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Mobile Augmented Reality for Collaboration in Operation

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Abstract**—**Mobile augmented reality (MAR) tracking targets from the surroundings and aids operators for interactive data and procedures visualization, potential equipment and system understandably. Operators remotely communicate and coordinate with each other for the continuous tasks, information and data exchange between control room and work-site. In the routine work, distributed control system (DCS) monitoring and work-site manipulation require operators interact in real-time manners. The critical question is the improvement of user experience in cooperative works through applying Augmented Reality in the traditional industrial field. The purpose of this exploratory study is to find the cognitive model for the multiple task performance by MAR. In particular, the focus will be on the comparison between different tasks and environment factors which influence information processing. Three experiments use interface and interaction design, the content of start-up, maintenance and stop embedded in the mobile application. With the evaluation criteria of time demands and human errors, and analysis of the mental process and the behavior action during the multiple tasks, heuristic evaluation was used to find the operators performance with different situation factors, and record the information processing in recognition, interpretation, judgment and reasoning. The research will find the functional properties of MAR and constrain the development of the cognitive model. Conclusions can be drawn that suggest MAR is easy to use and useful for operators in the remote collaborative works.

Keywords**—**Mobile augmented reality, remote collaboration, user experience, cognitive model.

I. Introduction

VIRTUALLY continuum combines reality with virtual reality, and together forms an augmented reality as the derivative [1]. Augmented reality is an emerging technology that real-time superimposing computers generated content into a scene of the physical world. Through capturing current surroundings with a camera, users are able to interact with both the real world and synthesis graph. This technology had been used in the industrial field of design, maintenance, processing and layout. In 1990, Tom Caudell coined the term virtual reality and employed it to support Boeing`s engineering process. Even with the development of IT and communications, the head mounted device remained expensive and presented ergonomic issues, while a holographic projector has problems with visual quality and stability, and the smart mobile as a portable device has the potential for installation at a low cost. Augmented reality is developing rapidly in the field of education, entertainment and advertising. The mobile application in the production field will affect productivity for each factory, as a result of the integration of information and professional workflow. Augmented Reality may change the way that humans interact with machines.

Augmented reality can be used in different scenarios such as maintenance and control, training and support for the complex and interactive data and procedures visualization [2]. In the production industry, operators have to understand equipment specifications and operating procedure, and they need to monitor and maintain the system; also, operators have to troubleshoot and prevent accidents. MAR helps them track the data from the surroundings [3] for information exchange between colleagues. In multitasks, such as commissioning of the equipment and troubleshooting of system, some of the operators (monitors) are responsible for monitoring the distributed control system (DCS) in the control room, while other operators (inspectors) are inspecting the system and equipment at the work-site, the monitor and inspector have to remotely communicate with each other for real-time collaboration in continuous tasks.

A complex pipeline system and multifarious equipment synthesize the production workshop, such as the clean-type heat recovery steam generator project (HRSG). The first problem is the factor related to the working situation, the numerous system layouts and equipment specifications take mental focus and workload for operators with regard to either working memory or long-term memory. Secondly, remote communication such as the accuracy of the description by monitoring and misunderstandings of meanings by inspectors are susceptible to failed execution. The other problem is the collaboration among operators, which calls for adjusting the system and equipment in a timely manner in an emergency, the influx of data requests to monitor and ensure the safety of integrated system, and the change of device parameters updates inspectors and decreases damage to equipment.

A. Research Questions

Computer-supported cooperative works (CSCW) combine teamwork reorganization with application technology, which is supported by computer science. The characteristics include continuous task, remote interaction, communication and coordination. Effectiveness, efficiency and satisfaction are considered human-centered factors, so the critical question is how to improve the user experience of MAR in collaboration with operators.

1) How can operators be helped to reduce mental workload by the use of MAR?
2) What kinds of information can help remote communication between monitors and inspectors?

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3) How can operators be helped to cooperate with each other for task performance?

B. Objectives

In the collaboration of MAR, information exchange and data monitoring ensure the safety of a system, remote collaboration for the human-computer interaction is easy to understand, so that operators reduce the prevent inappropriate operation which can lead to serious consequence. MAR collaborated with traditional operation processing could improve user experience and reduce working stress for multi-task performance.

1) MAR could help operators maintain attention to predict for executive control.
2) MAR could help operators to have remote interaction for complex task performance.

Fig. 1 Circulating Water Pump

This research focuses on MAR supported collaborative work for operators for the commissioning of a circulating water pump (see Fig. 1). The operators have to deal with working situation, task-oriented work-flow, data communication and signal feedback. The result could be used for the centrifugal pump such as feed water pump; condensate pump; drain pump and circulating water pump in the steam turbine unit (see Fig. 2). According to the work content, MAR can expand to operation and maintenance in the production industry, and operation includes system monitoring and data recording, maintenance, including troubleshooting, equipment start-up and stop.

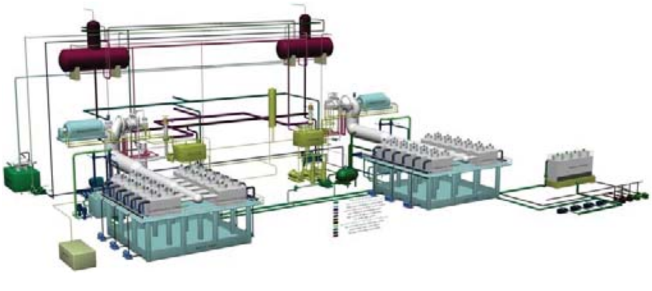


Fig. 2 Steam Turbine Unit

II. Literature Review

Augmented reality combines the real and virtual environment in a 3D space for real-time interaction [4], through overlapping text, image, animation or 3D objects into the real environment seamlessly [5], users perceive information as real in their surroundings [4]. From the first augmentation of real photos present in Auto CAD software with the evaluation of manual alignment, augmented reality can be applied in the collaboration of the layout arrangement. In order to improve user experience, MIT built a desktop system for 2D drawing, 3D simulation to relay out, from off-site to on-site collaboration [6].

