Supporting Tele-Assistance and Tele-Monitoring in Safety-Critical Environments

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ABSTRACT
Underground mines are hazardous environments. With more and more high-tech machines being introduced in mines, mine operators are under pressure of keeping machinery running smoothly as well as maintaining safety. To address this issue we have developed a remote guiding system called ReMoTe to allow an offsite expert to guide and monitor real time an onsite mining operator. This system brings offsite expertise to operators when and where it is needed (and in doing so supporting on-the-job training) and in the same time providing operators with the ability to monitor their level of stress (self monitoring) as well as allowing shift supervisor to remotely monitor their staff stress level. In our view the combination of these two services is key to increasing the productivity of the mines while supporting operators' safety. This paper describes ReMoTe and discusses how safety concerns are addressed in the design and evaluation of it.

Author Keywords
Remote collaboration, safety, near-eye display, tele-monitoring, tele-assistance.

ACM Classification Keywords
H5.m. Information interfaces and presentation: Miscellaneous.

INTRODUCTION
Mining is an inherently dangerous industry. The job of mining operators is changing at a fast pace: from manual to machine based labor, and from onsite operation of machines to fully automated, semi-automated and tele-operated machines. These changes are introducing new risks/dangers for maintenance operators working in the mining industry. The productivity and safety of mines relies on effectively supporting the changing role of mining operators. On the one hand, maintenance operators rely on assistance from automation experts that are not located onsite. On the other hand, these operators are often under a lot of stress/pressure to repair and fix complex machinery while minimizing any potential delay in production.

Although a number of systems have been presented in the literature to support remote guidance scenarios in which a remote helper guides a local worker performing manipulation of physical objects. Supporting remote maintenance in mines poses additional challenges, particularly for safety reasons [Alem et al. 2012]. While the increasing focus on safety has helped improve mining procedures, the dangers onsite seem to remain, even in countries with high safety standards such as Australia and USA. It was reported that approximately 6000 people died in underground coal mines alone in China each year [Tu 2007].

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More specifically, first, maintenance operators are highly mobile operators needing their hands for conducting their maintenance tasks. This implies the use of wearable computers and wearable devices. One key safety issue is to ensure that operators' spatial awareness is not compromised by the technology.

Second, mining operators work in 8 hours shift, not getting enough sleep prior to starting shift work is a key risk factor. Helping operators monitor their own level of fatigue/stress during their shift work can be done using wearable sensing devices. Questions to be asked for this could be: Would using a monitoring device lead to safer behavior? What about when operators are working in a team?

Third, conditions in mines can be highly dynamic and unpredictable. Systems would need to involve sensors that can monitor and react to changes to minimize risk and achieve "zero harm" for humans. Users should be enabled to interact with the systems without information overload and in a safe and efficient manner.

This paper presents ReMoTe [Alem et al. 2011] with a focus on safety considerations. ReMoTe is the remote guiding technology that connects remote experts with on-site operators to provide real time assistance when required. It allows remote experts to guide onsite maintenance workers on the job at the time of need. Supporting this asymmetrical form of collaboration is challenging, particularly for safety-critical workplaces that are different from traditional desktop or office settings such as mine sites [Heyer and Husoy 2012]. We briefly describe ReMoTe in the next section.

REMOTE
Mine site environments pose unique challenges to the use of collaborative tools and technologies, mainly due to the non-stationary nature of the work required to be undertaken by mining personnel. Thus, the proposition of the research undertaken is that the system to enable a remote helper to guide/assist a local worker in performing machine maintenance or repairs must, among others, adhere to the following requirements:

- collaborating partners should be able to verbally communicate with each other
- the helper needs to see the workspace of the worker to understand and monitor the status of the collaboration
- the helper should be able to point to the objects in the workspace and use other hand gestures to guide the worker
- the worker needs to see the hand gestures made by the helper to understand what actions the helper requires the worker to undertake
- both hands of the worker should be free for manipulation of physical objects
- the worker should be able to walk around, rather than being confined in a fixed position
- the overall system should be easy to learn and intuitive to use.

Fig. 1. Helper station (left) and worker station (right) of ReMoTe

ReMoTe was developed to address these and other requirements, such as communication latency. As shown in Figure 1, the ReMoTe system is comprised of a Helper station and a Worker station. The Helper station consists of a PC, a large touch-based monitor mounted with a camera. The Worker station consists of a wearable PC and a helmet mounted with a camera and a near-eye display. Both sides are connected via a wireless network and collaborators communicate with each other through speaker/microphone headsets. During the remote collaboration, the worker camera records the video of the workspace which is shown to the helper on the display. The helper talks to the worker and performs hand gestures over the video when necessary. At the same time, the hand gestures are captured by the helper camera and shown to the worker on the near-eye display.

