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Using augmented reality devices for remote support in manufacturing: A case study and analysis

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A B S T R A C T

Industry 4.0 forces increased digitization, production flexibility, improvement of employee competences and integration of employees and IT systems within an enterprise. To this end, state-of-the-art systems and IT solutions, such as the Virtual Reality (VR) and Augmented Reality (AR), are implemented. New systems must be integrated with the existing IT architecture, and their implementation forces the enterprise to provide network access with sufficient bandwidth to fully benefit from the capabilities of new technologies. The paper discusses the practical application of modern AR solutions in the industry, with a special focus on remote support for maintenance operations and training of production employees. Two experiments aimed determining the impact of various environmental conditions on the possibility of using the AR Remote Support are described. Basing on those experiments it is possible to determine the environmental conditions required to use HoloLens 2 AR goggles in two dedicated remote support applications.

A R T I C L E I N F O

Keywords:
Smart manufacturing;
Industry 4.0;
Remote support;
Augmented reality (AR);
Virtual reality;
HoloLens 2;
Ambient noise;
Wi-Fi networks

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1. Introduction

In Industry 4.0 [1], which forces increasing digitization and automation of the manufacturing environment [2], workers' capabilities can be enhanced and augmented with new systems, machines, tools and advanced human-machine interaction technologies [3]. One of them is the Augmented Reality (AR), which, alongside the Virtual Reality [4], is one of the keys and most promising technologies for Industry 4.0 that can be used to support both factory workers and engineers at the workplace [5, 6]. The AR can be achieved by overlaying the information space, containing real-time task-relevant information, on top of the physical space [7]. AR applications remotely support new as well as experienced workers in task performance and with interactive repair instructions [8]. Despite all its advantages, the AR technology has not been used widely so far in real contexts of various complex industrial operations [9]. The reasons are complex, including the high cost [10] and inconvenient use of the AR equipment [11, 12], and the need for the enterprise to ensure adequate network capacity and IT infrastructure (including digitalization of products, processes and services [13]).

Even at the beginning of the 21st century, obtaining technical assistance or expert support required the physical presence of an expert who had the necessary knowledge and could solve the problem or instruct the employee [14]. This solution works well for small production companies where most of the activities are concentrated in one hall. In the case of larger enterprises, where production is distributed among many plants, the need to provide expert support in each of them may generate additional costs.

Remote support can help reduce costs by eliminating the physical presence of experts on the factory floor [15]. Unfortunately, voice communication may be insufficient if the problem is serious or difficult to describe, or the employee who is physically on site does not have sufficient competence to describe the problem. One way to solve the problem it to take a photo of the faulty resource and send it for expert assessment using email or cloud storage service. If the photo quality is good enough to provide the expert with necessary information, it can be annotated and sent back, or voice communication can be established to explain how to remedy the problem.

An AR remote support app which supports direct video and audio transmission can streamline the process by providing the expert with a better insight into the problem. Several of such applications has been developed so far; however, they all leave room for improvement. For example, the stabilization of annotations requires further enhancement [16]. Implementation of the AR technology, still under development, is very difficult in the industry due to technical limitations and ergonomics of devices. Nevertheless, its potential is widely recognized [17].

There are several solutions that support remote collaboration that use AR goggles, such as Microsoft Dynamics 365 (Remote Assist) or AR4vision. Although the applications can be used on tablets and smartphones, the software manufacturer recommends that the employee be equipped with AR googles to have their hands free, what speeds up the operations significantly [18]. The remote expert runs the app on a PC, Mac or other mobile device. Both solutions provide audio and video communication for remote expert support in the field of:

- maintenance and servicing of machines,
- monitoring and inspection tasks.

The use of AR4vision helps to achieve savings resulting from the reduction of repair time, travel and machine downtime. The benefits include [19]:

- reduced time of reaction and task completion by 40 %,
- reduced travel costs by up to 70 %,
- remote training of staff,
- remote control and operation of machines and devices,
- owing to a quick response operators or service technicians, 30 % of failures and problems does not generate costs related to downtime or damage to the machine.

However, reliance on these data should be limited, as the data are not confirmed by the results of the study results published in peer-reviewed scientific journals. Most of the AR solutions described in scientific publications are evaluated in laboratory conditions, whilst data from hands-on implementations are scarce. Nevertheless, there are many examples of laboratory tests and prototype systems described in the literature, which use the AR to support operators during assembly/disassembly [20-22], maintenance [23, 24], welding operations [25], or inspection activities [26].