As well as desktops, mobile devices are also applicable for augmented reality application. Mobile Augmented Reality (MAR) systems which enhance users' perception can be widely used anywhere and in any situation. With computer-presented information integrated with the real environment, they can real-time interact with MAR to pose and resolve queries, and collaborate with others [4]. In order to realize the technology, MAR is responsible for wireless communication and location-based services (LBS).

The virtual objects carry information for real-world tasks, which is more efficient than human performance. Tractica [7] investigated well-established MAR applications such as gaming and entertainment, and information. The principal analyst reported that categories such as retail and product visualizations, including industrial applications, will have a significantly higher user retention factor. The gradual promotion of MAR in industry is making slow progress which makes user research difficult to launch because of the working situation and classification, and therefore, it is a challenge to determine user needs and content requirements. Without enough specialized knowledge about the operation and maintenance, it is difficult for the researcher to find site objectives and functional specifications. This is a limitation in the development of MAR for maintenance and operation.

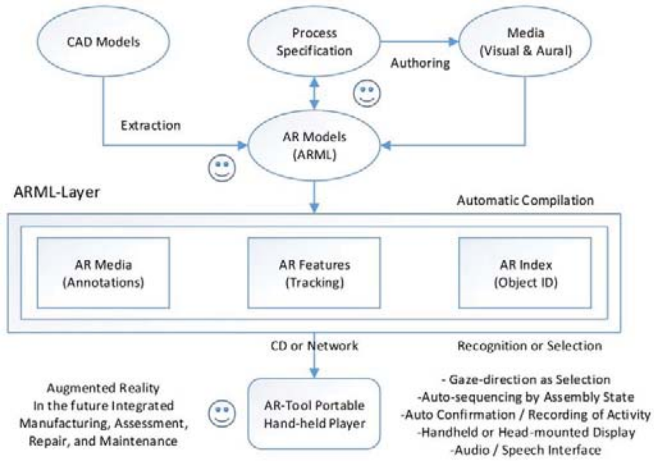


Fig. 3 Participants in Generating and Deploying AR Media

Augmented reality presentation is supplementary for human recognition processes, while cognitive psychology helps in information access, limit mistakes, improves user experience and task performance. Research creates AR media for annotation with instructions and information for manufacturing tasks, aircraft maintenance simulation using four methods: particular view, step guidance, automatic instruction, and selection to reveal. These types of AR media language (ARML) have the capabilities of information retrieval, prior knowledge, mental expectancy, procedural expertise, and reporting methods. The dynamics of information processing will improve user attention and discriminate functional and adjustable product [8]. The study provides a framework (see Fig.3) for deploying AR media and hopes integrate AR media with VRML, JAVA and HTML. However, it does not include any usability testing and experimental data, since the conceptual model needs to be tested in the real-life setting.

Collaboration helps multiple users' access and manipulates contextual information with independent locations, as a mechanism for human communication. A mobile collaborative AR enhances the remote presence between co-located users. A chess game demonstrates collaboration between a stationary user and a mobile user to communicate directly with virtual objects, and different hosts generated together share a 3D setting via the network for real-time interaction. Far field present world-stabilized 2D and 3D virtual annotation, near field manipulated browsed or navigated information [9]. The study provides a basis for MAR for the remote collaboration between stationary users and mobile users. However, the user interface needs an enhanced display quality, accurate interaction and a quick response. As a consequence, the performance of MAR automatically adapts to the negotiable platform [10].

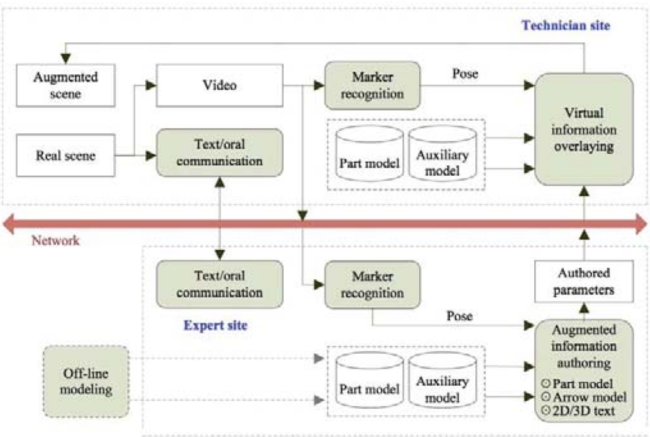


Fig. 4 Framework of AR based on a collaborative maintenance instruction platform

Augmented reality based on collaborative maintenance is a system used between remote experts and technicians for real-time instruction, and the network environment put forward to achieve efficient guidance for complex products. A framework of the instruction platform presents the maintenance processing with the scene, model and text information. The verification takes the example of gasoline engines which demonstrate static maintenance procedures and dynamic animated operation [10]. The research presents an AR-based framework (see Fig. 4), of which computer-supported collaborative instructions are used to exchange information for a knowledge intensive task. However, the laptop is not convenient enough to carry at the work-site, and operators need a portable device for the technician in an Internet environment.

