Implementation of Augmented Reality and **Drones to Serve Smart Cities**

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Abstract

Augmented Reality Technologies as such have been known since the first decade of the 21st century. However, due to the relatively high costs of terminal equipment, the lack of mass demand in industries, their unpreparedness to implement augmented reality in production processes, the limited use of augmented reality in the educational process, etc., this technology did not become networked. In the broadest sense of this word, the traffic generated by augmented reality significantly affects both the principles of network construction and its planning. The article is devoted to studying the interaction of augmented reality applications and control methods for Unmanned Aerial Vehicles. The study was carried out experimentally using the developed experimental stand. During the experiment, an augmented reality application was used to control the UAV. The assessments of the quality of service of the network and subjective evaluations of the quality of perception were obtained. The Hurst parameter was used to determine the relationship between the quality of communication network service and the quality of perception. The parameters of the communication network maintenance are determined to ensure the specified rate of perception when controlling the UAV using the augmented reality application.

Keywords: Augmented Reality, Virtual Reality, UAV, Internet of Things, processing time.

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1. Introduction

Augmented reality is one of the many technologies for human-computer interaction. Its specificity lies in the fact that it visually programmatically combines two initially independent spaces: the world of real objects around us and the virtual world recreated on a computer (AlKishri, & Al-Bahri, 2021).

Augmented Reality (AR) and Virtual Reality are rapidly developing technologies, the purpose of which is to expand the physical space of human life with objects created using digital devices and programs (Elmqaddem N., 2019). Unlike virtual reality, AR interfaces allow users to see embedded virtual objects in the real world and manipulate them in real time (Jung et al., 2018). Augmented reality is an intermediate link between reality and the virtual environment.

Augmented reality is an interactive technology that allows digital content to be superimposed on objects in the real world. Digital content overlays can include computer graphics, text information, electronic links, videos, and 3D objects. The superimposed virtual objects are read using digital devices: smartphones, tablet computers, multimedia augmented reality glasses, or a virtual reality helmet and specialized software products (Kipper & Rampolla, 2012).

The use of new information technologies (Yousif. J., 2011) and the social robot can enhance the facilities introduced in smart cities, such as education, entertainment, services, and manufacturing (Yousif. J., 2021; Yousif, M., 2021).

Kim (Kim et al.,2018) explored and reviewed the implementation of VR/AR in Quadcopter drones for entertainment. They also introduced a rich survey of the main characteristics of drones and their usages in the entertainment field. Ponnusamy & Natarajan (Ponnusamy & Natarajan, 2021) introduced a chapter that concentrates on the illustration and utilization of unmanned aerial vehicles (UAV), augmented reality (AR) technologies for Precision agriculture (PA), and smart farming.

Bauer (Bauer et al., 2021) investigated and reviewed the latest studies that deployed the Internet of Things (IoT) tools to enable the development of Smart City. Also, it surveyed the relevant experiences and embedded IoT tools in smart city services.

This paper studies the interaction of augmented reality applications and control methods for Unmanned Aerial Vehicles. For the study, an experimental stand was developed. During the experiment, the UAV was controlled using augmented reality technology. At the same time, the quality of service of the transmitted traffic was assessed. A subjective assessment of the quality of perception by observers was carried out. In the study, the characteristics of the

communication network operation are determined, which are required to ensure a given quality of perception when controlling a UAV using an augmented reality application.

2. Research Methodology

Controlling Unmanned Aerial Vehicles in urban areas is a difficult task since unforeseen obstacles can arise on the route of the UAV, which must be quickly detected and avoided (Khakimov et al., 2020, January). For the widespread introduction of UAV systems, it is necessary to ensure reliable and timely control of the vehicle. UAVs are actively used in flying sensor networks as a flying segment that collects data from ground sensors and delivers them to a server for further processing. Flying sensor networks have proven to be popular in the field of agriculture. It is necessary to monitor a large area in the industry and to monitor hard-to-reach and remote objects. For example, gas pipelines have also proven themselves as routers used to deploy a network in crowded places quickly.

It is customary to distinguish between three types of UAV control: manual, automated and automatic. In the first case of manual control, the UAV pilot is based on the UAV camera's video image format. With this control, augmented reality technology and tactile Internet applications can be applied to facilitate control tasks. Augmented reality allows you to add virtual data to objects of the surrounding physical world using specially designed display devices, notably augmented reality glasses. The functions of the tactile Internet include the delivery of information over the network about the impact on an object located at a distant distance and the transmission of a response back. Obviously, with such an exchange of data, the delivery delay should be as low as possible (Ribeiro et al., 2021).

To ensure stable control of UAVs using augmented reality applications, it is necessary to provide the solution of the following tasks:

- Transfer data on changes in the position of the pilot's head from the AR device to the UAV.
- Carry out the continuous transmission of video images from the UAV camera to the AR device.
- Ensure the fulfilment of the specified characteristics of the network.
- Assess the quality of perception in the implementation of the UAV control process using the DR application.