The AR technology can facilitate the implementation of new, innovative processes in industrial plants and improvement of the efficiency of existing ones. In particular, it enables the access to resources and knowledge bases, which in large enterprises and organizations combine hundreds of thousands of data and information sources [27]. Mobile AR technologies provide employees with easier access to resources, manuals, and user guides to solve everyday problems. They support remote work with specialists, even in geographically remote locations making it possible to quickly upload photos or videos to current reports. Additionally, they streamline communication among team members [28] and, in conjunction with other innovative technologies such as the Internet of Things and additive manufacturing, can affect supply chain management [29].

The AR has enabled an innovative approach to inspections, servicing and maintenance in the industry. Online data exchange and communication with other team members streamlines the process of problem solving by non-experts in each field. Supported by the AR solutions, service technicians are able to perform less complex repairs with virtually no need for prior training. For example, Bosch offers technologies that combine the Augmented Reality and live streaming in the production and servicing of machines. Digital information received by employees (e.g., data sheets, technical data) is supplemented by live recordings [30].

A widespread introduction of the 5G technology is bound to support the AR in terms of remote access to enterprise knowledge bases. The manufacturers of AR solutions predict that the full potential of AR applications will only be achieved only owing to the 5G network (characterized by low latency and very high bandwidth [31]). Thus, the AR will have an even greater impact on efficiency, cost reduction, safety and speed of manufacturing processes [32].

The authors carried out a number of activities aimed at setting recommendations for the developed solutions and the conditions under which those solutions can be effectively implemented, in cooperation with an enterprise developing modern solutions for companies implementing the Industry 4.0 concept. The paper presents results of research undertaken to determine the environmental conditions required to be able to use remote support for the HoloLens 2 device. Two experiments have been conducted to determine the impact of ambient noise and Wi-Fi network quality on the applicability of the solution. The first experiment aimed to determine how environmental conditions, such as distance, walls, and other Wi-Fi networks, affect the quality of audio and video transmission through a remote support app. The second one was conducted to check how ambient noise affects the understanding of expert's instruction during a remote support call.

The paper describes results of studies made in cooperation with an external software development company, whose clients are production companies operating in the automotive sector. The two conditions (noise and Wi-Fi) were marked as the most relevant (i.e. problematic) during the course of previous factory floor implementations. That is why particular attention were paid to them.

2. Materials and methods

2.1 Research concept and plan

Two experiments were carried out to determine the impact of various environmental conditions on the possibility of using the AR Remote Support. The first experiment examined the quality of the impact of the Wi-Fi signal quality on the reception of audio/video content in AR Remote Support applications. The second experiment was aimed at assessing how noise affected the understanding of expert's instructions when using HoloLens 2. A simplified plan of experiments is presented in Fig. 1.

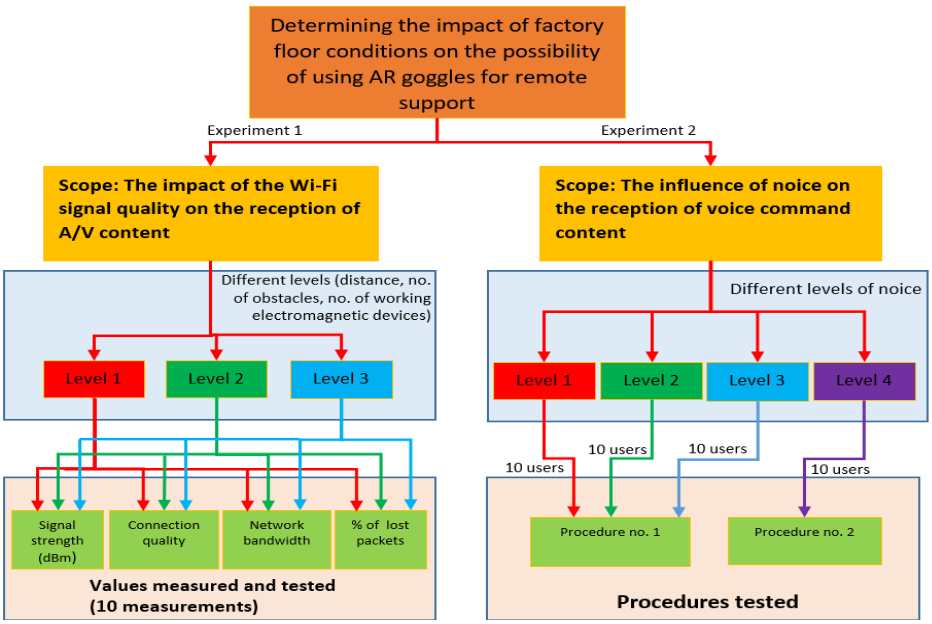


Fig. 1 Plan of experiments

2.2 Software and hardware used

Experiments were conducted using Microsoft HoloLens2 which is a standalone mixed reality device, that enables hands free interaction with displayed content. That type of interaction is possible with the help of voice commands, eye tracking, hand tracking and gesture recognition. This is made possible by a number of sensors, which are shown in the Table 1 that lists the device specifications.