In the next sections, we discuss how we addressed safety concerns during the design and development process of ReMoTe in a summative and reflective fashion based on the studies we have conducted (e.g., [Alem and Huang 2011, Huang and Alem 2011, Huang and Alem 2012]). We also present the progress of our on-going work along this line of research effort.

USER INTERFACE DESIGN

In terms of safety considerations, on the helper side, apart from a shared visual space which displays, by default, the video stream captured by the remote worker's camera for guiding purpose on the machines, the system also displays to the helper a panoramic view of the worker's workspace. This is to help the helper to maintain an overall awareness of the workspace and ensure that the worker is safe while moving around under his guidance.

On the worker side, we were interested in a design that will be hands free. Maintenance operators are often engaged in physical tasks requiring the use of their two hands for handling tools and performing actions on physical objects (assembling parts, removing parts etc). Therefore we limited our options to head-worn displays, instead of hand held devices, for the purpose of showing visual aids to the worker. In regard to head-worn displays, optical see-through and video see-through displays have been used for mobile AR guiding systems [Hollerer and Feiner 2004]. Optical see-through displays are semi-transparent, while video see-through systems present an indirect and mediated view of the environment. However, the feedback from end users indicated that dusts in mining sites can easily spread on the surface of optical displays, blocking the view of the worker and that both optical and video see-throughs offer a limited view of the worker's workspace. Not being able to see the surrounding environment fully and directly is risky for the worker in mining sites. This has led us to use near-eye displays.

Another design consideration is to support the mobility of mining operators. They need to be able to move around their workspace while still being aware of their environment. With a wearable computer and a wearable display, mining operators can focus their attention on their workspace and look up in the near-eye display in order to get the visual aids from the expert helping them.

Fig. 2. User interface of the Worker station

These considerations led us to the interface configuration shown in the left image of Figure 2. ReMoTe makes use of the helmet worn by operators and mounts a camera on the top of and a near-eye display beneath the brim of the helmet [Alem and Huang 2011].

In validating the design of ReMoTe we had two specific safety concerns in mind:

1. Usability and usefulness: to what extent the technology affects the maintenance task to be performed? Do users find it easy to use ReMoTe to the extent that they forget the technology mediation?
2. Spatial awareness: to what extent the use of a near-eye display affects the operator awareness of their

physical environment? Wearing a near-eye display partially obstructs the view of the operator (see the right image of Figure 2); this can potentially translate into a risk of the operator banging onto machinery around them. We conducted a study to assess to what extent the use of a near-eye display affects the spatial awareness of the operator.

In the next two sections, we presented two user studies that were conducted to address these two safety concerns respectively.

USABILITY AND USEFULNESS

In this study, two separate rooms were used to test the usability and usefulness of the ReMoTe system (for more details, see [Huang and Alem 2011]). One room was used to host the helper station while the other was to host the worker station. To mimic rough conditions in mines, we used a workshop room for the worker station which was full of equipments and tools. To test whether workers were aware of their surroundings while moving with the near-eye display, obstacles were deliberately placed in the trajectory of the worker. Only light boxes were used as obstacles to avoid workers being tripped over.

Six participants were randomly paired with one playing the role of helper and the other the role of worker. There were two different tasks. One was a representative task which is to assemble loose toy blocks while the other was a real task which is to replace broken parts of a PC. Workers were asked to move around the workshop room to collect objects specific to the task at hand under the guidance of helpers. After the tasks, questionnaires with usability ratings and open questions were filled. Then the pair switched the roles and repeated the process with similar tasks. Each session was video-recorded.

The study revealed that the participants were able to collaborate smoothly and finish their tasks within reasonable periods of time. Helpers were able to guide workers move around to pick parts or toys while workers were able to move around without bumping an obstacle indicating that they had good awareness of the surroundings. User comments and usability ratings were generally positive about the usability and usefulness of the system. For example, “the system should be useful in many situations.” “I find it very intuitive to use.” “It was kind of fun to receive instructions while walking around.” “Using hands was helpful when it was difficult to describe.” “Using hands made me feel like we were talking face-to-face.” “The near-eye display helped me to see what my partner could see.”

Following the laboratory testing, the next step is to have our system tested with real users and in real world workplaces not only on usability but also on safety concerns. This system so far has been demonstrated and tested with positive results in a range of events held for the mining industry and at sites of potential clients including companies that provide remote mine services.

SPATIAL AWARENESS

Spatial awareness is the ability to be aware of oneself in relation to his surrounding environment, or things in relation to each other in space. Mining is inherently spatial. Collision avoidance and underground navigation have long been most-discussed topics for mining technologies [Burgess-Limerick 2005]. In the hardware configuration of the Worker interface, the ear-eye display may block the upper part of the worker’s view. Therefore it is important to conduct a study to understand possible effect of near-eye displays on spatial awareness of workers.

