Tailorable Remote Assistance with RemoteAssistKit: A Study of and Design Response to Remote Assistance in the Manufacturing Industry

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Abstract. In this paper we present our findings from interviewing manufacturing employees about their remote assistance practices and requirements to remote assistance technology. We found that their needs were rather heterogeneous regarding mobility, camera setups and location of guidance. We built the prototype RemoteAssistKit (RAK) as a design response to their heterogeneous needs. RAK is a tailorable remote assistance solution, where different mobility modes, camera setups and locations of guidance can be explored and interchanged using a graphical user interface. RAK thus moves some of the design responsibility from the designer to the users, who are empowered to tailor remote assistance to their needs and preferences.

Keywords: Remote assistance · Interview study · Augmented reality · Tailorability

1 Introduction

In an industrial context remote assistance is required in situations where a "worker", typically a machine operator or machine technician, experiences a problem with a machine or piece of equipment and thus calls a "remote helper", typically an experienced colleague. The problem solving activity between the worker and helper is mediated by a communication system, which is either a dedicated remote assistance system or a more general purpose system, such as a video calling application.

In this paper we present our qualitative, empirical findings on remote assistance practices and needs of employees in the manufacturing industry. This is a rare view into the real world practices and needs of a specific group of users of remote assistance technology. Most research on remote assistance make use of lab controlled studies that rarely involve the perspectives of manufacturing employees, who we argue are lead users of remote assistance technology, because

The work reported here is funded by MADE Digital (Project 6151-00006B).

H. Nakanishi et al. (Eds.): CRIWG+CollabTech 2019, LNCS 11677, pp. 80–95, 2019.
https://doi.org/10.1007/978-3-030-28011-6_6

they benefit greatly from advances in the technology. Next, we present our design and implementation of RemoteAssistKit (RAK), which enables users to tailor remote assistance to their needs and personal preferences. RAK lets the users (the workers and helpers) explore mobility (mobile vs stationary user interface), different camera setups (scene camera, head-mounted camera or a combination), and guidance locations (display separate from the task space, heads-up display or AR directly in the task space) without the need for any programming knowledge by making available a graphical user interface with which they can tailor RAK using modular, (mostly) web-based software components that represent the different levels of mobility, camera setups and guidance locations. The motivation behind RAK is twofold. First of all, from interviewing industrial employees at three different manufacturing companies, it is evident that the employees have heterogeneous requirements to remote assistance technology, because of their diverse roles, tasks and environments - no one-size-fits-all. The motivation behind the modularity of RAK is to support their heterogeneous needs. Secondly, the use of camera setups, for instance scene cameras or scene and mobile camera combinations, and the location of guidance, including AR guidance, has not been adequately explored in a real setting outside the lab. Thus, we know little about the adoption of different camera setups and AR for remote assistance in the wild, including the manufacturing industry. RAK enables users to easily explore different configurations of camera setups and guidance locations trial-and-error style, and thus can be used as a research tool to better understand the usability and usefulness of different camera setups and guidance locations in various situations in the wild.

After describing the findings from interviews and RAK, we conclude the paper with a discussion of the limitations of and future work on RAK and its intended use as a tool for further scientific inquiry into remote assistance in the wild.

2 Related Work

In this section we present related work on remote assistance and heterogeneous user needs.

2.1 Remote Assistance

Different interfaces and interactions for remote assistance are typically compared with respect to how well the worker-helper pairs collaborate and perform on a given physical task. This includes comparisons of camera setups [5,8], guidance techniques [6,9] and the location of guidance [2,9].

Different camera setups have different strengths and weaknesses. With a handheld/head-mounted camera the worker can capture close-up machine details from various angles, but the video the helper receives is unsteady and hard to annotate [2]. With a scene camera (camera mounted in the environment) the video is steady and easy to annotate, but at the cost of loss of detail. Researchers have compared a head-mounted camera to a scene camera and found that worker-helper pairs performed best using the scene camera [5]. A combination of scene- and head-mounted camera, where the helper can select between the videos from the two cameras, might seem like the best of both worlds, but so far research on camera combos have not shown any performance benefits over just using a single scene camera [5]. Researchers have also compared different ways of remote controlling the movement of a camera, thus providing the helper with a degree of view independence [10,11]. Lately the use of 360-degree live video for remote collaboration has received some attention [12,14], because it can provide the helper with a view of the task space independent of the worker's orientation. However, the challenge is knowing where other people direct their attention in the 360-degree video.

