Mobile Service Technician 4.0 – Knowledge-Sharing Solutions for Industrial Field Maintenance

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Abstract. With the fourth industrial revolution, Industry 4.0, many work tasks are becoming knowledge intensive. At the forefront of the change are workers that are already mobile, working in the field with customers. We describe the human-centred design process that resulted in the Mobile Service Technician 4.0 concept. The concept illustrates how industrial field maintenance work could benefit from knowledge-sharing solutions based on Industry 4.0. The solutions utilize industrial internet, virtual and augmented reality as well as wearable technologies to improve mobile service technicians' daily work performance and work satisfaction. The Mobile Service Technician 4.0 concept illustrates the user experience of future maintenance work: feeling competent, feeling connected to the work community, and feeling of success and achievement by being better prepared for maintenance visits, getting situationally relevant support in maintenance operations, sharing knowledge with peers, and making maintenance reports effortless.

Keywords: Industrial field maintenance, knowledge sharing, user experience, augmented reality, virtual reality, wearables, social media, user studies.

1 Introduction

The fourth industrial revolution, often referred to as Industry 4.0, is already on its way. Enabled by advanced digitalization, industrial internet, cyber-physical systems and smart technologies, Industry 4.0 will change radically many work roles in industry [1, 2]. There will be significantly greater demands on all members of the work force in terms of managing complexity, abstraction and problem-solving [3]. For the industrial workers, the revolution is expected to provide opportunities via the qualitative enrichment of their work: a more interesting working environment, greater autonomy and opportunities for self-development [4]. Subsequently, the employees are likely to act much more on their own initiative, to possess excellent communication skills, and to organize their personal workflow; i.e., in future industrial environments they are expected to act as strategic decision-makers and flexible problem-solvers [4].

The anticipated industry transformation will affect all worker groups, but at the forefront of the change are workers who already are mobile and work in the field with customers. We have studied how the Industry 4.0 transformation could, at its best, influence industrial maintenance work so that both productivity and work satisfaction increase. To utilize the possibilities, both work processes and work tools need to be developed in parallel. We have developed augmented reality (AR)-, virtual reality (VR)- and wearable technology-based solutions that support mobile service technicians in their different tasks from preparing for maintenance operations to reporting the results. The research has taken the stance that, in order to succeed, Industry 4.0 requires more than merely introducing new technologies for maintenance work. In essence, for developing sustainable solutions, a shared vision of the future is needed. This will require a clear and extensive view of how the new technologies will be utilized, what kind of user experience is expected, and what kinds of new work practices will be developing, accordingly. The research questions guiding our work were:

1) What kinds of knowledge needs do industrial field service technicians have?
2) How could these needs be served with the best possible user experience utilizing the industrial internet and novel interaction tools?
3) What kinds of new maintenance work practices will be developing with new knowledge-sharing tools?

Our study was carried out as an industry-academia collaboration, where researchers and company representatives together developed the solutions. Industrial partners integrated the solutions into industrial environments while researchers were responsible for the development of novel technical solutions and user studies. Our study involved four industrial companies that all have substantial global industrial maintenance businesses: Bronto Skylift, KONE, Konecranes and Wärtsilä. While earlier studies have focused on single demos for a particular maintenance task, we have aimed at a more comprehensive coverage of maintenance work. In this paper, we present the concept of Mobile Service Technician 4.0: new practices and tools covering widely the daily work of maintenance professionals. We have illustrated the concept with AR-, VR- and wearable technology-based demos of tools that support preparing for a maintenance visit, identifying faults, carrying out maintenance operations, getting guidance from remote colleagues and finally reporting what was done during the maintenance visit. Based on small-scale evaluations with maintenance professionals, we assess the future potential of the solutions.

In the following, we first describe related research in Section 2. Then, in Section 3, we describe the methods of the study and in sections 4–6 the design process in detail: defining industrial and user requirements, developing and evaluating demonstration systems and finally introducing the Mobile Service Technician 4.0 concept that illustrates engagingly future maintenance work, thus communicating the solutions to wide audiences. In Section 7, we discuss the findings and their impacts, and in Section 8, we present conclusions and plans for future work.

2 Related Research

Lorenz et al. [1] forecast how Industry 4.0 will change industrial work roles, and they describe digitally assisted field service engineers who utilize tools for predictive maintenance. Gorecky et al. [4] as well as Romero et al. [5] describe factory operators integrated into the cyber-physical world so that their individual skills can be utilized. Optimal integration of physical and virtual reality is also pointed to by Longo et al. [6], who propose AR content and a personal digital assistant for smart factory operators.

AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [7]. Feiner et al. [8] presented one of the first prototypes of AR for maintenance. Since then, many researchers have compared using AR and paper-based instructions in industrial assembly and maintenance tasks. Results suggest that AR-based solutions are much faster to use, less errors are made, and the operators seem to accept the technology [9-12]. In hands-on maintenance tasks, a head-mounted display (HMD) often brings further benefits compared to a mobile display [11].

Azpiazu et al. [13] presented an AR remote assistance concept for giving remote support for train maintenance with video and audio interaction as well as AR-based instructions. Ferrise et al. [14] have studied AR and VR solutions in maintenance training and remote assistance with promising results from initial user studies. Bordegoni et al. [15] describe combining mobile and AR technologies for remote maintenance support for industrial products.

AR has been proven to have good potential in maintenance, repair, service, and inspection. However, AR systems still need to be improved, to make them more portable, accurate and stable as well as smaller, cheaper and lighter [16]. Zhu et al. [17] propose that maintenance support systems should evolve from passive manuals to active information providers, namely, filtering and rendering the information properly to the technicians by analysing the contexts.

