A Training-assistance System using Mobile Augmented Reality for Outdoor-facility Inspection

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***Abstract*— A training-assistance system using mobile augmented reality (AR) for outdoor-facility inspection was designed, developed, and evaluated. In inspection training for pole-mounted communication facilities for electric power supply operation, the realization of efficient, effective, and autonomous learning is desired. In light of these, three AR functions supporting inspection training, namely, pole navigation, visualization for facility attributes, and facility-defect search, were proposed. To realize these functions, a hybrid tracking method for accurate AR overlaying was proposed. Moreover, a prototype system was developed and evaluated at a real training site. The evaluation results show that the proposed system supports efficient, effective, and autonomous learning. In other words, AR technology can be applied to training in outdoor-facility inspection.**

Keywords-augmented reality; facility inspection; training assistance.

I. INTRODUCTION

Recently, demand for using smart devices has been growing, such as smartphones and tablets, to access various types of information during field work. Furthermore, with improving performance of such smart devices, “augmented reality” (AR) has been increasingly becoming a strong tool for supporting field work in various industrial segments [1]-[6]. In the electric power industry, improving efficiency of facility maintenance while retaining reliability has become a significant issue. Conventionally, high reliability of pole-mounted facilities for electric-power supply operation is ensured by periodic inspection. Recently, succession of inspection skills and maintaining inspection quality have become more important. Therefore, to nurture experienced inspectors, a supporting framework for efficient, effective, and autonomous learning is desired. As for the inspection training, a training assistance system using AR technology may become an useful solution.

In this work, a training-assistance system using mobile AR technology for inspection training of outdoor facilities was proposed. The organization of the paper is as follows. In section II, the workflow of typical inspection training was surveyed. On the basis of survey results, required AR functions for supporting the training were established in section III. After the requirements were defined, an AR-based training-assistance system and an effective user interface were designed, and several technical methods for the system were proposed in section IV. In section V, a prototype system was developed. In section VI, the availability and practicability of the prototype was evaluated by active workers and trainers at a real training site. On the basis of the evaluation results, the applicability of mobile AR technology to training in outdoor-facility inspection was examined. In section VII, some related works are introduced and compared with our work. Finally, the conclusion and future works are described in section VIII.

II. ISSUES CONCERNING INSPECTION TRAINING AND RESEARCH OBJECTIVE

Electric-power companies manage their communication facilities for electric-power supply operation. The inspection-target facilities (e.g., communication lines and ancillary equipment such as hangers and closures) are mounted on utility poles. Conventionally, communication facilities are maintained by periodic inspection. During the inspection of a facility, inspectors visually check the condition of the facilities (e.g., cracks, rust, distortion, various separation distances, and botanical collision). To check a facility comprehensively, an inspector has to learn the accurate knowledge about the target facilities, namely, the type, specification, normal and abnormal conditions. Recently, succession of inspection skills and maintaining inspection quality have become more important. Therefore, to nurture experienced inspectors, an effective training framework is desired. The objectives of the inspection training are described as follows.

(1) Ensure trainees understand types, specifications, and structures of the facilities.
(2) Ensure trainees understand how to inspect the facilities. That is, trainees are taught to concretely judge whether conditions of each facility are normal or abnormal and find defects comprehensively.

In the inspection training, the trainer gives several trainees specific guidance on inspection know-how. Improving efficiency of the training and trainees’ understanding are crucial issues.

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In consideration of these issues, AR technology was applied to facility-inspection training with the aim of realizing efficient, effective, and autonomous learning. Furthermore, a prototype training-assistance system using mobile AR technology was designed and developed, and its availability and practicability were evaluated at a real training site.

III. FUNCTIONAL REQUIREMENTS

First, in this section, a conventional training workflow is defined. Second, functional requirements to support the workflow and the system concepts are proposed.

A. Training Workflow

The inspection training is performed in a training site containing mock utility poles and pole-mounted communication facilities. Certain types of defects were preliminarily set in the mock facilities. The conventional training workflow is explained as follows. First, the trainees confirm the inspection target on a (paper) facility map. They move to the target and identify it while confirming it on the map. They confirm the target facility and its details (type, specification, structure, and so on) using paper-based manuals. After confirming the facility details, they check the condition of the target against a checklist. In other words, the trainees search for the preliminarily set facility defects. When they find a defect, they write an inspection report. These steps are performed at all facilities. Finally, the trainees receive feedback from their trainer.

