Virtual and Augmented Reality Solutions to Industrial Applications

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Abstract

This paper introduces a variety of virtual and augmented reality solutions for industrial applications. In addition the technologies and techniques required for producing these kind of solutions are presented. The issues studied in research projects referred here include data connectivity, processing and 3D visualization of construction models, positioning and tracking solutions and user experience design. An open database containing evaluations about available virtual and augmented reality platforms is also presented.

1. Introduction

During the last few years virtual reality and augmented reality have both been hot topics in the entertainment industry, but still the implementation of these technologies in industrial context has been lacking. While in industry various technological solutions are widely used with efficient results it is still usual to use tools that have been in use for over a decade. However there seems to be much to utilise in augmented reality (AR) and virtual reality (VR) technologies if one wishes to promote the information flow from the design bench to the construction process by enhancing the aforementioned processes with visual aids. Due to the requirements of the work processes, these solutions must be meticulously designed and have higher standards for current and correct information and thus they differ quite a lot from their entertainment counterparts.

Virtual reality refers to technologies that are used to generate virtual images and sounds to simulate physical presence in another environment. In VR the content can be linked to the real world, but it does not have to be. The physical location of the user is irrelevant to the content per se, but in a large system the movements of the user can be tracked and reflected into the VR world. Some of the content can be real time sensory data, for instance the user can navigate a virtual model of a building on the other side of the Earth, and see the air flow in a given ventilation duct. This allows remote monitoring, without physical presence. In training and education VR provides a low cost alternative to sending the learners on site. Additionally, VR allows simulated situations that would be hazardous to the user and costly to perform, like how to react in case a fire starts.

Augmented reality involves superimposing virtual content on the user's view of the real world. In AR, views from real-world environments are augmented with digital 3D-objects and/or other data in real time. The content can include real time data, e.g. the status of a given item, such as the temperature of a water pipe, or static data, like the material used for a given item. In the AR-case, the content is linked to the physical location of the user. Additionally, the user can be provided with access to further data, such as manuals or instruction for maintenance operations, based on the item(s) seen in the AR-view.

Mixed reality (MR) can be imposed by changing incoming information from all senses. Usually MR uses at least visual and aural methods but also olfactory, gustatory, and haptic can be used (see e.g. *Ranasinghe, Karunanayaka, Cheok et al. (2011), Colwell, Petrie, Kornbrot, et al., (1998), Ischer, Baron, Mermoud et al., (1998)*). Visual effects can be e.g. computer-generated 2D- and 3D-images or information superimposed on the real-world view captured from the camera of a smartphone, computer or other device (*Bujak, Radu, Catarbone et al. (2013), Heimo, Kimppa, Yli-Seppälä et al., (2017)*). Mixed image appears to its users as virtual and real objects coexisting simultaneously in the same space. (*Di Serio, Ibáñez and Kloos (2013), Seppälä, Heimo, Pääkylä et al. (2016), Heimo,* *Kimppa, Yli-Seppälä et al. (2017)*)

MR consists of various different setups and combinations of levels of reality and digitally generated material. As virtual reality experiences attempt to recreate all of these signals, AR only attempts to enhance the natural elements with some artificial information. Therefore MR covers the whole area between the physical reality and completely simulated virtual reality, illustrated in the famous Virtual Reality Continuum in Figure 1 (*Milgram, Takemura, Utsumi and Kishino (1994)*).

Figure 1. Levels of mixed reality.

In our project we have studied industrial applications of both virtual reality and augmented reality. A number of demonstrative applications have been built to study potential MR-assisted functions in construction and shipbuilding industries. In this paper we describe those demo applications and what has been learned through them.

The applications demonstrate certain solutions that are essential in many kinds of industrial applications. One such issue is connectivity to relevant databases where 3D CAD-models and related metadata are available. It enables the application to use real time data so that, e.g. the displayed model is always up to date, and it is possible to show actual, real time data from dynamic systems like air conditioning or water piping. Another common issue is indoor localization - how to define the user's location.

We have interviewed a number of potential users of VR/AR solutions among different industries. Demo applications have also been presented to people not familiar with the technologies, and their initial reactions and possible changes in opinions after that have been observed. The study gives light to questions like what people typically know about VR and AR in advance, and what kind of potential is seen in these technologies for usage in various functions.

We outline the current state of technology, regarding for example VR and AR glasses (HTC Vive, Oculus Rift, Microsoft HoloLens etc.), and what is still needed for a real breakthrough. We discuss the findings from the user interviews, and we give an estimate how quickly such solutions can be taken into use in industrial processes.