VR has received much attention in recent years and omnidirectional videos, aka 360° videos, enable remote operation, telepresence and offline viewing of real environments using VR technology including HMDs [18-21]. HMDs can provide an immersive and enjoyable experience with high sense of presence [22-26]. Omnidirectional videos provide the viewer freedom to choose what part of the environment they focus on. This is, at the same time, a strength and a weakness as the videos can capture a lot of information, including tacit knowledge of maintenance operations, but viewing the videos can also lead to the feeling of being lost or missing things [26, 27]. Prior research has frequently found this fear of missing out, and using interactive elements [28, 29] and guidance embedded in the video are potential tools to alleviate the issue. Viewers of ODVs can be guided with diegetic cues and nondiegetic cues [27]. Diegetic cues are natural parts of the virtual environment. In the industrial maintenance context, these ques come naturally from the objects and activities in the videos but understanding them often requires the expertise only experienced personnel has. Explicitly adding such cues, like filmmakers do [30], is not realistic in an industrial context where capturing the videos is a secondary task. Non-diegetic cues are elements added on top of the virtual environment, such as arrow symbols on top of the video pointing to the direction of the action. These can be added if manual content creation can be afforded, or suitable machine vision solutions are created, e.g., to identify certain equipment.

Franssila [31] identified the dynamic nature of knowledge needed in maintenance work: on one hand, the official documentation is constantly updated, and on the other hand, new knowledge on the field is constantly created. Orr [32] points out the social aspect in knowledge sharing. Maintenance personnel often share stories about past fixes and difficulties in them. Organizations are increasingly adopting social media technologies to enable personnel to interact and share knowledge. Huang et al. [33] found that, at its best, social media could add multivocality, increase reach and richness in communication, and enable simultaneous consumption and co-production of content.

AR will be a key technology in Industry 4.0, as it enables connecting virtual information to the physical world [1, 4, 6]. Previous research has studied widely AR in maintenance. However, user studies in actual industrial environments are rare, as the focus has been mostly on technical feasibility [34]. When user studies have been done, they typically focus on usability [34]. VR is another key technology that facilitates experiencing virtually physical environments that would be difficult to access physically or that do not yet exist. In the field of industrial maintenance, omnidirectional video-based VR has shown promise in remote operation and telepresence. It has also been used to document an environment's equipment and while most of the current implementations are exploratory or aimed for marketing purposes, omnidirectional video capture has potential, since it can capture rich detail of activities and the environments, including a lot of tacit knowledge.

3 The Method

Our human-centred design process was targeted to define the overall concept of future maintenance work, where novel tools are utilized. The main phases of the design process are illustrated in Figure 1. The iterative design process consisted of (1) identifying the knowledge-sharing needs with the participating companies; (2) defining design implications based on the identified needs; (3) developing the demonstration systems, evaluating them with users and refining the systems accordingly, and (4) gradually defining and illustrating the final concept of Mobile Service Technician 4.0 based on the development and evaluation results of the demonstration systems. We use the term design implications for user requirements interpreted to design goals to emphasize this connection. In the following sections, these four phases and their results are described in detail.

The representatives of the four companies shared within the project group their view of the knowledge-sharing challenges and development needs. These needs were complemented by studying current maintenance work in the field. The researchers carried out user and field studies at maintenance sites of three companies (Konecranes, Bronto Skylift and Wärtsilä) to gain more in-depth understanding of current maintenance work. The data was collected from maintenance technicians by semi-structured interviews and by direct observations of their actual maintenance work. At each maintenance site, two to four researchers participated in the observations, and one of them interviewed the maintenance technicians.

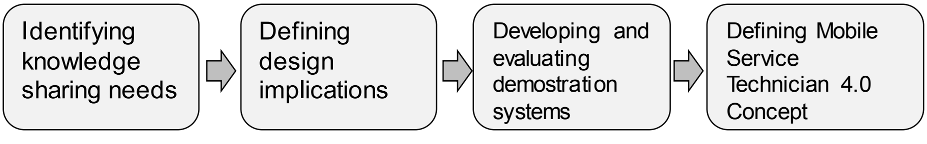

Fig. 1. The design process

The user interviews followed the principles of core-task analysis [35], which is a methodology for studying work practices and includes exploring the interviewees' conceptions of good work practices and practitioners. Two maintenance workers in both the Wärtsilä and Konecranes cases and one worker in the Bronto Skylift case were interviewed. The observations ranged from a general overview of a maintenance site to selected and detailed maintenance tasks. The observations included capturing videos and photos of the maintenance activities and sites [36].

Based on the results of the user studies, we identified main knowledge-sharing needs in maintenance work. The needs were further analysed to design implications, which were the basis for the demonstrators that we designed and implemented in collaboration with industry and academia. The researchers evaluated the demonstration systems with maintenance technicians and maintenance experts. The aim of the evaluations was to get initial feedback of the solutions' potentials. That is why we evaluated the solutions only with small groups of users. Still, most test users were maintenance professionals. The evaluations were focused on user experience [37, 38], usability [39] and user acceptance [40, 41]. User experience studies aimed to study how the users felt using the solutions. User acceptance focused on perceived ease of use and perceived value to the user.

4 Knowledge-Sharing Needs

4.1 Industrial Service Business Needs

The four participating companies shared common maintenance challenges related to the long life cycles of their products (cranes, elevators, ship engines and power plants as well as aerial platforms and appliances), and a large variety in models and spare parts, which create substantial information needs for the service technicians. In some cases, the maintenance services also cover other companies' products, which further increases the information needs. The companies knew that their maintenance personnel possess a lot of tacit knowledge, and they were worried that the knowledge may be lost with aging and retiring personnel. In the following, we briefly describe the maintenance contexts in the four companies, focusing on the maintenance environments, current challenges in maintenance work, and the identified development needs.

Bronto Skylift is the global market leader in truck-mounted hydraulic platforms, manufacturing and servicing appliances for rescue and firefighting, as well as for construction work. Their product range includes approximately 50 models with advanced modularity that enables numerous client-specific modifications. The aim to improve maintenance work was based on a need to link information from various sources, to share information, and to facilitate field reporting directly to the service server. Contextually relevant information would improve the efficiency of service visits, and gathering field information could be utilized in preparing for forthcoming maintenance visits, thus contributing to continuous improvements.