B. Functional Requirements and System Concept

Functional requirements for the training-assistance system using mobile AR are described as follows. The system is "paper-less" and implemented on a general-purpose tablet. In view of applicability to the inspection training, the conventional training workflow should also be supported by the system. To realize efficient, effective, and autonomous learning, the three main AR functions required are summarized as follows.

(1) Pole navigation
Trainees confirm their location and surrounding facilities on a digital facility map and AR. The system assists in identifying the target facility.

(2) Visualization of facility attributes
Trainees acquire facility information (type, specification, structure, and so on) by AR, which enables the user to link the real facility to that information.

(3) Facility-defect search
The system not only provides defect information to trainees but also assists autonomous defect search utilizing AR.

IV. SYSTEM OVERVIEW

This section describes technical detail of the proposed system and the concrete methods to satisfy the three above-listed AR functional requirements.

A. Pole Navigation

Conventionally, trainees move to a target facility while confirming the target location on a map. Therefore, a facility-navigation function for identifying the target was devised. The function informs the trainees of their relative locations in regard to surrounding facilities. The proposed pole-navigation method and user interface are shown schematically in Figure 1. The location (latitude and longitude) of each utility pole is stored in a database. A rough user location is obtained from the GPS (global positioning system). User heading is obtained from acceleration and geomagnetic sensors mounted on the tablet. First, surrounding facility's data is retrieved from the database on the basis of GPS location of the user. Location and heading of the facility in relation to the user are calculated. On the basis of the calculation results, AR tags are mapped onto the tablet's screen as shown in Figure 1. The center of the screen represents user location. Each AR tag shows the relative distance and heading of surrounding poles. Relative distance from each pole to the user is represented by the tag's color and size. These AR tags are rendered every time the GPS location and user heading are changed.

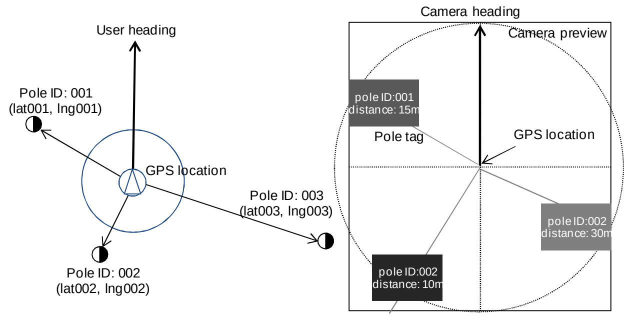


Figure 1. Pole-navigation function and user interface.

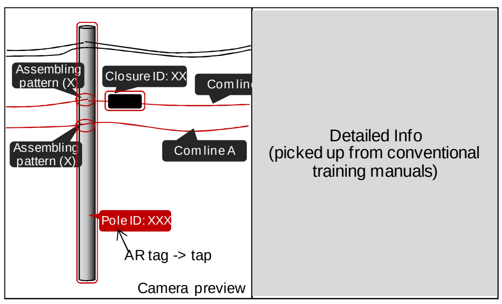


Figure 2. Visualization of facility attributes and user interface.

B. Visualization of facility attributes

This function enables visualization of facility information (hereafter, attributes) using AR. The function and user-interface design are summarized in Figure 2. The AR contents are defined for each type of facility. Detailed information is not suitable for visualization by AR because it is "floating" in accord with the live camera motion of the tablet. Therefore, AR is only used to point out the position of the target. Facility ID or type is displayed using AR. If the user taps an AR "balloon," detailed information appears on the right side of the screen. In this way, the user can link the real facility to related information.

To realize the function explained above, an accurate AR method is needed. In general, AR technologies are classified as vision-based or location-based methods [7][8]. Vision-based methods identify target objects by using features obtained from images. Moreover, they can be categorized as either of two approaches: marker-based [9] or marker-less [4]. In case of marker-based approaches, the target objects are identified by recognizing artificial markers. Applying marker-based approaches to pole-mounted facilities seems a distant prospect because an enormous number of markers are required. Location-based methods, on the other hand, identify target objects on the basis of GPS location, heading, and geographical locations of target objects [10][11]. While such approaches have a merit of low computational cost, their identification accuracy is low because of measurement errors. The location-based method seems to be suitable for this case because geographical locations (latitude, longitude, and ground height) of the facilities are already stored in the database.

