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Situation-dependent remote AR collaborations: Image-based collaboration using a 3D perspective map and live video-based collaboration with a synchronized VR mode

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ABSTRACT

The development of the Internet and smart devices has made it possible to support remote collaborations, which allows the expert and the worker to share information and co-work together in various and dispersed industrial fields. However, collaborations that exchange only audio and video information have limitations in the guided instruction of tasks, training of workers, and understanding of the situation. As augmented reality (AR) technology is considered to provide a more intuitive and immersive visualization and interaction in physical workspaces, many research works have been conducted to integrate AR into remote collaboration. Usually, there are two different types of AR collaboration depending on the shared media: 1) image-based AR collaboration and 2) live video-based AR collaboration. However, most of the previous research works cannot effectively support not only visual augmentation suitable for the situation but also accurate and effective annotations in the shared AR space. In this paper, we propose a situation-dependent remote AR collaboration approach that can selectively support either image- or live video-based AR collaborations: 1) image-based AR collaboration using a 3D perspective map and 2) live video-based AR collaboration with a synchronized VR mode. In particular, in the case of a certain situation with a limited network connection or limited HW/SW capabilities of the smart device, the image-based AR collaboration is more preferred. However, existing approaches cannot provide an integrated AR space from shared images. The proposed image-based AR collaboration enables to construct a 3D perspective map from the shared images taken in three or more directions, which can provide an integrated AR space for more effective AR annotations for remote collaboration. In the case of a normal situation without such problems, the live video-based AR collaboration should be supported. However, previous works have inherent problems such as inaccurate and mismatched AR annotations when the viewpoint of the live video is changed. The proposed live video-based AR collaboration with a synchronized VR mode can provide more effective and accurate 3D annotations by synchronizing virtual objects with physical objects. In particular, the VR mode can provide a complementing VR view of the AR-based physical space. In addition, through quantitative and qualitative experimental evaluation, we have conducted comparative studies with previous works. The results of this research show that the approach presented in this research has higher qualitative evaluation such as human behavior and task usability, as well as higher quantitative evaluation such as task performance and accuracy. Therefore, it is expected that the proposed approach can provide more user-oriented collaboration that considers user's situation and device performance in various industrial applications.

1. Introduction

Recently, with the advent of the Internet, smart devices, mobile apps, and social network services, information sharing has become possible anytime and anywhere through live video call, image sending or instant messaging among physically dispersed people. In such an infrastructure, remote collaboration is an important feature that cannot be missed in various industrial tasks. When workers are faced with problems that are difficult to solve by themselves, they try to solve these problems with the help of experts in distant locations. Sharing visual information during such remote collaboration helps to enhance mutual understanding and work efficiency. However, sharing only image or video-based information is limiting proper communication and interaction, due to insufficient situation understanding and

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inaccurately guided instruction [1,2].

In general, a remote worker who has to solve task problems often does not know what information to send to an expert when explaining his/her situation, due to the lack of relevant knowledge, or does not properly understand the expert's instructional feedback. In the case of the expert, it may be difficult to recognize the remote problem correctly just by seeing images or video scenes. In particular, it is even more difficult to solve the problem by sharing only visual information when carrying out complex tasks such as machine inspection, repair or maintenance. To overcome this problem in remote collaboration, it is essential to combine visual information with other 3D annotations and interaction metaphors such as augmented reality (AR) [1,2,3,4].

AR technology can provide realistic immersion and various visual guides because it can superimpose virtual information into physical artifacts [5–10]. For this reason, it has been applied to different industrial fields such as entertainment, smart factory, medical training, safety, and maintenance. In particular, advances of mobile devices can make AR technologies more viable, and can make it easier to access AR-based assistance anytime and anyway. Thus, it is expected that the worker can interact with the AR-supported visual information, thereby improving the degree of understanding of the working situation, and making the efficiency of performing tasks faster and more accurate through the remote collaboration.

Several previous works have been conducted to support remote collaboration using AR technologies [4,5,7,11,12]. Most of them tried to facilitate remote collaboration by augmenting virtual annotations, such as arrows on 2D images or live video scenes, so that the workers can achieve required goals more effectively, such as assembly and maintenance. However, there is a lack of research on how to locate such annotations accurately in the shared AR space when synchronizing the virtual annotations with physical objects. In addition, depending on the working situation such as network speed and HW/SW capabilities of smart devices, it is crucial to adaptively support either image- or live video-based AR collaborations. Furthermore, most of the previous works have not fully evaluated their methods with respect to qualitative and quantitative aspects regarding task performance and interaction behavior that are dependent on the worker's situation.

