |
| | 5 | IN | 4938 | 0 | MI | 4350 | 0 | KA | 4949 | 31 | SH | 5118 | 3 | | | |
| | 6 | TO | 4771 | 0 | KA | 4245 | 3 | TS | 4953 | 1 | TS | 4327 | 62 | | | |
| | 7 | TS | 5722 | 0 | TS | 2957 | 0 | SH | 3498 | 0 | MI* | 1795 | 0 | | | |
| | average | | 5159 | 80.29 | | 4290 | 73.43 | | 4842 | 951 | | 4604 | 1188 | | | |
| Day 3 (subtasks of problem solving) | 1 | MA | 5209 | 4000 | TO | 5411 | 4000 | MA | 5386 | 4000 | TO | 5262 | 4000 | TO | 5409 | 4000 |
| | 2 | MI | 5052 | 4000 | MI | 5045 | 2000 | MI | 5382 | 4000 | MA | 5224 | 4000 | IN | 5408 | 4000 |
| | 3 | SH | 4203 | 4000 | KA | 4938 | 2000 | SH | 5257 | 4000 | MI | 5182 | 4000 | MI | 5408 | 4000 |
| | 4 | IN | 4040 | 4000 | IN | 4816 | 2000 | TS | 4938 | 4000 | IN | 4941 | 4000 | MA | 5378 | 4000 |
| | 5 | TO | 4413 | 2000 | SH | 4761 | 2000 | KA | 4934 | 4000 | KA | 4544 | 4000 | SH | 5134 | 4000 |
| | 6 | TS† | 0 | 0 | MA | 5407 | 0 | IN | 4626 | 4000 | TS | 4520 | 4000 | KA | 4940 | 4000 |
| | 7 | KA† | 0 | 0 | TS | 4950 | 0 | TO | 5403 | 2000 | SH | 4519 | 4000 | TS | 4958 | 2000 |
| | average | | 3274 | 2571 | | 5047 | 1714 | | 5132 | 3714 | | 4885 | 4000 | | 5234 | 3714 |
| Day 4 (subtasks of transcribing words) | 1 | IN | 4384 | 4000 | TO | 5338 | 4000 | TO | 5406 | 4000 | | | | | | |
| | 2 | SH | 4224 | 4000 | MA | 5378 | 0 | IN | 4950 | 4000 | | | | | | |
| | 3 | TO | 5219 | 2000 | IN* | 2398 | 2000 | MA | 5407 | 0 | | | | | | |
| | 4 | MA | 5043 | 0 | MI | 3964 | 0 | MI | 5265 | 0 | | | | | | |
| | 5 | TS | 4126 | 31 | SH | 3861 | 0 | TS | 4951 | 62 | | | | | | |
| | 6 | MI* | 3535 | 0 | KA | 3508 | 62 | KA | 4942 | 62 | | | | | | |
| | 7 | KA* | 2527 | 0 | TS* | 2387 | 0 | SH | 4951 | 0 | | | | | | |
| | average | | 4151 | 1433 | | 3833 | 866 | | 5123 | 1161 | | | | | | |
| Day 5 (subtasks of problem solving) | 1 | TO | 5037 | 2000 | MA | 5332 | 2000 | TO | 5403 | 4000 | MA | 5134 | 4000 | | | |
| | 2 | TS | 4599 | 2000 | TO | 5283 | 2000 | SH | 4952 | 4000 | TS | 4845 | 4000 | | | |
| | 3 | MI* | 4260 | 2000 | IN | 5100 | 2000 | MA | 5399 | 2000 | IN | 4231 | 4000 | | | |
| | 4 | MA | 5217 | 0 | SH | 3564 | 2000 | TS | 5395 | 2000 | SH | 3625 | 4000 | | | |
| | 5 | IN | 5045 | 0 | KA | 4601 | 0 | MI | 5373 | 2000 | TO | 5248 | 2000 | | | |
| | 6 | SH | 3978 | 0 | TS | 4514 | 0 | IN | 5160 | 2000 | KA | 4265 | 2000 | | | |
| | 7 | KA | 3746 | 0 | MI† | 0 | 0 | KA | 4941 | 2000 | MI | 4789 | 0 | | | |
| | average | | 4555 | 857.1 | | 4056 | 1143 | | 5232 | 2571 | | 4591 | 2857 | | | |

## 5. 1 Automation

Table 3 shows relationship between awareness of pipe ruptures and control modes of the main pump. Subjects who control the plant manually can realize troubles easier than those who control it with automation because the former is in a control-loop.

