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Design of a user interface capable of visualizing radio frequency interference data in spatial context using augmented reality

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The proliferation of electronic devices and demand for high-speed wireless communication is causing congestion of the radio frequency spectrum, resulting in radio frequency interference. Interference hunting is the challenging and time-consuming process of locating and resolving RFI. Augmented reality has emerged as potential solution to address the rising prevalence of RFI by increasing the efficiency and accessibility of interference hunting. This paper explores application of AR to improve interference hunting by developing a user interface capable of visualising RFI data in spatial context. By exploring the interference hunting process and conducting a literature review into the state-of-the-art of AR, a set of guidelines has been created for developing user interfaces and user interactions. Additionally, examples of AR data visualisation have been reviewed. Preliminary user tests of an AR prototype have showed the potential of applying AR for interference hunting but also highlighted a need for robustness and user control.

Radio frequency interference, interference hunting, augmented reality, data visualisation, user interface

1. Introduction

In today's globally interconnected society, the amount of personal electronic devices and the demand for high-speed, high-volume wireless data transmissions is skyrocketing. As a result, the radio frequency spectrum is becoming increasingly congested, causing radio frequency interference (RFI). RFI can cause an array of issues, such as a decrease in signal quality, reduced data transmission speed and dropped telephone calls. In response, network operators are finding themselves increasingly confronted by the demanding task of interference hunting, which is the time consuming and challenging process of localizing and solving RFI. Consequently, there is a need to increase the efficiency and accessibility of interference hunting. Augmented reality (AR) is a technology that allows overlaying of virtual elements such as text or images over the field of view of the wearer, enhancing perception by addition of virtual content. It is expected AR has the potential to improve interference hunting process, for example by displaying measurement data in spatial context.

2. Analysis of interference hunting

Interference hunting is applied for commercial purposes, such as by network operators to restore network performance, but is also relevant for safety and security applications such as for detecting jammers, covert listening devices or protecting emergency responder communications [1]. Additionally, it finds applications in the military domain, such as for the successful operation of unmanned aerial vehicles (UAVs) [2]. There are many causes of RFI, but some common causes do exist. For example, leakage refers to when a signal normally shielded by a cable spreads its signal into the environment due to a broken cable. Secondly, bi-directional amplifiers, which are used to boost the connectivity in buildings or remote areas can cause interference if not they are not properly shielded. Thirdly, intentional interference such as jammers can be a cause of RFI. Lastly, illegal radio broadcasting emitters can cause interference for legal radio channels or TV channels on that same frequency.

2.1. Interference hunting process

The first step in the interference hunting process is establishing whether there is interference. Interference occurs when the frequency of two signals is closely similar and the geographical locations of these signals are in proximity, such that the power of the interfering signal is high enough to cause a disturbance [3]. The detection of interference typically relies on thresholding, meaning that one can speak of interference if a certain property, such as signal strength, exceeds a limit [4]. Typically, field strength is used to quantify the signal strength in the context of interference hunting, which has unit:

$$dB\mu V/m \quad (1)$$

Field strength quantifies the intensity of an electromagnetic field. V/m (Volts per meter) is a standard unit used to express electric field strength. It is a vector quantity that expresses the force that would be exerted on a given particle with a certain charge if it were to be present within an electric field. As radio frequency waves have both an electric and a magnetic field, the electric field strength also applies within this scope. However, the measured power of measured radio waves tends to be small, hence µV (microvolts) is typically used. Lastly, dB (decibels) is used to relate the field strength to a reference number. In practice, user reports of low data transmission speed or dropped telephone calls are one way that network operators would start an investigation.

The next step is verification. Operators set out with specialised equipment to further investigate. Devices such as spectrum analysers and monitoring receivers enable operators to receive and analyse radio signals. When interference is confirmed, the last step pertains localizing the source, which is typically a time-consuming and challenging process. First, the search area is narrowed using vehicles equipped with omnidirectional sensor, gradually mapping the area. When the searching area is sufficiently narrowed, operators set out on foot, equipped with a portable spectrum analyser or monitoring receiver, combined with a directional antenna, a process which is also known as direction finding (DF).

2.2. Direction finding

To determine the location of an RFI emitter, both manual and automatic DF methods exist. Typically, a combination of both is used in practice. In manual DF, a directional antenna is typically used, which is a type of handheld antenna that can be physically rotated and moved. These devices have a high radiation intensity in the direction in which they are pointed, meaning that signals are most strongly received in this direction [5]. As such, these antennas can be physically moved to determine the direction from which a signal is originating. Here, the direction is obtained by manually assessing the obtained signal strength in all directions.

Manual DF requires skill and is prone to human error. In response, automatic DF methods have been developed, which are more accurate. Many DF methods use the Angle of Arrival (AoA) with which signals arrive at sensor elements [6, 7]. AoA is directly related to the direction from the measurement location towards the source of interference [6]. Based on AoA measurements taken from at least two positions, the emitter can be localised using triangulation, as multiple directions towards the emitter intersect at the most likely point of origin [6, 9].