The MARIN2 research project led by the University of Turku was focused on industrial uses of augmented and virtual reality technologies. The project ran from January 2015 to March 2017 and continued the work started in the earlier MARIN project (2012-2014). The project had several industrial partners including infrastructure, construction and shipbuilding companies.

The research topics in the project had emphasis on data handling. Connectivity to databases containing plans, models and metadata is essential for many industrial applications. Data format conversions are often needed, and so is filtering and simplification of the models, especially when they need to be rendered on consumer level mobile equipment. Tracking algorithms and localization technologies were studied and developed. The project also did technology follow-up, testing and evaluating new commercial products. The project delivered demonstrative applications of AR and VR technologies and several publications about those. A web site collecting and delivering information about MR headsets and software development solutions was also built and is being maintained at ar.utu.fi/mrdb.

This paper begins with an overview of a few existing MR tools and a list of systematic literature reviews examining the current state of the art for various subjects. Then key technologies used in MR systems are presented in Chapter 3. Chapter 4 presents the demonstrators created in the MARIN2 project. Finally, some conclusions are drawn in Chapter 5.

2. Background / Related work

Airbus uses the Smart Augmented Reality Tool (**SART**), designed and developed by the Airbus subsidiary *Testia (2017)*. SART is an inspection tool at the aircraft fuselage assembly lines, as described in *Guillot (2016).*

SART is being used for inspection of mounting brackets in the aircraft fuselage. There are thousands of brackets in an airliner, and correct installation of each one has to be inspected. An AR solution for this specific task was designed and implemented initially in 2010, and it has been in routine use since 2011, with further refinements and updates during the operational period. The application includes a reporting tool, integrating the inspection task into one device. With the AR application Airbus claims to have reduced the inspection time to one fifth of what is needed using the traditional method involving paper or laptop based inspection sheets and Excel/Word applications for reporting. Also quality improvements (decrease of non-conformities) are reported - see *Cottet (2016).*

The SART process includes data processing where 3D-models and parts data are prepared to be run on a mobile device. This phase is done in the office before the actual inspection task. The inspection requires human approval for everything – according to aircraft industry regulations – as an automatic system can’t approve the inspection results. Thus SART is designed as an assistant for human operators, not as a fully automated system capable of unsupervised work.

The actual SART tool runs on a tablet computer, with a specific camera module attached to it. In the inspection work, it uses a marker-based, in-house developed tracking method with millimetre scale accuracy. A markerless solution exists too, having lower accuracy, but being useful in some applications. The markers are set to place by the operator during the work task. Typically one marker every 3-5 metres in sufficient, but it depends on individual working styles. The marker-based solution ensures good localization, although it also requires some effort from the operator. For example, an aircraft fuselage has a lot of repetitive elements, making correct localization by an automatic, markerless system very difficult.

The tablet device is used with a light neck strap or harness, which makes carrying it relatively easy. The currently available AR glasses would be impractical and inconvenient for continued use. The tablet can be used continuously for half a workday, and its battery is changed or charged during the lunchbreak.

Another example of the recent development would be the **EdcAR** system. It has been developed for the European Space Agency (ESA) by Technical Research Centre of Finland (VTT), Thales Alenia Space, and Institute of Communications and Computer Systems, Greece. *Helin (2016)* presents the system, as well as two use-cases. These two use-cases are (1) AR supported telecom payload coax cables assembly, and (2) AR based on-board training and remote support for centralized cabin filter replacement in ISS. The EdcAR AR-system has been designed to give a simple solution based on standards for portability and expandability. With this in mind, things like modularity and reusability have been highlighted in the development. These were achieved by using *ALVAR (2017)* 2D/3D tracking system on top of the Unity engine with ROS (an open-source Robot Operating System) providing the platform support. The team reported the following lessons learnt:

- Point cloud tracking works really well, but needs expertise in set-up
- Main show-stopper is usability and processing power of AR-goggles

- EdcAR system works with smart phones and tablets
- A lot of resources was spent to the backend system and loading content in real time
- A fully Unity-based system could show much better features of AR and would also enhance performance

Within the MARIN2 project a number of systematic literature reviews were conducted about subjects related to the industrial use of augmented and virtual reality solutions. One review collects information about use of depth sensors in augmented reality applications *Taskinen & al. (2015).* Usage of inertial sensors for movement tracking on a map is the theme in *Kaustinen & al. (2015)*. Advances in monocular model-based tracking are analysed in *Lahdenoja & al. (2015)*, while articles about hardware accelerated visual tracking algorithms are collected in *Korhonen & al. (2015)*. Developments of user interaction technologies in mobile AR are presented in *Härkänen & al. (2015)*. All these literature reviews are available in the Technical reports series of the University of Turku, which also provides other reports from the research areas.

