# Using Virtual Environments to Evaluate the Operational Benefit of Augmented Reality

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## *ABSTRACT*

*At the Norwegian Defence Research Establishment (FFI) we have been experimenting with simulated Augmented Reality (AR) since 2006. We have used virtual environments to evaluate the operational benefit of AR functionality in combination with a Battlefield Management System (BMS) in combat vehicles. Three experiments have been carried out with professional combat-vehicle crews playing through relevant scenarios in virtual environments. The data collected from these experiments, including quantitative measurements, feedback from the participants through questionnaires and after-action review sessions, supplemented by observations of the usage of the system, is being used in the ongoing process of designing a real AR system for combat vehicles.*

*The simulated AR system is designed for use in combat vehicles like infantry fighting vehicles and main battle tanks. It works in conjunction with an experimental BMS, also developed at FFI, and visualizes information like Blue-Force Tracking, observations and waypoints, in the form of graphical symbols directly in the sights and periscopes of the commander, gunner, and driver. This enables the vehicle crew to better exploit the BMS information while keeping their eyes fixed on what is going on in the battlefield. The AR system also makes the BMS information more intuitive. Basic input to the BMS can be given as simple voice commands, to provide a hands-free user interface.*

*Initially our experiments with simulated AR were conducted using an in-house developed combat vehicle-simulator based on the commercial game Unreal Tournament 2004 (UT2004). Later, Virtual Battlespace 2 (VBS2) has taken over as our primary simulation platform for experimentation with simulated AR, since it offers a more complete virtual environment for military virtual simulations.*

*The experiments have shown that the simulated AR system results in faster and more accurate perception of the BMS information, and thus better overall situational awareness. In small test scenarios we observed an average reduction of up to two thirds in target acquisition times.*

*The general idea behind this work has been to test emerging technologies and new concepts in a virtual environment by developing virtual prototypes. Using this method we can evaluate the operational benefit of technology that is not yet available, and assess what properties it should have in order to give the maximum benefit to its users. This approach can also be used to evaluate operational performance and compare different systems in a procurement process.*

*In this paper we describe the general method we have been using, the simulated AR system, and the experiments we have carried out. We also present the most important results from the experiments and the lessons learned from developing and working with a simulated AR system, which has served as a virtual prototype and a technology demonstrator.*

# 1.0 INTRODUCTION

At the Norwegian Defence Research Establishment (FFI) we have been experimenting with simulated Augmented Reality (AR) since 2006 [1]. We have been using virtual environments to evaluate the benefit of AR functionality in combination with a Battlefield Management System (BMS) in combat vehicles, by developing virtual prototypes. Three experiments have been carried out with professional combat-vehicle crews playing through relevant scenarios in virtual environments. The data collected from these experiments, including quantitative measurements, feedback from the participants through questionnaires and after-action review sessions, supplemented by observations of the usage of the system, is being used in the ongoing process of designing an operational AR system for combat vehicles.

The simulated AR system is designed for use in combat vehicles like infantry fighting vehicles and main battle tanks. It works in conjunction with an experimental BMS, also developed at FFI, and visualizes information like Blue-Force Tracking (BFT), observations and waypoints, in the form of graphical objects displayed directly in the sights and periscopes of the commander, gunner, and driver. This enables the vehicle crew to better exploit the BMS information, even in critical battle situations, since it allows them to keep their eyes fixed on the battlefield. The AR system also makes the BMS information more intuitive, and increases the vehicle crew's overall situational awareness. Basic input to the BMS can be given as simple voice commands to provide a hands-free user interface.

Firstly, this paper describes the background for this work, including a short introduction to AR technology. Then, the overall method used in this work is presented, followed by a description of the simulation system, including the latest version of the simulated AR system. After this, the simulation experiments are presented. Finally, this paper summarizes the most important results from the experiments, the lessons learned from this work, and some ideas for future work.

# 2.0 BACKGROUND

Our first work with simulated AR, dating back to 2006, was for an FFI project on Battlefield Management Systems (BMS) for combat vehicles. We conducted a simulator experiment with the purpose of examining the operational benefit of possible future functionality in a BMS. This experiment was carried out by using an in-house developed simulator called NORBASE [2], which was based on the commercial game Unreal Tournament 2004 (UT2004). One of the possible features we examined was the use of AR to display BMS information directly in the commander’s and gunner’s sights. The main results from this experiment were that AR promised to be very useful, and the simple game-based simulator was accepted by all participants as an appropriate tool for experimenting with this kind of new technology [3]. Figure 1 shows images from the simulated AR system in NORBASE.