The automatic system developed for this experiment is 'silent' in a sense that it has no alarm system and has no way of telling their current operating condition. The silent nature of the automatic systems has caused some inconvenience when the main pump was controlled automatically. Indeed, 'auto-supply' can activate the main pump and can maintain the flow rate at subsystem B around 20, which prevents subjects from understanding the malfunction (see, [4]).

**Table 3: Awareness of pipe rupture and control mode**

| control mode | automatic | manual |
|---|---|---|
| repaired in the first stage | 6 | 14 |
| repaired in the second stage | 22(6)* | 4 |
| accident occured | 3 | 0 |

*: the plant was shut down by the automatic control system six times in 22 trials

## 5. 2 Mental model

We have obtained some pieces of evidence which suggest that one factor responsible for poor SA lies in deficiencies of the mental model itself. Poor SA has been observed at various level of SA as following.

level 1: Some subjects with poor mental model on the plant dynamics did not know which parameters were critical for the plant safety. For example, subject TS has kept the main pump ON for 87 time units at Day 2 trial 2. While the pump was ON, he focused his attention on flow meter 2. He had not been aware of that the pump was ON until the flow rate at subsystem B exceeded the UB level.

level 2: Even if an 'ordinary' subject could achieve the level 1 SA, he sometimes could not integrate various data to comprehend the situation. At Day 4 trial 3, level meter 2 failed at some time point. The failure mode was to give the reading smaller than a true value. A pipe rupture occurred 30 time unites after the level meter failure. Subject IN thought that the ratio of the reading of level meter 1 to that of level meter 2 was abnormal. However, he felt that the ratio of the reading of level meter 2 to that of flow meter 1 was normal. He failed to integrate these pieces of information for recognizing the failures.

level 3: Humans are able to predict future system states with adequate mental models. Each subject must predict future flow rate or fluid level to determine when he must monitor the display and control the plant. At Day 2 trial 2, Subject IN checked the display too many times because he could not predict future states, and he failed to complete the sub-task. He could perform only the half of his duty (see, Table 2).

## 5. 3 Workload and mental pressure

Table 4 illustrates time elapsed before taking countermeasures against a failure. One interesting fact is that some subjects could find out failures in the "three-failure scenario" more easily than "two-failure scenario" (see Day 5, Trial 3 and 5). The mental workload of subjects in the three-failure scenario might be higher than in the two-failure scenario. However, subjects could easily recognize that "something is wrong" in the three-failure scenario because the more failures occur simultaneously, the more indicators read abnormal values at the same time. The mental workload does not always badly affects a score of a trial. The problem is whether subjects are ready for detecting failures or not.

At Day 2 Trial 2, subject TO, who was one of persons with a very good mental model on the plant dynamics, intended to engage 'auto-shutdown'. However, he engaged 'auto-supply'. 'Auto-supply' had been engaged for 115 time units. He sometimes tried to turn the main pump ON or OFF manually not knowing that 'auto-supply' had been engaged, which means he failed to be aware of the current control mode. "This was the first time to perform the solving problem sub-task in the competition. I was under pressure to cope with the new sub-task," commented the subject.

**Table 4: Time elapsed before taking countermeasure against a failure**

(a) pipe rupture

| Name \ Day-Trial | 2-5 | 3-2 | 4-2 | 4-3 | 5-2 | 5-3 | 5-5 |
|---|---|---|---|---|---|---|---|
| MA | 34 | 35 | 5 | 2 | 6 | 18 | 2 |
| SH | 34 | 72 | 46 | 72 | 64 | 74 | 66 |
| KA | 25 | 90 † | 72* | 71 | 74 | 27 | 63 |
| IN | 36 | 64 | 29 | 75* | 5 | 65 | 64 |
| TO | 11 | 68 | 14 | 22 | 23 | 57 | 28 |
| TS | 78* | 89 † | 65 | 75* | 66 | 66 | 63 |
| MI | 76 | 63 | 73* | 68 | 69* | 89 † | 67 |