Early work on remote assistance suggests that providing the remote helper with the ability to use a pointer on shared video of the task space is ineffective, whereas sketching on the video is beneficial, because sketches are representational, i.e. can express complex 3D object manipulations [6]. Kirk et al. [9] compared freehand sketching to unmediated hand gestures on video and found that unmediated representations performed the best. In the same study, Kirk et al. also compared the output locations of the helper's gestures - external monitor vs. projecting gestures on the table surface of the task space - and did not find a significant difference in performance between the locations. In recent years, the helper's guidance techniques have increasingly been explored using augmented and virtual reality [1,2,7,12]. A common approach to AR remote assistance is that the helper uses a PC or tablet to make 2D annotations on live video/images of the task space, and then the worker's AR device interprets and registers the annotations in 3D task space [2,7].

2.2 Heterogeneous User Needs

Tailorability of component-based groupware has received interest within the CSCW community, because *the inter- and intra-individual differences constitute the need for system designs, which can [...] exhibit different behaviour in different usage situations, and accommodate individual and group needs and preferences* [15]. According to Hippel et al. one strategy for addressing heterogeneous user needs is that the manufacturer of a product or service provides the users with a "user innovation toolkit" [16]. A user innovation toolkit partitions product or service development into solution-information-intensive subtasks and need-information-intensive substasks. This allows the users to focus on need-information-intensive subtasks - they know what they want - while the manufacturer focuses on solution-information-intensive subtasks - they know how to produce the users' individual designs. We argue that RAK can be described as a user innovation toolkit with a sparse solution space, because RAK allows users to explore different remote assistance configurations trial-and-error style until they find a configuration that works for them. Providing the users with the means to innovate and customize a product using an innovation toolkit has been shown to improve user satisfaction of products, including security software [3] and consumer watches [4].

The work closest to ours is that by Speicher et al. [14], who created a modular, customizable remote assistance system, 360Anywhere, providing support for multiple collaborators, 360° cameras, projectors, sketching in the 360° video, session persistence and rewind of video features. Their argument for creating the system is similar to ours: they wanted to cater to users' heterogeneous collaboration and augmentation needs. But the challenges they address with the system and the intended use scenarios are different. Their major concern are the challenges of using 360° video and the intended use scenarios are primarily set in an office environment and includes brainstorming and an online lecture. In our work we focus on making the camera setup and location of guidance tailorable to the specific needs of manufacturing employees during remote assistance on physical tasks.

3 Interviews with Manufacturing Employees on Remote Assistance

Over the course of a year we visited three manufacturing companies in Denmark. Company A CNC mills metal molds for internal use in the process of manufacturing of toys. Company B manufactures, sells and services large inline printing machines, which can print on a variety of product packaging. Company C manufactures, sells and services wind turbines. We interviewed two employees from each company. Our contact persons inside the companies selected the employees based on their experience with remote assistance. The interviews were semi-structured and lasted between 21 min–49 min, with an average of 27 min. All employees were male between 25 and 50 years old, and one of the interviews took place on Skype. The employees from company B were interviewed together, hence they are referred to as E3-4. During the interviews, we asked questions about their daily work, current remote assistance practices, problems that required remote assistance, technologies used for remote assistance, mobility needs, and requirements to a remote assistance solution. With these interviews we hope not to generalize, but to show the diversity of tasks that require remote assistance in industry and the heterogeneous requirements to the design of remote assistance technology. For a quick overview between the relationship between employees and companies refer to Fig. 1.