Therefore, in our previous study, a robust identification algorithm was proposed [12]. The algorithm is an advanced approach for conventional location-based methods. It uses GPS data as well as data from acceleration and geomagnetic sensors. Concretely, the facilities are identified on the basis of not only a tablet's current location and heading obtained from these sensors but also object distance (i.e., the distance between the user and the object being inspected) by a triangulation method using acceleration and geomagnetic sensors. The facilities can be identified robustly without being influenced by measurement errors of the sensors.

A target facility is initially registered and AR objects are overlaid accurately by a robust identification method. After the target is identified, it should be continually tracked so that the AR contents can be overlaid accurately. Therefore, a hybrid tracking method is proposed. The proposed method realizes accurate tracking using a combination of tablet's attitude angles and line-detection results from camera images (see Figure 3). First, the overlaid AR objects after the robust identification keep tracking the target facility by using the tablet's attitude angles (yaw, pitch, and roll) as shown in Figure 3(a). Simultaneously, line objects are detected by using a probabilistic Hough transform and line-segment clustering (Figure 3(b)). The objectives of line detection are horizontal lines corresponding to the communication lines and vertical lines corresponding to the utility pole. In an outdoor situation, it is difficult to detect these lines only because captured images contain various background noises. Detected line objects are therefore narrowed down (Figure 3(c)). Concretely, detected line objects located near the sensor-based AR objects (Figure 3(a)) are extracted. The amount of horizontal correction is calculated by using the AR object for the pole and a couple of vertical lines (Figure 3(d)). The amount of vertical correction is calculated by using the AR object for the communication lines and the same number of horizontal lines (In Figure 3(e), the number of lines is two). The overlaid positions of the AR objects are translated by using these correction amounts. These steps are launched after the identification process is finished and repeated. In the training operation, the AR rectangles and lines shown in Figure 3(a) are hidden, and this procedure is performed in the background. The accurate tracking by the proposed hybrid tracking method realizes our training assistance functions.

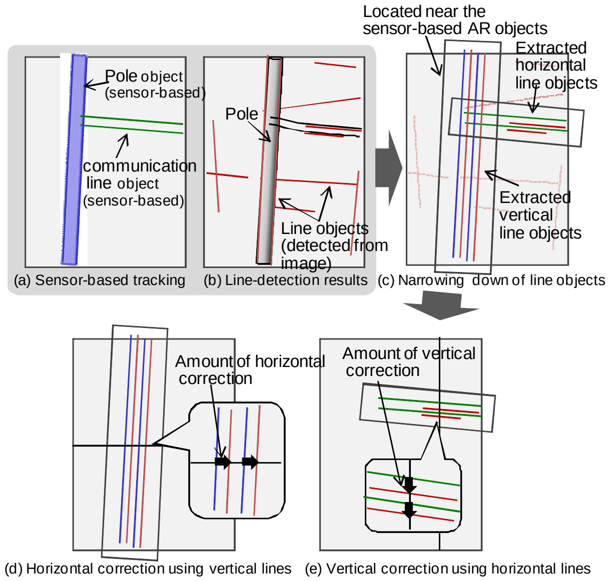
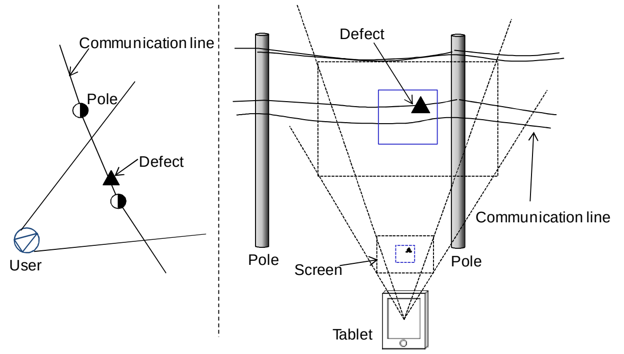


Figure 3. Summary of hybrid tracking method.