Table 1 Microsoft HoloLens 2 specification [33]

Parameter group	Parameter type	Parameter value
Display	Optics	See-through holographic lenses (waveguides)
	Eye-based rendering	Display optimization for 3D eye position
Sensors	Head tracking	4 visible light cameras
	Eye tracking	2 Infrared (IR) cameras
	Depth	1-MP Time-of-Flight depth sensor
	Inertial measurement unit (IMU)	Accelerometer, gyroscope, magnetometer
	Camera	8-MP stills, 1080p30 video
Audio and speech	Microphone array	5 channels
	Speakers	Built-in spatial sound
Compute and connectivity	Wi-Fi	802.11ac 2×2
	Bluetooth	5
	USB	USB Type-C DRP
Fit	Weight	566 grams

Two different software for AR remote support were used in experiments:

- Microsoft Dynamics 365 Remote Assist,
- Apzumi Spatial.

Microsoft Dynamics 365 Remote Assist allows the user to transfer visual instructions in the form of:

- files (graphic formats and PDF) containing digital machine documentation or operating / repair instructions,
- graphically applied comments on photos (screenshots) made by a service technician equipped with the AR goggles,
- annotations in the form of arrows (they can be anchored in the AR user space) to refer to specific parts of the machine or resource.

The Dynamics 365 platform also offers the Dynamics 365 Guide solution. It is a tool dedicated to the AR goggles, which enables employees to learn while working or in a training session by enabling access to holographic, interactive instructions. The app lets the user scan QR codes for procedures, located in the place where the job should be done. The database contains graphic files, movies, and 3D models for the operators to see what to do and where. It can be used as a learning tool as well as to support the performance of daily tasks and reduce the number of errors.

The solution includes easy-to-use forms for creating training content (step-by-step instructions, procedures illustrated with images, videos, and 3D models). The user equipped with HoloLens 2 can change the location of instructions / procedures in his workspace (move them to specific places, near a given machine or production line), or the instructions can move with the user. Extensive procedures feature prompts pointing to tools and parts that will be needed, as well as instructional data (e.g., presentations of how and where a given tool should be used).

Apzumi Spatial, developed by Apzumi, is an AR application designed to support production workers as well as maintenance and repair staff. The application also offers support in the training of new employees and the implementation of new products [34].

The application allows to display product visualizations, training procedures, production and operating procedures assistance, as well as connect with other users using the AR goggles and the Internet platform. The content of the platform can be created by the employees. It can be created by users themselves; however, most users will not have the right competences required. The content posted on the platform is typically multimedia (text, images, videos) and interactive animated

3D models. 3D models can be prepared by designers and 3D graphic designers, and the substantive content (the content of the manual) by trainers responsible for training, as well as specialists and experts. To access the platform content, the user needs to scan a QR code, generated for each 3D model or procedure in the phase of content creation.

The remote support module supports connection with specialists / experts in the given field, which facilitates remote service. Due to the high requirements for wireless connectivity, the module is treated as a separate layer of the system with specific requirements.

2.3 Wi-Fi requirements for video and audio transmission

In wireless communication, the dynamically changing network conditions (including link bandwidth, latency, packet loss, etc.) may affect the quality of audio and video connections, especially if devices such as AR goggles are used. Connections are also possible in environments with reduced link capacity; however, the quality of operation of selected functions may be severely deteriorated.

To effectively use the developed solution dedicated to the HoloLens 2 goggles at a satisfactory level, a minimum link bandwidth of 1.5 Mb / s (upload / download) is required. It applies to:

- peer-to-peer (P2P) video calls in Full HD resolution (1080p at 30 frames per second),
- reception of content and high-quality sound (15 fps).

However, an analysis of results of the first practical tests of the HoloLens 2 goggles, available on industry portals, shows that to obtain the optimal quality of video connections (i.e., without interruptions in the reception of video content), a bandwidth of at least 4-5 Mb should be provided [35]. However, even such wireless link parameters do not guarantee video connections with the expected / required image quality.

The minimum requirements for the Wi-Fi bandwidth for selected scenarios performed with the use of HoloLens 2 goggles (assuming that the device is located within the optimal range of the access point) are shown in Table 2.