Industrial Augmented Reality (IAR) applying emerging technology into product design, manufacturing, de-commissioning, inspection and maintenance, as the user expects automatic processing in a real-life scenario. Through critical evaluation by work-flow integration, scalability, cost beneficial, out of the lab, user tested, out of developers' hands, involvement of the industry, the researcher [6] found commissioning to have a specific and clear work-flow, and is necessary for industrial development. It seems difficult to create a prototype for commissioning. The reason is lack of integrated work-flow in the industrial application; they suggest that the research on the iterative process of the scalable solution be based on user feedback. The new IAR would not only improve user performance on routine tasks, but could provide guidance for new work-flow.

III. Methodology

Multiple monitors discuss the commissioning and work with distributed control system (DCS) in the control room, some inspectors manipulate equipment at the work-site with the aid of MAR, and they share the procedure and reference information in the multi-application environment [9]. Monitors need to understand the equipment situation that inspectors are facing at the work-site, as well as understand the system operating information given by the monitors in the control room [6]. For this reason, they have to collaborate with each other to avoid the volatility of the system and equipment.

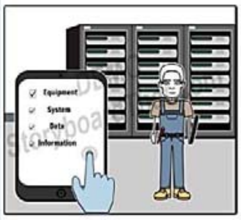
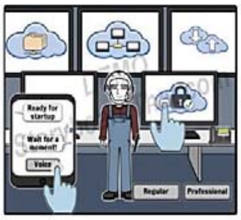
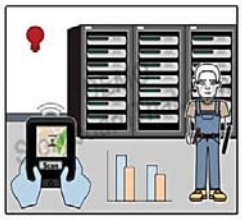
A. User Research

Through the questionnaire, the operators consider commissioning as a representative of operation that is an important for monitoring and inspection. After interviewing experts, it was found that manipulating procedure was not only a key issue to remotely collaborate in real-time, but also data information, in this experimental research, a circulating water pump was set up to convey cooling water to a condenser in a steam turbine unit.

In routine commissioning (see Fig. 5), monitors are responsible for signal collection and data analysis, while inspectors are responsible for the equipment operation. Thus, they remotely collaborate to ensure safety during production. When inspectors receive instruction from the monitors for the equipment manipulation [5], monitors supervise the value changes and predict system stability. After inspectors give feedback to the monitors about the operation procedure, the inspectors apply an instrument (vibration meter, infrared thermometer) for data detection. They exchange information in real-time from system preparation, to equipment start-up and stop, for the collaborative operation.

B. Interface and Interaction Design

After the user research, the Quality Function Deployment (QFD) statistic method was used analyze user needs and translate them into specific design processing. From the score of the user relative weight, the most often used modes were remote communication for cooperation, checking equipment structure, operating status and data collection.

	Check and Startup				
Sub Task	Ready to commissioning circulating water pump, compare progress mutually with task list	Personalization based on work content, and cooperate to startup pump	Monitoring startup & working current, detect noise of pump and motor, outlet water pressure	Every 30 minutes detect and record to fill circulating water pump commissioning operation table and save data	Operator detection of circulating pump inlet pressure, outlet pressure, main pipe pressure
Story Board					
Scenario	Kevin in worksite take potable device scan equipment and pipeline to make sure everything ready, Lee check information and data on DCS in control room	Lee send a voice massage to Kevin that ready for startup, after confirm DCS to click startup button and then monitor value changes about circulating water pump, meanwhile, guide Kevin select valve wrench to open outlet valve, manual rotate outlet valve to maximum	Lee keep attention of any warning with sound and flash whether startup & working current more than 57 ℃; Kevin take listening stick check special noise of circulating water pump and motor by recorder, analysis and check safety range	Kevin get notice and come back worksite, scroll wheel to fill form and save data, he share to Lee for backup after finish, Lee monitor circulating cooling system in 4 hours commissioning, Kevin check DCS interface with 3D diagram when necessary	Kevin scan instrumentation and main pipeline to get water pressure which come from DCS, and compare with each other to verify accuracy with difference, a data out of safety range, the alarm warning for troubleshooting, Kevin go and adjust valve opening to prevent accident
Considerations/ Influencers	How can they synchronization complete inspection?	Which method easy to use for communication in such noisy environment?	How could get sensitive of vibration value increased which beyond safety range?	How could operator recording startup current, at the same time opening outlet valve?	How operator get accurate information by increase sensitivity and improve detection efficiency?
Pain-Points	Check items omissions cause system or/and equipment startup failure (human error: lapse)	Operator lack of experience to use F (valve) wrench that rotation to open outlet valve (human error: knowledge based mistake)	Operator misjudge the vibration of pump and motor lead to bearing damage (perception: tactile and audio sensation)	Operator forget to save the data and without any backup (human error: lapse)	Operator don`t know what should do first at emergency situation, and lost chance for troubleshooting (decision making)
Functionality	1. Dynamic Articulation: Ability to check equipment structure; (6.0; 5.6)	1. Interactive Audio: DCS & pump exchange startup massage; (7.6; 5.2)	1. Measurement: Noise of equipment; (7.2; 4.5)	1. Contexture Listing: Recording sheet with value scope for fill/save/ share/backup; (4.7; 6.0)	1. Change Skin: Monitor flow variation and early warning; (5.8; 4.5)
	2. Contextual Listing: Ability to follow up progress; (4.7; 4.5)	2. Tool Selection: Guide valve opening by using of testing tool; (4.6; 3.0)	2. Image Guidance: Startup current & working current; (5.9; 1.5)	2. Architecture Diagram: Ability to tracking status and signal on DCS interface; (4.7; 5.2)	2. Flow: Main pipeline & outlet/ inlet water pressure; (5.9; 3.7)
		3. Label: Quickly access module with custom settings; (5.3; 2.2)		3. Interactive Audio: Provide reminder service for periodic check; (7.6; 2.2)	3. Measurement: Ability to verify accuracy of meter by simple calculation; (7.2; 3.0)