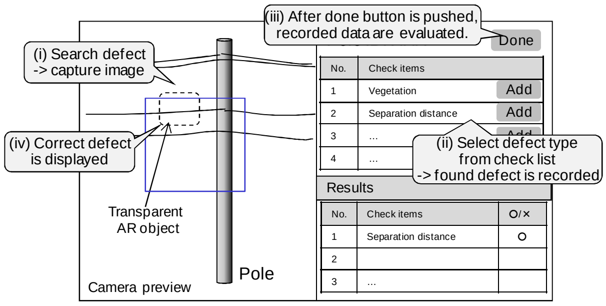
C. Search for facility defects

As mentioned before, the training facilities have some preliminarily set defects. The trainees learn how to inspect a facility by searching for these defects. The training-assistance system should not only provide defect information to the trainees but also assist autonomous defect search using AR. Therefore, a function for searching for autonomous defects is proposed. A summary of the proposed function is described in Figure 4. The defect locations (latitude, longitude, and ground height) are also stored in the database. AR objects for the defects are overlaid as transparent objects. The correction amounts obtained from the hybrid tracking method are used to overlay the AR objects for defects, too. First, the user searches for a facility defect. If the user finds a defect, they capture an image containing the defect the inside of the blue box shown in Figure 4(b). After capturing the image, the user selects a corresponding defect type from a check list. Once a defect type is selected, the captured image and selected defect type are linked and recorded. After the defect search is finished, the recorded results (i.e., defect type and position) are evaluated. That is, captured-image position and selected-defect type are checked by comparing them with actual defect data, and the user is informed whether or not their recorded data is correct. Finally, a hidden AR object is displayed to inform the user of the correct data.

The proposed function assists the trainees to search for facility defects autonomously while actually thinking for themselves. Moreover, learning how to inspect facilities becomes more enjoyable for the user in a similar manner to a treasure hunt.



(a) Example of defect search.



(b) Design of user interface.

Figure 4. Summary of searching for facility defects.

V. SYSTEM IMPLEMENTATION

Based on the technical methods described above, the prototype system was implemented on an Android tablet. Operation examples of each function are shown in Figures 5, 6, and 7. In Figure 5, an example of pole navigation is shown. On the left side of the screen, relative distance of each pole from the user is represented by the tag's color and size. A red tag means near the pole. On the right side of the screen, a facility map and the user's location are displayed.

Examples of the function for visualizing facility attributes are shown in Figure 6. AR is only used to point out the target position. Facility ID or type is overlaid using an AR balloon. In Figure 6(a), a pole ID is overlaid on a live camera view. If the user taps the AR balloon, detailed information about the pole is displayed on the right side of the screen. In Figure 6(b), two assembly patterns, one closure, and two communication lines are pointed out by the AR balloons. As shown in Figure 6, the AR objects are overlaid accurately by the robust identification and the hybrid tracking methods. An example of the hybrid tracking is shown in Figure 7. In normal operation, the hybrid tracking is performed in the background. Therefore, the AR rectangles and detected lines are hidden. In Figure 7, the blue rectangle and the green -lines were overlaid by sensor-based tracking. The red lines were obtained by line detection. The amounts of horizontal and vertical corrections (expressed in pixels) obtained by the hybrid tracking are displayed on the upper side of screen.