3. Technology review

This section presents a summary of findings about devices and technology platforms that were studied during the MARIN2 project.

3.1. Display devices

Head-mounted VR glasses are being developed by several companies, and new models are released frequently. In March 2017 the two best-known VR glasses were *Oculus Rift (2017)* and *HTC Vive (2017)*. The operation and display specifications for the current generation models are fairly identical for the two products. Both have a 2160 x 1200 pixel resolution display (1080 x 1200 per eye) and 110 degrees field of view. Positional tracking is done using sensors located in front of or around the user, giving a few square metres of floor area (tracking volume) for the user to move around in. Both support specific, tracked hand motion controllers with several interaction buttons, although with Vive these are included in the basic system, while for Rift they must be purchased as an extra. Currently, Vive can do positional tracking within a slightly larger area than Rift. On the other hand, Rift seems to be a more polished product from the consumer point of view, with a simpler setup and built-in headphones. But both products are expected to get updates in the future, and the “leading position” may well change. As these are just display devices, the performance of both systems depends mostly on the computer being used, which is not sold as part of the system. In fact, a high performance computer for these displays will cost more than the VR glasses.

Compared to the experiences with earlier versions of e.g. Oculus Rift systems, dizziness or motion sickness seem not to be a major issue any more, according to *Heimo, Sakari, Säntti and Lehtonen (2017)*. This is due to the improvements in both computer performance and in the actual display hardware. The current Oculus Rift and HTC Vive VR glasses can be successfully used in visualization of complex industrial and architectural models: the image quality is high enough, even though it cannot yet match human acuity. New interaction solutions taking advantage of e.g. hand motion controllers have emerged with these displays, and widely accepted conventions seem to be forming, as summarized by *Hayden (2016)*. One such popular concept is moving by teleportation: the user points with a hand controller to a point in the virtual ground, and when pressing a button, jumps instantly to that point. This method helps avoiding the motion sickness that can often be experienced when moving continuously in the virtual environment. With continuous movement in the virtual environment, the sensations from the visual system and inertial sensing organs are in conflict, whereas with the instant location change the senses remain in harmony.

Google Cardboard (2017) and *Samsung GearVR (2017)* based solutions were also studied. These are low-cost systems that utilise a mobile phone that is attached to a head-mounted mask. Development efforts were focused on desktop-based glasses, due to the performance requirements imposed by highly complex CAD-models.