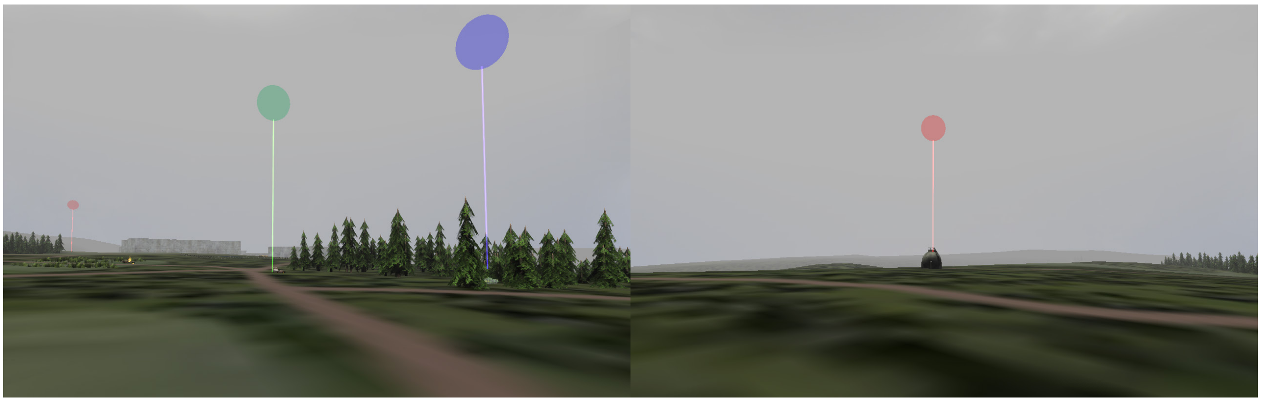

**Figure 1: The AR system in NORBASE from the early experiments with simulated AR in 2006.**

After this first experiment, the next step was to move AR from the laboratory to the field. For this task, collaboration with the Norwegian AR technology company Augmenti (then AR-Lab) was initiated. Augmenti had already developed AR technology for several civilian applications. In October 2008 we jointly conducted a field trial where AR in infantry fighting vehicles was demonstrated. The field trial was a success, and demonstrated not only that this technology was useful for the vehicle crew, but also that it would be possible to develop and implement this technology in the near future. Figure 2 shows the AR system prototype used in the field trial.

After the field trial, FFI initiated a follow-on project aimed at developing AR for operational combat vehicles. Within this project further simulator experiments were conducted, the first of these in May 2009. This time VBS2 was used as simulation platform, since it offered a more complete virtual environment for military simulations. In addition, the Norwegian Army had now started to use VBS2 for training, and it was convenient for us to use a simulation platform familiar to the Norwegian Army.

The latest, most comprehensive, and most successful, simulation experiment was carried out in November 2011. VBS2 was still used as simulation platform, but this time we had a much more detailed and sophisticated implementation of the AR system. One of the primary goals for this experiment was to get feedback from the participants to support the development of a real AR system. We needed to know how such a system might be used, what the participants considered to be the most important functionalities and aspects, and what they would like an AR interface to look like. The real-world AR system is being developed in parallel to our experiments, and the results from these experiments provide valuable input to this development process.

A prototype of the real AR system was also demonstrated under the multinational exercise Bold Quest 2011 in September 2011. The AR system was then used in conjunction with a commercial BMS (Teleplan FACNAV), and the target acquisition and surveillance system Vingtaqs (from Vinghøg).

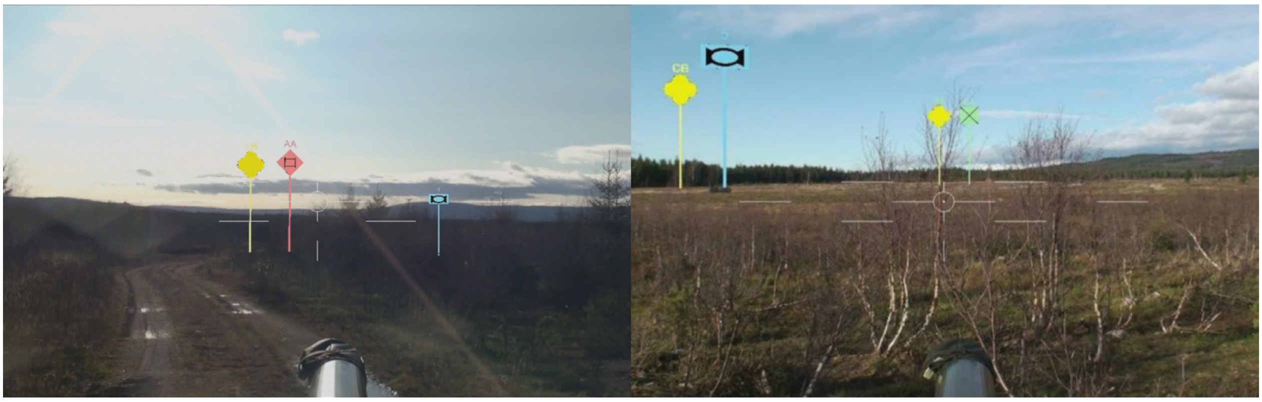

Figure 2: Prototype of a real AR system used in the field trial in October 2008.

## 2.1 Augmented Reality (AR)

AR is a technology for real-time mixing of virtual, computer-generated data with data we perceive from the real world. This gives the user an augmented perception of reality. Mainly, AR means adding virtual objects, in the form of computer graphics, to visual data from the real world. The virtual objects typically provide information in a way that improves the user’s situational awareness, thus helping him or her to perform real-world tasks better.

AR can be defined as a system that has the following three properties [4][5]:

1. Combines real and virtual objects in a real environment.
2. Runs interactively, and in real time.
3. Registers (aligns) real and virtual objects with each other.

## 2.2 Technology

An AR system consists of the following components:

1. A display device that shows the real world alongside the virtual objects. This can be a monitor, a Head-Mounted Display (HMD) or a special optical see-through HMD. If a monitor or a standard closed-view HMD is used, a video camera is needed to capture the real scene.
2. A tracking system for accurately tracking the user's viewing direction and position. The system needs this information to calculate the position and orientation of the virtual objects. Possible technologies for a tracking system are digital cameras or other optical sensors, GPS receivers and inertial measurement units.
3. A virtual scene generator to render the virtual objects at the correct positions. This is usually a computer with AR software.

In addition, an AR system may include devices for interaction with the system. Figure 3 illustrates the concept behind an AR system. To get really good AR systems, where the virtual objects appear so realistic that they are virtually indistinguishable from the real environment, there is a need for further development and new technology for both display devices and tracking systems. For applications where realistic appearance of the virtual objects in the real environment is not so important, the AR technology is starting to mature.

