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Safety Training System using Plant Simulator for Distance Cooperative Work in Chemical Plants

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According to a recent report by the Japanese government, about 40% of accidents in the chemical industrial complex are caused by human factors. At the same time, due to changes in the social structure, problems of retirement of a large number of mandatory retirements at the manufacturing site and technical inheritance due to a decrease in the labor force population have been pointed out. To convey accurately indication information of work in chemical plant, we need safety education systems to support operators/workers to follow correct operating procedures without human error. In this study, it is used a dynamic plant simulator instead of a real chemical plant to reproduce the behavior of the plant. Plant operators can use tablet PCs in the field or desktop PCs in the control room. The proposed system can display information on the tablet PCs that have been standardized to include various operational procedures under regular conditions as well as during emergencies. In addition, the field worker can control plant simulator from onsite using mobile small PCs. The plant information is stored in a database that can be accessed and used as needed. The field operators can communicate with the control room about ongoing situations using the camera included in the tablet PC. In many chemical plants, onsite workers cannot quantitatively know the degree of a valve opening, and in order to know whether the work they did was appropriate, they must contact the control room. To solve this inefficiency, in this system, the process value of the plant simulator is routed to the tablet PC. Under the present circumstances emergency training to prevent accidents at chemical plants is not enough although their importance is recognized. We expect that this system can be used for safety training/education using a real onsite work environment.

1. Introduction

1.1 Recent accidents in Japan

In past few years, there have been many catastrophic explosions and fires in chemical industries in Japan. Following pictures in Figure 1 (METI Japan, 2016) show the tragic explosion and fire accident occurred in the large-scale facilities. These accidents were initiated by various causes, for example, equipment failure, leakage from pipe/devices which caused by corrosion and erosion, mishandling by operators during operations/covering procedures.

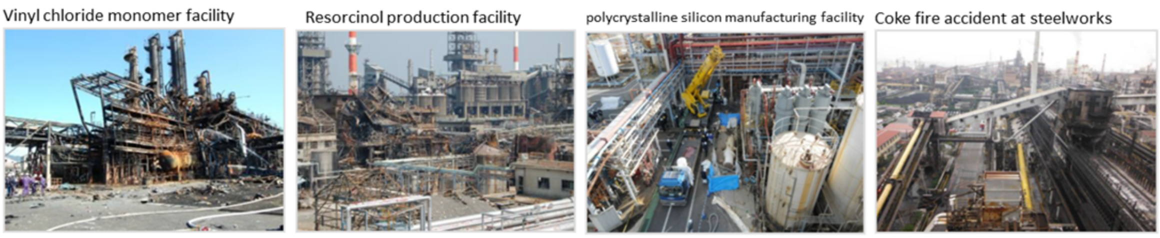

Figure 1: Recent accidents in Japan

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It was truly regretful that the injuries and the death of employees due to these accidents, and the damage was expanded to the local residents as well. According to a recent report by the Japanese government, about 40% of accidents in the chemical industrial complex are caused by human factors, including misjudgment, misoperation, recognitions and confirmation error. In FY2017, there were 252 accidents reported by 679 establishments in special disaster prevention areas such as petrochemical industrial complexes. Of the total number of cases, 101 (40.1%) were due to human factors,139 (55.1%) were due to physical factors (e.g., corrosion, equipment failure), and 12 (4.8%) were due to disasters such as earthquakes, arson, and others.

1.2 Background of the accidents

By investigating these accidents, it should be recognized that hazards easily break through layers of defences, barriers and safeguards. When we think about the reason why many serious accidents occur, changes of Japanese social situation and industrial structure become clear to be one of primary factors of these accidents. The company culture also depends on changes of Japanese social situation and industrial structure. This point caused lower sensitivity to hazards by limited experience of hazards during the childhood under the protected safety environment. Change of industrial structure reduced level of proficiency in technical skill/knowledge of operator. As a result, operators in plants are less able to identify hazard in chemical plants caused by lack of sensitivity/knowledge for potential risk and understand the overall picture and the individual contents of processes for engineers and workers. And lack teamwork also take place in realistic chemical plants operations. Operators/workers cannot adequate correspond to abnormal situation in chemical plants. One way to solve problems, high-tech safety instrumented system should be introduced to chemical plants. Most of the problem should be solved by high technology development and introducing to real plants. However, problems related human should be solved education and training to improve sensibility for safety, to development of ability to identify potential hazards, to reduce mishandling/erroneous operation. Improve human skills by safety education.