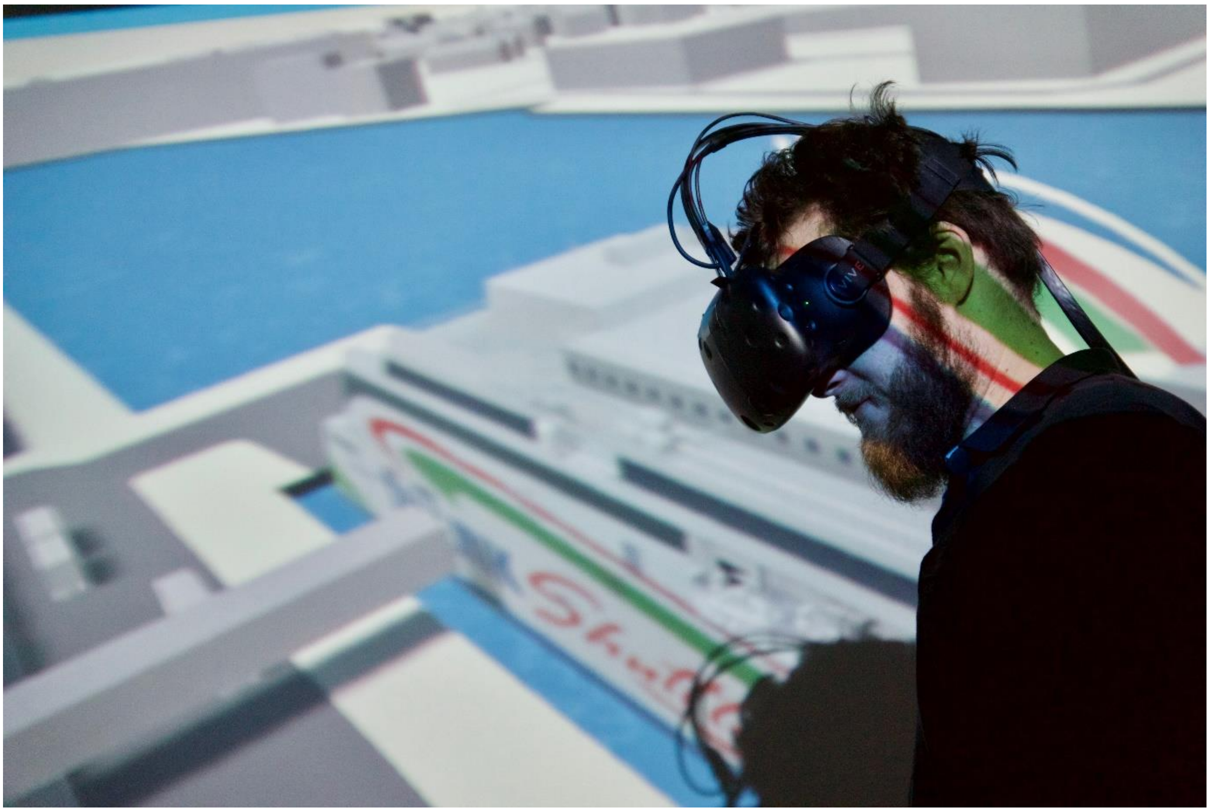

Figure 2, ShipVR

Augmented reality glasses with see-through optics have been commercially available for several years, but the speed of technical progress with them has not been very fast. *Vuzix (2017), Epson (2017)* and *Brother (2017)* are some of the companies that offer wearable AR glasses. However, so far there has not been a great hit among such products, and new model releases occur rather rarely. The products still seem like curiosities aimed at research and development use rather than complete packages that would offer a commercially attractive solution. Technologically the products suffer from a limited field of view, they are typically rather heavy to be worn for long time, robust tracking systems are missing and the availability of software content is very limited.

Google Glass (2017) was a much hyped augmented reality product a couple of years ago, but the first generation was a commercial failure. Google aimed to create an unnoticeable wearable device, one that could be used as easily as ordinary spectacles. That led to a design with a very small, off-centered display and nearly no capabilities for tracking. In the end, most researchers, e.g. *Zerkin (2013)* do not consider it an actual AR device. However, Google has since then launched the *Glass at Work (2017)* program for certified partners to deliver enterprise solutions for Google Glass. One such application is used by Boeing in aircraft production as explained in *Wheeler (2016)*. Google is reportedly working on a new generation of devices with a similar concept but improved specifications.

Microsoft (2017a) HoloLens has set a new standard on AR glasses. It has a few strong and unique features that give it an advantage over its competition:

- It has a very robust tracking that does not need markers, and actually adapts to the environment: it recognizes walls and other shapes of the room and can estimate its own location very accurately.
- The devices is fully untethered and autonomous. Computing occurs in the device itself, so it needs no wires or connected backpacks for the equipment to function.
- The device can interpret user’s hand movements and use them as input. This can be very handy, although long interactive sessions can also be tiresome. A lightweight controller

device is also supported, to help avoid the arm fatigue problem commonly known as the *gorilla arm syndrome (2003)*.

The field of view in HoloLens in one of its less impressive features: it is only about 30 x 17 degrees, which means you often lose sight to some content. It is, however, good enough to give a fairly good view of the virtual content around you. The glasses need to be tightened around the wearer's head, which means long sessions might get tiring. The device itself is not very heavy but battery capacity imposes a practical time limit on usage.

Instead of glasses it is also possible to use smartphones and tablets for AR applications. Then the augmented content is put on the online video on tablet's display or even on laptop display (see SART in the previous chapter). This solution works quite well in cases when there is no need to move around but instead take a snapshot of some view and inspect that view in detail.
Tablets have a few advantages over AR glasses:

- The user can instantly switch between the AR view and reality view.
- The weight of the device is not carried by the head.
- Tablets are often already standard equipment in industrial environments, so new equipment investments are minimal.

However, the computing performance in tablets may not be sufficient for some applications. Typically this may be the case when the models to be displayed are very complex. Then a desktop computer is needed, or the software and displayed content must be optimized for mobile devices. Another drawback is that the user's hands are occupied when carrying a tablet, unless it is worn in a harness or strap. Stereoscopic perception is also missing from the tablet display, which may be a significant factor for some applications.

Tablet, when held in front of the user's face, may also block the view, causing hazards in the workplace. This can be at least partly avoided with a dedicated tracking camera that can be aimed to other directions than the tablet display. It allows keeping the tablet in a working pose, as in the SART solution (Section 2).

3.2. Software tools

In AR applications a key element is the tracking method, i.e. how accurately and robustly the augmented data can be placed over the surroundings. There are many commercially available platforms (for example *Wikitude (2017)*, *SightSpace Pro (2017)*) that offer coarse tracking based on geolocation, or GPS, magnetic compass and gravity sensors. This is sufficient for e.g. some travel applications but not for highly accurate localization.