KONE is one of the global leaders in the elevator and escalator industry. KONE's technically diverse maintenance base contains more than one million elevators and escalators with many manufacturers and equipment generations. The lifetime of the equipment to be maintained is long. The motivation for new maintenance work was based on the challenge to acquire a skilled workforce, especially in developing markets as well as the need to get access to the vast amount of tacit knowledge possessed by experienced technicians. Promises for productivity improvement were seen also at optimizing the time on-site without sacrificing maintenance quality or safety as well as fixing the equipment right the first time.

Konecranes provides maintenance service and spare parts for all types of industrial cranes and by all manufacturers globally. Konecranes service has several thousands of service technicians working globally both in industrial crane and machine tool service. The overall research objective for Konecranes was to improve the efficiency of their technician's service visits by identifying reliably the equipment and system. This is connected to the need to report and record service findings promptly. The efficiency of internal service processes was also part of the objective, and they were looking for means to support work planning and reporting during service visits.

Wärtsilä is a leading service provider in the marine and energy sector. The maintenance sites, ships and power stations, are complex buildings and identifying the maintenance target in the environment can be demanding. The life cycles of the equipment to be maintained are long, even decades. Maintenance personnel have a lot of tacit knowledge related to individual maintenance sites, but sharing it could be improved. Finding the required information can be demanding and time-consuming for field service engineers. To minimize the maintenance breaks at the customer end, maintenance personnel should be better prepared for upcoming maintenance work.

To conclude, the companies saw development needs in better preparation for maintenance visits, identification of the maintenance targets, integrating information from various sources to support the maintenance person, making tacit knowledge visible, sharing the knowledge and quicker reporting. The companies were looking for solutions that would overall optimize time on site and thus minimize maintenance breaks. These developments would benefit both the customer and the service provider with more efficient and better-quality services.

4.2 Knowledge Needs in Industrial Maintenance Work

The user studies with the maintenance technicians revealed how challenging the maintenance personnel's work is: they need to master various maintenance sites; use various maintenance tools and devices; use different information and reporting systems, and actively communicate with other workers and customers. Moreover, they need to solve complex problems under time constraints. The field observations gave insight into the challenging *work environments*, which include noise, high temperatures and humidity, confined spaces, high places, greasy surfaces and poor lighting. These conditions place restrictions on the technology to be used, regarding both ergonomics and robustness.

The equipment to be serviced is large and heterogeneous. Typically, the maintenance technicians search *maintenance instructions* from paper documents or document databases. In document databases, the documents are often stored in PDF or other formats not originally designed for mobile use. Individual equipment may have undocumented device-specific "quirks" that need to be learned. Maintenance documentation is often downloaded and stored locally, or printed and paper manuals are used. Thus, revisions to the maintenance instructions do not reach everyone in the field.

In some cases, the information systems are accessible only in the office and the local paper manuals may not contain the latest updates. When *preparing for a maintenance* visit, the maintenance technician has to make sure that the needed information and equipment is available at the maintenance site, and that the information is valid for the maintenance target. Furthermore, (s)he needs to know where the manuals or other information sources, as well as target-specific tools, are located at the site.

Communication is a routine element in maintenance work as regular communication with colleagues and client/customer is always needed, but it is especially important when encountering problems. On-the-job learning is crucial in maintenance work, and experienced colleagues are an important source of information. Face-to-face communication is seldom possible, and on the phone, it is difficult to explain the situation at hand.

Sometimes the field personnel develop their own ways of performing maintenance tasks. Currently, information is often shared informally from worker to worker. Maintenance technicians may use some – often local – discussion forums or social media groups where they share these quirks and tips. This tacit knowledge remains out of safety and risk assessment, and this may lead to sharing undesirable ways of working.

Maintenance reporting is typically done after the maintenance visit, either on site or at the office. Sometimes technicians make handwritten remarks during the visit and actual reporting takes place later in the office, which practically means double reporting. The technicians need to report to their own company's reporting systems but sometimes also to the customer's systems. Video and photos are not used frequently even if the interviewees thought that they would be useful.

To conclude, the technicians wanted to have easy access to up-to-date maintenance instructions, documentation and data, both when preparing for a maintenance visit and during the visit. The technicians also wanted better tools for communication with their colleagues when they needed advice. The technicians considered reporting to be time consuming and frustrating, so they welcomed any tools to make reporting easier.

4.3 Design Implications

We discussed the industrial needs and the results of the user studies in a series of workshops with the project partners. During the workshops, we analysed the industrial needs and the user needs to the following design implications:

1. **Support the technician in preparing for the maintenance visit.** The technician should feel confident when going off to a maintenance visit; (s)he should feel well prepared and know what to expect at the site.
2. Give the technician **contextually and personally relevant guidance** and support during the maintenance operation. The worker should be confident about getting the necessary support and guidance in fault identification and in maintenance tasks, so that (s)he knows what to do and where to ask for advice if needed.
3. Give the technician **easy access to human support** when the written guidance is not sufficient. The technician is often working alone at the customer site, but (s)he should still feel like a part of the work community and that other people are available in case (s)he would need help.
4. Provide **knowledge-sharing tools** that facilitate connections to peers, and encourage the experienced technicians to share their knowledge. The technicians should not be forced into certain practices but they should be allowed to suggest alternative ways to act.
5. Support **smooth work flows**, especially in reporting that finalizes the maintenance task. The technician should be able to do the reporting in parallel to the maintenance operation.

5 Knowledge-Sharing Demonstration Systems

Based on the design implications, we started the implementation of demonstration systems. The aim was to demonstrate several individual tools that would support the mobile service technician throughout his/her daily work. Table 1 describes the demonstration systems and their relation to the design implications. In the following subsections, we describe the demonstration systems, how they were evaluated with users as well as the user evaluation results.

Table 1. Design implications (DI) and corresponding demonstration systems with the participating company.