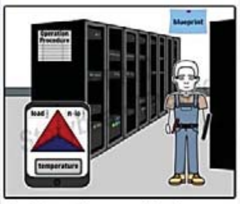
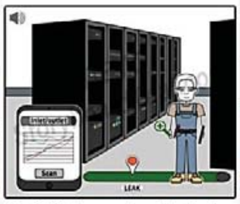
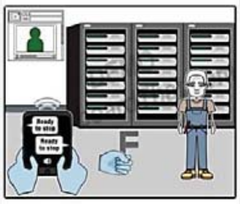
	Maintenance and Recording			Stop	
Sub Task	Pump and motor bearing temperature of load side and non-load side	Horizontal, vertical and axial vibration of pump and motor in load side and non-load side	Check leakage of oil and water, lubricating oil level, inlet and outlet temperature of circulating water	Connect with each other, screw outlet valve, switch-off circulating water pump on DCS display	After pump stopped, if reverse, should change electric valve to manual close
Story Board					
Scenario	In dark environment, Kevin turn on flashlight assist camera track pump, but he need distinguish load and non-load side, click metaphor to open blueprint and also get aid how to use infrared thermometer, detect bearing temperature which less than 65 ℃, motor temperature less than 55 ℃	Lee send voice massage ask check process , Kevin response that he can`t find gauging points, Lee search database and send 3 videos about detection from horizontal, vertical and axial orientation which vibration less than 0.06mm, Kevin scan equipment and relevant part pop up for help	On DCS, Lee monitor inlet/outlet temperature of circulating cooling water, after scan system diagram that he get line chart every half hour which no more than 10 ℃; in worksite, Kevin looking for leak point and mark out on module, he labeling the oil level less than 1/3 need oiling in the near future	Kevin finish the final detect and data record, he send a massage to Lee ready to stop, Lee make sure the safety of system and send a video support Kevin to close outlet valve, after close by valve wrench and notice Lee for click stop button on DCS screen	After circulating pump stopped, find reverse of motor and flow backward in pipeline though scan system and equipment, he change electric valve to manually shut down, tell Lee outlet valve closed .
Considerations/ Influencers	How to improve working efficiency that operator keep attention on monitor system and equipment?	How could make sure measuring point correspond with the data recorded correctly?	How to locate and check leakage point (seal, flange, plug, coolant) with easy ways?	How could match cooling water system condition with stop of circulating water pump?	How to check liquid flow direction in pipeline system?
Pain-Points	Operators monitor equipment operating status, but bearing temperature deviation from the normal range for a long time (situation awareness: monitoring)	Accidentally fill in the data of vertical column to axial column after detect vibration, vice versa (human error: slip)	Operator let slip of a leak point, without cooling water cause motor burned out (Human error: slip)	Operator completely close outlet valve, and stop pump on DCS, without pre-close the circulating water pump at first (Human error: rule based mistake)	Operator does not recognize the pump reverse situation, resulting in the damage of motor (situation awareness: cue detection)
Functionality	1. (Dis)Assembly: Pump/motor bearing temperature of load/non-load side; (7.1; 4.5)	1. Video Guidance: Remote cooperation by text/voice/video; (5.3; 6.0)	1. Architecture Diagram: Inlet & outlet temperature of circulating cooling water; (4.7; 4.5)	1. Video Guidance: Pump switch off status from DCS; (5.3; 5.2)	1. X ray: Ability to scan and check circulating pipeline system. (6.6; 3.7)
	2. Label: Turn on flashlight in dark surrounding; (5.3; 3.7)	2. Occultation: Horizontal, vertical and axial vibration of pump/ motor; (9.8; 6.0)	2. Label: Mark leak points/oil level by label; (5.3; 4.5)	2. Interactive Audio: Pump outlet valve close massage; (7.6; 2.2)	
	3. Product Description: Ability to check procedure or blueprint by metaphor; (5.3; 1.5)	3. Rotation and Zoom: Guide operator find gauging point; (8.6; 3.0)	3. Image Guidance: Ability to statistic and analysis data with line chart; (5.9; 3.7)		

Fig. 5 Commissioning Operation of a Circulating Water Pump

In product design, Questions, Options, and Criteria (QOC) is used to optimize the function requirements and balance the choice for the information architecture. From MAR, the most popular medium used includes images of texts and graphics, 3D models of sections and exploded view, as well as AR videos. Comprehensive analysis of the commissioning situation, user-based and function-based relative weight are combined to create the application (see Fig. 6) of the MAR.