Marker-based tracking solutions are also supported on several platforms, for example *Layar (2017), Wikitude (2017)* and *Vuforia (2017)*. These are based on recognizing a simple, typically black-and-white 2D rectangular object with some internal pattern, and calculating the device location from the marker image. Such systems can achieve good accuracy (within a few millimetres or better) in the area where markers are distributed. For many industrial applications such accuracy is needed, and markers are not necessarily a major problem in these environments, so a marker-based system can be a feasible solution. However, if the system can only recognize the markers and not the actual objects of the working environment, any dynamic changes in the environment are not taken into account, which may limit the potential applications.

Markerless tracking means a system where the device localization is not based on dedicated graphical markers in the environment. The general idea of markerless tracking is using the camera signal for recognition of 3D features in the environment and comparing them to a 3D-model made in advance, or to create a model of the current environment on the fly and then continuously tracking the device's location in that model. Some industrial localization systems exist that are based on beacons –

transmitting optical, radio or audio signals – that are in fixed locations in the working space, and the location of devices is calculated from the timings or travel times of the beacon signals.

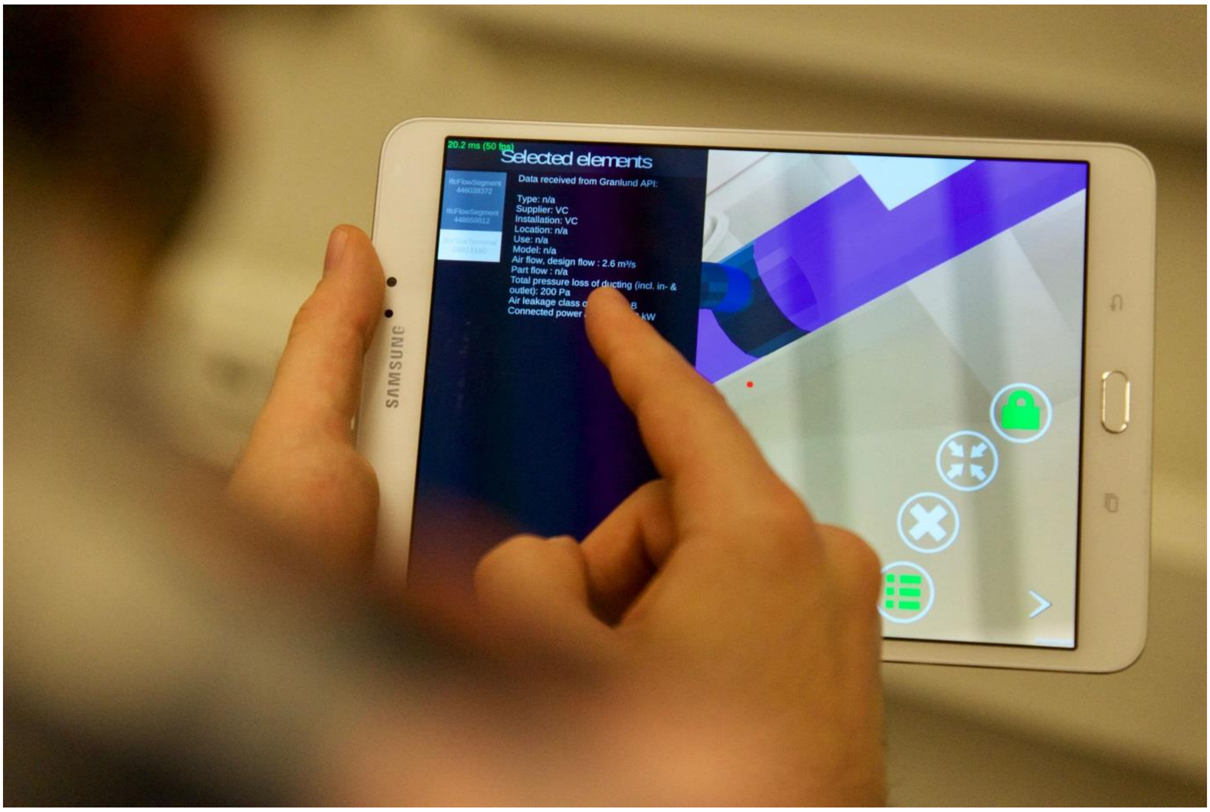

Figure 3, Indoor AR

Some small companies in the tracking business (most notably Metaio) have been acquired by other companies, and in some cases this has meant that the solution disappeared, at least temporarily, from the market.

A significant number of augmented reality software development solutions, such as libraries and software development kits (SDKs), were reviewed during the project. The results of these reviews were organized into MRDB, *Mixed Reality Solutions Database (2017)*. MRDB currently contains information on a total of 89 unique augmented reality solutions ranging from computer vision libraries to software companies. The database is maintained and kept up to date by University of Turku.