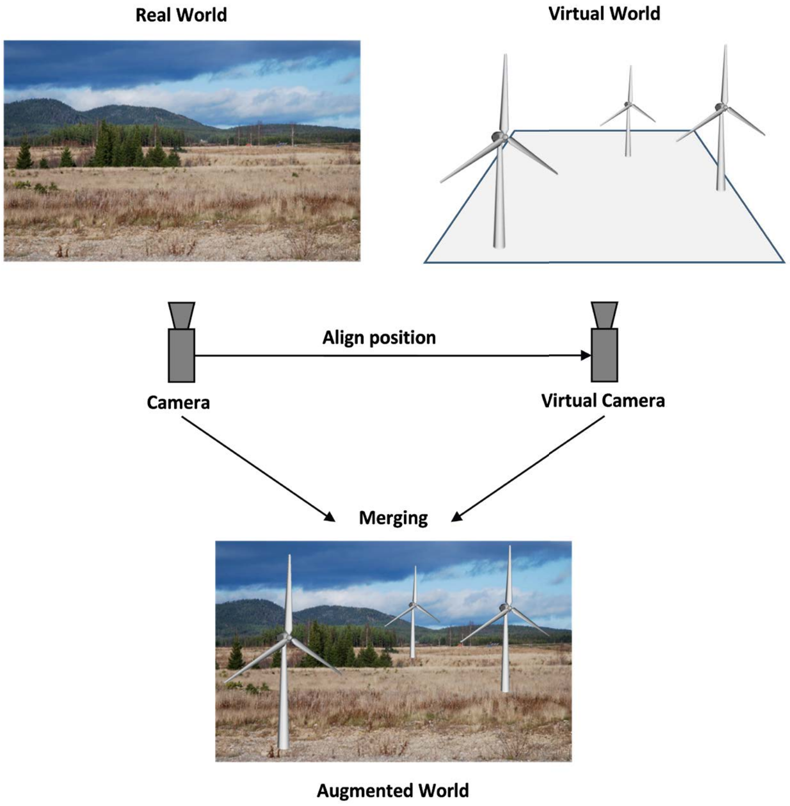

**Figure 3: Concept behind an AR system.**

## 2.3 Military Applications

In military aircraft and helicopters pilots have been using Head-Up Displays (HUD) and Helmet-Mounted Sights (HMS) with AR for several years. These systems provide the pilot with navigation and flight information, and for some systems ground or air targets can be marked with graphics.

AR systems that display tactical battlefield information are now being developed for ground soldiers and combat vehicles [6]. Typically these systems will be used to increase situational awareness through visualization of Blue-Force Tracking (BFT) data and points of interest like observations and targets.

AR is also being used for military training [6][7], but so far mostly for experimentation purposes. Here virtual enemies are visualized in the real world [8][9], and live and simulator-based training are combined, so that real soldiers and vehicles can train together with virtual forces operated from simulators, in a two-way real-time interaction between real and virtual units.

## 2.4 Simulated AR

By using high-end Virtual Reality (VR) systems, it is possible to simulate displays spanning the Mixed Reality (MR) continuum [10], including both VR and AR [11]. This makes it possible to study the effects of display fidelity independent of display technologies.

A simulated AR system adds graphical AR objects to a virtual scene. Recent research has found that there are minimal differences between using simulated AR and real AR, when AR is used for search tasks [12]. This strengthens the validity of the results from our experiments with simulated AR.

# 3.0 METHOD

The general idea behind this work has been to test emerging technologies or new concepts in a virtual environment by developing virtual prototypes. Using this method we can evaluate technology that is not yet available, decide whether or not it should be developed, and even assess what properties it should have in order to give the maximum benefit to its users.

We have conducted human-in-the-loop simulation experiments with a virtual prototype for a new technology. The experiments have been carried out with military system operators playing through a set of scenarios both with and without this new technology. The size of the experiments has ranged from platoon to company level, and the technology under evaluation has been modelled with a sufficient level of detail to make an appropriate representation. The collected data from the experiments have been both quantitative measurements and qualitative feedback from the participants during after-action review sessions and through questionnaires.

Parallel to the experimentation with the virtual prototype, there has been a project for developing a real-world prototype of the new technology. There have been several iterations with further development of the real-world prototype, followed by new experiments with a more refined virtual prototype. Figure 4 illustrates the concept behind this approach.

In addition to AR, we have also used this approach to evaluate Active Protection Systems (APS), UAV support, and different weapon and ammunition types. FFI has also taken a similar approach to evaluate the performance of different army structures [13][14].