3. Augmented Reality

Augmented reality (AR) uses technology to enhance the user's perception of the environment by addition of virtual elements [10]. In AR, the focus is on the real environment, meaning that it can find practical applications in various domains beyond entertainment, such as in product design and virtual prototyping [11, 12], for maintenance and assembly [13], medical applications [12, 14] and education [11]. While the technology has been in development for more than 50 years since the first AR prototype by Sutherland [15], it is only in recent years that it has gained popularity in the commercial sector in around 2009 [16]. The popularity of AR devices is expected to increase strongly in the coming years, with the combined AR and VR market being $46 billion in 2019 but expected to have the potential to boost the global gross domestic product by $1.5 trillion by 2030, out of which $1.1 trillion would be attributable to AR [17].

3.1. User interface design

User interfaces are crucial, not only for AR, but also in many other products such as smartphones and computers. A user interface (UI) is an interface with which a user can interact with a machine or software. In the context of this work, user interface refers to a virtual interface that facilitates input and output and can present visual data such as images or text. Designing user interfaces for AR can be challenging, as it is heavily dependent on context, such as background objects and their colours and textures, as well as heavily influenced by lighting conditions. As such, guidelines are necessary to design a successful AR user interface. To identify these guidelines, a literature review was conducted. The first identified aspect is cognitive load. Reducing cognitive load of a UI is necessary to minimize cognitive strain on the user [18]. To not distract users [19], AR content should be kept to a minimum by only providing relevant information [20]. Further, movement of content should be limited [21] and UI elements should be simple and not obstruct the user's view [20].

Secondly, content placement is relevant in AR as it has an impact on the physical interactions required, affecting how straining interactions are [20]. For example, having the user rotate their head frequently and to large angles can be straining and uncomfortable. Digital content should adapt to the behaviour of the user and for example adapt its position or rotation to the user's viewing angle [21].

Thirdly, personalisation is an important factor. Flexibility during use is an important aspect for AR interface design [22], which can also refer to offering various means of user input. Offering the user choice in the type of control method will increase the usability of the application [23], as it would make it suitable for multiple use situations. Flexibility can be defined as enabling users to adjust the appearance based on preferences, such as adjusting the brightness or rearranging virtual objects [20]. Fourth, colour use can be a contributing factor to the success of AR user interfaces. Due to the wide array of use contexts and lighting conditions, colour use can be challenging. For example, colour of AR content, which is partially transparent, can blend with the background colour of the real environment [24]. Solutions for example including utilizing a light sensor to adjust the brightness of virtual content based on the lighting conditions [25] or colour harmonization methods, which use algorithms to automatically change the colour combinations of both real and virtual elements in AR interfaces [26]. More simple solutions include using billboards, which display content such as text over a solid, single coloured shape to enhance contrast in all situations, although this could reduce immersion. Lastly, the form of virtual objects can contribute to the success of the UI. For example, the form of objects should not distract users and therefore be simple but should also communicate its intended function to the user through applying well known metaphors, also known as affordances [20].

3.2. User interaction

AR facilitates new methods for user interaction, such as eye-tracking, voice control and hand gestures. However, care should be taken that these new interaction methods provide added value, rather than being a gimmick. Gestures are used frequently in AR applications, such as pressing an AR button or tapping in the air. This refers to registering movement of the user's hands or arms as a means of input. These gestures can be used to design input methods that are more instinctive [27] However, these gestures should be easy to perform and not need challenging coordination of movements [21], and should prevent fatigue by avoiding having the user hold up their arm repeatedly or for prolonged periods of time [28]

Eye-tracking can be an interesting interaction method, which can cost less energy to perform than using gestures. However, implementing eye-tracking without being straining can be challenging [29]. One way to do so could be implementing an attention-based model, in which the system would predict that a user is wanting to interact with a button based on eye movement. Examples are presented by [30] and [31], in which such an attention-based model was used to display extra information about art objects in a museum based if they are looking at this object for a certain amount of time.

Voice control can be a useful interaction method, which is not exclusive to AR devices but also used for smart devices such as smartphones. This can offer a way to exercise control when both hands are occupied. However, challenges can be misinterpretation of spoken words [23] as well as ambient noise [32]. To avoid misregistration of spoken words, it is recommended to use concise, simple words and not using multiple commands that sound similar [33].

While novel interaction methods such as gestures and gaze would enable users to have both hands free, [28] argue that such methods can lack precision and can be straining, making them unsuitable for prolonged use. One potential alternative is using tangible objects for control, such as projecting virtual control surfaces over physical objects or using physical objects as a means of control input.

Tangible objects can result in a more intuitive method to interact with AR interfaces [16]. For example, [28] presented a method to project a virtual control surface over a physical object for the user to interact with.

Furthermore, when looking at interaction from a broader view, feedback is also important. The system should provide feedback in response to a user's action [19] such that the user knows that their action was successfully registered [22]. People have so called mental models, or in other words expectations how virtual objects will behave and react, based on their personal experiences, and by designing interactions based on these mental models, a lower cognitive load can be achieved [20].