In MARIN2 a panorama tracking implementation, described in detail in *Forsman (2016)*, was developed for outdoor purposes. Panorama tracker is a visual tracking method for monocular cameras. The basic idea of the tracker is to create a panorama map of the area parallel to the tracking. The tracking is based on natural features that are tracked using template matching with the OpenCV library. The tracker works only in 3 degrees of freedom, which means that it tracks rotation only, but not translation. The advantage of the tracker compared to e.g. simultaneous localization and mapping (SLAM), is that the implementation is quite simple, and since the tracker only tracks rotational movement, it is not required to estimate the depth of the tracked features. The tracker is usable on high-end consumer tablets. The largest restrictions are that the tracker has to be reinitialized every time that the user moves to a different location, or whenever the tracked scene has changed too much for the tracker to function.

3.3 Interfaces to databases

An essential part in both AR and VR applications is the connection to databases where the models and related metadata reside. For this purpose the BIMconnect solution was developed, described in detail in *Riikonen, Arvo and Lehtonen (2017)*. It is an open source asset for transferring data from BIMServer to Unity based applications. It enables importing IFC models that exist on BIMServer directly to Unity applications, as well as examining related metadata.

The 3D CAD-models of a bridge, ship or buildings are typically very large in terms of amount of data. For being able to visualize then fluently in AR/VR applications where computing capacity is limited, techniques for simplifying the models have been studied. The results of studies are in *Arvo & al. (2015)*.

3.4 Positioning

Typically MR systems require the location of the user to be known. In case of an outdoor application, Global Positioning System (GPS) can be used. GPS systems in modern phones and tablets provide reasonable accuracies, and if that is not sufficient, Real Time Kinematic (RTK) extensions can be adapted (see *Sakari & al. (2016)*). However, GPS cannot be reliably used indoors. Acquiring the user position with non-visual methods is required, since a building can have several rooms which appear identical. These cannot be identified simply based on the images from the camera. Several solutions for this problem exist, and the selection of the most suitable technique is case dependent. The location can be detected by visual markers, which have to be placed in each room, and linked to the 3D-model. This method is very straight forward, but laborious. Also, the markers can be less than attractive. Some buildings can already have RFID devices used for access control. These can be used to notify the system of the current location.