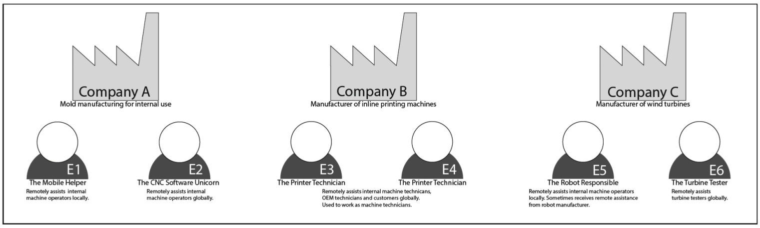

Fig. 1. Overview of company-employee relationship

Employee 1 - The Mobile Helper. E1 was responsible for managing the purchase, implementation and maintenance of CNC machines and additional equipment used in the process of manufacturing metal molds at company A. During the interview he focused on a very important machine, a washing machine specially designed to clean the mold parts between each step in the manufacturing process. Importantly, he described how this was the only washing machine of its kind in the mold factory and thus it was costly whenever it stopped working. He was the main responsible for helping the machine operators fix any problems with the washing machine and he needed to do so quickly. Remote assistance involved remotely accessing the human machine interface (HMI) of the washing machine and video calling the machine operators using FaceTime to see the current state of the machine. The machine operators were not expected to assemble/disassemble parts of the machine, only to be able to operate the machine interface.

Employee 2 - The CNC Software Unicorn. E2 was responsible for the robot-control software on the CNC machines at company A, and globally responsible for remotely helping with software problems on the machines. He was the only person in the company in this position. Thus, if a machine operator in China or Mexico experienced software-related problems with a CNC machine he would call E2. Remote assistance involved remotely accessing the human machine interface (HMI) and video calling to see how the robotic parts of the machine behaved as he executed different software programs. According to E2 most problems could be solved by simply accessing the HMI and talking to the machine operator on the phone (no video communication required), because E2 was very familiar with the software and behaviour of the machine. However, sometimes he would benefit from seeing live video of the machine. Again, the machine operators were not expected to assemble/disassemble parts of the machine, only to be able to operate the machine interface.

Employee 3 and 4 - The Printer Technicians. E3-4 worked for company B, the manufacturer of inline printing machines. These machines are large (several meters long, wide and high) and can print on practically any type of product packaging. E3-4 had experience as service technicians, responsible for installing and servicing printing machines at the customer factories, and as remote experts, which are called upon by either the customers or colleagues, when machines need to be troubleshooted. Example problems with the machines included leakages and undesirable artifacts on the printed material. Sometimes the solution was as simple as cleaning a sensor, and at other times parts of the machine had to be disassembled and reassembled. As remote experts E3-4 helped colleagues, the service technicians, visually troubleshoot the mechanics of the machine to see if everything was mounted or aligned correctly down to every bolt. E3-4 stand out from the pool of interviewees by being the only ones who remotely assisted with problems on their customers printing machines, whereas the other interviewees provided remote assistance on internal machines/equipment. So, pressure was on to find the right solution to a problem with a printing machine as quickly as possible, because downtime of a machine in production was costly for their customers.

Employee 5 - The Robot Responsible. E5 worked for company C and was hired as a skilled worker on the production floor. He recently became responsible for the robot which lubricates bolts for the windmills, but had 8 years of prior experience with robots in manufacturing from a previous job. The robot was the only one of its kind in the company worldwide and, according to E5, he was currently the only one internally with the competencies to program the robot. The robot was popular among the people on the production floor, because it relieved them from having to lube the bolts by hand, which was painful for their hands and shoulders. Sometimes his colleagues wanted to use the robot, when he was not present, for instance he might have a sick day. Because they did not have the same experience and competencies as E5, he had to remotely assist them in the use of the robot, which he accomplished using two separate software programs. E5 could remotely access and control the software on the computer connected to the robot using TeamViewer and send robot programming files to his colleagues on the production floor. He could not however remote control the movements of the robot. Additionally, E5 had installed a webcam in the environment that provided an overview of the robot and could be accessed from a program on his phone.

Employee 6 - The Turbine Tester. E6's job was to test the turbines for faulty electrical circuits and mechanics before they left the factory at company C. He had 8 years of experience as a turbine tester, and before his current job, he worked as an ordinary electrician. E6 used a "test player", a specialized computer, that he connected with cables to a section on the turbine to run tests. The test player contained a program for running tests on different sections on the turbine and would throw an error message if something was wrong with the electrical circuits or mechanics of the section being tested. The error messages did not always explain the exact cause of the error and so it was the testers job to hunt for the cause of the error by checking that cables had been connected correctly and the mechanics are working as expected. Due to E6's experience as a turbine tester, he was tasked with remotely assisting colleagues in other countries, whenever they encountered an error message they did not understand or could not find a cause for. He made use of a video calling app (he used a PC, while his remote colleagues used a smartphone), because he needed to see the turbine to be able to investigate the causes of a particular error message. Often troubleshooting an error involves compared a schematic of electrical wiring to video of the actual wiring.