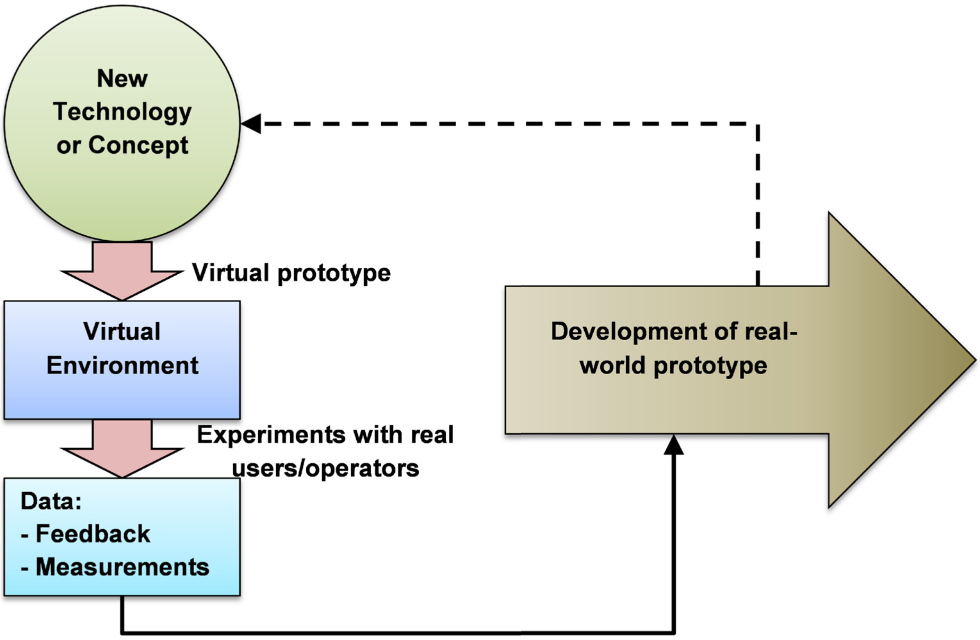

**Figure 4: General method for experimenting with and developing new technology or new concepts, by using virtual environments.**

## 4.0 SIMULATION SYSTEM

Initially, we developed an in-house combat vehicle-simulator based on UT2004, but we switched to VBS2 in 2008, considering this to be a better simulation platform for experimenting with simulated AR and BMS. In this section the latest version of the simulated AR system, used in the latest experiment, is briefly described. The simulated AR system works in conjunction with an experimental BMS, also developed at FFI.

### 4.1 Virtual Battlespace 2 (VBS2)

VBS2, from Bohemia Interactive Simulations, is a game-based virtual environment for military training and experimentation. VBS2Fusion is a C++ based Application-Programming Interface (API) for VBS2.

### 4.2 Battlefield Management System (BMS)

To be able to experiment with various BMS functionality, we developed our own experimental BMS comprising basic functionality like Blue-Force Tracking (BFT), points of interest, and tactical graphics. The BMS has a touch-screen user interface.

### 4.3 Simulated AR System

We have developed a simulated AR system for use in combat vehicles. It provides the commander, gunner and driver with information in the form of graphical objects in their sights and periscopes. The system works in conjunction with our experimental BMS, and visualizes information like BFT and observations. The system is designed to look like real AR systems, and the graphical objects are drawn in a two-dimensional graphical overlay. We also simulate the end-to-end system delay that is present in real AR systems, causing registration errors when motion occurs. A more comprehensive description of the simulated AR system, and the details on its implementation, can be found in [15].

### 4.3.1 AR Objects

Figure 5 illustrates an AR object used in the system. All AR objects have the same structure, and consist of the following five components:

1. A symbol that shows the AR object's affiliation and type. We have used symbols from the MIL-STD-2525C standard for military map marking symbols [16].
2. A unique text string that represents the AR object's ID, which is drawn above the symbol.
3. A number giving the distance in meters from the vehicle to the AR object. The distance is shown on the right hand side below the symbol.
4. A dot that represents the actual position of the AR object on the ground. This dot is in white color if the vehicle has line of sight to the AR object's position; otherwise it is in red color.
5. A vertical bar connecting the dot and the symbol. The bar has the same color as the symbol, in accordance with the AR object's affiliation.

To avoid too much cluttering, the AR system has a minimum and a maximum distance for when AR objects are shown. Preferences like transparency, size, and whether or not the AR objects should be scaled with distance, are set in a configuration file for the AR system.

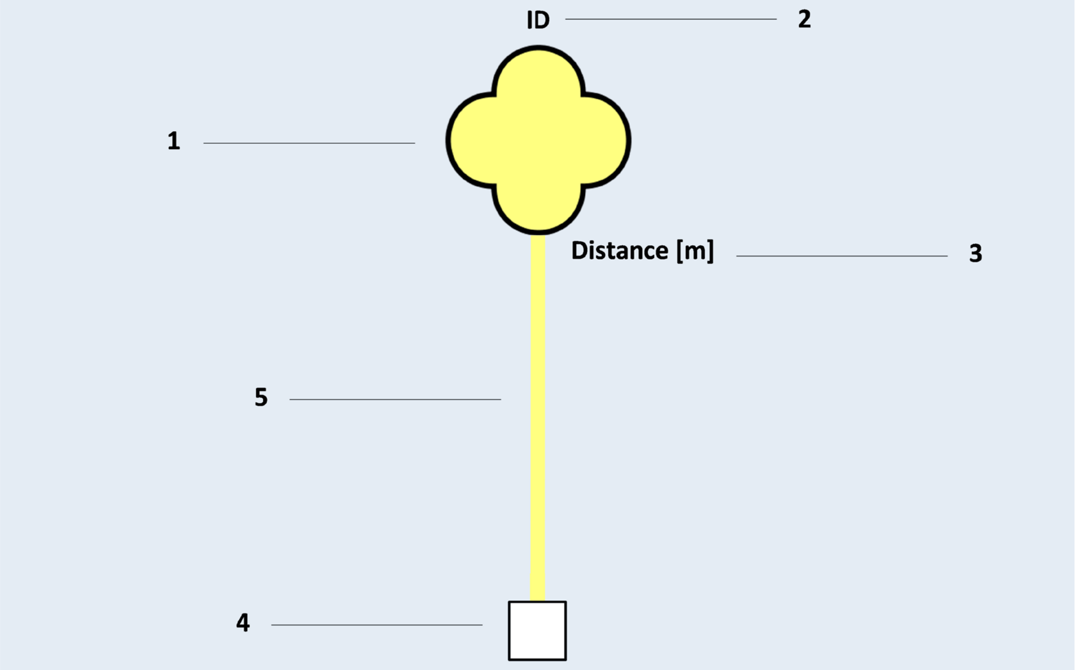

Figure 5: The five components of an AR object.