1.3 Challenges for safety education

Sustainable operation of chemical installations and plants worldwide depend heavily on how procedures and standards are implemented as much as on how the human-machine interface is responsive to sudden mechanical failures, natural disasters or human mistakes. These environments are best managed within well-established practices defined and known as safety culture. After the FUKUSHIMA accident, people in Japan in general feel anxious about nuclear engineering and technology. Also chemical industries field have the same situation. It is urgent required to rebuild the public trust that has been lost in safety of large-scale facilities. Science and technology should be linked to the welfare for human beings. Our societies need to be assured regarding the safety and reliability of industrial facilities to prevent accidents. Training-by-Doing is as a Key for Safe Actions. Because, when we face to an emergency event, it is often made a mistake. Each person and groups of people have different values and beliefs, which ultimately affects social awareness and creates difficulties in partnership. Therefore, to build and enhance safety culture in our society and workplaces, engineering safety training/education is especially important. (Pasman et al. 2013)

2. Purpose and approach to the safety training system

2.1 Current Status and Issues of education/training for workers in chemical plant

In many chemical industries in Japan, practical education is mainly conducted in two ways. One is OJT (On-the-Job-Training) and the other is OFF-JT(Off-the-Job-Training). The following table 1 summarizes the current state and issues of education/training for plant safe operations. OJT is a type of training method and in-house education method performed in the company. It refers to vocational education of employees through doing real plant maintenance and operation in the workplace. OFF-JT is an education and training in which employees temporarily leave regular work and acquire expert knowledge and skills. It is the purpose of vocational education to enable employees to work accurately. Actual chemical plant work is carried out among multiple workers in a remote cooperative work environment via role sharing. Safe control of chemical plant has the following dangers, reaction hazard of chemical materials, the inability to directly touch chemical product, the fact that control room and work sites are separated from each other cannot directly confirm each other's work. Especially troubles due to human factors tend to occur in unsteady work such as accidents, disasters, and start-up and shut-down of chemical plants. However, until now training of such work has recognized its importance, but it has not been practiced much. In this research it is developed the safety training system for these issues. As candidate solution to problems, education and training for development of safety culture are considered. In this paper, integrated instruction system consisting of dynamic simulator, virtual reality and argument reality system are proposed to educate/training for chemical plant operators. Aims are to bring up operators who have high sensitivity for hazards in plants, excellent skills for stable plants operation and abilities to cope with abnormal/emergency situation in plants.

Table 1: Current status and problems of education and training of plant operation

Education subject	Types	Ways of education / training	Number of trainee	Problems to be solved
・Monitoring and operation at start-up ・Shutdown operation ・Operatuon procedure ・Emergent measures and evacuation in case of accidents	①OJT (On-the-Job-Training) Education/Training in accordance with their supervisor or veteran	Acquisition of knowledge and skills in practical work process	1 person	・Decrease of Start-Up and Shut-Down opportunities because the plant keeps stable. ・Decrease of educational leaders due to decrease of skilled workers. ・The lack of theoretical knowledge of the operaters due to change work environment rapidly. ・Education / training related practice at operating plants, such as abnormality response operations is impossible.
	②OFF-JT (Off-the-Job-Training) Education that temporarily leaves ordinary work on site	Knowledge acquisition by classroom learning	1 person	There is an opinion that knowledge-centered educational contents are not practical.
		Experiential education using mock-up of chemical plants	1 person	・Required cost is large, and large spaces are required. ・Training items with the risk of plant can not be carried out due to danger.
		Training using a dynamic symulator equipped with DCS	1 person	・Since it is operated only by DCS or PC, it is greatly different from actual plant oparation. ・Since it is a two-dimensional graphs and charts display, it is difficult to understand actual plant work and arrangement and it can not be applied to actual work.
		Web Learning	1 person	It is passive learning. Educational effect is weak only by giving knowledge.
・Emergency response ・Fault diagnosis and Corresponding operation		Education/teaining under distance cooperative work environment	Cooperation by multiple people	Necessity has been recognized, but it has not been realized.

2.2 Plant operator activities to recover from abnormal condition

Before developing the system, plant operator activities are organized as follows. Operators cope with the abnormal condition of the plant by their synthetic judgments. They think their synthetic judgments based on their knowledge, experiences and the manual of the plant. Their synthetic judgment is composed of 6 thinking activities. (Hori et al. 1999) These activities are described in the following.