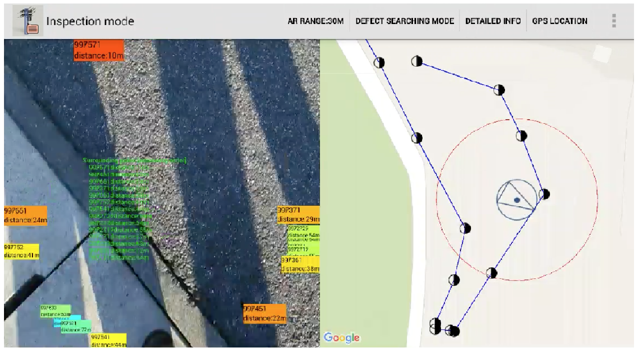
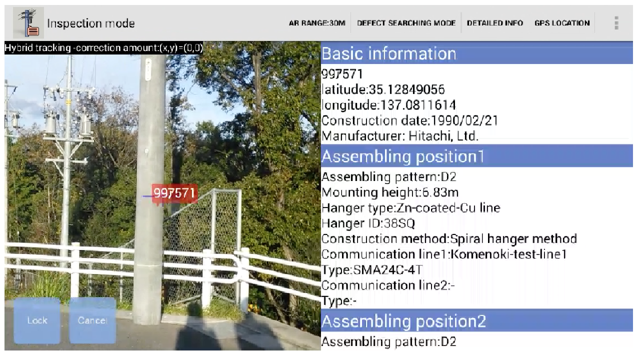
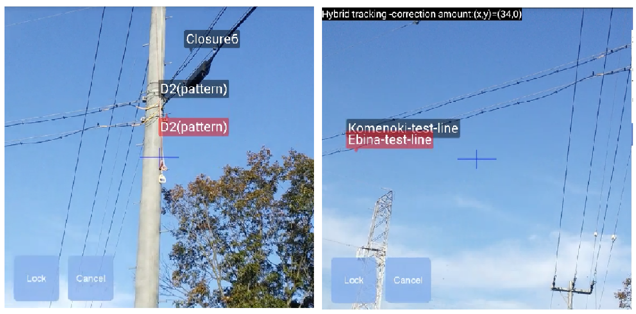


Figure 5. Pole navigation.



(a) Utility pole.



(b) Attachments (left) and communication lines (right).

Figure 6. Visualization of facility attributes.

An example of the facility-defect search function is shown in Figure 8. In this example, one facility defect was preliminarily set. The defect type is insufficient separation between two communication lines. In Figure 8(a), the user searches for the defect and captures an image containing the detected defect point inside the blue box. After capturing the image, the user selects a corresponding defect type from the check list on the right side of the screen. In Figure 8(b), the recorded data (position and type) are evaluated, and the user is informed of the evaluation result. After that, the hidden AR object is displayed to inform the user of the correct data.

As explained above, the correct operation of proposed AR functions were confirmed by prototyping.

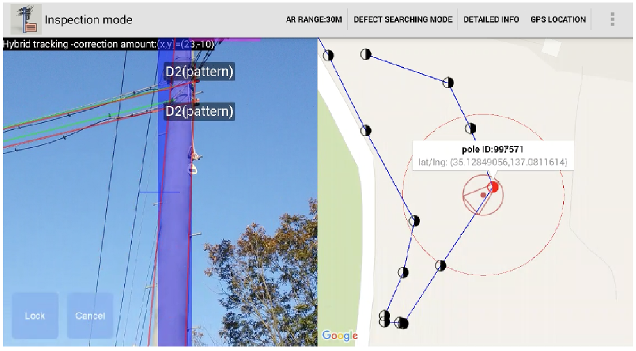
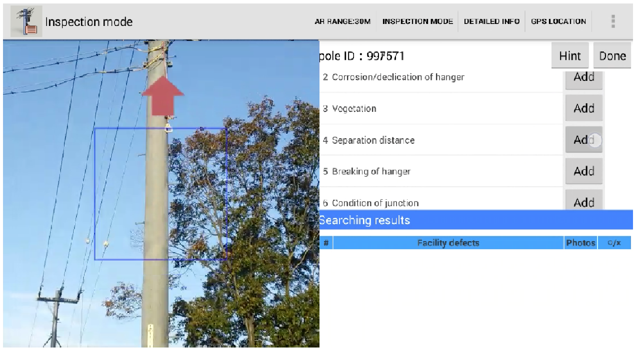
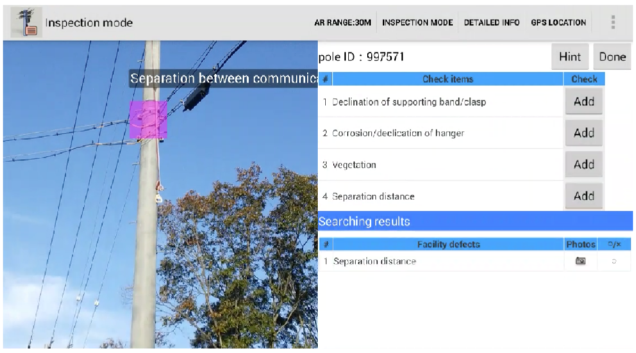


Figure 7. Hybrid tracking.