(b) Level meter failure

| Name \ Day-Trial | 3-6 | 4-2 | 4-3 | 5-3 | 5-5 |
|---|---|---|---|---|---|
| MA | 42 | 43 | 18 | 30 | 24 |
| SH | 172 | 68 | 181 | 226 | 80 |
| KA | 137 | 24 | 168 | 220 | 98 |
| IN | 108 | 90 | 75* | 226 | 81 |
| TO | 49 | 30 | 48 | 88 | 43 |
| TS | 135 | 48 | 105* | 192 | 56 |
| MI | 53 | 23 | 173 | 129 † | 98 |

(c) Heater 1 failure

| Name \ Day-Trial | 4-3 |
|---|---|
| MA | 24 |
| SH | 75 |
| KA | 33 |
| IN | 56 |
| TO | 53 |
| TS | 44 |
| MI | 15 |

(d) Heater 2 failure

| Name \ Day-Trial | 2-3 | 3-5 | 4-2 | 5-5 |
|---|---|---|---|---|
| MA | 31 | 19 | 32 | 22 |
| SH | 71 | 41 | 52 | 74 |
| KA | 58 | 39 | 122 | 45 |
| IN | 34 | 43 | 43 | 61 |
| TO | 28 | 15 | 16 | 12 |
| TS | 196 | 41 | 56 | 30 |
| MI | 82 | 21 | 66 | 30 |

## 5. 4 Human-interface

Subject MI intended to activate the emergency pump, but what he actually did was to activate the emergency waste. Some mode confusions have been observed in the control of the main pump, which are due to indistinguishable switches (for details, see [4]).

Subject SH recognized that some malfunction occurred at Day 3 Trial 6. The main pump was controlled automatically at that time. In the trial, level meter 2 failed in a mode to give the reading greater than a true value. "Although the reading of level meter 1 was smaller than the reading of level meter 2, the former was decreasing and the latter was increasing. That seemed abnormal for me," commented the subject after the trial. Since flow meter 1 showed a normal value, he did not take seriously this situation and did not recognize the level meter failure. Then he turned the main pump OFF, because he felt that the flow rate into subsystem B would exceed the UB level in the near future if the pump was kept ON. The true level of tank 2 was decreasing, and he should have activated the pump for getting a good score.

Some accidents or plant shutdowns are due to poor feedback of command input by a subject. For example, subject MI found a pipe rupture and pressed the repair button at Day 4 Trial 2. He used the automation to control the main pump. Unfortunately, the repair command was ignored and the pipe was not repaired. The repair system of the pipe rupture was not ready for accept any command at that time. The human-interface did not tell him the abortion of repair. He was never aware of the unsuccessful repair of the pipe, and the plant was shut down automatically when the pipe rupture went into the third stage. If he had known that the repair command was not accepted, he would have tried it again and could have repaired the pipe successfully.

## 5.5 Improvement of the human-interface

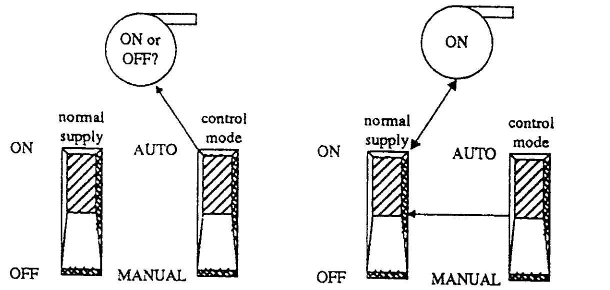
We have made an interview for each subject after a trial. Some useful comments are given below:

Q. How should the system interact with you?
(MI) *I need feedback from the system in some way every time I give a command for doing something.*
(MI) *The system should beep out an alarm when something becomes wrong.*
(TS) *The system should give an alarm verbally when something becomes wrong.*
(MI, IN) *The system should take time-delay of the flow into account, and each flow meter should contain a reference value which shows 'the expected flow rate to be observed.'*
(MI, IN) *I need information about differential value of each parameter (such as the flow rate, the temperature, the fluid level).*
(MA) *I need an indication which states a heater is active when the heater is in its normal operating condition.*

Q. How should the automatic control system interact with you?
(MA) *Some sound (such as sound of motors or of flow of the fluid) can tell us that the automatic control keeps the plant under control and activates the pump.*
(SH) *The 'normal supply' switch should be turned 'ON' or 'OFF,' even when it is the automatic system which controls the pump. If so, the motion of the switch would tell us what the automatic system is doing.*

Q. How do you think about the human-interface?
(SH) *Thermometers are not as informative as flow meters. I cannot easily detect any movement of the reading of the temperature.*
(MI) *I sometimes lose sight of the mouse cursor during a trial.*

(TS, KA) *The mimic diagram on the display annoys me because I have to watch all indicators around when I monitor the display.*




(a) Former design of switch. Suppose AUTO is engaged. Do you figure out whether the main pump is ON or OFF?