### 4.3.2 Blue-Force Tracking

The BMS provides Blue-Force Tracking (BFT) of all vehicles that are connected to the system. The BFT data are sent to the AR system where they are visualized by AR objects. Figure 6 shows an example with BFT symbols drawn on the BMS screen (to the left), and the virtual scene viewed through the vehicle commander's sight with AR objects marking the blue forces (to the right). The information is shown from the perspective of the vehicle with ID 1-1, looking at two friendly vehicles with IDs 1-2 and 1-3. On the BMS screen the blue dots mark the vehicles' position, the short blue lines mark the vehicles' direction, and the pairs of two long blue lines in a "V"-shape mark the gunners' viewing sectors. In addition, there is a short orange line on vehicle 1-1 that marks the direction of the Laser Range Finder (LRF), which is also the commander's viewing direction.

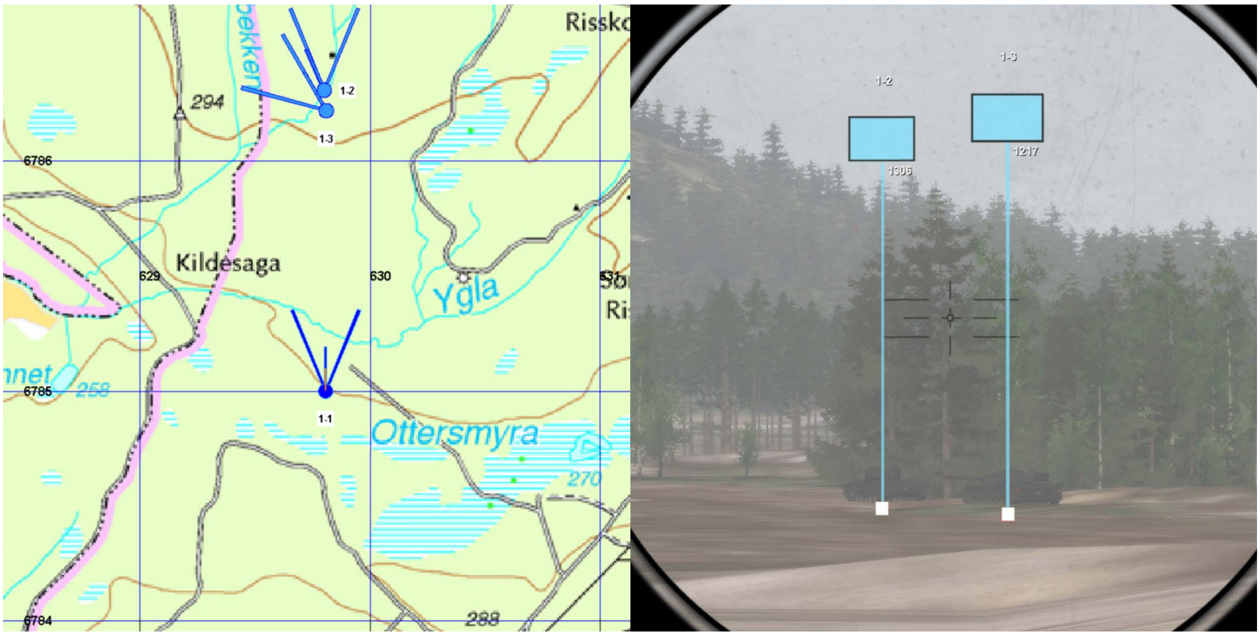

**Figure 6: Blue-Force Tracking on the BMS screen (to the left) and through the commander's sight (to the right).**

### 4.3.3 Observations

It is possible to mark positions of interest by adding observations in the BMS. Observations can be assigned an affiliation and a type. The data for the observations are sent to the AR system where they are visualized by AR objects in the same manner as the BFT data. The observations' affiliation and type can be changed, and the observations can be moved or deleted via the BMS user interface. Figure 7 shows four observations displayed on the BMS screen (to the left), and the corresponding image seen from vehicle 1-1 commander's sight with AR objects (to the right). The observations in our experimental BMS have unique two-letter IDs.

**Figure 7: Observations on the BMS screen (to the left) and through the commander's sight (to the right).**

### 4.3.4 Laser Range Finder

We have integrated a vehicle-mounted Laser Range Finder (LRF) with the BMS. This LRF is operated by the vehicle commander. When the LRF is triggered, the target position is sent to the BMS, and this makes it possible to select positions directly from the terrain. In a real system the LRF's target position must be found by using the measured distance and the LRF's orientation. The position is shown on the BMS screen for a few seconds, and during that period the commander can accept this position as an observation by selecting “Confirm” from the BMS user interface. By default, the observation is added as an unknown ground observation, but this can afterwards be changed to the correct affiliation and type.

### 4.3.5 Speech Recognition

We have also experimented with speech recognition to provide a handsfree user interface to the BMS, using the DynaSpeak speech-recognition engine. The commander can then say: “Confirm!”, to have the position from the LRF accepted as an observation. In addition, he or she can specify affiliation and type through voice commands. For example, if the commander points the LRF at an enemy vehicle and says: “Confirm enemy vehicle!”, an observation with affiliation and type according to this command will be created.

### 4.3.6 Simulated System Delay

In a real AR system the end-to-end system delay can be defined as the time elapsed from the moment that the tracking system measures the viewpoint’s position and orientation, to the moment when the generated AR graphics corresponding to that position and orientation appear in the display. End-to-end system delays cause registration errors when motion occurs, and the objects drawn by the AR system will remain at their old screen positions during this delay, creating display lag.

