Science Fiction Prototypes Illustrating Future See-Through Digital Structures in Mobile Work Machines

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1 Introduction

Full visibility of the terrain and targets is an important challenge in the operation of mobile work machines. The machine operator must see the work targets at all times, while the machine and its parts are moving. Furthermore, the operator must be aware of any pedestrians in the proximity of or passing by the machine. However, providing full visibility is not always possible due to occlusions caused by for example boom motion or obstructions caused by the machine structure. The lack of visibility slows down the use of the machine, endangers others working and moving in the area, and physically stresses the operators, due to constantly avoiding and peering around obstacles. From the operator's standpoint, having as many of the structures as transparent as possible, would provide a more ergonomic, safe and productive work environment.

The see-through structures, comprised of new visualization methods and Augmented Reality (AR) solutions, may provide several possibilities for enhancing mobile machines with virtual elements and thus improve the operators' user experience (UX) and usability. Currently, such technologies for augmenting the driver's field of view in traffic have mainly been studied by the car industry, but not excessively in the mobile machine context. Consequently, the research introduced here presents such opportunities for the work machine context, essentially through

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Science Fiction Prototypes (SFPs) that illustrate the diminishing of occluding objects and enhancing the work machine operators' field of view.

In recent years, design has increasingly been applied as an instrument to challenge and speculate about future technological and societal developments, rather than merely as a method for developing durable products [1]. Science Fiction Prototyping has been identified as a practical method for this line of work in technology research [2, 3]. Principally, the SFPs created by the method have been presented as stories grounded in current science and engineering research that are written for the purpose of acting as prototypes for people to explore a wide variety of futures [2]. In general, the earlier technology-driven SFPs have conversed the discussed research relating to Augmented/Virtual/Mixed Realities (AR/VR/MR), such as those demonstrated, for example, in [4, 5]. In this paper the aim is yet to designate potential technologies more thoroughly, engage many other supporting technologies to the SFPs and, conclusively, evaluate the prototypes. For supporting the earlier research, the firm emphasis in this paper is on the two final steps of the SFP method, "human inflection point" and "exploring the implications, solution or lessons learned" as validated, for example, in [6, 7]. Furthermore, for advancing the method, this paper introduces Vision Concepts [1, 8], which may well be seen to complement the SFP method in general. Hopefully this will extend the more visual approach to the creative prototyping process that has been previously initiated briefly, for example, by [9, 10].

Consequently, the remainder of this paper is structured as follows: first, there is a brief description of the context-relevant earlier works, followed by a detailed account of the process, methods, and data sets of the research; accompanied by a brief discussion of the field study investigations and their results. Subsequently, the main contribution is the SFPs complemented with the Vision Concepts. As the reflecting outcome of the process, the paper concludes with a brief evaluation of the creative prototypes and a short-term consideration of the potential technologies.

1.1 Background of the Context and Related Work

In general, the research presented in this paper refers to such terms as Augmented Reality (AR) and diminished reality. Augmented reality is defined as an interactive real-time system that combines real and virtual elements in 3D [11], whereas diminished reality is generally considered to be a system where objects are removed from the real environment and, according to Herling & Broll it is a sub-area of Mixed Reality (MR) [12].

An important aspect, in this context, is the management of occlusion, that is, the way that occluding and occluded objects are treated and visualized. Aside from simple video analysis-based approaches, for example by [13, 14], the more sophisticated methods are based on extracting objects from 3D reconstruction, feature detection and segmentation [15]. In cases where foreground occluding objects are contextually unimportant, the application has used diminished reality solutions to deal with occlusions [12, 16]. In those cases, the occluding object is completely removed and the whole virtual object is shown in its place. On average, the methods using background information collect and process knowledge of the 3D structures of the scene, which they then take into account. These methods typically achieve good visual quality, but require more processing capacity. Another proposed solution for occlusion management is "X-ray vision," where the real environment and the augmentation are blended in a manner that creates an illusion of seeing through or inside a real object [17].