(a) Search for defect .



(b) Evaluate recorded data and inform user

Figure 8. Search for facility defect.

VI. EVALUATION

The developed AR system was evaluated as follows. On the basis of the evaluation results, the applicability of the proposed system to outdoor-facility-inspection training was examined.

A. *Evaluation Approach*

The proposed AR system was evaluated in the field (at a training center). In the evaluation, seven users were selected from active workers and trainers belonging to the power distribution department, and the communication facility department of Chubu Electric Power Co., Inc. They evaluated the system by comparing it with that used in conventional inspection training (because they already have knowledge of the training). While using the proposed system in the evaluation trial, they experience the training workflow. After finishing the trial, each user evaluated the system by questionnaire, which was based on the web-usability scale (WUS) [13], the technology-acceptance model (TAM) [14], and the AR acceptance model [15]. The questionnaire consists of 20 statements on a five-point scale (1 (disagree) to 5 (agree)) and a free-comment field. The statements were categorized into five categories: usability, autonomy, efficiency, understanding, and applicability. Autonomy, efficiency, understanding are defined in accordance with our research objective. Besides, usability is an important factor because insufficient usability may hinder the evaluation of the proposed AR functions. The statements are listed as follows.

Usability:
- The system was easy to use.
- It responded quickly to my commands.
- It was easy to understand.
- It was easy to make substantial use of the system.

Autonomy:
- The support of a trainer was unnecessary.
- Learnt to use the system was anxiety-free.
- Learning by using the system was enjoyable.

Efficiency:
- Facility information could be acquired when needed.
- Information necessary for training could be acquired.
- Learning was smooth.
- The system is more useful than paper-based manuals.

Understanding:
- It was easy to find where a facility.
- I could determine facility attributes easily.
- I could quickly learn how to inspect a facility.
- The AR contents in the left side of screen are useful.
- The detailed information appearing on the right side of screen is useful.

Applicability:
- The system is applicable to inspection work.
- The system matches the objective and workflow of inspection training.
- The system is promising for inspection training.

- I will recommend the system to new employees.

B. Evaluation Results

The evaluation results are summarized and discussed. In Figure 9, the average scores for each category were expressed as a radar chart. Average score and standard deviation for each statement are listed in Table 1. According to the figure, the average score for each category was more than 3.0, which shows the proposed AR system was given positive feedback. The category "efficiency" received the highest score among the five categories. Especially, the statements "Facility information could be acquired when needed." and "Information necessary for training could be acquired." received high scores over 4.0. For "autonomy", the statement "Learning by using the system was enjoyable." also received a high score over 4.0. The evaluation results show that the proposed AR functions and system are useful for the inspection training. As explained above, whereas the users give positive feedbacks regarding the proposed AR functions and system, the category "applicability" gets a lower score than those for the other categories. It consists of several statements for evaluating the user's intention to apply the AR system in inspection training. The low score for applicability infers that the users have some reservations in regard to applying the AR system in inspection training. To determine the reason for the slightly lower score for applicability, the free comments written by the users are reviewed as follows. Some examples of the comments are listed below.

- This system might miss facility defects that should be found.
- When the user moves in the wrong direction or chooses the wrong target, assist functions to correct these errors are required.
- The system is useful because it assists with an autonomous defect search. However, the training contents are insufficient. For example, the user should be taught not only how to identify each defect but also why it is defect and the safety risk is poses.

These comments suggest two future tasks in regard to improving the proposed AR system. First, assist functions to correct wrong operation by the user are required. It is assumed that these comments may influence the score for the statement "Learning to use the system was anxiety-free." Second, more training materials should be prepared. The AR system should cover the same training contents as those taught in the inspection training course. Moreover, the proposed AR system will be more effective if additional training materials are displayed using AR.

As described above, the evaluation results show that the proposed AR functions and system support efficient, effective, and autonomous learning. If the two above-described tasks are accomplished, the AR system will be truly applicable to training in outdoor-facility inspection.