We implemented this effect in our simulated AR system in order to investigate how these delays affect the participants’ assessment of the system. This also makes the simulated AR system more realistic in terms of emulating the real system. The delay can be adjusted (the default value is 0.1 seconds).

### 4.3.7 Implementation

The simulated AR system was implemented in C++ using VBS2Fusion. VBS2Fusion has functions which makes it possible to draw graphical primitives and text into the VBS2 window. The AR system is compiled as a plugin Dynamic Link Library (DLL), which is used by the VBS2 engine.

# 5.0 EXPERIMENTS

The three simulation experiments (in 2006, 2009 and 2011) have been carried out in FFI’s Battle Lab facility. The size of the experiments has ranged from platoon to company level, and each of them lasted for one week.

## 5.1 Participants

We have used professional combat-vehicle crews in our experiments. Most of these participants had combat experience, having served in international operations. To play the Red forces we used scientists and engineers from FFI, supervised by a professional military leader.

## 5.2 Experiment Setup

In our first experiment, when using the UT2004-based simulator, our focus was on BMS functionality. Since a BMS is primarily a tool for the vehicle commanders, we focused on making the vehicle commander’s simulated situation as close to reality as possible. Because available military personnel are short in supply, the simulated combat vehicles were operated by two-man crews, combining the roles of driver and gunner, while letting the commander maintain his/her role.

When we moved to the more realistic VBS2 based simulator, the flaws in the two-man crew approach became more evident. It was difficult for the participants to combine two roles, and it also became clear that the communication between the crew members became unrealistic. Since BMS and AR are tools for improving communication, we saw this as a potential problem. Testing a scenario with a three-man crew confirmed that three-man crew representation was required to realistically replicate the workload of the key roles. Speech communication had so far been taken lightly, but this was now highlighted as an area we needed to simulate more realistically, in order to examine the communication within the platoon/company in a proper manner.

The operators and components in the simulated combat vehicle from the latest experiment are shown in Figure 8 (to the left). The BMS was placed between the gunner and commander, with the commander operating it while allowing the gunner to observe it. The driver was given a screen displaying the BMS image, but without the ability to operate the BMS. Figure 8 (to the right) shows a picture of a simulated combat vehicle in use during the experiment.

For our latest experiment we used the voice over IP (Internet Protocol) application TeamSpeak 3 for voice communication. It was set up to give each participant three separate channels: the vehicle, platoon and company channel. The participants listened to all three channels simultaneously, while choosing which channel to talk on. In addition, all participants had the sound from the simulator on their headphones, and the vehicle commanders' microphones were also connected to the speech recognition system, allowing them to give voice commands to the BMS.

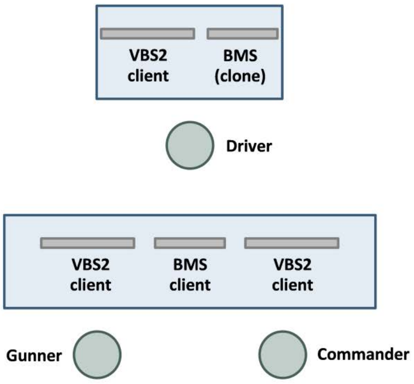

**Figure 8: Operators and components of the simulated combat vehicle (to the left), and a simulated combat vehicle in use (to the right).**

## 5.3 Scenarios

The scenarios we have used can be divided into two categories. The first category consists of rather large scenarios, where the participants are given a mission and choose how to solve it. These scenarios were extracted from scenario classes designed for national defence studies, and were used for experimenting with new technology in different realistic settings. This allowed us to observe how the participants adapted to the new technology, and enabled them to give us feedback on how useful they assessed the technology to be, and how the corresponding systems should be designed to fit their needs. The results from these scenarios were qualitative in nature, and consist of observations of how the participants used the system, and questionnaires filled out by the users, both regarding usefulness and interface.

The second category of scenarios were smaller, with a very narrow scope, where the participants were given a specific task to perform, and were even told how to perform it. This category of scenarios was designed to give us quantitative data on how much a specific technology improved the crew's ability to perform certain, limited tasks. We had three such scenarios:

1. **Maze:** In this scenario, all participants played the role of the driver. They were to traverse a "maze" in the form of a town with several blocked streets. They had different technology available to them, and we measured the time it took them to get through the maze with different technology. AR was not a significant technology in this scenario.

2. **Attack by fire:** The participants were to perform an attack by fire on an enemy position consisting of several vehicles. This was done several times, both with and without AR. We then compared the results to see what impact AR had on the performance.

3. **Target acquisition:** In this scenario, all participants played the role of the gunner. Everyone started the scenario looking at a specific point in the terrain. An object of interest (for instance an enemy vehicle) was then added to the scene. The participants were tasked to find this object based on an instructor's description of the target, and oral directions on where to find it. This scenario was repeated several times, with and without the use of AR to mark the target. We measured the time it took for each of them to locate the target, and place their crosshair over it.

### 5.4 Collected Data

During the experiments we collected qualitative data from questionnaires, feedback from the participants through after-action review sessions, and general observations of the usage of the system. We also collected quantitative performance data for specific tasks. Moreover, all executions of the scenarios were logged and recorded on video.

## 6.0 RESULTS

The results from the experiments can be divided into general observations, answers from questionnaires, feedback from after-action review sessions, and quantitative measurements.