In general, the industrial vision-based systems for displaying occluded and invisible objects, have mainly been investigated by the car industry, with Land Rover's Transparent Hood[1] system being a notable example, as well as the Urban Windshield concept by Jaguar Land Rover. Within the mobile work machine industry, there have been lesser attempts at reducing the amount of occluding structures through the physical design of the cabins and vehicles. One example in the tractor industry, is the Driver Extended Eyes by Deutz-Fahr[2], which presents the occluding areas in a separate monitor. An interesting issue in the car industry concepts has related to how the cameras are placed (topology), and this has been specifically studied in solutions targeting a bird's-eye view synthesis (e.g., Daimler's 360° camera[3]). The systems usually embed multiple sensors (RGB cameras, time-of-flight depth sensors and infrared sensors) for multi-modal sensing and subsequent data fusion. Another trend is the consideration of AR applications and wearable devices, such as head-mounted displays (HDM), hand-held devices or AR- and smart glasses. Such devices have been introduced, for example, with BMW's Mini Augmented Vision concept[4] and devices, such as Microsoft's HoloLens, and Innovega's iOptik[5] cybernetic contact lenses.

Although the automotive industry has been working on similar technologies as those of interest here, it should be noted that their application areas are not as complex as that of the mobile machines, with respect to robustness, accuracy, prolonged use, etc. In this context, it is also critical that the provided solutions do not conflict with other requirements, such as structural integrity, safety, and operational capacity. Moreover, as most of the described technologies in the car industry are still in their infancy or in concept form, timely research in this context is motivated.

2 Process, Methods, and Datasets

The research presented in this paper places the work machine operator as the center of attention. The conducted research investigates primarily the operator's core tasks and the working environment, and secondarily, the supporting technologies. To study the role of human activity in the mobile work machine context, the project has

[1] https://www.youtube.com/watch?v=L7j1daOk72c

[2] https://www.youtube.com/watch?v=CqCLS1reawM

[3] http://techcenter.mercedes-benz.com/en/360_degree_camera/detail.html

[4] https://www.youtube.com/watch?v=j7TYxmsUBuA

[5] http://innovega-inc.com/index.php

employed the practice-theory approach to human factors [18], which emphasizes the role of user experience [19], encourages the active participation of users [20] and demonstrations through effective concept design [6, 21, 22], which in this case was carried out with the means of the Science Fiction Prototyping [2, 23] and Visual Concepts [8].

The research process included three main tasks. The first one was to become familiar with the application areas through visits to different machine vendors and work sites, at four different locations. The second task was to create four SFPs, including Visual Concepts, which were the design outcome of the field study investigations. The third task was to evaluate the creative prototypes and assess their short-term technical feasibility.

2.1 Field Studies

The objective of the site visits was to identify the visibility, human factor and user experience needs of current machine cabs, in addition to operators' expectations of new see-through and augmentation opportunities. The investigations included four locations in Finland: tractor machine vendor's facilities at Suolahti, a work site arranged by a harvester machine vendor in Luopioinen, a machine vendor's test mine in Tampere and an operational mine in Orivesi, and a vendor's test area for cargo handling solutions in Tampere.

To evaluate the visibility needs, safety aspects and UX expectations, the expert machine operators were interviewed, in situ, at the abovementioned machine vendors' work or test sites, during January–February, 2016. The participants were selected from among the test drivers or customers of the project's participating companies. The evaluations included seven operators (all male) with an average age of 36.9 years. The participants had work experience ranging from 3 to 23 years; they operated a machine from a couple of hours to 50 h/week and all were very interested in new technologies. The data collection methods were observations, semi-structured interviews, a questionnaire, video recordings, and photographing on location [18, 24, 25]. The procedure included audio recording, signing a consent form, collecting operator demographics, filling in the questionnaire and core task investigations concurrent with the operator carrying out the work task.

2.2 Concept Evaluation

The Science Fiction Prototypes were based on the aforementioned user research and illustrated the anticipated future see-through and augmented information concepts. To evaluate the UX of the prototypes, there was a user research setup established with experts in the work machine industry. In general, the participants' backgrounds were related to industrial design, machine development and management as well as test driving. The web questionnaire was active for a 3-week period in October–November 2016. In all, ten (10) experts (all male) participated in the Web survey; their average age was 41.3 years and their work experience ranged from 6 to 30 years. Again, the participants were selected from among the employees or the customers of the participating companies: three operated tractors, five harvesters, one in the mining industry, and two in the lifting business. All were interested or very interested in new technologies. The participants were introduced to the visual prototypes via a presentation[6] that was embedded in an online questionnaire. The online survey consisted of both closed and open-ended questions, and the participants assessed important features of the UX concepts (using a 5-point Likert scale: 5 = very important and 1 = unimportant) specifically created for this project. The interview and online survey data were further transcribed and qualitatively analyzed.