A limitation of our interview study is that the interviewed employees had most experience in the role of the remote helper and primarily answered questions from their perspective as helpers. However, E5 would sometimes take on the role of the worker, when he needed help from the robot manufacturer.

Fig. 2. Machine operators/technicians at company A, B and C need remote assistance to solve problems with different machines, including large printing machines at company A (left), special washing machine for molds at company B (middle), and bolt-lubing industrial robot at company C (right).

Furthermore, E3-4 had previously held job positions as service technicians, but now - due to their large experience - held management level jobs, and thus would primarily take on the role of the remote helper. This means that these employees should be able to understand the remote assistance needs from the perspective of the worker. In future studies, we would acquire more participants with more extensive experience as the worker (Fig. 2).

4 Interview Findings

The interviews with employees from manufacturing companies revealed that they had heterogeneous needs for remote assistance, but also some needs in common. Below we describe their needs and possible design and research implications.

Need Support for Existing Remote Communication Equipment. First of all, despite the employees different tasks and working environments, all employees had in common that they used software to remotely access the machine interface (VNC Connect, TeamViewer etc.). This granted them access to status information on the machine, sensor data, and in some instances the ability to control certain parts of the machine. Additionally, they all used video communication software, like FaceTime or Skype, on their smartphones or PCs to obtain live video of the current state of the task space. The video feed contains information not available in the machine interface, and vice versa the machine interface contains information not available in the video feed. A design implication may be to combine the two software programs into one program by augmenting the video feed with manipulable sensor data and other status information using augmented reality. Further research is needed to understand which is beneficial to the remote helper: an augmented view of the task space in which he can consume status information and control machine parameters, or the traditional separation between the abstract representation of the machine and video feed.

Need Support for Varying Degrees of Mobility. In E1's case the need for mobility was a result of the importance of a particular machine, the washing machine, and the urgency of reacting to requests for help anywhere at anytime. *E1: I prefer helping them (the machine operators) right away, because it is very important that the washing machine is running, because parts (of a mold) in the washing machine risk getting destroyed, if they stay in there for too long E1: Often I am in the supermarket or picking up the kids (from school), when they (the machine operators) call me.* E5 seemed to enjoy the mobility of the smartphone, because he enjoyed checking the status of the robot at his convenience. He was proud of being in charge of the robot as the only one in company C. Thus, his preference for using a smartphone seems more emotional than rational. *E5: In the morning when I wake up, I have to check the status of the robot (from his phone).* For E6 remote assistance involved comparing a schematic of electrical wiring to live video of the actual wiring. E6 believed it was easier to access schematics on the PC than on the phone and thus preferred to use a PC for remote assistance. *E6: On the PC I have the drawings and I can show them (his remote colleagues) the drawings [...] it will be too difficult to do it on the phone, I think.*

Generally, employees whose main purpose it is to give remote assistance can be expected to be in an office where stationary, powerful hardware for remote assistance is available, including VR and advanced tracking equipment. However, employees that take on remote assistance tasks sporadically throughout their work week, as is the case of all of the interviewed employees, cannot be expected to always be in their office upon a request for help and thus need mobile alternatives. E1's situation at work describes this best. At the time of the interview, he would regularly take part in project meetings at company A. *E1: My current situation at work requires me to be in two places, about 2 km apart, and I would like to have it (remote assistance functionality) on the phone, because I don't bring my computer (to project meetings 2 km from his office).*

As the above accounts show, some employees require to be mobile due to specific circumstances, while others do not. The implications of the mobile helper for the design of remote assistance is the need to explore guidance techniques on tablets/smartphones by taking into account their limited screen real estate, multi-touch and sensory capabilities. Another important thing to consider are the seamless transitions between mobile solutions and stationary solutions with comparatively more computational power, which have not received much research attention. Our prototype RAK handles the transition between a mobile and stationary solution by making use of a device agnostic web application running on both smartphones, tablets and desktops. Furthermore annotations, i.e. the sketches made on a device, is persisted, so when the helper transitions from one device to another, sketches will re-appear.