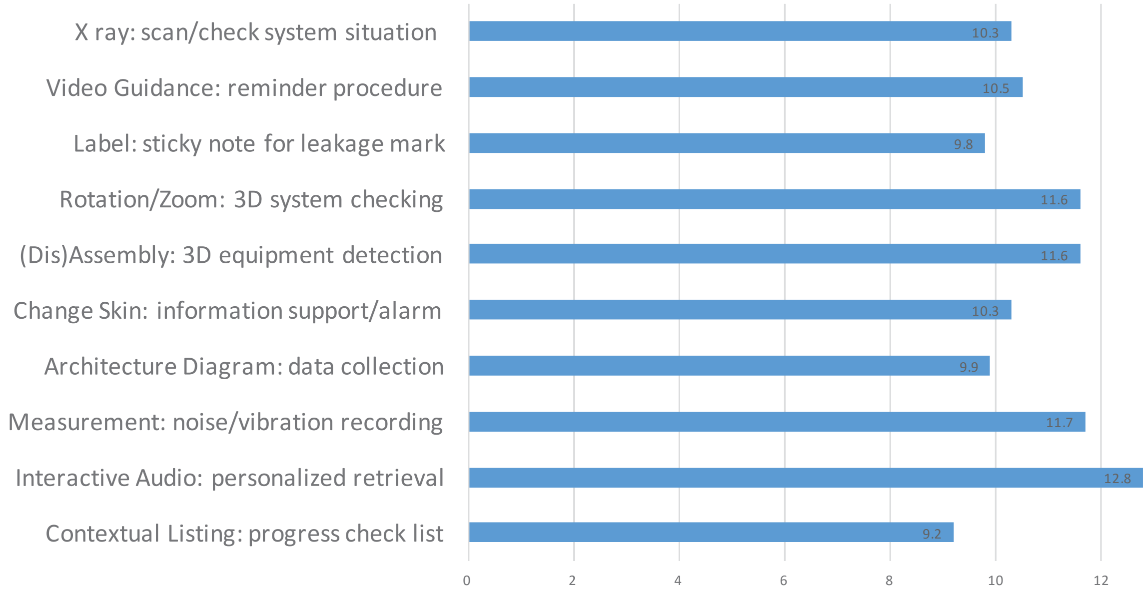


Fig. 6 Application-based Relative Weight

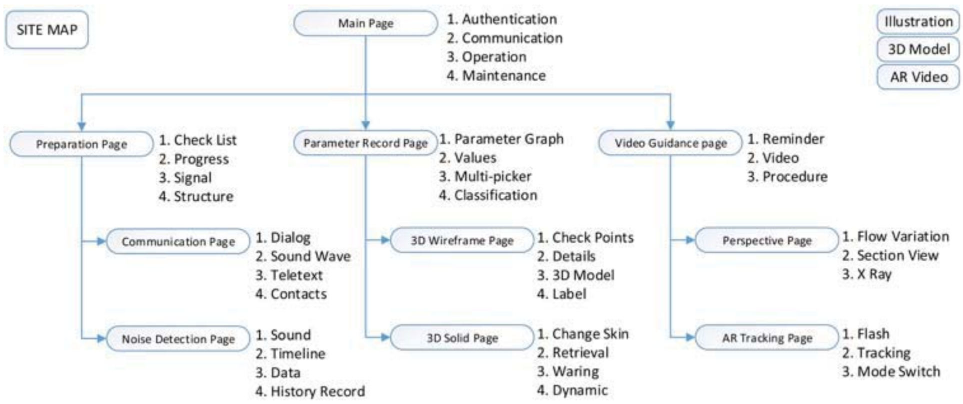


Fig. 7 Interaction Flow Chart

In order to integrate information to design the user interface, the information structure (see Fig. 7) is divided into three main parts with an event-based layout. Check and start-up tasks take audio and text as the preparation group, and are responsible for item check, information transfer and signal record. The task of maintenance takes a 3D model as a parameter record group, is responsible for data collection, technical support, and information retrieval. The task of stop takes AR (video) as a video guidance group, is responsible for indicating a problem, acts as a reminder situation, and system scanning. Even though the information architecture is lacking equipment and system classification, they are evenly distributed in the sequence and easily accessible, so as to quickly reach the aim from root node to leaf nodes. It takes four steps at a minimum and nine steps at a maximum for intermediates and experts, and even novices, to scan the target get the information needed.

As a function-oriented design, data visualization for the operating record, such as line chart easy understanding, fish-eye solves the limitation of screen size. Bold and minimalist content for an intuitive and natural interface, for instance, are assistive touch scans which can be accessed rapidly. Color and iconography emphasize actions, like a real-life situation embedded in an adjustable translucent interface. Animations and dimensional affords interaction, such as a GIF file or AR video help understand complex problems [12].

Fig. 8 Mobile Augmented Reality User Interface

The prototyping of the mobile application is created by the software of Justinmind, and installed on an iPhone 6Plus. The problem of the prototyping (see Fig. 8) is the difficulty to turn on the camera for real-time testing, so pictures of the real-life situation are used for the tracking background instead. As a user-centered design, the product needs extra attention on situation awareness, self-determination, remote collaboration and human error. For the interaction aspect (see Table I), some functions already realized in this prototyping, including collaborative operation and expert instruction, and other functions are expected for future use.