3 Results

3.1 Field Studies

In essence, the aim of the field studies was to define the core tasks and activities of the machine operators, visibility issues relating to occlusion caused by the cab/machine parts, technologies that are currently used to help the situation and expectations relating to the forthcoming see-through structures and augmented information.

Tractor

The first field visit was carried out with a test driver from Valtra Tractor (T4) in the machine vendor's outdoor facilities. In general, the core tasks, with the tractor, are related to multiple chores such as farming, front loader work, road maintenance, transport, lumbering, special working solutions (related for example to airports and military operations). Specific challenges concerning the machine cab were related to a constantly changing environment such as one involving location (field, farm, road, forest) as well as the season/weather. For example, in wintertime, ice and snow caused unexpected occlusions and low sunlight was described as blinding the driver.

Consequently, the visibility challenges related to the design of the machine, which was seen to be a compromise between different features (e.g., engine frame/visibility, different tools in front of the machine (the large size of the tools),

[6]The full presentation can be found on: https://indd.adobe.com/view/bb24016d-3eca-48ee-b646-894571cc831b

the need for backing up with the trailer and lifting loads, for example, to the truck, snow when snowplowing (where it is important to see what has already been done)). In summary, the most notable visibility issues for the machine were related to:

- Tractor tools in front of the machine, especially the front loader
- The engine cover being too high/big
- The driver being unable to see the target object
- The driver being unable to see the corners of the machine
- The driver being unable to see people around the machine
- General visibility too close and below.

Harvester

The second field visit was carried out with a forest machine operator using John Deere harvester (1270 E) in a privately owned forest. The core task was to cut down trees (motivated by delivering a profit to the forest owner). Operator characteristics were described as: capable of working alone and skillful in minor maintenance operations. Environmental challenges were related to location and weather changes and the fact that the forest has diverse conditions during the year, that is, the best season for work was stated to be when the ground was frozen (encompassing a few weeks in autumn/spring) in Finland.

The most critical visibility issue was related to the boom in front of the harvester, with other challenges being associated with the engine frame, snow in the trees, darkness in wintertime, the fact that the operator should be able to see the whole tree (top) and rocks in the ground while driving. Consequently, to summarize, the most notable machine visibility issues were related to:

- The boom being in front of the machine
- The boom operator being unable to see the target object
- The cab and engine frame blocking the view
- The operator being unable to see the corners of the machine
- Snow in trees, darkness in wintertime
- The inability to see to see the whole tree (top).

Mining Drill

The field visits were continued by studying several mining machines in two locations: a test mine (with a test operator) and an operational mine (with a driller). During the visits, the research group was introduced to several drills; ultimately, the Sandvik Jumbo (DD530-S60C) was selected as presenting most of the vital occlusion problems, during its use with core tasks, related to tunneling (e.g., drilling holes). Unlike the previous two environments, the mine was described as being a social environment, in which the communication with coworkers and other stakeholders was carried out during the tasks by walkie-talkie. The particular challenges in the mine environment related to darkness, dustiness and muddiness.

The main visibility challenges of the machine were related to drilling upfront, booms, manipulation of booms, darkness, the machine frame, pedestrians, and driving. To summarize, the most notable visibility issues for the machine were related to:

- Machine frame blocks the view
- Drills/booms, in front, block the view
- Engine cover is too high/big
- Unable to see all parts of the machine
- Difficult to estimate the space needed by tools
- Unable to see people around the machine
- Difficult to see around curves.

Cargo Handling

For defining the visibility issues relating to the cargo handling, the machine vendor offered their outdoor testing area for the investigations. At the location, several machines were introduced (e.g., an RTG, reach stacker, terminal tractor, and forklift), yet during the visit, there were no operators working in the environment. The main core tasks were stated to relate to the moving of containers (from ship to shore, stack to truck) and the work environments comprised ports, terminals, distribution centers and heavy industry. The work settings were described as social environments. The physical environmental challenges were seen as being diverse, with conditions being highly dependent on the location and weather, including snow, ice, wind and sand.

The main visibility challenges were related to the cab frame, spreaders, containers, driving tasks, other vehicles, and weather conditions (including, for example, fog, rain, dark, sunlight, and wind). The most notable visibility issues were related to:

- The cab frame or spreader blocking the view
- The load (container) blocking the view
- The operator being unable to see the target object
- The operator is unable to see other vehicles (especially behind them)
- Difficulty understanding depth via the camera view
- Too small a camera display.