### 6.1 General Observations

One important observation identified in the first experiment, and again in the two later experiments, was that AR was not primarily used for enemy observations. In many of the scenarios, enemy observations were of little value after a short period of time, since the enemy tended to move away from the location where they had first been observed. The participants used AR rather for establishing reference points, which they referred to in voice communication. This practice was used also without AR, but then natural objects like boulders, buildings or peculiar trees were used as reference points. With the ability to shoot laser at a position in the terrain and establish an AR object there, seen by everyone, unique reference points could be established whenever and wherever they were needed. Without AR, communication on the radio could sound like this: "The center of the target area is the large, green house" or "Look to the left of reference point Large Rock". Using AR, communication was much smoother and more precise: "Target area Alpha Charlie" or "Observe the area around Bravo Delta". Here, the phonetic letters correspond to the unique two-letter IDs assigned to each AR object.

We also noted that the participants became familiar with AR very quickly, and used it extensively throughout the experiment. It increased the speed and precision of communication, and shooting laser for creating an AR object was the preferred method for establishing reference points, indicating observations and designating areas for observation. Occasionally, someone said something like: "Enemy observed to the left of the trees where the road makes a turn", and got the swift reply on radio: "Shoot laser and make an AR object" from someone else, as they much preferred to have the description in form of an AR object.

It is important to notice that a vehicle commander spends much time with his/her head out of the hatch. From this position it is difficult to see both the BMS and the sights with AR objects. In our experiments, AR was not available to a commander in this position. This caused the commanders to frequently change positions, as they wanted access to AR and BMS when communicating with other vehicles, but had a much better view of the vehicles immediate surroundings from above the hatch.

## 6.2 Questionnaires

Questionnaires were used both to have the participants evaluate various functionality, and to get their view on how the AR system should be designed. The participants were also asked to evaluate the quality of the simulator and the experiment as such.

In our first experiment, the participants were asked to rate the benefit of the different BMS functions. Presenting BMS information through AR was considered very useful. This was also underlined by the participants in the following two experiments.

In all our experiments the participants generally regarded the simulator and experiment setup as being appropriate for this kind of analysis. On a scale from 1 to 5, the participants on average gave the simulator a score of 4.3 in the 2006 experiment and a score of 3.9 in the 2011 experiment. The experiment as a whole was given an average score of 4.7 in 2006 and 4.0 in 2011.

The questions on the design of the AR system asked the participants to rate several alternatives for various aspects of the appearance. For some aspects the participants overall had either no clear preference, or they had different preferences. However, we also got some clear, consistent answers. One such aspect concerned the size of the AR objects. We asked whether the AR objects should always have the same size on the screen, or if they should scale with distance as if they were real objects. The participants seemed to agree that the AR objects should have a fixed, rather small size on the screen, and not scale with distance. Another question concerned the transparency of the AR objects. There was a clear preference for semi-transparent AR objects.

## 6.3 After-Action Review

During the experiments we had several after-action review sessions. One subject we discussed was the size of the AR objects. The result from the questionnaires, that the size should be fixed, was further elaborated on during these discussions. The participants expressed the view that the AR objects should be as small as possible, but large enough for distinguishing between different types of objects. This in turn motivates for making the different types of objects as easily distinguishable from each other as possible.

Other feedback concerned the number showing the distance to the AR object. This was considered important by the participants. When asked about the display lagging of the AR objects, caused by the simulated end-to-end system delay, none of the participants considered this a problem, contrary to our expectations.

The speech-recognition system worked well, and was widely used by the participants. This was clearly preferred to the alternative, which was using buttons on the BMS. The participants agreed that the system was useful, but expressed doubt as to whether it would actually work in a real vehicle.

Finally, as we have often heard from participants in similar experiments, they expressed the importance of keeping the AR system simple and intuitive.

### 6.4 Quantitative Data

Quantitative data were collected from the three smaller scenarios, described in section 5.3.

AR proved to be particularly useful for marking a specific point in the terrain, for instance an observation. We therefore designed a scenario for investigation of acquisition times, i.e., time to find specific targets in the terrain with and without AR. The participants were tasked to find specific targets based on an instructor's description of the target, and oral directions on where to find it. The results are shown in Figure 9. Each participant repeated the task about ten times for all three categories of targets. AR had a significant impact on target acquisition times, reducing them by more than two thirds on average. The category "several AR objects" indicates that there were several AR objects in the scene prior to the search for the target. This caused slightly longer target acquisition times compared to "clean" scenes, but the difference was not large.