1. Fault Detection: Operators detect a fault of the process based on the alarm and the plant condition.
2. Prediction of Effect of Fault Propagation.
3. Judgment of Necessary of Corrective Action
4. Fault Diagnosis: Operators identify hardware or software malfunction based on data of process variables, their knowledge and experiences at the same time of the previous activity.
5. Decide the Best Corrective Action
6. Circumstantial Judgment after Emergency Shut-down: Operators grasp the situation after the shutdown.

Accidents in chemical plants may expand due to misrecognition, erroneous judgment, etc. by humans. The purpose of this study is to support these human skills by safety training.

2.3 Integrated information using chemical plant simulator for “training by doing”

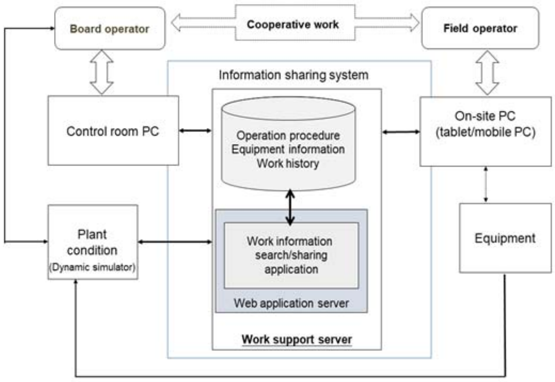
Not only knowledge but also practical work training is important for plant safety training. The proposed system considers sharing the operational information that is required to prevent misoperation and misjudgment onsite. (Komatsubara,2008) In this study, it is used a dynamic plant simulator instead of a real chemical plant to reproduce the behavior of the real plant. By sharing real-time onsite information, a cooperative work environment between the board operators and the field operators is established. (Nakai et al. 2017) In addition, by checking the information of the plant simulator on site and inputting necessary operation information, it is possible to carry out the failure response training using the on-site work environment. In order to implement the system, the information that is essential to the running of the chemical plant needs to be clarified and classified as follows (Nakai et al. 2017):

1. Standard information such as operation procedures and P&ID diagrams.
2. Onsite images. This is dynamic information that changes in real time.
3. Sensor data of the dynamic simulator depending on the onsite and control room work.
4. Communication for working requires interactivity

Various information are mixed at the work site of the chemical plant, and an experienced plant operator who performs rapid troubleshooting uses thus information to decide the optimum handling work. In this research, work instruction information is presented effectively to workers with little experience. By sharing information on the control room and on site, training close to actual work became possible. (Nakai et al. 2014) Experience activities are literally activities that are experienced in the field through their bodies. Among them are "indirect experiences" that learn sensuously through the Internet, television, etc. in addition to "direct experiences" actually involved in the real thing to be realized, "simulated experiences" learned simulatively and through simulated models. Training-by-Doing is a technique that connects both actions and brings about better results.

3. Safety training system for distance cooperative work

Education and training so far mainly focused on learning by one person, primarily on education in the classroom or mock-up equipment. To keep working safety, communication is important because on-site work of chemical plants is usually conducted by multiple people. (Nakata, 2007) In this research, it is implemented instructional information and information sharing function for multiple workers in the system. The outline of the proposed system is shown in Figure 2. Work information can be shared by multiple devices connected to the local area in order to use the web browser. The system and the dynamic simulator communicate with each other through the WEB API. Figure 3 shows the communication between dynamic simulator and client PCs.