DI No	Demonstrator
1	**Preparing for maintenance (Bronto Skylift):** With a VR application, the technician can prepare and practice before the maintenance visit.
2	**Fault identification (KONE):** The technician is supported in identifying and interpreting error codes. **Contextual guidance in maintenance operations (Wärtsilä and Konecranes)**: The technician gets contextual data and step-by-step instructions for the required maintenance operation with AR-based tools.
3	**Remote support (Wärtsilä):** The technician gets hands-on guidance by a remote expert with video views and AR tools.
4	**Knowledge-sharing with peers (Konecranes):** The technicians can share guidance and hints to their colleagues. AR connects the guidance to physical maintenance objects.
5	**Effortless reporting (Konecranes):** The technician can use wearable systems to make reports on-site during the maintenance operation.

5.1 Preparing for Maintenance

Approach. Service technicians would benefit from being able to remotely observe the machine in need of maintenance as well as the area around it. Viewing previous maintenance operations of the particular machine could also be helpful. This way, technicians could prepare for the upcoming maintenance tasks with, e.g., sufficient tools and documentation, and even proper training. By viewing the relevant parts of the previous maintenance, they could identify the specifics of the particular machine and the context it has been in, observe working methods and procedures of other maintenance personnel and identify required tools, parts and safety equipment.

Fig. 2. Screen capture from omnidirectional video of Bronto Skylift maintenance hall. Users can freely observe the skylift and the location with a head-mounted VR solution.

We implemented with Bronto Skylift a demonstrator system that provided remote access to the maintenance site utilizing VR and omnidirectional videos. The demo was evaluated with 34 users who compared the solution to a CAVE-based system. The participants of this study were not maintenance experts and all were naïve with respect to interacting with omnidirectional videos.

Solution. To offer remote access to maintenance sites, we looked into omnidirectional videos and VR [23]. Omnidirectional videos cover the full scene (Figure 2) and as such allow the viewer to potentially see "everything" around them. In addition, the use of omnidirectional video in recording the maintenance operations would capture a lot of the tacit knowledge relevant to maintenance. Viewing said videos with a VR headset allows the user to view omnidirectional videos naturally, as the viewport moves based on the user's head orientation.

Fig. 3. Left: Amaze360 physical setup. Right: Amaze360 application view. The viewport is divided in two for a stereoscopic effect. An activated interface content element is shown at the centre of screen.

For viewing and interacting with omnidirectional videos, we developed Amaze360, a head-mounted VR application (Figure 3, left) that allows the user to freely observe omnidirectional videos, as if observing the real world. The application supports interactive omnidirectional videos, i.e., the videos can be embedded with interactive interface elements, that can be triggered to gain more information on the surroundings (Figure 3, right), or to move from one video to another, allowing users, e.g., to observe the surroundings or the machine from different angles. In addition, Amaze360 has the support for displaying 3D models, which can depict a certain location (e.g., a power plant) or a device (e.g., a crane). Omnidirectional video spheres can be embedded within these 3D models and users can then navigate between the videos. With the Amaze360 application, technicians are offered a remote view of, and information on, the maintenance location through omnidirectional videos, embedded content, and 3D models. Technicians can utilize the application for observing the characteristics and limitations of the space, as well as observing the condition and particularities of the machine being maintained.

Evaluation method. We assessed the expectations and user experiences of presenting omnidirectional videos with embedded content in an industrial setting. We wanted to compare HMD and CAVE, since CAVE systems have been used extensively in industry and we wanted to observe how these two mediums differ in terms of user experience and immersion. With 34 participants, we compared the Amaze360 solution to a CAVE system called cCAVE [23]. This system consisted of a rotating chair and of eight displays set in a form of octagon. The chair has rotation sensors that send data to the system, which then updates the display content. We logged all user actions from both applications and collected information from the users with questionnaires.

Evaluation results. We found that both systems offered a positive user experience that exceeded the already high expectations. The HMD (Amaze360) seemed better suited for viewing interactive omnidirectional videos than the CAVE system. Amongst the most positive identified qualities of HMDs were pleasantness, clarity, speed, and ease of learning. The HMD was also regarded as the more immersive platform. The participants felt that they could observe the surroundings as if they were physically in the depicted location. Immersion is important as it indicates how closely the HMD simulates being on-site. Our early results are a promising indication of the potential of HMDs and omnidirectional videos in industrial use.

5.2 Fault Identification

Approach. Our fault identification demonstration system was focused on elevator maintenance. The life cycles of elevators are very long. With new elevators, the fault codes are transferred through wireless connectivity but with older elevators, this is not yet possible. Error codes are indicated by LEDs and/or numeric codes on a display (Figure 4). With KONE, we implemented a 3D tracking-based demonstrator system, which interpreted the error codes and gave maintenance guidance accordingly. The demo was evaluated internally at KONE with nine maintenance experts during different phases of the development.

Solution. In a maintenance situation, the service technician typically starts analysing the situation from the elevator maintenance panel. The maintenance panel presents error codes with four digits on seven-segment displays (SSD), and depending on the code, the service technician needs to check several LEDs to pinpoint the potential error source. The error code tells the actual error (e.g., elevator failed starting) and LEDs indicate causes (e.g., door did not close). Depending on the elevator configuration, there can be 200–400 unique fault codes and several causes for each of those, which are hard to remember.

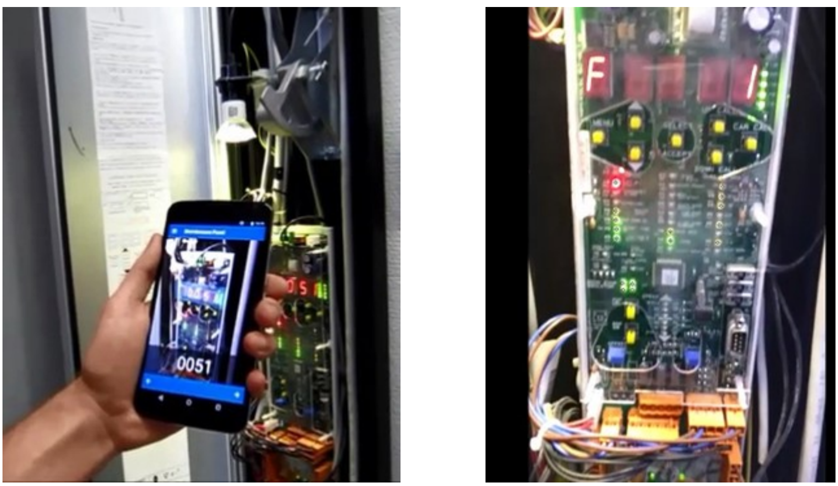

Fig. 4. The demonstrator: On the left, mobile application, (Fault 51 detected). On the right, image of detected maintenance panel with LEDs recognized.