Visibility Issues and Augmented Information

In the questionnaire, the expert interviewees were requested to estimate (in percent) how well they could currently see the target object outside the cab. The average of the first interview group was 72.86% (responses varied between 55 and 85%). The participants clearly indicated that the occlusion problems were related to the cab structures and machine parts. Furthermore, the experts stated that they were

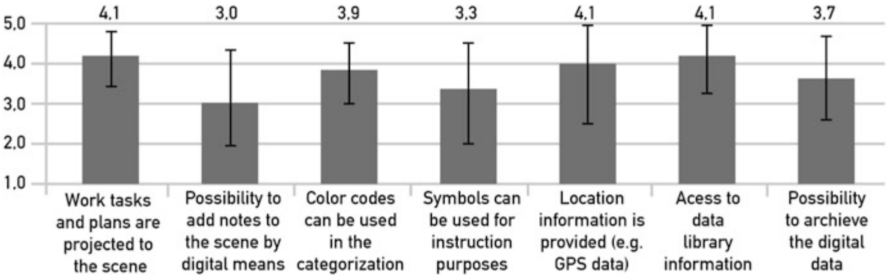

Fig. 1 Augmented information for the field of view, as defined by users

not always able to trust the information that they received with current assisting instruments (monitors and mirrors): 57% stated that they were satisfied with them, 43% were not.

As the aim in this research was to consider making parts of the machine cab transparent by digital means, it was suggested that simultaneously some instructional data and augmented information could be presented to the operator. Consequently, the participants were required to assess what kinds of augmented information they preferred in order to help them with the tasks pertaining to the operation of the machine. These issues were traced from a literature study comprising, for example, [13, 15, 16, 26–29]. Figure 1 presents the results.

3.2 Science Fiction Prototypes

Distinguishing the visibility problems and demands for augmentation led to the creation of Science Fiction Prototypes with Visual Concepts that provided further means for continuing discussion with the expert machine operators. In essence, they illustrate tractor work for snow plowing, harvester work in a frozen forest, mining machine operation in narrow tunnels and future cargo handling solutions. The focus was on future see-through solutions and augmented information cases and it is expected that some of their features will be exploitable in the very near future, some after 5–20 years.

Snow Plowing (SFP 1)

In the first SFP, the target machine was a tractor and the case focused on front loader work during a snow plowing task (see Visual Concepts in Figure 2). The user experience issues related to control, safety and common sense; issues that the expert tractor drivers described as being important operator characteristics. The opportunities for the see-through structures, in this case, were based on the remark that the driver was unable to see the corners of the machine and the people around the machine (see Figure 2, left). Furthermore, the prototypes were inspired

Fig. 2 Left: With transparent tractor pillars, it is easier to observe people in proximity of the machine. Right: Static information about the plowing area is projected to the driver

by remarks from the surveyed tractor drivers who stated that winter conditions for snow plowing were a particularly challenging task.

Figure 2 (right) presents information on how the plowing area is projected to the driver. Overall, the concept was inspired by an earlier study by Schall et al. [17], titled "Simulated looking through solid objects." The research, relating to civil engineering, demonstrated an AR application that displayed underground gas pipes and power lines targeting maintenance and network planning. Regarding user studies, the concept was inspired by a remark from a driver who proposed that the digital information should provide some static structures of a city (e.g., information on the pavements, location of obstacles, and manhole covers). In general, augmented information should support the moving of the machine and provide additional visual cues that encourage fast decision-making. Here, technological challenges are related to accessing and maintaining up-to-date maps of the environment that provide information of the surrounding infrastructure, accurate positioning of the machine in relation to the environment and the robust registration of the AR information on top of the real-world view.

Cutting Trees in a Winter Forest (SFP 2)

In the second case, the target machine was a harvester, and the SFP focused on the task of cutting trees in a winter forest. The concept was based on user clarification, according to which the best season for work was when the ground is frozen; although in wintertime, snow causes various other challenges, as it falls from the tree tops and covers the operating scene. The Visual Concept presenting the see-through structures (in Fig. 3, left) focused on the critical visibility issues with the harvester: the boom in front of the machine that restricted the capability to see the target object. In this SFP, the means to make the boom transparent is referred to as "optical camouflage" technologies presented, for example, by Kiyokawa et al. [29].