Table 2 Minimum Wi-Fi bandwidth requirements for selected scenarios [36]

Bandwidth (minimum)	Scenarios
30 kb/s	audio P2P
130 kb/s	audio P2P with screen sharing
500 kb/s	video P2P, 360p at 30 fps
1.2 Mb/s	video P2P, 720p at 30 fps
1.5 Mb/s	video P2P, 1080p at 30 fps

2.4 Experiment No. 1 – Influence of Wi-Fi quality on the AR remote support

The scope of experiment No. 1 was to investigate the impact of Wi-Fi signal quality on the reception of audio / video content. It was assumed that the tests were to be carried out at three levels, corresponding to three different distances from the access point and three different numbers of electronic devices up and running, affecting the electromagnetic interference generated:

- Level 1 (place: Smart Factory (SF) laboratory of an area of approx. 35 sq. m)
  - distance from the access point: 2-4 m (obstacles: no),
  - number of running electromagnetic devices: 4 (one notebook running in the active Wi-Fi connection mode, one Wi-Fi router – access point used, two smartphones in the active Wi-Fi connection mode).
- Level 2 (place: Virtual Reality (VR) laboratory of an area of approx. 60 sq. m)
  - distance from the access point: 6-10 m (obstacles: 1 partition wall),
  - number of running electromagnetic devices: 11 (three PC monitors, two PC base stations, two laptops, one Wi-Fi router, three smartphones in the active Wi-Fi connection mode).
- Level 3 (place: Rapid Prototyping (RP) Laboratory of an area of approximately 80 sq. m)
  - distance from the access point: 16-22 m (obstacles: 2 reinforced concrete walls + 1 partition wall),

- number of running electromagnetic devices: 16 (one notebook running in the active Wi-Fi connection mode, one Wi-Fi router, seven wireless Wi-Fi cameras, five devices for 3D printing, two smartphones in the active Wi-Fi connection mode).

The experiments were carried out within the range of several local wireless network access points available in the building of the Faculty of Mechanical Engineering, the Poznań University of Technology (Fig. 2):

1. SF laboratory (level 1) – 9 local networks.
2. VR laboratory (level 2) – 9 local networks.
3. RP laboratory (level 3) – 11 local networks.

The variables in the experiment were therefore the distance from the target point (different Wi-Fi signal strengths) and the electromagnetic disturbance.
The tested values were:

1. Signal strength (dBm).
2. Connection quality (assessed on a scale of 1-5).
3. Network bandwidth (measured in Mb/s when transferring a file of 500 MB).
4. Percentage number of packet errors in relation to the number of packets received (%).

For each level, ten attempts were made to download a file located on an external server using the Dropbox application. During the data download process, the bandwidth and signal strength of the Wi-Fi network were measured, and the number of communication errors was counted (a ping application was used to calculate the percentage number of erroneous packets in relation to the number of packets received).
Then, based on the obtained measurements, the connection quality was assessed on a Likert scale of 1-5.

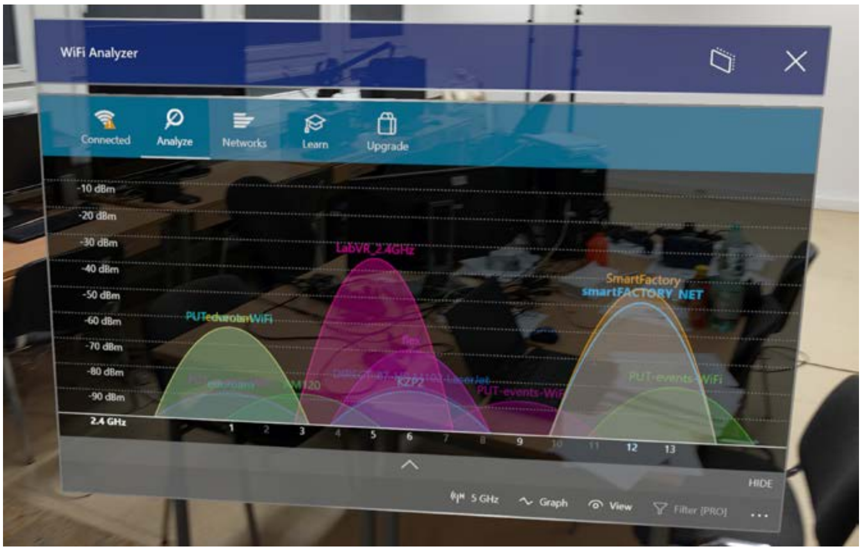


Fig. 2 Interference of various Wi-Fi networks – view in the Wi-Fi Analyzer application