Need Support for a Variety of Camera Setups. Some of the interviewees had considered or were already using specific camera setups. E5 for instance had taken the initiative to install a scene camera in the robot cell, which he could access remotely from his phone. *E5: I have mounted a web camera inside (the robot cell), so I can see how the robot is positioned right now (from his smartphone).* Thus, E5 could remotely check on the status of the robot, even when no workers were present locally. Upon showing us around on a printing machine in their test facility, E3-4 told us that they had considered to use a small wireless camera by placing it on the printing unit adjacent to the unit undergoing maintenance, while showing the helper's guidance on video from the camera on a tablet/smartphone placed in front of the worker. Thereby, their idea was to make use of the industrial environment to provide the helper and worker with a shared over the shoulder view of the printing machine. E1 mentioned that with a few scene cameras he could capture the most crucial areas on the washing machine, and suggested to use the scene cameras to both live transmit video and record activities in the task space, thereby supporting him in identifying how mistakes were made after the fact. *E1: It would be interesting with constant surveillance of the machines [...] A bunch of cameras in the production that one could log into and use to go back in time, because many of the errors are related to persons making mistakes [...] I know who used the machine last (because of digital logging) [...] but they used the machine in a different way (than intended) and we don't know why a certain error occurred and how the situation was (at the time the error occured) [...] or when the error occurred, because they left the machine to itself"* At the time of the interview, E6 was planning to use a commercial remote assistance solution, where the camera was part of a heads-up display or smartphone, thereby providing the helper with a view through the eyes of the worker. *E6: I am participating in a project right now, which involves the use of a commercial remote assistance solution. We are implementing this in Russia now so I can support them (the turbine testers in Russia). The plan is that I use a laptop and they use glasses (heads-up display) or a phone, whatever they prefer.* E6 would remotely troubleshoot the electrical wiring of turbines, so sometimes he required close-up views of the wiring to compare it to schematics, and therefore using a head-worn/handheld camera made sense. It is evident that many of the employees had already considered and some experimented with the benefits of particular camera setups. Interestingly most of the solutions that were considered or in use included scene cameras, while most commercial solutions today include wearable cameras that capture video from the point of view of the worker either through a handheld smartphone or a head-worn solution. The use of scene cameras in industry raises some questions that have not been answered in current research on scene cameras. Those questions include: "How feasible is a solution, where one or more scene cameras are mounted ad hoc in the environment?", "How time consuming it is to mount one or more cameras ad hoc in the environment?", "How feasible it is to permanently mount scene cameras that covers specific areas of a machine and are the workers concerned about video recording of their activities?", "Does scene cameras capture the areas of the task space in enough detail that the helper can give feedback on the worker's object manipulations, or is a scene camera + mobile camera combo needed?". In RAK we aim to support the experimentation of camera setups by letting the worker choose between a scene camera (webcam), mobile camera (tablet/smartphone camera) or scene+mobile camera setup.

Need Support for Visual Guidance and a Variety of Visual Guidance Locations. The helper providing visual guidance to the worker was believed to be useful, especially to avoid misunderstandings of employees with poor English skills that do not share terminology with the helper. This feature was brought up by both E2 from company A, E3-4 from company B, and E6 from company C. They all remotely assist colleagues in other countries.

E2: There is this communication barrier which limits how well you communicate (with people from China and Mexico) [...] I see some benefits of remote assistance technology, because I can see what you (the machine operator) are looking at, and I can draw something on a screen or show you where to locate something.

E3-4: At the same time you (the worker) show me something with the camera, you are able to see something on your screen, where I've added a layer of information. Often the OEM technician does not know the technical name of the mechanic components [...] their English is primitive [...] I don't always understand what he says.