TABLE I
SUPPLEMENTARY EXPLANATION AND EXPECTATION

1. IPhone 6 Plus IOS 9	6. Slip
Personalization: Role definition Camera: Scan objectives Categories: Modularization Icons: Ease of recognition	Measuring Point: Pre-marked & labeled Magnifier: Working principle Details: Specific situation Information Sort: 3D visual display
2. Rule-based Mistake	**7. Decision-making**
Checklist: Follow up progress Fisheye: Information tracking Signal: Synchronous operation 3D Equipment: Intuitive items	System Retrieval: Data collection System Identification: Change skin Automatic Diagnosis: Early warning Dynamic Model: Troubleshooting
3. Knowledge-based Mistake	**8. Knowledge-based Mistake**
Cognition Library: Speech conversion Collaborative Operation: Judgment Audio Frequency: Volume adjust Contacts: Selection of operators	Reminder: Communication Expert Guidance: Specification Tool Selection: Data requirement More Info: Operating Procedure
4. Perception	**9. Cue Detection**
Pre-recorded: Represent data Accurate Data: Identification Data Analysis: Understand record Three-axis Measurement: Wireless	Orthographic View: 3D reconstruction Zoom in/out: Ease of observation Flow Variation: Reverse awareness X Ray Animation: Catch attention
5. Lapse	**10. Monitoring**
Laser Pyrometer: Check temperature Stroboscope: Detect speed Multi-picker: Upper and lower limits History Inquire: Contradistinction	Flash: Environment detection Style-box and Spinner: Assistance QR Code: Check point recognition Mode Switch: Information gathering

C. Usability Testing

Six subjects were selected from a university with different academic backgrounds, which are associated with the position set in clean-type heat recovery steam generator projects (HRSG), operators in six working units that remotely collaborate with each other for real-time task performance, boiler unit, desulfurization unit, water treatment unit, steam turbine unit, electrical unit, and thermal control unit. In order to recreate the scenario and position for testing, the subjects were selected from with backgrounds in mechanical engineering, environmental engineering, chemical engineering, production engineering or automation engineering. This experiment measures the performance on task actions, such as task completion time and task performance rates, as well as a heuristic evaluation which assists in investigating the user interface and understanding the usability of the application. This testing was set for subjects from the engineering faculty, who used a smartphone with the Justinmind application. A camera was used to record the performance and a stopwatch was used to record the time taken, as the subjects performed the experiment while following the task list. After executing the tasks, the subjects were required to complete a system checklist applying critical evaluation.

This experiment explores the collaborative operation, and also gathers assessment data about the effectiveness of MAR. The experiment is divided into three groups (see Fig. 9) by task performance. Group 1 was required to gather visual information during operation. Participants are asked to scan the objects to observe the liquid flow direction in the system and detect the equipment's internal structure. If the warning dialog appeared on the MAR interface, the subjects were required to check the supported data or search for relevant information to make the correct decision for the manipulation. Group 2 involved monitoring for potential risks. The subjects are asked to collect equipment operating data and check history records. They collaborate with each other to remotely communicate to identify abnormal data, and to then make the necessary operation adjustment. If the data were recorded normal and stable, the subjects needed to check the task procedures to go to the next step. Group 3 was required to record data as part of a routine inspection. The subjects were asked to collect data about vibration and temperature, classify the information and analyze the data, and mark failure points or checkpoints by using virtual label as the warning. If they experienced problems during the inspection, an AR video was available to instruct them about the specification.

IV. RESULTS

The results were used to verify the usability of MAR used for the remote collaboration between operators in the production industry. The test results were divided into four aspects: task performance, time taken, satisfaction and heuristic evaluation.

Fig. 10 presents the differences in user performance among the 10 sub-tasks. It shows that 33% of subjects failed in the execution of sub-task 4 (awareness). The subjects found it difficult to detect the clues about the flow direction after tracking; the reason was that the perspective of the 3D equipment is very important, in order to grab the attention of the subjects in the complex system. A total of 17% subjects failed on sub-task 6 (task processing) and sub-task 10 (equipment specification), they did not have experience about this working procedure; it was easy to make lapses or rule-based mistakes, and therefore, the application is better for the trained novice or intermediate. That is as 33% of the subjects considered sub-task 2 (track or scan objects) and sub-task 3 (information retrieval) biased in tough performance situations, and the tracking point created a problem for the subjects in getting the required result, and the data support was regarded as limited and failed to meet their needs, and therefore information optimization and being able to mark the points of failure are helpful to users for accurate decision-making.