We implemented a mobile phone application to recognize and track, in 3D, one specific maintenance panel (Figure 4). In addition, the application automatically recognizes the error codes from the SSD displays, and it detects which LEDs are on. The user views the maintenance panel via the mobile phone display, and after the system has identified the fault, it gives the user feedback on the identified error code and the error source indicator LEDs (Figure 4, left). After that, the user can proceed to view the textual explanation of the fault and related maintenance guidance. We made a simple decision tree for test cases that are relatively easy to carry out with the physical elevator. Based on the identified error code and the LEDs' statuses, the application used the decision tree to identify the exact error situation.

Evaluation method. Five experts working in maintenance development evaluated the demonstration system informally, and four additional maintenance experts were involved earlier in the design phase and in intermediate evaluations. The system was tested with a physical test elevator and with recorded videos of the elevator's maintenance panel.

Evaluation results. It turned out that the computer vision-based fault recognition was not mature enough for actual use. However, the contextual guidance with the decision tree approach was useful and the main benefit comes from easy access to relevant maintenance guidance. Even if the user would type in the error code and LED status by hand, the overall system would be beneficial as it could thereafter guide the user as intended.

5.3 Contextual Guidance in Maintenance Operations

Approach. In actual maintenance operations, access to versatile and situationally relevant guidance is important for service quality and productivity. The guidance needs vary on different service sites, in different service operations, and with individual service technicians. The industrial partners saw AR-based contextual guidance as a potential solution. That is why we implemented three demonstration systems, each with a slightly different focus [36]. With Wärtsilä, we implemented a demo that gave AR-based step-by-step guidance during the maintenance operation (Figure 5). The demo was evaluated with two maintenance technicians. With Konecranes we implemented a demo, with which the technicians could see with AR real-time data of the maintenance targets on their smart phones. The demo was evaluated with seven technicians. The third demo utilized location tracking to guide the technician to the maintenance site (Figure 6). This technical demo was not evaluated with users.

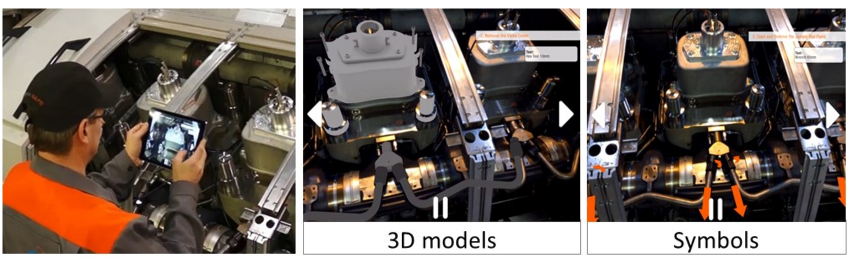

Fig. 5. Demonstration system 1: The maintenance technician can get animated AR guidance as 3D models and symbols [36].

Solutions. The first demonstration system was focused on *step-by-step AR guidance* during maintenance operations. The user views the maintenance target via a tablet PC, and sees the augmented guidance in the view (Figure 5). Animated guidance in the form of 3D models and symbols enables showing how to carry out maintenance operations. Step-by-step contextual guidance enables maintenance technicians to proceed at their own pace, acknowledging when each maintenance step is completed.

The system ensures that all necessary maintenance procedures are performed, and maintains a log of the operations in the customer's system.

The system uses 3D markerless tracking in the form of 3D point cloud recognition. Visual guidance is provided and stitched to the 3D point cloud, correctly oriented on the physical product in the form of 2D drawings, 3D models, or symbols. The correctly oriented point cloud tracked by the software on the mobile device allows information to appear in physically relevant locations.

AR can be used to provide from internet and IoT-based systems real-time data related to a component, such as its usage data and fault codes. This was studied in the second demo, where the maintenance technicians were using smart phones to get *augmented contextual information* about selected components (e.g., condition, lifetime, alerts, and fault codes). The user views the maintenance target via his/her smart phone and sees the data related to identified devices and components augmented in the view. The AR application used ALVAR tracking SDK (http://alvar.erve.vtt.fi) both for marker-based tracking (on the device's cover, enabling augmented "X-ray" view inside it) and for image-based tracking (for the actual device).

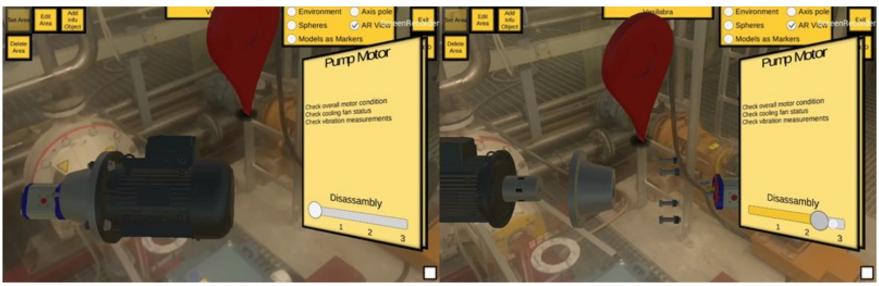

Fig. 6. Demonstration system 3: Location tracking combined with contextual AR guidance using Google Tango platform.