2.5 Experiment No. 2 – Impact of noise level on the quality of conversation

To determine the impact of noise level on the quality of conversation, tests were planned and then carried out at four levels:

- Level 1 (place: SF laboratory) – silence; no devices turned on (approx. 30 dB on average),
- Level 2 (place: SF laboratory) – presence of two interviewers (approx. 50 dB on average),
- Level 3 (place: SF laboratory) – presence of two interviewers and the production line switched on (approx. 70 dB on average),
- Level 4 (place: RP laboratory, presented in Fig. 3.) – conversation with an expert, accompanied by the Airpress HL155/25 compressor (1.1 kW) switched on (approx. 85 dB).

Fig. 3 Rapid Prototyping Laboratory containing multiple additive manufacturing devices and IP cameras

To determine the impact of noise level on the quality of conversation, tests were planned and then carried out at four levels:

Two remote support procedures were prepared for the experiment:

1. Procedure No. 1 (purpose: control of the control box elements, place of implementation; Smart Factory Lab – SF).
2. Procedure No. 2 (purpose: test activation of a selected device for additive manufacturing and change of selected settings, place of implementation; Rapid Manufacturing Laboratory – RP).

Both procedures are presented in the Fig. 4. Both procedures were performed by users wearing HoloLens 2 glasses and using Apzumi Spatial Call application (Fig. 5) and Dynamics 365 Remote Assist (Fig. 6).

The values tested were the reception of the content of audio commands as part of the procedures performed (%) and the fluency of the conversation and video transmission assessed by an expert who connected with the user of the AR goggles.

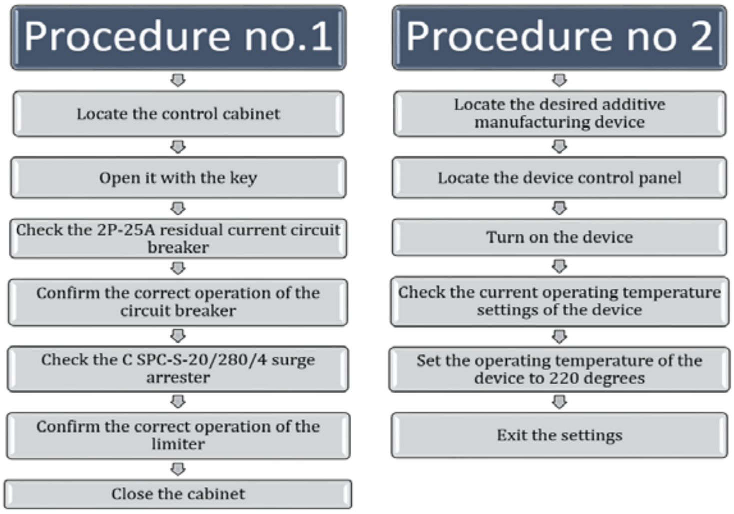


Fig. 4 Procedures carried out in the experiment No. 2

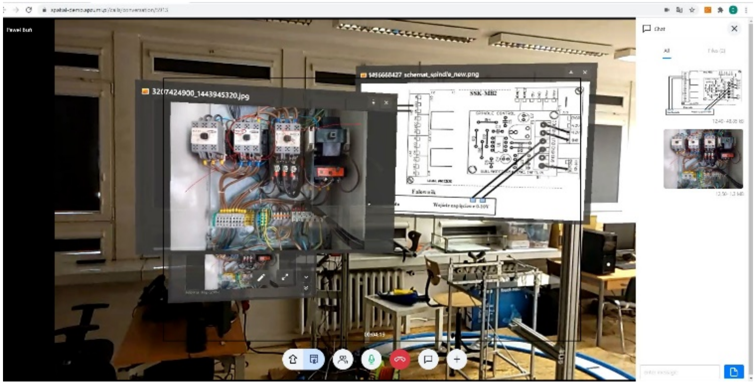


Fig. 5 Expert view in remote mode – Apzumi Spatial Call application (VR Laboratory)