Further, it is recommended to offer guidance and documentation for the application when the user needs assistance or does not know what to do [19]. Lastly, while AR can provide a profound level of immersion, care should be taken to protect the safety of the user. This deep state of immersion could decrease situational awareness and result in accidents [34]. Hence, it is recommended that designers take the user context into account and for example incorporate reminder to be aware of your surroundings. At current however, little guidelines have been found in literature to design AR applications for safety.

3.3. Data visualisation

The development of AR has resulted in a new research area, which is that of immersive analytics [35] Immersive analytics is concerned with the way AR can help interpretation of data and facilitate decision making [36]. The work by [35] suggests that immersive data visualisations can help understanding and perception of data. Additionally, using AR for visualising data can introduce a new level of data interaction and add a dynamic aspect to the data [37]. However, the most appropriate method of visualising data in AR depends on the use case.

An example of a device that visualise data in such a way are for example the acoustic imager, which visualises the normally invisible sound on a screen. By using an array of microphones, the source of the sound can be accurately determined, which is visualised in the form of a heat map on the screen. AR data visualisation is also receiving attention in the automotive industry, to display data such as the current speed, the speed limit, and the distance to the next car over the windshield. In this way, the user does can stay focused on the way ahead without having to look away from the windshield.

An example of an AR data visualisation application in scientific literature is for example presented by [37], who developed a method to visualise the user's travelled route over a map. Work by [35] demonstrated how AR can be used for a new level of data interaction and visualisation, using a tangible orb that represents planet earth, over which data can be displayed, or and which can also be used to control an AR earth globe of a larger size, such that when the tangible orb rotates, the AR globe will also move. Lastly, [38] presented a method to assess ergonomics and visualise these assessments using AR. Their method displays a virtual skeleton over a person, which is then used to determine if their current posture is ergonomic.

4. Prototype

5.1. Prototype development

To demonstrate the capabilities of AR to visualise interference data in spatial context, a prototype was developed for the Microsoft HoloLens 2. First, several design concepts were made containing various functionalities. The first step was implementing the most fundamental capabilities, i.e., displaying measured parameters such as field strength in AR in real time. When this was successful, the functionality was extended by providing the data with spatial context by coupling the antenna's movement to the interference data. The movement of the antenna was tracked using a printed QR code and Microsoft Mixed Reality QR SDK. At even higher levels of complexity, a system was developed that facilitates creation of heat maps of the field strength, allowing the user to visually see a history of the measured parameters in all directions that have been scanned. This provides a visual method of assessing the direction in which the signal is strongest, and thus ascertaining the direction in which the signal emitter might be located. Additionally, a video streaming solution was implemented using Mixed Reality WebRTC, a set of open-source libraries for video streaming in mixed reality. Lastly, control menus were added to allow for adjustment of settings on the receiver through the AR headset, such as centre frequency and bandwidth.

5.2. Preliminary user tests

The prototype was successfully developed and tested with four expert users. Although a sample size of four persons is too small to draw statistical conclusions from, it did provide valuable feedback for future development. For the testing setup a signal generator was hidden in one of 13 equal cabinets. Participants were first tasked with locating the generator using only the receiver and directional antenna. During the second round, they were additionally equipped with the AR prototype. The time was recorded during both rounds and qualitative questions were asked in between tests and after. All participants had very little experience with AR.

5. Discussion

A quantitative improvement of the total searching time was not demonstrated, as the average time it took to find the generator increased from 102 seconds without AR to 179.6 seconds with AR. This difference can mainly be attributed to insufficient reliability of the application, which was also the main point of feedback from test users. The insufficient reliability is predominantly caused by inconsistent tracking of the antenna, which is expected to be caused by the implemented tracking method using a QR code. Alternatively, the colours of objects in the test environment could have affected the tracking capabilities. However, all four participants recognized the potential efficiency increase of the application given that the reliability is increased. In the current interference hunting process, operators must constantly shift their focus of attention between the screen of the receiver and the environment, whereas AR can enable operators to directly observe the measurement data in spatial context, resulting in a more seamless user experience. However, all participants reported that they found data interpretation to be easier with the AR visuals than without. Additionally, AR improved the intuitiveness of the process, as the intuitiveness was scored on average 7.4 out of 10 in the test without AR and 8.5 out of 10 in the test with AR.

6. Conclusion

While the user tests have shown that at current, the prototype does not result in a statistical efficiency increase, the intuitiveness of the process was shown to have increased by visualising RFI data in AR. As such, the project is a success, as the main goal was to develop an AR user interface capable of presenting interference hunting data in spatial context, which was achieved.

Participants struggled with insufficient robustness and reliability of the application, which were the main contributing factors to the increase in the average searching time during the second round of testing in which AR was used. The main reason for this is expected to be the tracking method using QR codes. Potential other methods for tracking that might be more robust could be model-based tracking. Nevertheless, all involved participants expect that AR has the potential to significantly improve the interference hunting process, mainly due to potential efficiency increase and improved simplicity, if the future developments focus on enhancing the robustness. The work presented has laid the groundwork for further development and has opened the door for various other implementations.

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