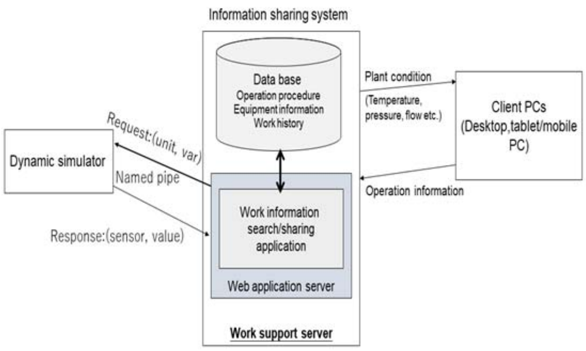


Figure 2: Outline of the proposed system

Figure 3: Connected with dynamic simulator

3.1 Instructional information using VR(Virtual Reality)and AR(Augmented Reality) technology

In an emergency, the operator is required to make a quick decision in order to prevent the expansion of the accident. But an untrained operator cannot respond enough to emergencies. (Hara et al. 2015) Education/training of non-stationary operation for workers is needed. However, reproducing the non-stationary conditions to actual equipment or mock-up cannot be performed because it is dangerous. Also a company requires a huge cost to build a mock-up of the plant facilities for education. VR is a technology that is artificially creating a sense of reality. AR can function in ways that enhance one's current perception of reality. (Ishii et al. 2013) In chemical plant, due to the installation of similar aggregating pipes and valves, there is a risk of serious damage occurring due to operate wrong valve. With advances in computer technology, the proposed system shows the relevant operating procedures and accurate equipment information using AR and Image recognition. The field operators captured the equipment through the camera of tablet PC. The name of equipment and operating information are shown in the display. The AR marker shows an image of a set pattern, which is indicator for specifying the installation site and displaying additional information, the name of equipment and process condition etc. The operator identifies target equipment with the camera, and can confirm the correct operating procedure on the tablet PC. (Yating et al. 2015) The work information is displayed to the operator first, after the task has been completed, the next work procedure is presented by updating the plant information.

3.2 Creating the training scenario using accident case/malfunction procedure

In this research, it is aimed to develop a system that can be applied to training by distance cooperative work environment which requires communication similar to real work such as work instructions and reporting. In order to convey training purposes, the system makes a training scenario to provide information to the operator. Explosions and fires that are highly dangerous and cannot actually be experienced are reproduced using VR technology. The plant model in a virtual plant and the sensor data of DS are linked by the system. Therefore, the change of the plant condition in a real plant is reflected to virtual plant. The training scenario is created with reference to accident cases or malfunction operation procedures. Since the information of the plant simulator and the operation procedure can be referred to from multiple mobile terminals, it is possible to cope with the training of distance cooperative work for multiple people. In the training, instead of operating the actual equipment, the trainee input the operation amount from the mobile terminal to the plant simulator. Since the sensor data of the simulator is displayed on the terminal, the trainee can confirm the success or failure of the work at the onsite or the control room. An example of training scenario creation is shown in Figure 4. The created scenario is stored in the database of the system.

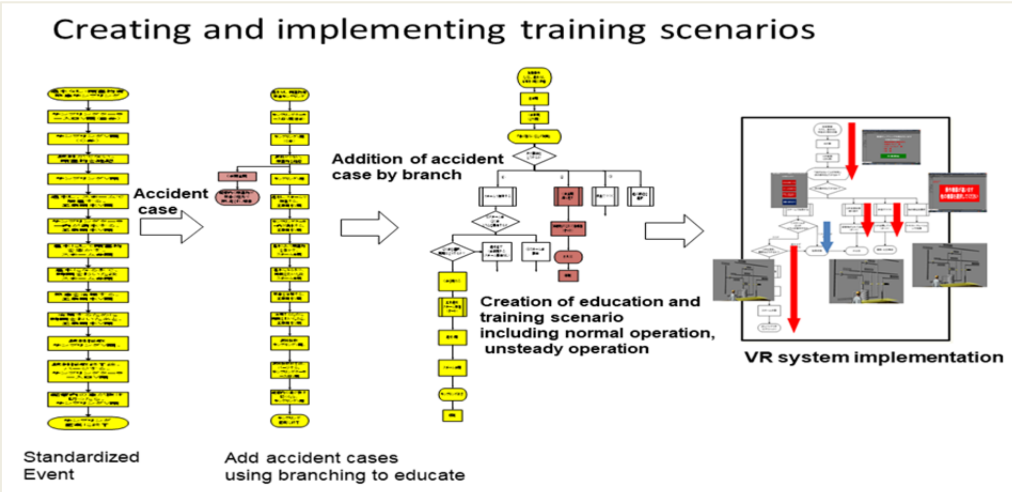


Figure 4: Creating the training scenarios and instructional information

4. Case study of the HDS Plant Procedure

4.1 Malfunction scenario: VGO feed trouble

This system was implemented assuming a malfunction within the HDS plant simulator in Figure 5. The database for this system stores the information necessary for performing correct work, and field operators can use this system on tablet PC or a small device such as an android smartphone connected to a local area network. The main functions of this system are the selection and presentation of operation information, the acquisition and display of sensor data from the plant dynamic simulator, sharing real-time images, and communication by text message. In addition, the trainee can control plant simulator using mobile device in Figure 6.