The augmented information in Fig. 3 (center and right), focused on the problem that the operator cannot see the whole tree top when making assessments, and during wintertime the forest is dark and there is snow in the trees. The Visual Concept

Fig. 3 Left: semi-transparent harvester boom; Center: areal drones inspecting the forest conditions; Right: color-coded guides for indicating the conditions of trees

(in the center of Fig. 3) presents how aerial quadcopters scan the logging area, for example, with point-and-shoot cameras and long-range sensors, before the machine operator begins the work task. In such a case, the augmented information allows the operator creating a full real-time map of the work area, and the condition of each tree within the area (in Fig. 3, right). Furthermore, the operator may use the information to plan the categorization tasks and bucking measures. Also, the digital scene may include other information such as work area information, notes, and symbols.

As a reflection, the technology required for building such an environment map may be based on a variety of different sensors, as the reconstruction task is not time-sensitive. This falls under the concepts of photogrammetry or Simultaneous Localization and Mapping (SLAM), where a geometrical model of the environment is built, piece by piece, by a sensor moving, in the space, over time. It can be done by cameras on the machine, itself, while it moves through the forest, or, for example, by a drone independently mapping out the trees beforehand. Most likely, a visual map is sufficient for getting the optimal information from the scene, so some scene analysis has to be performed, either through conventional machine vision to extract straightforward measurements (tree thickness, straightness, and height) or through more sophisticated machine learning (the identification of trees, the planning of which trees to leave, and what length to cut logs into).

Drilling Holes in the Mine (SFP 3)

In the third SFP, the target machine was a driller, and the case concentrated on mining tasks that related to manipulating booms and driving in the dark. The opportunities for the see-through structures focused on the machine frame and drills/booms that blocked the view (see Fig. 4 at left), an engine cover that is too

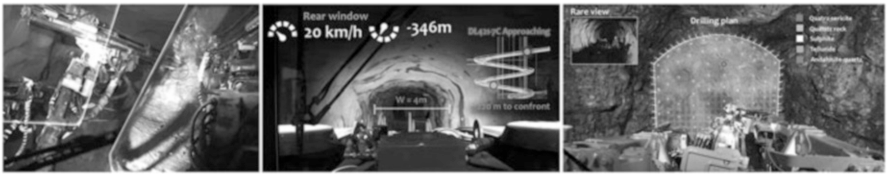

Fig. 4 Left: pillar is made transparent for revealing the drill; Center: augmented information when driving in a tunnel; Right: the drilling plan and colorful analysis of the stone material

high, the difficulty of the operator to estimate the space the tools need and the difficulty of seeing around curves. The human factor requirements related to the challenging lighting conditions, the need to improve the safety of the people in the proximity of the machine and the need to support the moving of the machine.

The SFP was inspired by the interviewed mine machine operators, who explained that while driving in narrow tunnels, the booms obscured the view and it was difficult to observe other traffic in the tunnel. In Fig. 4 (center), the augmented information provides statistics about the machine, tunnel, and distances. Because the mine is a social environment, the interviewees mentioned that they would prefer to communicate with other coworkers by visual means. Also, the machine operators mentioned that it would be convenient to have the drilling plan placed exactly on top of the drilling area. As a fictional idea, the operators imagined that it would be convenient to have an analysis of the stone material of the drilling area, as it influences the drilling and "pull out" maneuvers of the drill; these suggestions are illustrated in Fig. 4 (right). From a technical point of view, as the mining environment is relatively static, it allows for time-multiplexed reconstruction. A specific need is to have reliable communication, both on the inside and the outside of the mine, to relay the maps and the drilling plan information. Since coordinating the actions inside the mine due to the tight spaces is a significant issue, tracking the position of vehicles and personnel and synchronizing the information between all actors, is of key importance.

Lifting Cargo in the Sky (SFP 4)

In the fourth SFP, the target machine handles cargo and the concentrates on a task of moving containers. The opportunities for the see-through structures, in this case, were related to the cab frame that blocks the view from the target object. In this situation, the operation position is usually not ergonomic and current camera displays are too small and restrict depth perception from the view.