The employees expressed different ideas on where to locate the guidance in the worker's task space. E2 talked about the possibilities of AR, where guidance is located directly in the worker's task space, but without any notion of the benefits of using AR. Upon showing us around on a printing machine, E3-4 explained that they considered to show the guidance on live video on a tablet/smartphone placed in front of the worker, while the camera, responsible for capturing video of the printing machine, was mounted on the adjacent printing unit behind the worker. E6 was piloting a commercial solution, where guidance was shown on live video on either a handheld smartphone or heads-up display. While they agreed on the usefulness of visual guidance, none of the employees reflected on the benefits and drawbacks of different guidance locations, for instance comparing AR guidance to guidance on video. It is clear from the empirical research on remote assistance - dominated by controlled lab studies - that visual guidance in live video of the task space is helpful during remote assistance, however a clear advantage of using AR guidance has yet to be demonstrated [2,7], especially in the wild. RAK enables users to experiment with different guidance locations and compare non-AR guidance on video and AR guidance during real remote assistance. Hence, in future work we hope RAK can be used to identify the characteristics of real remote assistance tasks, where AR guidance is preferred over non-AR guidance and vice versa.

Create Ownership for Solutions Among Super Users. Some employees (E2 and E5) had in common that they got to modify machines and technology for their work and thus had become the in house experts or super users.

E2: I developed the software for the machines [...] I am responsible for the machines globally, so if somebody has a problem in Mexico, they call me.

E5: I have mounted a web camera inside (the robot cell), so I can see how the robot is positioned right now (remotely from his smartphone) [...] I have numbered each door on the computers (the computers on the robot) [...] I can tell them (his colleagues) "go to door number 1 and take out the controller" [...] I don't have to use the technology (remote assistance solution), but I want to [...] I keep going until it works.

The above accounts provide examples of employees in the manufacturing industry trialing remote assistance solutions on their own premises, and some even create their own remote assistance solutions. E2 and E5 were clearly proud of their position in the companies and the responsibility they had been trusted with to choose, create and modify technology for internal use, including remote assistance technology. This bottom up approach to innovation in the manufacturing industry is exactly what we intend to support on a smaller scale with the tailorability of RAK - rather than have management impose a specific remote assistance solution on the employees. This should make actual users of the technology more accepting of it and increase the likelihood of successful adoption, because of a sense of responsibility and ownership for the technology.

5 Design of RemoteAssistKit

From our interviews with manufacturing employees it became clear that one specific remote assistance solution might not satisfy their heterogeneous needs for mobility, camera setups and guidance locations. That is how we were inspired to design RemoteAssistKit (RAK).

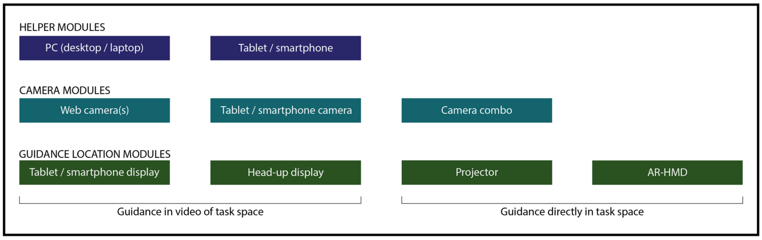

Fig. 3. The modules of RemoteAssistKit. The helper modules, camera modules and guidance location modules can be interchanged and combined in different ways.

With RAK we provide the users the flexibility and power to design their own remote assistance solution by mixing modular, interchangeable software modules to match their task requirements and preferences without the need of any programming knowledge. Thus we move the need-intensive-subtasks of developing a remote assistance solution to the users [16]. RAK consists of three types of modules: helper modules, camera modules and guidance location modules. See Fig. 3 for a conceptual overview. The modules can be combined in different ways and make up different design configurations of RAK, as illustrated in Fig. 4.

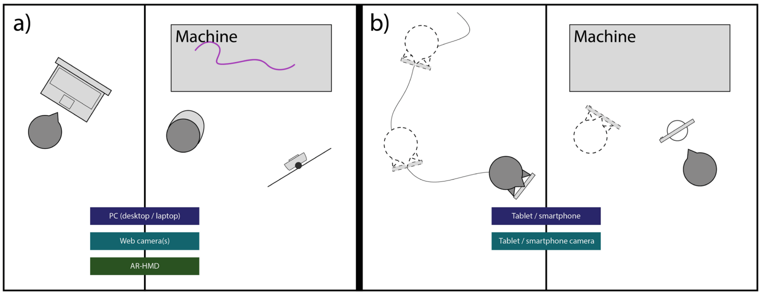

Fig. 4. Two example configurations of RAK seen from a top view. (a) The helper uses a laptop to sketch on live video from a web camera mounted in the worker's task space, while the worker wears and AR-HMD to see the sketches registered in 3D to the task space. (b) The helper is on the move and uses a smartphone to sketch on live video captured from a tablet in the worker's task space, while the worker sees the sketches on the tablet. The tablet is either mounted on a tripod or held by the worker