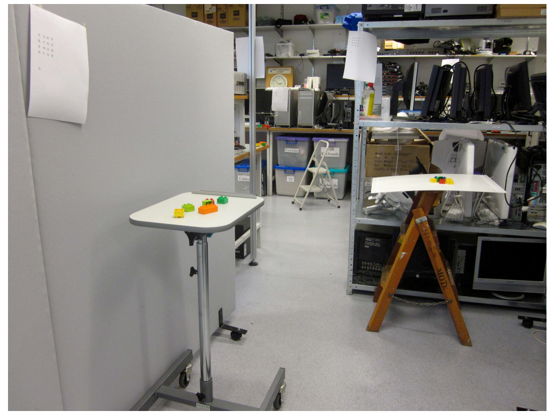

Fig. 3. Spatial awareness room setup

The study was conducted in a workshop room which was divided into six sections (see Figure 3). Twenty-three participants were recruited wearing a helmet mounted with a near-eye display. There were two tasks that were created so that participants needed to read information from the near-eye display and to navigate around the sections. First, five Chinese characters were shown on the near-eye display with each corresponding to a section. At the entry to each section, there was a paper sign which included the target Chinese character among a number of other distracting characters. Participants were required to find the target character to enter the section one after another. Second, in each section, they were required to assemble toy blocks into a pre-specified model shown on the near-eye display. After the tasks, the participants answered a questionnaire about spatial awareness and usability. As a control condition, participants also performed the same tasks using a hand-held device.

In this study, the spatial awareness was measured as the extent to which participants can recall where they had been and in what order these places were visited [Passini and Proulx 1998]. During the task performance, the experimenter observed the process, took notes and recorded the related data including the number of times the obstacles were hit if any. The results showed that the hand-held device received a higher user preference score. However, this study did not find any evidence indicating that the near-eye display negatively affected task performance and spatial awareness of the participants. For more details on the findings of the study, see [Huang and Alem 2012].

CURRENT DEVELOPMENT

While the tele-assistance part of the system is largely completed, the development of the tele-monitoring function is still on-going. This section reports on our progress.

A worker's state of mind and body plays an important role in operating safely in mine sites. Therefore, it is important to observe their mind and body state remotely so that a proper guidance can be provided. Body sensors have been used in electronic health system as remote monitoring tool, especially in tele-care or tele-homecare (e.g., [Reeves et al. 2006]). We decided to exploit this success by incorporating body sensors in ReMoTe with the aim of providing safety to mine operators. For example, we can use ECG to monitor the stress level of the mine operator. It helps to co-relate the stress level of the operator with the spatial environment captured through the ReMoTe helmet camera. The expert can then incorporate this knowledge while guiding the operator.

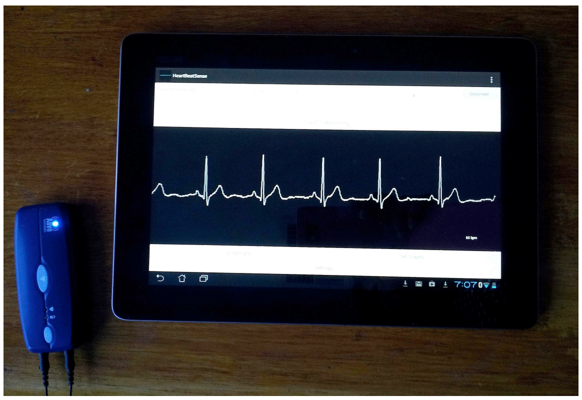

Fig. 4. ECG Remote Monitoring System

More specifically, we are currently investigating the use of wearable body sensors for monitoring purpose. As stated in the beginning of this paper, mining operators work in 8 hours shift work, a well documented risk associated with this type of work is the risk associated with working while sleep deprived. Miners need to be alert as things can go wrong very quickly. Our system explores the use of a heart monitor to be worn by miners during their shift work. The heart monitor device will send the data to a tablet for analysis; the data will then be correlated to level of stress and visualized/displayed for operators to monitor themselves. Figure 4 displays our ECG monitoring system. A worker connects ECG sensors to his body and starts the heart activity monitor. The worker then runs an app on a smartphone device, which connects to the sensors via Bluetooth. The app will then read live streaming ECG data from the sensors and will send this data periodically to the Cloud. Using the Cloud, a worker's cardiac state can be monitored and assessed remotely.

We are interested in exploring if operators will change their behavior as a result of using the heart monitor. Would they lower their workload as a result of this? This is early investigation and we hope to report some findings in the next publications.

CONCLUDING REMARKS

In this paper, we have presented our design, development and evaluation effort of ReMoTe in addressing safety concerns of technologies to be used in mines.

It should be noted that ReMoTe was developed to support tele-assistance and tele-monitoring in safety-critical mine environments. Although safety concerns had been addressed in the design process and in the laboratory evaluations, it is important to have it evaluated with real users in real world mine sites so that the benefits of it can be fully understood, particularly for maintaining or improving safety of onsite operators. This will be our future work.

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