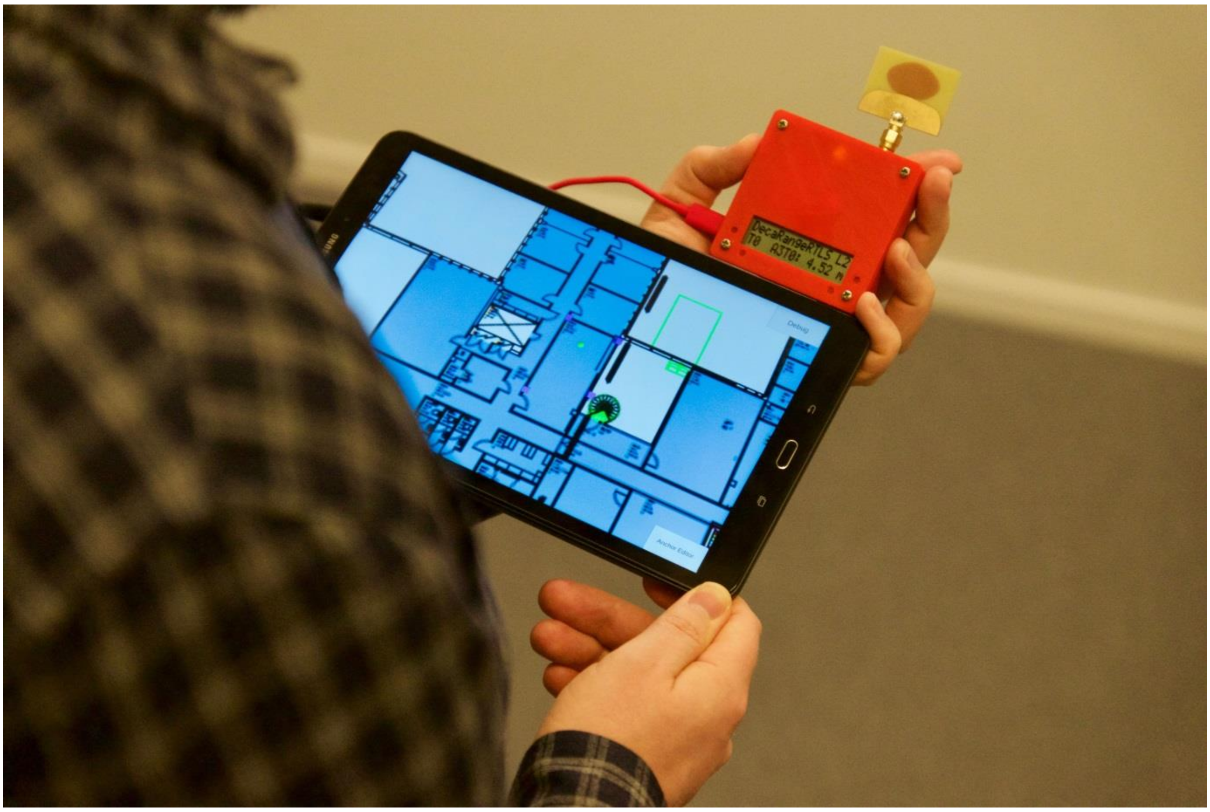

Figure 4, Indoor Tracking

In some cases the WiFi networks in a building have been used to create a map of the network names and strengths, but this solution is volatile to changes. Especially if the building is shared between different parties, each controlling their own networks. The solution that was found to be the most robust and accurate, with limited set up required, is based on ultra-wideband (UWB) radio technology. It requires a few anchors to be placed in known locations, and the system can calculate the user's position based on those. The system tolerates walls and other obstacles rather well, since all of the frequencies are not required for detection. The number of the anchors depends on the size of the building, and to some degree on the required accuracy. Typical ranges for UWB systems are in the order of tens to hundreds of metres, depending on the materials, and the system requires contact to 3 or 4 anchors. 3 anchors provide localization in 2D environment, and with 4 anchors the user can visit different floors as well, since the system provides a 3D location. The accuracy is in the order of few centimetres, which is more than sufficient for most purposes.

4. Demonstrators

In total nine demonstrators have been created for being able to cover different kind of environments (indoor/outdoor), different kind of users and use cases (e.g. visualization, reviewing/inspection, user instructions) and for testing some technological aspects. All the demonstrators have been implemented using the *Unity (2017)* game engine. Unity offers an application development environment and tools for presentation of virtual 3D content and user interaction, but it is not an AR environment in itself. Thus, to make AR applications, an AR library or development kit is also needed.

4.1. VR Demonstrators

ShipVR is a virtual reality application built for HTC Vive. The main purpose of the application was to create an immersive visualization of the Tallink Megastar vessel before its construction work was finished. The vessel can be observed from the outside in a simplified dock-environment and from the inside in the duty-free shop of the vessel. A miniature “doll-house” version of the duty-free shop is also presented. The 3D-models of the ship and its duty-free shop were supplied by Meyer Turku.

Movement inside the virtual environments has been implemented by teleporting. When holding the teleport button the application projects a teleportation curve from the tip of the Vive motion controller. The user can then designate a suitable teleportation destination, and after releasing the teleport button, the user is relocated to the new position. The transition is smoothed by using an animation that simulates blinking eyes. As in all Vive applications, it is also possible to move by physically walking inside the tracking volume.

BridgeVR is a virtual reality application built for Oculus Rift. The object is a road bridge. The application allows for dynamically loading IFC-models from an online server into a virtual environment. Several movement options are presented for the user to allow easy and quick navigation in the possibly large-scale environments. Visibility of parts of the models can be toggled on and off, and metadata contained in the IFC-model can be inspected inside the scene. The user experience can also be customized by letting the user select between different object highlighting and movement options.

Figure 5, Bridge VR

The application is controlled with an Xbox 360 or Xbox One controller. Movement inside the virtual environment has been implemented by using joysticks and gaze teleporting, while user interface elements and model objects can be selected with gaze. BIMServer and BIMconnect were used in conjunction to make dynamic loading of CAD-models possible. IFC-model data is streamed directly from BIMServer and the models are constructed one-by-one into Unity.

BuildingVR is a virtual reality application that is based on BridgeVR. The main difference between BridgeVR and this is that as well as displaying static metadata contained in the loaded IFC-models, BuildingVR contains components that allow gathering data from the design databases. In this demo was used as an example Granlund Designer, a building information application by Granlund. The integration with Granlund Designer allows for combining the models of the buildings/spaces in the application with real-time sensor data contained in Granlund Designer. This means that inspecting e.g. the models of air conditioning systems gives the user real-time data about the state of the selected air conditioning components.