The interviewed employees had varying needs for mobility. Some helpers are able to answer calls from a worker using the computer in their office, while others, due to the urgency of the call, will need to be able to give help on the go. RAK supports these varying needs for mobility. Currently, two different helper modules are included in RemoteAssistKit. (1) A mobile helper module, which allows the helper to provide remote assistance on the go using a tablet/smartphone. (2) A stationary helper module, with which the helper can use a desktop/laptop PC to provide remote assistance. Both modules make use of a pointer and freehand sketching as the means to provide visual guidance in a shared live video feed of the worker's task space. The interactions for pointing and sketching vary only slightly between the tablet/smartphone and PC implementations due to variations in the input method - touch on mobile device and mouse on PC. Transitions from PC to mobile device or vice versa is supported as annotations are persisted, meaning sketches made on one device will reappear on another device, as long as the same "virtual room" on the server is shared between the worker and helper.

The interviewed employees had varying needs for the camera setup. Some helpers wanted to be able to check on equipment, when no workers were around locally or to view recordings of machine failures, which required the use of scene cameras. Some needed detailed views of a task space area, thus they used a head-worn/handheld camera. In RAK we wish to support the employees' varying needs for and experimentation with camera setups. Therefore, three different camera modules are included in RAK. (1) A web camera module which uses one or multiple web cameras to capture the task space. The web cameras must be mounted as scene cameras in the environment. (2) A mobile camera module, which uses a handheld mobile device (smartphone/tablet) to capture the task space from the front facing or back facing camera. The handheld device may be held by the worker, mounted on a tripod or attached to a machine in the environment, thus acting as a scene camera. (3) A combined webcam+mobile camera module. All camera modules have in common that they live stream video to the selected helper module.

The interviewed employees expressed different ideas on where to locate the helpers guidance in the worker's task space, but did not reflect much on the benefits and drawbacks of different guidance locations. We believe that by getting them to experiment with different guidance locations, it will teach them about their requirements to the location of guidance and how it may differ depending on their remote assistance tasks. Therefore, four different guidance location modules are included in RAK of which two have AR capabilities: (1) An external display module, which shows the helper's guidance (transmitted from the helper module) on live video of the task space (transmitted from the camera module) on an external display. This external display module runs on a smartphone/tablet, so the worker can quickly and easily bring it with him and place it in a way that makes the helper's guidance viewable, while he executes some task on a machine. (2) A heads-up display module, which shows the helper's guidance on live video of the task space on a heads-up display. We used the Mira headset, a head-mounted frame in which a smartphone can be mounted to create a head-mounted display, and we created an application for the headset, which shows video hovering in the left corner of the eye, similar to the experience of using a heads-up display. (3) A projector module, which uses a projector to project the helper's guidance directly onto the task space, as long as the task space is (approximately) a planar surface. The worker is required to follow a calibration procedure to align helper's guidance to the real task space before remote assistance can commence. (4) An AR-head-mounted display module which - as the name implies - uses an AR-head-mounted display (MS Hololens) for displaying the helper's guidance directly in the task space. We make use of the rather simple spray-paint technique [13] to interpret the helper's 2D guidance in 3D, which leaves room for future improvement. The AR-HMD module makes use one or more scene cameras (tablet camera or web camera), and it is the helper's 2D pointing and sketching in the video feed(s) of the scene camera(s) that is interpreted in 3D on the worker's AR device. The interpretation works by aligning a virtual camera to the real scene camera by scanning a marker on the real camera with the AR device. See Fig. 5 for an example of the AR-HMD module combined with the mobile camera module and the stationary helper module.