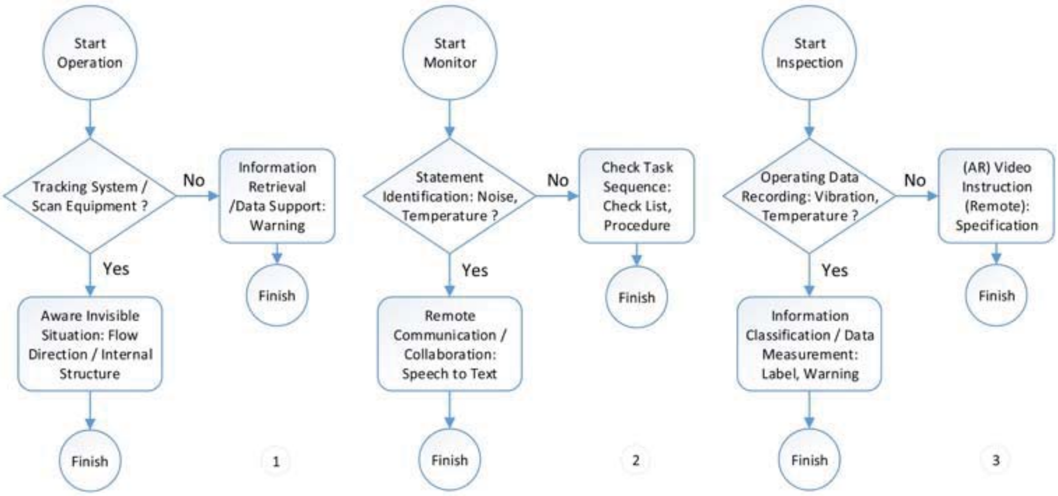


Fig. 9 Action Sequence of Collaborative Operation

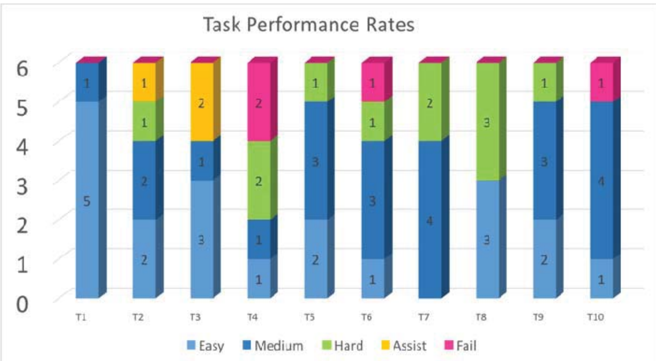


Fig. 10 Task Performance by Scored Criteria

Fig. 11 Time Spent on Task Performance (Mean)

Half of the subjects believed that sub-task 8 (data collection) and sub-task 9 (information recording) were not easy for information classifying, recording, retrieving and checking, this calls for a well-organized system to have personal and public information available and which is distinguished by access permission [11]. Meanwhile, 33% of subjects thought sub-task 7 (remote communication) was difficult for execution. For the knowledge-based mistake, they believed that MAR supported collaborative works to relieve operators from the heavy stress of dealing with multiple tasks, and if operators need to solve the complex problem, they might confuse the information selected; the key point is the information priority issues of Augmented Reality. In summary, the subjects showed high performance on all tasks, and the results provided the direction and recommendations for future studies.

Fig. 11 shows the average time taken to complete each task. It shows that sub-task 4 (clue detection) and sub-task 6 (action sequence) take more time (around 58.4 seconds), much higher than the mean. Except for subtask 1, the values of other sub-tasks take around 40 seconds on average. The reason for sub-task 4 taking 58.2 seconds was due to situation awareness, which takes a long time to find the understand during system monitoring, and therefore the subjects required to rely on their working memory to make a decision before the information gathering was complete, creating stress. The reason of sub-task 6 lasting 58.7 seconds was the skill-based lapse, as subjects take existing processes in the procedural knowledge, and mistakes occur when the rule invoked does not match the actual situation, and therefore, they needed more time to recover from the negative situation. The likelihood of mistakes is increase for the stage of working memory, which meant that more time was required for information processing for completing sub-task 4 and sub-task 6. The solution could be a helpful and informative notification when operators are faced with a complex task.

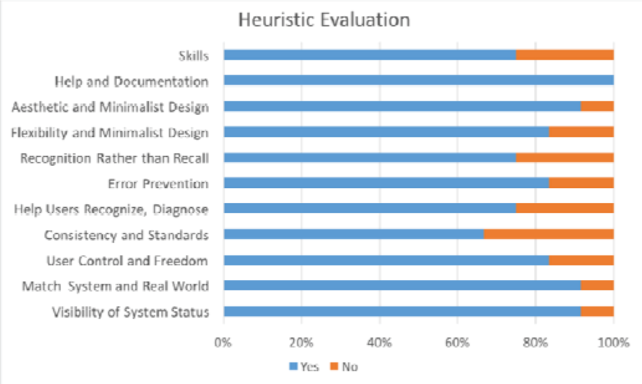


Fig. 12 Heuristic Evaluation Statistic

Fig. 12 presents that the heuristic evaluation for the MAR application. Six subjects were used as evaluators, while 78% of the usability problems in the user interface were detected by the prediction formula created in 1993 by Nielsen and Landauer. Some 33% of the subjects highlighted problems related to consistency and standards. The color and transparency make it difficult to attract attention on the interface, in order to embed information into the real world. Transparency is a method for the user to recognize the situation, and also color selection is important for the presentation mechanism such as body-stabilized and world-stabilized presentation [9]. Another 25% of subjects pointed to problems with regard to aspects of recognition, diagnosis, and skills. The system supports both novices and experts; however, the MAR application needs the function of feedback for error prevention and correction, such as informative notifications. The application has visual clues for easy scanning; while the failure recognition icon may easily mislead subjects between controls and actions. The mobile interface operations are easy to learn and use, as a function-oriented application, the system needs more functions to adjunct and be applied to the turbine unit.

Meanwhile, 17% subject thought that there were drawbacks with regard to flexibility, freedom and error prevention. With a catalog shortcut for quick accessibility and flexibility, both novice and expert operators could track information on multiple levels. The low-frequency task has the responsibility to make it easy for operators to easily remember, such as troubleshooting, and they can easily reverse their action in the task performance. The MAR application prevents operators from making errors by proving the required supporting information, and optimizing entry memory which improves the working efficiency for information retrieval. Only 8% of the subjects considered the visibility of the system status, match between virtual and reality, a minimalist design. After operators finished a group task, they could check the working procedure or get navigational aids, such as place markers, for notification of the tasks consistent with the necessary action, such as data recording to get the exact values for decision-making. Only essential information is present on the MAR interface, the labels are brief, familiar and descriptive. Most of subjects believe that the MAR application is helpful in the production industry, as well as in their fields. The information should be accurate, complete, and understandable. Overall, the interface of the MAR application receives 82% approval for high performance, while 18% say small imperfections need to be improved.