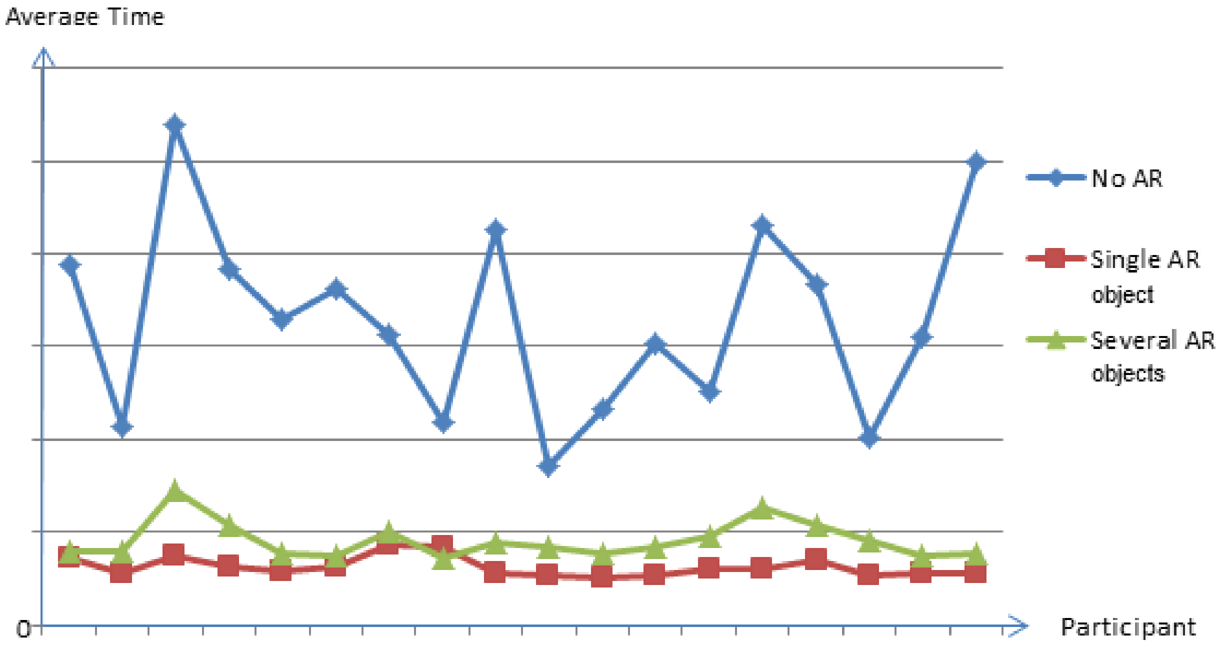

**Figure 9: Average target acquisition times with and without AR for the 18 participants in the latest experiment.**

Another small scenario included an attack by fire on an enemy position. The participants were to advance simultaneously over a hill and attack the unsuspecting enemy. This was done twice with AR, and twice without AR. With AR, the Blue force eliminated every enemy vehicle before they managed to fire a single round. This was partially due to the AR system helping them engage the "correct" targets, and avoiding that several vehicles attacked the same target, leaving other targets unengaged. Without the AR system, some of the participants ended up engaging the same enemy units, and the enemy units which were not immediately engaged managed to fire back a few rounds before being destroyed.

The last small scenario, the maze, did not involve AR, and so we will not discuss this scenario further in this paper.

## 7.0 LESSONS LEARNED

Carrying out experiments in virtual environments with virtual prototypes of new technology has proved to be very useful, both for evaluating operational benefit and for improving design and functionality in the development phase. Even with fairly simple simulators, it is possible to evaluate operational benefit of a system. If the goal is to acquire more detailed input on how a system should be designed, or to compare similar systems, it is important that the simulation platform and the virtual prototype have a resolution and fidelity that is high enough to capture the differences between the tested solutions.

The virtual prototype of the AR system has given us the opportunity to involve the users at an early stage of the development. It has also been very useful to demonstrate to stakeholders the functionality of the AR system through the simulator. The virtual prototype makes it possible to experiment with AR in situations that are hard or impossible to achieve in the real world because of cost, safety or availability issues. Using the simulated AR system, we are for instance able to evaluate the benefit of the AR system in high-intensity operations. Virtual prototypes also make it possible to evaluate the benefit of technologies that are not yet available in real life.

After conducting several simulation experiments, we have learned that time spent on preparation and testing is a key factor to success. Our experiment in 2011 was a big success, and one reason is that we were able to set up the simulation system in the Battle Lab facility several weeks prior to the experiment, and use these weeks for thorough full-scale testing.

Developing good questionnaires is challenging. The questions need to be phrased in a way that minimizes misinterpretations, and there should not be too many questions. Also, when rating functionality on a certain scale, it is our experience that different people use the scale in different manners. This can affect the results, particularly when there are few participants. It is therefore important that the questionnaires are designed properly, that they are part of the testing prior to the experiment, and also that they are explained properly to the participants.

## 8.0 FUTURE WORK

Currently the simulated AR system can only visualize Blue-Force Tracking and observations from the BMS. In the future it would be interesting to test out appropriate ways of visualizing other tactical information from the BMS like boundary lines used in operations, or to mark minefields or other hazardous areas. It could also be possible to visualize sensor information like gunfire locations and incoming threats.

In the future, sensor platforms (both aerial and ground based) and rapid information sharing over networks will probably make it possible to develop systems that can provide close to real-time red force tracking on the battlefield. It would be interesting to simulate the operational effect of providing this information directly to the BMS and the AR system.

FFI has recently upgraded VBS2 to VBS3. For future experiments we would therefore like to port the simulated AR system to VBS3.

The Norwegian Army has been experimenting with the virtual reality (VR) head-mounted display Oculus Rift in combat vehicles, to let the crew “see through” the vehicle by using cameras. The next step is to include AR in this system to visualize BMS information. For further experimentation and evaluation of operational benefit it could be useful to build a virtual prototype of this system in VBS3, which now supports Oculus Rift.

## 9.0 SUMMARY AND CONCLUSION

This paper has presented our work with simulated AR in virtual environments. We have developed a virtual prototype of an AR system for combat vehicles that visualizes information from a BMS. By conducting simulation experiments in virtual environments, we have been able to evaluate the operational benefit of the

AR system and gained useful input on how the system should be designed.

The experiments have shown that the AR system results in faster and more accurate perception of the BMS information, and thus better overall situational awareness. In small test scenarios we observed an average reduction of up to two thirds in target acquisition times. The results and lessons learned from the experiments are being used in the ongoing project for designing a real AR system for combat vehicles.

The general idea behind this work has been to test new technologies or new concepts in a virtual environment by developing virtual prototypes. Virtual prototypes make it possible to experiment with new technology and new concepts in situations that are hard or impossible to achieve in the real world because of cost, safety or availability issues. This approach can also be used to evaluate operational performance for different systems and comparing them in a procurement process.

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