Location tracking can guide the worker at a site to find the required location for the maintenance operation. In the third demonstration system, we combined location-tracking techniques with AR-based contextual guidance. We were using the Google Tango platform (Figure 6), which has a built-in location-tracking feature that uses inertial measurements working in combination with Tango's area learning capabilities. This demonstration system showed the possibility to add different checkpoints, using the Tango tablet, to any area that was previously "scanned" with Tango's own area learning tool. The checkpoints can hold any kind of information, such as mechanical datasheets, measurement values or animated work instructions. When the maintenance worker enters the checkpoint area with the tablet, the relevant information pops up for the worker.

Evaluation method. The *step-by-step AR guidance* demonstration system was evaluated with two maintenance technicians. Participants were given a brief introduction and demonstration on how to use the system. Then they were given a test task to carry out with a tablet: check the machine condition, open the maintenance order, select the operation, walk to the target, put on the AR guidance, perform a disassembly using AR guidance, and finally, accept the task performed. After performing maintenance activities, participants completed questionnaires and they were interviewed.

The *augmented contextual information demonstration system* was evaluated together with the effortless reporting demonstration system in two phases during the development work. The first phase field study was made at a customer site. A service team of five maintenance technicians carried out their typical service activities and utilized the demonstration systems that consisted of a HMD, smartwatch and smartphone. The second phase field study was carried out with two maintenance technicians. In both field tests, there was an introduction for the participants and a brief training on how to use the system, with a hands-on demonstration. Their goal in the test was to perform maintenance procedures for a predefined target. Data was gathered by observations, questionnaires and interviews.

Evaluation results. Our findings from the user studies give evidence that AR technologies serve well in providing contextual instructions and information in field maintenance work. The user experience of the solutions was positive. The maintenance technicians proposed that AR contextual guidance could be useful especially for novice workers, but also for more experienced maintenance technicians if the maintenance task is rarely carried out or if the maintenance operation is complex. Even if the system was intruding on their work practice, the technicians felt that they could focus on their work while using the system. They commented that one of the advantages of AR guidance is that instructions are easier to keep updated, and can be more illustrative than paper manuals. In addition to maintenance guidance, the technician appreciated the possibility to get information about the maintenance history and previous maintenance operations.

5.4 Remote Support

Approach. Even if the maintenance technician has access to various knowledge sources during the maintenance operation, there is still sometimes a need for assistance from human experts. With Wärtsilä, we implemented an AR-based remote assistance system. The demonstrator system was evaluated with two maintenance technicians.

Solution. The industrial internet, as well as new interaction tools, provide promising solutions for remote assistance. Remote human assistance tools can support human-to-human collaboration by giving the remote expert a hands-on experience of the maintenance target, and on the other hand giving the maintenance technician in the field an experience of the presence of the supporting expert.

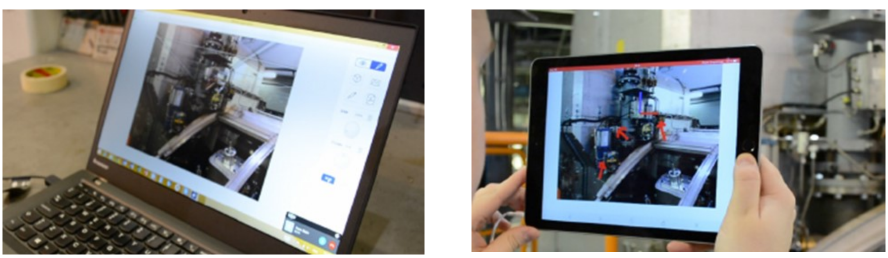

Fig. 7. The remote expert shares the same view with the field maintenance technician and can give guidance with AR symbols.

The purpose of an AR-based remote assistance solution is to support communication and information sharing between a maintenance technician and a remote expert. With an AR solution, the technician and the expert can share the same view of the maintenance target, in which both can add visual elements (Figure 7).

Voice communication supports the collaboration. In the demo, the maintenance technician was using a tablet PC and its camera as a medium to transfer images and video of the maintenance target. The remote expert shared visual indicators of the view on the tablet, indicating how and with which components to proceed. The remote expert used his PC to give this guidance. The added value to ordinary video conference calls is that visual elements that are placed in the user's view on the tablet remain in place. This enables the field service engineer to put the tablet down while working. After the job is done, when the tablet is raised back into position, the markings have remained in place. This eases the workflow and enhances communication during remote support, where speed and accuracy of service are critical.

Evaluation method. The demonstration system was evaluated with two maintenance technicians. Participants were given a brief introduction and demonstration on how to use the system. They could try out the system and they were observed and interviewed.

Evaluation results. The idea of the remote support concept was considered valid and it supported well communication, but fluent use of the application will require more interaction design. The given guidance can be stored so that it can later be used as maintenance support in similar situations without the presence of the expert. For the company, the demonstration system has been an eye-opener in understanding what the possibilities really are and how they can be utilized.

5.5 Effortless Reporting

Approach. The service technicians considered reporting as additional work and a frustrating phase that hindered them from closing the maintenance case. With Konecranes, we implemented a demonstrator system that utilized different wearable solutions to ease reporting. The solution was evaluated with seven maintenance technicians.

Solution. We focused on developing a reporting solution that would make on-site reporting easier and would minimize the reporting after the site visit. Moreover, the solution should encourage the technicians to report also their own observations.

Fig. 8. The wearable system for reporting maintenance tasks. © Konecranes

We developed a wearable system, with which technicians were able to document and report service findings with wearable devices on site (Figure 8). The demonstration system included a HMD, a smartwatch and a smartphone. The technician started the maintenance process with the smart phone, checked information and data from different maintenance targets with the smart glasses, and then selected the maintenance target with the smart watch. The technician wrote the maintenance report with the smart phone. The technician could complement the report by photos that he took with the HMD utilizing the smart watch as the controller. Finally, (s)he could check the report with the smartphone before submitting.

Evaluation method. The demonstration system was evaluated together with the augmented contextual information demonstration system as described in section 5.3 [36].