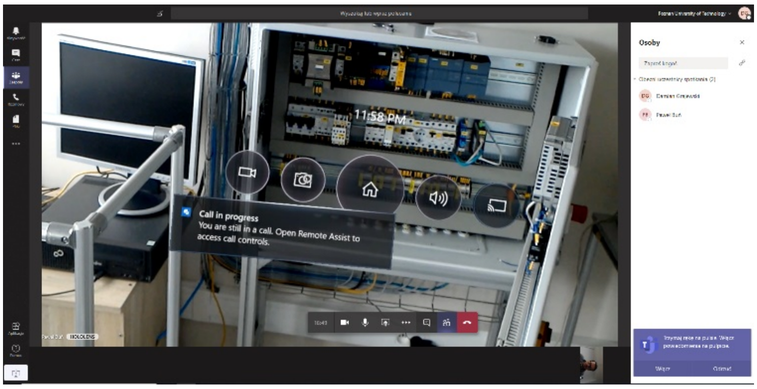


Fig. 6 Expert View in Remote Mode – Dynamics 365 Remote Assist App (SF Laboratory)

3. Results and discussion

3.1 Experiment No. 1

The experiment examining the impact of the Wi-Fi signal quality consisted in 10 attempts, for each of the three levels defined above, to download a file located on an external server using the Dropbox application. During the data download process, the bandwidth and signal strength of the Wi-Fi network were measured, and the number of communication errors was counted (a ping application was used to calculate the percentage number of erroneous packets in relation to the number of packets received). Based on the obtained measurements, a subjective assessment of the connection quality made (on a scale of 1-5).

The results of the experiment are shown in Fig. 7. Interference levels are based on distance from access point (4/10/20 m), obstacles (no obstacles/ partition wall/ 2 reinforced walls, 1 partition wall), number of electronic devices up and running (4/11/16) and number of local Wi-Fi networks (9/9/11).

In addition, the maximum distances from the target point were set to ensure the reception of content at a satisfactory level:

1. in the absence of obstacles – 20 m,
2. with one obstacle (a partition wall) – 12 m,
3. more than one obstacle (a reinforced concrete wall + a partition wall) – 6 m.

Exceeding the maximum distances resulted in a significant decrease in the quality of the connection, as expected. A person wearing the AR goggles reported problems with receiving the data sent by the expert, while the expert noted a decrease in the quality of the A/V signal (Fig. 8).

A decrease in the video transmission quality and disturbances in the audio transmission impeded the conversation and made it impossible to understand the instructions given by an expert in the Remote Support application. Therefore, further in the study, this Wi-Fi network configuration was abandoned.

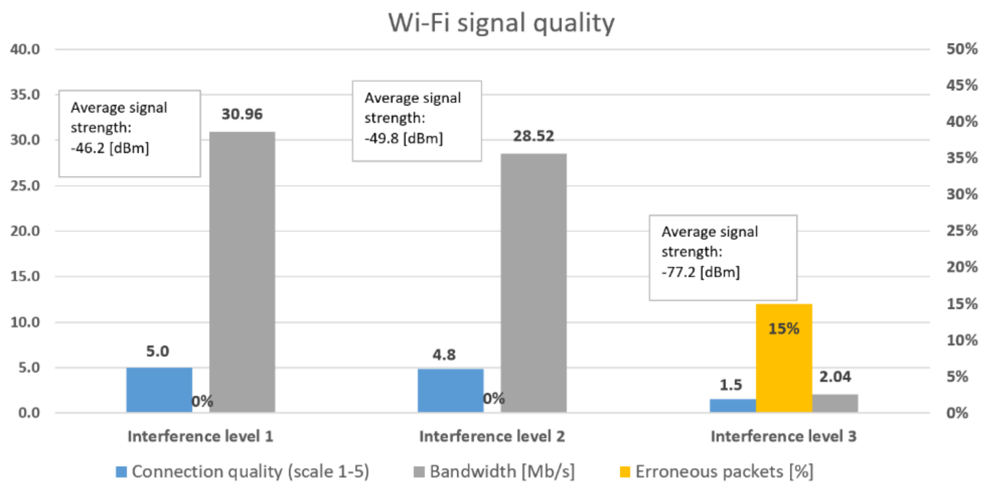
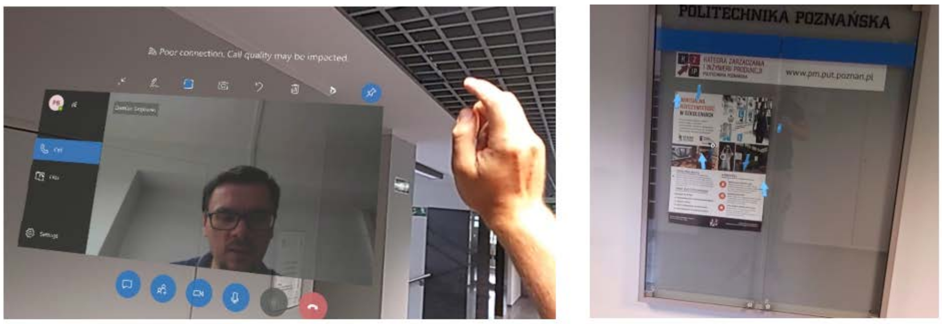