In the future, the cargo handling terminals, harbors and port yards could, themselves, be seen as a complex intelligent machine that is constructed of sensors, cameras and remotely controlled intelligent machines (see Fig. 5). In the last SFP, the future cargo handling terminals are operated from a remote-control center that visualizes the sensor and camera data, and provides intelligent operating systems

Fig. 5 Left: Sensor-embedded port yard that is remotely controlled

Table 1 Preferred Augmented Information

Topic	Percentage (%)
Information about the work area is presented in the operator's field of view	70
Areal drone scan the working area and the information is projected to the field of view	60
Location of other staff is presented in the field of view	20
Target work (e.g., the drilling plan) is projected to the field of view	10
Instructions are projected to the field of view	10

for remote operators. Operators can control intelligent machines for example by using new interaction techniques such as speech and gesture control, as described, for example, in [7].

3.3 Results of the SFP Evaluation

When analyzing the user expectations of the SFPs, the Web respondents' interest in each of the four scenarios correlated with their machine's operation background. In general, all of respondents found the Visual Concepts to be plausible, as well as desirable. The transparency level of the concept figures was sufficient according to 60% of the respondents, while 40% expected the pillars and tools to be even more transparent. Again, 60% expected to have a color outline marking the digital transparency area. As to color preferences, 30% preferred orange/yellow; 20% blue/turquoise, 10% green and 40% another color or no color. As a further commentary, all respondents reported that the main distance they needed to be able to see from the cabin was between 5–50 m (on average 23.5 m). All of the respondents reported needing the see-through information of the scene when the machine was moving.

Table 1 demonstrates which of the augmented information topics the expert respondents found to be useful, based on the SFP concepts.

3.4 Consideration of the Technologies

In general, the main challenge in the building of see-through solutions is to dynamically capture changing visual information of outdoor scene elements, especially those that are outside the operator's field of view; then to convert it to a representation suitable for fast and error-free processing, and finally, to visualize it to the operator. With technology that is available today, creating such a visualization system is generally possible by simply stacking enough sensors and hardware. However, the main challenge for the development is to consider what kind of design is realistically feasible and practical for actual use. To achieve a robust and practical implementation, a compromise must be reached between visual quality, operating speed and the amount of additional hardware required to run it. Another challenge is the fact that the information should be collected in a robust way that is invariant to lighting and environmental changes (e.g., presence of dust or haze). The implementation of see-through structures can be presented as two interconnected components, namely, environment sensing and in-cab visualization, with some amount of processing steps in between, needed to map sensor data into various displays.

In environment reconstruction, there are several different sensors available that have their suitable properties. A key aspect in processing is to be able to deal with incomplete and noisy data. While similar topics have been extensively studied for example in compression and transmission research under the umbrella of error concealment, such approaches are inherently problematic considering the operator may have to make safety critical decisions, based on the information provided by the system. Therefore, whatever interpolation or other filling methods used to deal with missing scene information must be applied carefully, in order to avoid providing false information.

Due to the complex structure of work machines and their cabins, visualization must be partially done in areas not covered by opaque cabin elements, but window surfaces. This prompts the use of transparent visualization media. In automotive and aviation applications, heads-up displays have been investigated, where the intent is to show for example selected numerical information to the operator. The existing solutions typically use either direct or virtual image formation techniques for producing the images. In this context, the disadvantage in virtual image systems is that all the components require significant amounts of space, are expensive to produce and provide only small viewing areas and angles. Direct image formation appears to be more pertinent, as it forms the image, in one way or another, on the glass itself, and can be implemented by either projecting images onto an appropriate semi-transparent medium (glass embedded with refractive elements, glass beads etc.), or by placing light emitting components into/onto the glass itself (transparent LCD, OLED, TASEL).

4 Conclusions

New see-through applications and advanced augmentation solutions are expected to influence strongly on future industrial work tasks. It is obvious that clear visibility of the work target means remarkable improvements in the accuracy and productivity of mobile work machines. In addition, the novel see-through technologies are expected to increase the safety and user experience of the machine operation.

This paper presents Science Fiction Prototypes illustrating see-through and augmented information concepts that do not merely focus on the machine structures and technical solutions, but also emphasize the targeted operator practices and preferences. This approach is seen to benefit the industry in the long run, as supporting technologies are currently developing fast. Future work in the area will continue by building a physical Mixed Reality demonstrator for a tractor by employing some of the abovementioned technologies. Taking into account the results of the study, the digital information in this demo will be delivered straight into the windshield of the operator.

As a further note, the concept cases illustrated subtly how, in the longer term, the presented technologies are evidently moving towards remote operations, which may well build upon the digital augmentation technologies presented in the Science Fiction Prototypes. It should be noted, that the case study focused on four explicit machine operation contexts, but, the core ideas may be further employed with other similar intelligent machine working environments.

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