4.2. AR Demonstrators

OutdoorAR is an augmented reality application built for high-end customer-grade tablets. The application can be used to augment a 3D-model in an outdoor scenario. The initial placement of the model can be done either manually, or by using a GPS based system that uses 2 distinct GPS locations. The tracking in the system is based on the panorama tracker, which is only capable to track the rotational movements of the device, so the tracker has to be reset whenever the user moves to another location. Panorama tracker is a markerless tracker, so it doesn't require any markers or previous knowledge of the area. *Forsman, Arvo and Lehtonen (2016)*

IndoorAR is an Android tablet application that combined results from several different research areas. The application guides its user to the maintenance target with a dynamically updating indoor map, downloads the CAD-model of the maintenance target from a server, and allows the inspection of the maintenance target via augmented reality. Several objects can be selected for inspection, and static metadata from the IFC-model as well as real-time data from Granlund Designer are displayed to the user. The functionality of the application is based on several subsystems.

Tracking is handled using the *Vuforia (2017) SDK* and the tablet's gyroscope as a backup. Vuforia's marker tracking and extended tracking are used to calculate the exact pose of the user, while the gyroscope of the tablet is used as a backup if the visual tracking system fails to determine the pose.

Indoor localization is handled with an UWB (ultra-wideband) system that uses UWB beacons by Decawave. The system calculates distances to UWB beacons that are situated close by and then uses triangulation to determine the exact position of the user.

Dynamic loading of CAD-models is made possible with a combination of a BIMServer and BIMconnect, in very much the same way it is done in BridgeVR and BuildingVR.

Displaying real-time data from the environment is made possible with a component that communicates with the Granlund Designer API (application programming interface). The system extracts component identifiers from the metadata contained in the IFC-model and then uses those identifiers to request for component specific real-time data.

4.3. Small Scale Demonstrators

HoloLensAR is a simple proof of concept created for Microsoft HoloLens. The application contains the 3D-model of the air conditioning system situated in the office building. The air conditioning system is positioned so that it is overlaid directly on top of the real-life system. After positioning the model, real-time data from the air conditioning system can be fetched from the relevant databases. In this case it was Granlund Designer.

PhoneAR is a proof of concept for using the commercial augmented reality SDK Vuforia in a device training/maintenance application for Android tablets. The application shows step-by-step visual instructions for the usage of a Cisco IP phone. The visual instructions are overlaid directly onto a live video feed. This is accomplished by recognizing the phone using the tracking functionality in the Vuforia SDK.

OfficeVR is a virtual reality application that is based on BridgeVR. Most of the more complex functions of BridgeVR have been removed, but the graphical fidelity has been improved. The main purpose of the demo is architectural visualization using CAD-models and virtual reality tools.

4.4. User experience

Three usability tests were carried out, all varying with different MR systems, different test subjects and different test settings. This was due the variance in the target groups, company aims and suitable times. The test settings include quantitative and qualitative testing as well as observing the use-situations. Preliminary results show positive feedback from most of the test subjects.

According to the test subjects the potential to use VR and AR in industry seems good. Users saw that the technology could improve their work processes and they were eager to implement the solutions to their use. The was an interesting notion that the VR and AR development should be focused on their specific field where it would be a big improvement (but not necessarily to others) thus giving a hint that if everyone feels this way, perhaps they are suitable for many of those fields.

While the larger analysis of the results is still on-going, we argue that these systems - when designed correctly - a) do not generate a large-scale user-resistance and b) will improve the work process of most of the stakeholders in the industrial field.

5. Conclusions

In this paper, the current state of commercially available display hardware and software tools supporting augmented and virtual reality were discussed. The current level of sensor and display technology, even in consumer-oriented devices, allows creation of viable augmented and virtual reality solutions for industrial use. In the software field, more robust positioning and tracking solutions are wanted – this is especially the case with markerless tracking, for which a commercially available, truly efficient and robust solution seems to be missing. For coarse positioning, UWB technology offers a working solution, at least in cases where using a beacon system is acceptable.

These AR and VR proof of concepts and prototypes implemented in the MARIN2 project covered several different areas. These solutions were rather easy to produce given the fact that no applications alike were produced before. During the 4-year research period the technology took huge leaps in both AR and VR of which the last leap – the Microsoft HoloLens – made the biggest impression. While before the tracking and other base-level programming took most work in the development of AR solutions, the new technology frees the resources for content creation. In addition the VR technology has taken huge leaps in both quality and prize. Therefore it seems likely that these solutions will get cheaper and thus more common in near future both in entertainment and industrial sectors.

AR and VR solutions were tested by potential users from the partner companies in the project. Feedback from them supports the view that such tools would be useful and potentially could be taken as part of their work. Thus it seems that from both the perspective of work and workforce, as well as from the economical point of view, developing and implementing AR and VR as a part of industrial work processes seems an idea worth considering.

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