In most previous research works in the remote collaboration, the image-based collaboration and live video-based AR collaboration were widely used. However, for the image-based collaboration, a main problem is that although multiple images can be shared, it is difficult to provide an integrated AR space from the shared images, since there is no 3D spatial relationship between the shared images and tagged annotations. In addition, for the live video-based collaboration, when a perspective view or viewpoint is changed, there is a mismatching problem between physical objects and virtual annotations. Therefore, it is difficult to accurately coordinate the annotations.

In order to effectively solve these problems related to the previous image- and live video-based collaborations, this paper proposes a situation-dependent remote AR collaboration approach that can adaptively support either image- or live video-based AR collaborations by applying the image-based AR collaboration using a 3D perspective map and the live video-based AR collaboration with a synchronized VR mode. In the case of a certain situation with a limited network connection or limited HW/SW capabilities of the smart device, the image-based AR collaboration is more preferred. However, previous approaches cannot provide an integrated AR space from shared images. The proposed image-based AR collaboration enables to construct a 3D perspective map from the shared images taken in three or more directions from the remote worker, which can provide an integrated and perspective AR space for more effective AR annotations for remote collaboration. In the case of a normal situation without such problems, the live video-based AR collaboration should be supported. However, previous works have inherent problems such as inaccurate and mismatched AR annotations in the live video when the viewpoint of the worker is changed. The proposed live video-based AR collaboration with the synchronized VR mode can solve this problem, and can provide more effective and accurate 3D annotations by synchronizing virtual objects with physical objects through natural feature-based AR tracking. In particular, the VR mode can provide a complementing virtual view of the physical situation augmented by AR. Furthermore, we have conducted quantitative and qualitative experiment analyses with a conventional image-based collaboration and a live video-based AR collaboration that have been widely used in previous research works. To verify the advantage and originality of the proposed method, we have performed comparative analyses by evaluating several user studies related to 3D printer, coffee machine, and robot manipulator. The results of these analyses verify that the method presented in this research has higher quantitative evaluation, such as task achievement, in addition to higher qualitative evaluation such as usability than the previous research results. Therefore, it is expected that the proposed AR collaborative approach can provide more efficient task assistance and user-centric collaboration.

The contribution of the proposed paper is as follows. First, the image-based AR collaboration using the 3D perspective map can provide an integrated 3D AR space constructed from the shared images, and thus can support spatial annotations rather than 2D planar annotations for effective remote task assistance. Second, the live video-based AR collaboration with the VR mode can synchronize the physical artifact and its corresponding virtual object so that it can augment more accurate AR annotations on the physical artifacts. Therefore, it can improve mutual understanding between the expert and the remote worker. Third, quantitative and qualitative analyses through comparative experiments between the proposed approach and existing approach prove the advantage and usefulness of the proposed approach.

This paper is organized as follows. Section 2 discusses related work, while Section 3 presents the proposed situation-dependent remote AR collaboration approach. Section 4 evaluates the advantage and originality of the proposed approach by conducting an experiment evaluation through several user studies. Section 5 presents conclusions and future research directions.

2. Related work

Previous research works have proposed various remote collaboration methods to improve mutual work understanding, task efficiency, and information sharing [1,2]. In particular, this section reviews image-based collaboration, live video-based AR collaboration, and annotation and interaction tools for helping the remote worker understand the instruction more easily and perform the task more effectively. Annotation refers to the visual information generated by users participating in collaboration. This visual information refers to the form of a circle, an X, an arrow, or a free style drawing. Recently, many research works have been actively conducted to support effective annotations and natural interactions using not only images, audio and video scenes, but also AR.

2.1. Image-based remote collaboration

When the network speed is slow or the smart device has limitations on HW and SW capabilities, the live video cannot be transmitted and shared. In this case, the image-based collaboration is preferred. Nevertheless, sharing images and annotations on them can enhance mutual understanding between the remote worker and the expert. Chen et al. [4] proposed an approach to sharing images, and to supporting 2D sketch-based annotations on them. They introduced a remote support system that was designed for car drivers in need of help from a professional expert in the office. The proposed remote collaborative method that allowed the helper to sketch 2D annotations was compared with the voice-based collaborative method. Although there was not much difference between the two methods, users have commented that the sketch-based annotations were more intuitive and easier to