(b) Improved design of switch. The left switch tells the state of the pump, whichever position (AUTO or MANUAL) the right switch takes.

**Figure 4: Improving design for switch**

Employing one comment from the above, we show one improvement of the human-interface. The conventional 'normal supply' switch works only in a manual control mode. Subjects did not realize whether the main pump was ON or OFF (see, Fig. 4) when the automation was active: The normal supply switch 'ON' did not mean the pump 'ON' in the automatic mode. We have improved the switch so that it tells the pump state more clearly. The new switch is turned 'ON' ('OFF') when the pump is 'ON' ('OFF'), which helps subjects to understand what the automation is doing.

## 6 Concluding Remarks

Through our experiment, subjects who control the plant manually could acquire sufficient SA and could get a very good score. We can say that the human-interface we have developed was good enough to control the plant manually.

However, manual control was not always good for managing with main and sub-tasks simultaneously. Some subjects required automation for controlling the plant to complete sub-tasks. As has been shown in our experiment, the human-interface has affected seriously the achievement of SA, especially when the plant was controlled automatically. We have shown an example for improvement of the human-interface for aiding situation awareness in an automatic control mode. We are now evaluating the effect of the improvement and investigating further progression of the human-interface.

## Acknowledgments

This work has been partially supported by the Center for TARA (Tsukuba Advanced Research Alliance) at the University of Tsukuba, and Grant-in-Aid for Scientific Research 07650454 and 08650458, the Ministry of Education, Science, Sports and Culture.

## References

[1] Billings, C. E., *Human centered aircraft automation: A concept and guidelines*, NASA TM-103885, 1991

[2] Endsley, M. R., Toward a theory of situation awareness in dynamic systems, *Human Factors*, Vol. 37, No. 1, pp 32-64, 1995

[3] Inagaki, T., Situation-adaptive responsibility allocation for human-centered automation, *Trans. SICE of Japan*, Vol. 31, No. 3, pp. 292-298

[4] Inagaki, T. , and M. Itoh, Trust, autonomy, and authority in human-machine systems: Situation-adaptive coordination for systems safety, *Proc. CSEPC*, 1996, Kyoto, Japan, 1996 (to appear)

[5] Lee, J. , and N. Moray, Trust, control strategies and allocation of function in human-machine systems, *Ergonomics*, Vol. 35, No. 10, pp 1243-1270, 1992

[6] Okano, M., *The montage of aircraft accidents*, Vol. 5, ANA, 1994 (In Japanese)

[7] Norman, D. A., *The Psychology of Everyday Things*, Basic Books, 1988

[8] Rouse, W. B., On looking into the black box: prospects and limits in the search for mental models, *Psychological Bulletin*, Vol. 100, No. 3, pp. 349-363, 1986

[9] Sarter, N. B., and D. D. Woods, How in the world did we ever get into that mode? Mode error and awareness in supervisory control, *Human Factors*, Vol. 37, No. 1, pp 5-19, 1995

[10] Sarter, N. B., and D. D. Woods, Situation awareness: A critical but ill-defined phenomenon, *The Int. Journal of Aviation Psychology*, Vol. 1, No. 1, pp. 45-57, 1991

[11] Sheridan, T., *Telerobotics, Automation, and Human Supervisory Control*, MIT Press, 1992

[12] Vicente, K. J., and J. Rasumussen, Ecological interface design: Theoretical foundation, *IEEE Trans. SMC*, Vol. 22, pp. 589-606, 1992

[13] Wickens, C. D., Designing for situation awareness and trust in automation, *Proc. IFAC Integrated Systems Engineering*, pp 365-369, 1994

[14] Woods, D., The effects of automation on human's role: Experience from non-aviation industries, In Norman and Orlady (eds.), *Flight Deck Automation: Promises and Realities*, NASA CP-10036, pp 61-85, 1989