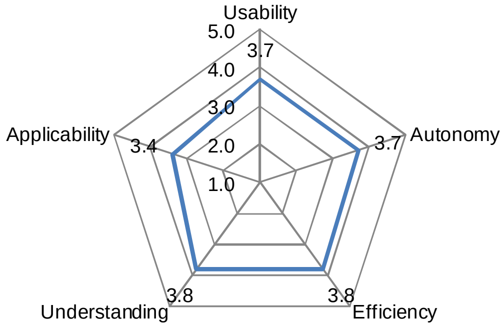


Figure 9. Summary of evaluation result.

TABLE I. AVERAGE SCORE AND STANDARD DEVIATION FOR EACH STATEMENT.

Categories	Statements	Average scores	Standard deviations
Usability	The system was easy to use.	3.6	0.7
	It responded quickly to my commands.	3.1	1.0
	It was easy to understand.	3.9	1.0
	It was easy to make substantial use of the system.	4.1	1.0
Autonomy	The support of a trainer was unnecessary.	3.6	0.9
	Learnt to use the system was anxiety-free.	3.0	1.1
	Learning by using the system was enjoyable.	4.4	0.5
Efficiency	Facility information could be acquired when needed.	4.3	1.0
	Information necessary for training could be acquired.	4.1	0.8
	Learning was smooth.	2.9	1.0
	The system is more useful than paper-based manuals.	4.0	1.1
Understanding	It was easy to find where a facility.	3.6	0.9
	I could determine facility attributes easily.	3.7	1.0
	I could quickly learn how to inspect a facility.	3.3	1.2
	The AR contents in the left side of screen are useful.	3.9	0.8
	The detailed information appearing on the right side of screen is useful.	4.4	0.5
Applicability	The system is applicable to inspection training.	3.1	1.1
	The system matches the objective and workflow of inspection training.	3.7	1.0
	The system is promising for inspection training.	3.4	1.3
	I will recommend the system to new employees.	3.1	1.0

VII. RELATED WORKS

In industrial segments, several researchers have discussed applying AR technology to industrial education and training. For example, an AR-based educational system for automotive engineering has been proposed [1][2]. Moreover, support systems for aircraft maintenance, namely, a marker-based registration method and a marker-less camera-pose estimation method, respectively, have been proposed [3][4]. An interactive AR application prototype for industrial education and training applications has also been proposed [5]. In [5], their system was applied to a simple virtual demonstration of assembling/disassembling procedures. In these works, the target facilities onto which AR information is overlaid are used indoors or located locally. Moreover, the above-described systems only present maintenance or assembly procedures by AR. From the perspective of training, these systems may not support autonomous learning sufficiently. In industrial education and training, trainees should be taught not only "how" they should work but also "why" they should work in accordance with the procedures in the manual. As described above, AR-based autonomous training systems that teach the ability to think for oneself have not been studied so much.

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On the contrary, a mobile AR application for visualizing maintenance data about power-distribution facilities was proposed [6]. It was developed for facility-inspection work, not for inspection training. In detail, a conventional location-based approach was applied. However, the measurement errors of sensors mounted on a tablet were not considered. In the fields of industrial education and training area, applying AR technology to outdoor widely-scattered facilities has not been studied so much.

VIII. CONCLUSION

A training-assistance system for outdoor-facility inspection using mobile augmented reality was developed and evaluated. In early phase of the research, conventional inspection training for pole-mounted communication facilities was surveyed. On the basis of the survey results, three AR functions to realize efficient, effective, and autonomous learning, namely, a pole-navigation function, a visualization function for facility attributes, and a facility-defect search function, were proposed. A hybrid tracking method was also proposed to realize accurate AR overlaying. Moreover, the prototype system was evaluated by active workers and trainers using questionnaire at a real training site. The evaluation results show that the proposed system supports efficient, effective, and autonomous learning. In other words, AR technology can be applied to training in outdoor-facility inspection.

In future work, the proposed AR system will be improved on the basis of the feedback obtained from the evaluation. Furthermore, the effects of using the proposed system on training will be evaluated by further field evaluations by more test subjects.

After applying the proposed system to the facility inspection training, some technologies for supporting inspection work will be developed and evaluated (e. g., facility defect detection using image recognition).

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