Evaluation results. The maintenance technicians commented that the wearable system could have a positive impact on their work and could make their work easier. The role and linkages between each device were easy to understand, and each device was easy to use in itself. Due to the number of devices, the use of the system was a little bit too complicated and interfered with working. In work situations, there were many practical problems such as the smart watch being stuck under a work glove, missed access to the HMD in situations where the technician had to take the helmet off, or difficulties in taking photos in dark or confined spaces. Despite the challenges, the maintenance technicians explained that they would accept using the devices during the maintenance operations if that would reduce reporting needs afterwards.

5.6 Knowledge-Sharing with Peers

Approach. In our interviews with maintenance technicians, user-initiated knowledge-sharing was often described. The technicians, for instance, described how they often write down notes for the next maintenance visit, for example on the cover of the machine to be repaired. The notes serve both the maintenance person for their next visit, and their colleagues. With Konecranes, we implemented a demonstrator system that integrated AR and social media solutions to support contextual knowledge sharing. The solution was evaluated with ten maintenance experts.

Fig. 9. Accessing contextual social media during a maintenance task. © Konecranes

Solution. We developed an AR-based social media solution (AR SoMe), which recognizes target objects based on one or more reference images [42]. This enables also tracking the target object so that social media messages can be attached to the object in the video view (Figure 9). The reference image(s) are identified with the target object using ALVAR Tracking SDK.

When the user views the maintenance target via his/her smart phone, an icon indicates that there are AR SoMe discussions related to that particular machine. The user can then open the discussion and add his/her own comments. To create a new discussion, the user can view the maintenance target via the phone, and choose to start a discussion. In the AR SoMe system, each target object is automatically provided with a unique hashtag marked code, which can then be edited for a more meaningful title. A new target object is created simply by taking one or more reference images. When the same object is viewed again, it is recognized by comparing the visual appearance to the reference images, and then the associated hashtag is returned. This makes it possible to attach social media messages to that particular object.

Evaluation method. In a focus group consisting of eight maintenance professionals, we presented the AR SoMe concept to the participants with a video that illustrated using AR SoMe in an office environment. Later on, when the actual demonstration system was implemented, it was evaluated with two service technicians [42].

Evaluation results. The professionals in the focus group, as well as the two service technicians, liked the idea and the possibility to share not only text, but also video or voice messages. They saw that contextual social media could network maintenance technicians in a natural way, and could replace separate networking applications that have not been well adopted in the workplace. User-generated data could complement official maintenance documentation with practical knowledge from the field. The professionals in the workshop also realized that the knowledge could serve not only the maintenance object, but also similar objects elsewhere: "Someone could tweet that these settings work well on the brakes, and another technician could see the advice for other similar brakes right away". The professionals in the workshop as well as the two maintenance technicians discussed the quality of the shared information and how trustworthy the information would be. They thought that the user community would help in assessing the relevance of the information and moderating the content. The two service technicians considered the demonstration system implementation useful, easy to use and the user experience was good. They commented that helping and guiding colleagues, when needed, is rewarding and tools that facilitate knowledge-sharing are very welcome.

6 Mobile Service Technician 4.0 Concept

Parallel to working with the demonstration systems, in a series of workshops, we gradually built the common vision of the project group of future maintenance work. The vision, Mobile Service Technician 4.0 concept, was illustrated with an animated video (https://youtu.be/Cqq3TCLA3WM) that described how maintenance work would change with the new solutions to be developed.

Figure 10 illustrates our Mobile Service Technician 4.0 concept and foreseen changes in maintenance work. In today's maintenance work, a major obstacle is missing access to situationally relevant information and data. When preparing for a maintenance visit, the service technician often has very limited knowledge about the problem at hand, because (s)he has to rely on what the customer is describing. Similarly, once at the maintenance site, the technician has limited access to knowledge and tools at the office. The Mobile Service Technician 4.0 concept facilitates easy access to situationally relevant knowledge by utilizing tools based on AR, VR and wearable technology. The concept includes both new maintenance practices and new tools.

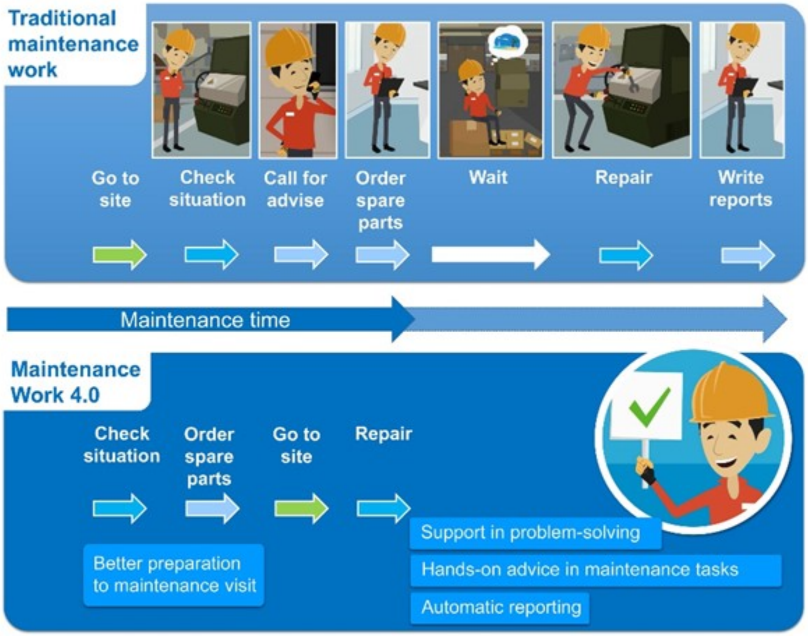

Fig. 10. Illustration of the benefits of the Mobile service technician 4.0 concept.

Better preparation for maintenance visits is supported by virtual access to the maintenance site, where the service technician can familiarize him/herself with the site well before actually heading there. The technician can also access data at the site such as measurements and maintenance history. Based on the user studies with our demo based on HMD and omnidirectional video, the solution was felt immersive, pleasant and easy to learn. The solution has industrial potential to make preparing for maintenance visits more effective and pleasant.