Fig. 13 Perceived Ease of Use and Usefulness

Fig. 13 shows the evaluation of MAR applied in the production industry for remote collaboration between operators. The statistic methods take a one sample T-test, and presents the average satisfaction of easy to use (M=5.2) and usefulness (M=6.2), which are significantly easier than the norm (M=3.5). The effect size is large. Most of subjects believe that the MAR application is easy to use (72.3%) and useful (88.6%). In conclusion, MAR is easy to use among operators and is useful for the remote collaborative task.

V. Conclusion

This research discusses how the MAR application assisted to operators for remote cooperation during complex task performance. In the commissioning of a circulating water pump, the operators used the MAR device to aid them in task execution during routine works. The literature review found a gap between MAR and remote collaboration. The application was created with the characteristics of data and information visualization for a user interface, and remote communication and cooperation for interaction design. After testing the mobile device, the results verified that MAR helps operators hold their attention to predict for executive control; also the application helped operators in remote interactions in regard to complex task performance. Thus, the application could have widespread appeal because of its usefulness and ease of use.

Augmented reality can be used to track the attention of operators, to check equipment and systems, as well as record and classify data for decision-making. Operators can take MAR access to the public interface check, and it could be concluded that MAR is easy to use and useful and allows for optimized data and information retrieval, and access in a private interface allows to operators to stick personalized virtual notes. Most importantly, MAR supports collaborative works and helps train novice and intermediates in real-time remote communication, so as to relieve working stress and avoid human error. User interface data visualization inspires operators to cooperate between monitors and inspectors in the multiple task performance. Color and transparency are two main factors that influence the presentation mechanism and the appropriate MAR pattern contributes to symbol recognition, which instructs on the task execution. With the help of MAR and assistive shortcuts, operators can quickly access the multiple levels and track information, such as the labels for problem-solving. Positive feedback supports accurate and understandable information for operators for prevent errors, such as notification offering brief descriptions, etc.

For the future works on interaction, MAR needs to add more functions and apply them in the complex system. For example, positive feedback can benefit clue detection so as to prevent and correct errors. Perspective adjustment helps operators to hold attention during AR tracking. Intelligent notifications assist operators in routine task processing providing optimized information. For the interface, MAR needs to be improved with regard to data and information visualization, so as to help reduce the mental workload for operators. For instance, infographic classification can benefit low frequency tasks to be remembered easily. Presentation mechanisms assist operators in image recognition with consistency and standards. The procedure priority criteria support operators in collaborative works so as to avoid knowledge-based mistakes.

REFERENCES

[1] Billinghurst M, Kato H, Poupyrev I. MagicBook: transitioning between reality and virtuality. In: CHI' 01 Extended Abstracts on Human Factors in Computing Systems. New York: ACM, 2001. 25–26.

[2] Diotasoft, Augmenting Industries, 2016, Augmented Reality for the Industry (Online), Available: http://www.diota.com (July 02, 2016).

[3] Colley, A., Häkkilä, J., Rantakari, J., 2014, "Augmenting the Home to Remember – Initial User Perceptions", UBICOMP '14 ADJUNCT, Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication, September 13 - 17, 2014, Seattle, WA, USA, pp. 1369-1372

[4] Mekni, M., Lemieux, A., 2014, "Augmented reality: Applications, challenges and future trends", In Proceedings of the 13th International Conference on Applied Computer and Applied Computational Science (ACA-COS '14), volume 20 of Recent Advances in Computer Engineering Series, April 23-25, 2014, Kuala Lumpur, Malaysia, pp. 205-215.

[5] S.K. Ong, J. Zhang, Y. Shen, A.Y. Nee. Augmented reality in product development and manufacturing. In Handbook of Augmented Reality (2011), pp. 651–669 Springer New York.

[6] P. Fite-Georgel, "Is there a reality in Industrial Augmented Reality?" In 2011 10th IEEE International Symposium on Mixed and Augmented Reality, 2011, pp. 201–210.

[7] Tractica, Augmented Reality for Mobile Devices, 2015, Installed Base of Mobile Augmented Reality Apps to Reach 2.2 Billion by 2019 (Online), Available: https://www.tractica.com/research/augmented-reality-for-mobile-devices/ (June 18, 2015).

[8] U. Neumann and A. Majoros, "Cognitive, Performance, and Systems Issues for Augmented Reality Applications in Manufacturing and Maintenance," Proc. IEEE Virtual Reality Ann. Int'l Symp.(VRAIS 98), IEEE CS Press, Los Alamitos, Calif., 1998, pp. 4-11.

[9] Reitmayr., G, Schmalstieg., D, 2001, "Mobile Collaborative Augmented Reality," In Proc. ISAR'01 (Int. Symposium On Augmented Reality), 2001, New York, NY, USA, pp. 114-123.

[10] Wang, J. Feng, Y. Zeng, C. Li, S. (2014). An augmented reality based system for remote collaborative maintenance instruction of complex products. In IEEE International conference on automation science and engineering (CASE), Taipei, Taiwan. pp. 309-314.

[11] Lin, T., Liu, C., Tsai, M., and Kang, S., 2015, "Using Augmented Reality in a Multiscreen Environment for Construction Discussion", Journal of Computing in Civil Engineering, 2015, 29(6): 04014088.

[12] B, L, Chui. L, Kunho. (2015). LG`s G3 GUI: A slick smartphone GUI rides the new wave of digital modernism. In magazine of interactions, volume 22 issue 1, January and February, New York, NY, USA. pp. 12-15.

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