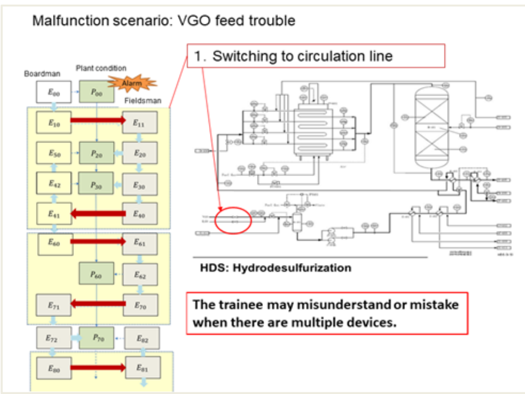


Figure 5: Cooperative operation model

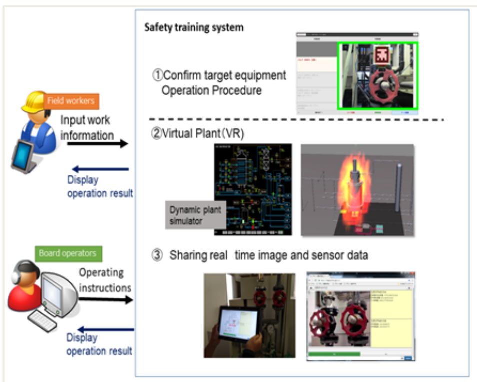
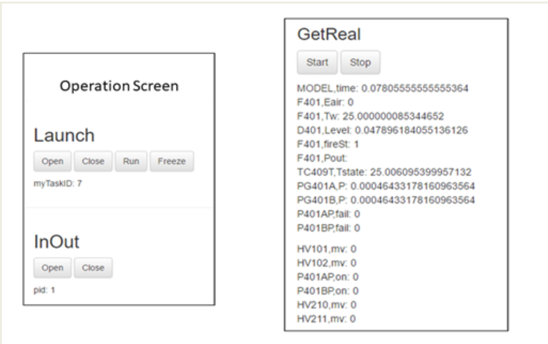


Figure 6: Instructional function for safety training

4.2 Connected dynamic plant simulator

In this system, bidirectional communication is performed between the simulator and the mobile terminal used by the trainee via a server in order to perform work training by distance collaborative work. Figure 7 and Figure 8 show the connecting of simulator when implemented with this system. The trainee performs work while confirming the behavior of the plant reproduced by the plant simulator with a portable terminal such as a tablet PC. At this time, the trainee inputs the operation amount of the operation target device to the tablet PC instead of moving the actual equipment. Each trainee in the control room and the work site carries out the work while communicating. Since the system using an internet browser, it can work with multiple users using a terminal connected to the network to share the real-time images on site and check the plant information by the simulator.



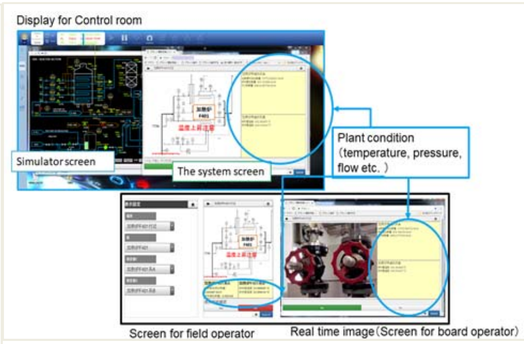


Figure 7: Operation screen for control

Figure 8: Connected dynamic plant simulator

5. Conclusion

Recently, it is pointed out that the site workers knowledge and skill is declining in the chemical industry fields in Japan due to several severe accidents occurred. Main causes of these accidents could be related to human behavior in the emergency operation. By investigating these accidents, it is recognized that employees have lower sensitivity to hazards by limited experience of hazards in their job site and in their early life. Most of the problem should be solved by high technology development and introducing to real plants. However, this is a primary safe measure and then requires on-site operator intervention. To improve this situation, the safety education and training system have developed to increase the ability to respond to emergencies such as the accident/disaster as a team. In the system, augmented reality (AR) technology for information presentation and virtual reality (VR) environment for education and training are applied, and dynamic simulator was used to describe the plant dynamic behavior. The main functions of this system are the selection and presentation of operation information, the acquisition and display of sensor data from the plant dynamic simulator, sharing real-time images, and communication by text message. In addition, the trainee can control plant simulator using mobile device. For the future, it is expected that this system will be applied to evacuation drills etc. using on-site workspace.

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