The helper must select the helper module, and the worker must select the camera and guidance location modules using a graphical user interface. See Fig. 6 for a screenshot of the web based user interface for selecting modules. The user interface connects helpers and workers using the concept of virtual rooms - one helper and one worker per room. A helper/worker can join an existing room or create a new one to start communicating with each other. The helper joins a room with a helper module on a smartphone/tablet or PC, while the worker joins a room with a camera module and possibly a guidance location module on his devices. They select which modules to use in the drop down menus and click the join button next to the modules, upon which they are redirected to the selected module applications.

Fig. 5. Example configuration of RAK. (a) Screenshot of the helper's interface. He uses a PC to sketch on live video from a smartphone in the worker's task space. (b) The worker wears an AR-HMD to align a virtual camera to the front-facing camera of the smartphone. (c) Because of this alignment, the worker can see the helper's sketches in AR on the task space, in this case the annotations point to some puzzle pieces on a whiteboard.

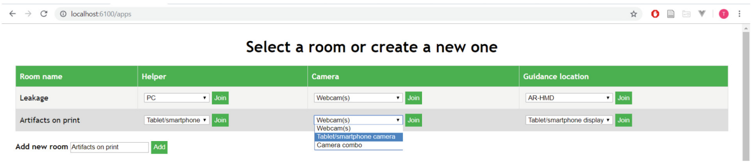

Fig. 6. User interface which connects helpers and workers using the concept of rooms. In the example the rooms are named after the problems that require assistance

5.1 Technical Implementation

RAK consists of a distributed set of applications running on the helper's and worker's devices. The two helper modules (mobile and stationary), the camera modules (web camera, mobile camera, combo) and the guidance location modules (external display, projector, head-up display) are single page web applications written in ECMAScript 6 and transpiled to pure JavaScript. Thus, these modules are device agnostic in that they can run in a browser on both a desktop/laptop PC or on a tablet/smartphone. The modules make use of the p5 javascript library for drawing the user interface. Additionally, the AR-HMD guidance location module runs on an MS Hololens and is a Universal Windows Platform (UWP) app written in C-sharp. The helper, camera and guidance location modules need to communicate during setup and when certain events, such as sketching events, occur. This communication is implemented using websockets and a Node.js server. The Node.js server also works as a signalling server for setting up WebRTC video streaming between the helper and camera modules and between the camera and guidance location modules (the latter only applies to the external display and head-up display modules).

6 Discussion of System Limitations and Future Work

Previous work on "user innovation toolkits" has shown that making need-intensive tasks the responsibility of the user leads to greater user satisfaction [3,4]. However more research is needed, where RAK is put in the hands of the manufacturing employees, to understand whether they will take on the need-intensive tasks of configuring RAK, or whether they regard it as time consuming work in an already tight schedule. In future work we put RAK to the test through a design workshop, where manufacturing employees (machine operators, service technicians and remote supporters) explore the different configurations of RAK in a real, familiar industrial use context on real machine problems. By completing this workshop it is our hope that the participants will reflect on their current remote assistance practices, design future practices that matches their needs, and generate knowledge about the feasibility and usefulness of the different design configurations in a real industrial use context - hence answering some of the questions related to remote assistance in the wild, for instance "How feasible is a solution, where one or more scene cameras are mounted in the environment?" and "Are there any industrial tasks where AR guidance is particularly well/ill-suited?".

An important aspect of remote assistance that we did not yet modulparize in RAK is the content of the visual guidance. RAK currently only supports pointing and sketching. In a possible future implementation we would like to modularize the content of the visual guidance providing the helper with the option to choose between sketching or using natural hand gestures. The natural hand gestures have been shown to lead to better performance between worker-helper pairs in controlled studies [9].

7 Conclusion

We have presented our findings from interviewing manufacturing employees about their remote assistance practices and needs. Furthermore, we have presented the design and implementation of the tailorable remote assistance prototype, RAK, which serves as a design response to the at times heterogeneous needs of employees. Especially, employees exhibited heterogeneous needs and preferences for mobility and camera setups due to differences in the problems they assist with and the task environment of the worker. In the future, we plan to use RAK as a tool for further scientific inquiry into questions regarding the helper's need for mobility, and the feasibility and usefulness of being able to configure camera setups and guidance locations during remote assistance in the wild.

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