The mobile service technicians that we were working with thought that in ordinary scheduled maintenance operations they usually knew what to do and did not need guidance. However, in corrective maintenance support is needed in *fault identification* and interpretation as well as in guidance in maintenance operations. With AR solutions, the maintenance technician can get situationally relevant *support in problem-solving* as well as *hands-on guidance* in a situationally relevant form. Our demos supported contextual fault identification and gave contextual guidance during the maintenance visit. This contextuality has potential to improve the efficiency of maintenance work remarkably.

Hands-on support from the work community is important, as mobile service technicians often work on customer premises on their own. Peers can provide the support with the AR and social media-based knowledge-sharing solution, which we demonstrated. The solution has potential in creating a community of service technicians based on content sharing. Our remote support solution demo also supports the technicians in feeling connected and gives handy tools for both communication and guidance. With the communication tools, the maintenance technicians get possibilities to develop their competence and build their reputation as appreciated peer-to-peer support persons. This may further motivate service technicians to share their knowledge.

Effortless reporting is supported by wearable tools that facilitate reporting the maintenance visit already at the site, thus finalizing the maintenance task. The technicians were very motivated to adopt the wearable solutions that we demonstrated, to get rid of reporting after the maintenance visit.

In accordance with the expectations for Industry 4.0 [4, 5], the Mobile Service Technician 4.0 concept will support technicians acting as strategic decision-makers and flexible problem-solvers. Compared to traditional service work, the concept will increase the efficiency of maintenance work and make the service technician feel competent, feel connected to the work community and experience success and achievement in their work.

7 Discussion

In this study, we aimed to answer the following research questions:

1) What kinds of knowledge needs do industrial field service technicians have?
2) How could these needs be served with the best possible user experience utilizing the industrial internet and novel interaction tools?
3) What kinds of new maintenance work practices will be developing with new knowledge-sharing tools?

Industrial field service technicians have extensive *knowledge needs* due to the long life cycles of the products to be maintained and the large variety in models and spare parts. The knowledge needs are related to knowing the maintenance site and the maintenance target, identifying faults, finding ways to repair the faults, preparing other maintenance operations and reporting the work done. Official information is not always up-to-date and the maintenance personnel possesses a lot of tacit knowledge. Access to this knowledge is occasional and the tacit knowledge may gradually be lost with aging and retiring personnel.

To *respond to the knowledge needs*, service technicians need both novel tools and new work practices for all the phases of the maintenance work. The Mobile Service Technician 4.0 concept introduces a selection of knowledge-sharing tools based on AR, VR and wearable technology. The concept also introduces *new maintenance practices* including better preparation for the maintenance visit, various ways to get guidance and support in maintenance operations and on-site reporting. While earlier studies have typically focused on one specific tool for industrial professionals, our aim has been to study the field service work more widely, focusing on a whole maintenance visit and the different activities related to it. The Mobile Service Technician 4.0 concept supports Industry 4.0 expectations of qualitative enrichment of industrial work: a more interesting working environment, greater autonomy and opportunities for self-development [4]. Industrial companies can utilize the concept, the related sub-concepts and the evaluation results in planning how and in which order they could renew their field maintenance tools and practices.

Our studies show the actual value of AR guidance: it facilitates connecting guidance to the context, the situation at hand. A major challenge is how to produce AR guidance efficiently. That is why situations where guidance is actually needed should be carefully considered. Remote support with AR can be easier to take into use, as it does not require content creation. On the contrary, remote support operations can even generate support material that can be useful in other similar situations.

Previous research [31] has identified the dynamic nature of knowledge needed in maintenance work. Help from more experienced maintenance personnel is frequently presented in earlier research [7, 34] both as direct interaction and as remote support. Orr [32] emphasized the importance of social aspects in knowledge sharing. With our

AR SoMe knowledge-sharing tools, tacit knowledge can be made visible, it can be assessed, shared, and official documentation can be gradually updated based on it.

For the service technicians, the Mobile Service Technician 4.0 concept provides feeling of competence, feeling of being connected to the work community and experience of success and achievement. Feeling of competence is supported by providing easy access to situationally relevant guidance, giving easy access to remote experts as well as encouraging and supporting knowledge-sharing with colleagues. Connectivity is supported by social media-based contextual knowledge-sharing and by hands-on remote support. Experience of success and achievement is supported by the AR-based guidance, and facilitating the technician to finalize the maintenance case already at the site with wearable and automated reporting tools. For the companies, the impacts of the Mobile Service Technician 4.0 concept are expected to be in better service quality, optimized time at a maintenance site, better and quicker reporting and better understanding of the machines and the maintenance procedures in the field.

8 Conclusions and Future Work

Based on this research, it is evident that companies operating in industrial service businesses share very similar challenges and objectives. It is also evident that there is a need for dynamic visualization and contextual guidance solutions. According to the industrial companies participating in this research, the results were very promising: technology solutions are mostly mature enough to be applied in real use cases, and there is a lot of evidence of the overall benefits. Industrial maintenance work can become more pleasant and more efficient with the Mobile Service Technician 4.0 solutions.

In this study, we implemented demonstrators that worked well in illustrating the solutions to maintenance professionals. The demonstrators also facilitated small-scale user evaluations that gave insight into the potential of the solutions. The next step will be developing the solutions further and integrating them into industrial environments. Then we can study user experience and user acceptance in long-term use. For some solutions, long-term user studies will also require more mature AR equipment that will be ergonomic and safe for long-term use. The participating companies have started implementing the results in their business.

Acknowledgements. This study was funded by Tekes – the Finnish Funding Agency for Innovation (currently Business Finland) and was carried out as a part of the S-STEP research programme under DIMECC (Digital, Internet, Materials & Engineering Co-Creation Ecosystem). The authors are grateful to all the researchers and company representatives who contributed to and supported the work presented in this publication.

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