Fig. 7 Wi-Fi signal quality at selected interference levels

a)



b)

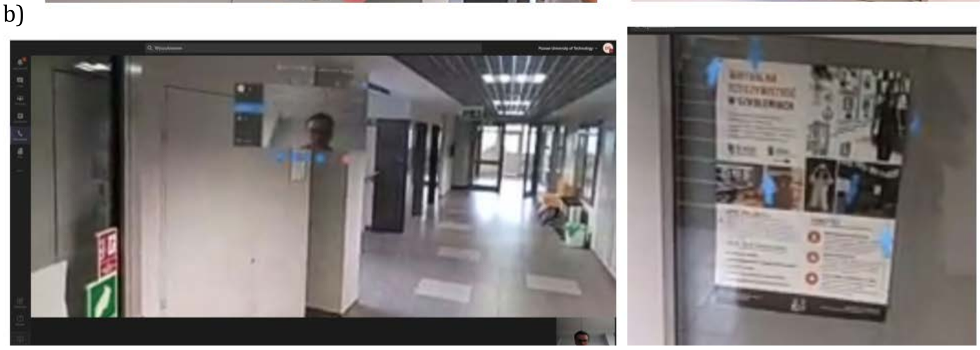


Fig. 8 View of the user of the AR goggles (a) and the expert in remote mode (b) in the case of exceeding the allowable distance from the access point

3.3 Experiment No. 2

Experiment consisted in examining the impact of noise on the ability to conduct a conversation and effectively implement the developed procedures using the HoloLens 2 glasses with the Apzumi Spatial Call application and the Dynamics 365 Remote Assist.

The values tested were the reception of audio commands, as part of the procedures performed (%), and the fluency of conversation and video transmission, assessed by an expert who connected with the user of the AR goggles. A total of 40 people took part in the study, testing both applications by implementing remote service procedures at four different noise levels (10 people for each noise level). The results and the average ratings are shown in Tables 3 and 4.

Based on a subjective assessment of the quality of conversation (reception of commands by the service technician and understanding of questions/answers by the expert) and video transmission (expert assessment in the remote mode), the functionality of both applications in terms of remote support of a production worker was compared.

Table 3 Results of experiment 2 (Apzumi Spatial Call application). ACC – Audio command comprehension, QA – Quality of audio, QV – Quality of video, AV – Average

Attempt No.	Level 1 (lab SF) ca. 30 dB			Level 2 (lab SF) ca. 50 dB			Level 3 (lab SF) ca. 70 dB			Level 4 (lab RP)ca. 85 dB		
	ACC (%)	QA [1-5]	QV [1-5]	ACC (%)	QA [1-5]	QV [1-5]	ACC (%)	QA [1-5]	QV [1-5]	ACC (%)	QA [1-5]	QV [1-5]
1	100	5	5	100	5	5	100	4	5	0	1	1
2	100	5	5	100	5	5	100	5	5	0	1	1
3	100	5	5	100	5	5	100	4	5	0	1	2
4	100	5	5	100	5	5	100	3	4	0	1	1
5	100	5	5	100	4	5	100	5	5	0	1	1
6	100	5	5	100	5	5	50	3	5	0	1	1
7	100	5	4	100	5	5	100	3	4	0	1	2
8	100	5	5	100	5	5	50	5	5	0	1	1
9	100	5	5	100	5	5	100	4	5	0	1	1
10	100	5	5	100	5	5	100	4	5	0	1	2
AV	100	5.0	4.9	100	4.9	5.0	90	4.0	4.8	0	1.0	1.3

Table 4 Results of experiment 2 (Dynamics Remote Assist App).. ACC – Audio command comprehension, QA – Quality of audio, QV – Quality of video, AV – Average

Attempt No.	Level 1 (lab SF) ca. 30 dB			Level 2 (lab SF) ca. 50 dB			Level 3 (lab SF) ca. 70 dB			Level 4 (lab RP) ca. 85 dB		
	ACC (%)	QA [1-5]	QV [1-5]	ACC (%)	QA [1-5]	QV [1-5]	ACC (%)	QA [1-5]	QV [1-5]	ACC (%)	QA [1-5]	QV [1-5]
1	100	5	5	100	5	5	100	4	5	0	1	1
2	100	5	5	100	5	5	100	3	5	0	1	1
3	100	4	4	100	4	5	50	4	4	0	1	1
4	100	5	5	100	5	4	100	3	3	0	1	1
5	100	5	5	100	4	5	50	3	4	0	1	1
6	100	5	5	100	4	5	50	4	5	0	1	1
7	100	5	4	100	5	5	100	3	4	0	1	1
8	100	5	5	100	5	5	50	4	5	0	1	1
9	100	5	5	100	5	5	100	2	5	0	1	1
10	100	5	5	100	5	5	100	4	5	0	1	1
AV	100	4.9	4.8	100	4.7	4.9	80	3.4	4.5	0	1.0	1.0

The most important observation concerning usability of the Apzumi Spatial Call solution dedicated to HoloLens 2 goggles in difficult industrial conditions is that at a noise level of approx. 50 dB, remote service can be provided conveniently. All the messages issued by an expert were understood without any problems by the users of goggles, thus it was possible to carry out the procedure. Neither the experts reported any problems with understanding the audio content. The situation changed at a noise level of 70 dB, where a decrease was observed in the comprehension of instructions and commands issued by an expert. Nonetheless, once repeated, the messages were understood, and the procedure performed. Additionally, a test was carried out at a noise level of 75 dB, which resulted in a significant decrease in the quality of audio content reception (down to 40 %). With the compressor running and the sound intensity exceeding 85 dB (level 4), it was practically impossible to talk. An additional difficulty was the distant location of the room (RP lab) where the compressor noise was emitted, which also led to a drop in ratings in the perception of video content. Slightly worse results were obtained from the tests of the Dynamics 365 Remote Assist application.

3.3 Discussion

Based on an analysis of the results, the following observations can be drawn:

- Terrain obstacles in buildings (walls, windows and doors) cause high attenuation and deterioration of the Wi-Fi signal quality.
- The presence of turned-on electronic devices generating electromagnetic field negatively affects the signal strength and connection bandwidth (decrease by ca. 10 %).
- Operation of other wireless networks causes interference; a large number of devices operating in particular bands causes the interference phenomenon.
- Low bandwidth when downloading 500 MB of data (the problem occurred at level 3). During the tests there were problems with the Wi-Fi connection on the HoloLens 2 device.

The studies were made in cooperation with an industrial company, which develops innovative industrial-grade MR platform, for automotive companies. Results of the described studies were directly implemented in the platform operation – a set of recommendations for the production companies was formulated, basing on the above-mentioned observations, and it was considered in future implementations.

4. Conclusion

The authors believe that the AR is a promising technology for remote employee support and expert consultation. With continuous access to database resources such as materials, device diagrams, 3D models and multimedia files, the employee is able to get an insight into the problem and figure out what repairs or maintenance works should be performed. However, both access to databases and expert consultation require Web access with sufficient bandwidth connectivity and appropriate network architecture. Applications such as Dynamics 365 Remote Assist and Apzumi Spatial facilitate the development of the IT layer, easy creation of databases and uploading of files containing all the necessary materials. Bothsupport audio and video connections of production workers with field experts. However, their use in the industrial conditions is difficult due to certain environmental circumstances which affect the network capacity, as well as the noise generated by machines, which can reduce the audibility of expert instructions.

The research into the use of an AR application dedicated to the HoloLens 2 device shows that communication with experts is possible at a noise level of up to 75-80 dB. Extensive operation of industrial machines also affects the quality of AV transmission, verified based on both the measurements of signal strength and a subjective assessment of employees. Therefore, applied in an industrial environment, the applications may require the use of Wi-Fi signal amplifiers [37].

Despite the above-mentioned limitations, users expressed a very positive opinion on both solutions and emphasized how valuable for them were the functions related to remote expert support, annotation and the possibility of sending photos, diagrams and other multimedia content.

The obtained results are new – the scientific contribution is clear determination of Wi-Fi and ambient noise conditions, under which a Mixed Reality application can function in the factory floor, which was not fully known in earlier literature. The results were implemented in selected industrial companies.

Further research planned by the authors will include, among others, tests in real conditions – in a factory floor, and a study of the impact of using Wi-Fi signal amplifiers on the audibility, file transmission and ability to carry out machine repairs or inspections using the described AR remote support applications. Another factor to consider is the use of a headphones and microphone, connected to an MR device, with active background noise suppression. Before implementing AR Remote support technology, managers who want to modernize manufacturing process should examine the factory floor conditions and consider the implementation of the above-mentioned solutions. However, until we carry out the research, we are not able to assess their effectiveness.

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