When controlling the UAV, the pilot changes the position of the UAV in space by turning or tilting his head through the augmented reality application, based on the video that comes from the camera installed on the UAV to the AR display device (Makolkina et al., 2017).

3. Features of data transmission when controlling UAVs

IoT devices afford flexibility, energy efficiency, and networks to transfer various types of data (Alattar & Azeez, 2021). As mentioned earlier, the pilot controls the movements of the UAV and the video camera installed on it by tilting and turning the head, i.e., changes in its position in space. During the experiment, the camera was placed on the UAV to ensure rotation along the vertical axis. Therefore, to ensure the maximum viewing radius, it was necessary to rotate the UAV itself in the required direction. The AR goggles are worn by the pilot and display the video stream from the UAV camera. Thus, the pilot sees the objects surrounding the UAV and can change the location of the UAV, thereby moving the camera in the desired direction. For the regular operation of the pilot, it is necessary to ensure a high-quality display of the video stream on the AR device and transmit a timely response to changes in the position of the controller's head to the UAV and the camera (Makolkina et al., 2017).

Thus, the response of the UAV must correspond to the commands of action. For example, when the head is tilted down, the camera must change its position and turn down as quickly as possible to make the video stream comfortable for the pilot to perceive. A gyroscope and an accelerometer installed on the AR device are used to accomplish this task. Data from the accelerometer and gyroscope about the change in the angle of inclination or rotation of the pilot's head are transmitted to the UAV. In turn, it understands this command as a control command and transfers it further, depending on the destination. Figure 1 shows the model of interaction between the DR device and the UAV. (Khakimov et al., 2020).

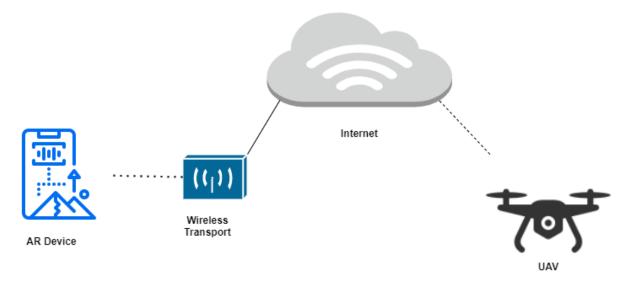


Figure 1. Model of interaction between the AR device and the UAV

However, video is high volume traffic and requires adequate bandwidth. In this experiment, you may encounter interference in the communication channel. Also, the quality of video information transmission is affected by such indicators of the quality of service as the level of loss and delivery delays. However, there is a need for accurate image enhancement techniques for processing the collected images from the transmitted videos (Abusham, 2021; Hasson et al., 2011; Al-Hatmi & Yousif, 2017). The deterioration of the values of these indicators leads to failures in the control of the UAV. It dramatically affects the quality of perception of the pilot and the control decisions made by him since they are carried out based on video data received from the UAV camera. Based on the above, a model of interaction in Figure 2 shows an augmented reality device and a UAV was developed for the study. Wi-Fi technology of the IEEE 802.11n standard was selected as a wireless data transmission technology. Within the framework of this standard, it is possible to transfer large amounts of data with a bandwidth of up to 150 Mbit / s, which is more than enough to solve research problems.

The following is a study of the influence of the network service quality indicators on the quality of the pilot's perception in the AR system when controlling the UAV.

4. Investigation of the influence of the quality of perception in augmented reality systems on UAV control

The hardware complex includes a UAV and a 3D Robotics IRIS Plus quadcopter with a GoPro video camera. Through the Wi-Fi gateway, the quadcopter is connected to the DR glasses via a wireless access device. Glasses from Epson Company Moverio BT-200, transparent binocular video glasses, were chosen as augmented reality devices. The Moverio BT-200 glasses are equipped with a gyroscope and an accelerometer and can communicate with other devices via a Wi-Fi hotspot. The block diagram of the experimental stand is shown in Figure 2.

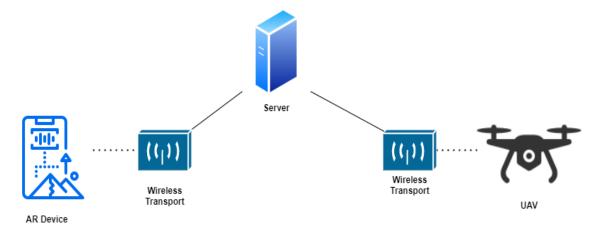


Figure 2. Block diagram of the experimental stand

In order to simulate the operation of a real network and introduce degrading effects into the network when transferring data between the DR device and the UAV, an additional server was added to the system under study, on which the free NetDisturb software was installed. NetDisturb software has a wide range of functions that introduces various interference into the network, namely increases the delay, and you can set various laws of delay formation, as well as change the level of losses and their frequency, the number of duplicated packets, and change the value of jitter. To intercept and analyze traffic, software was developed that can also assess the impact of changes in the quality of network service indicators towards deterioration on the quality of perception, i.e., display of video data and transmission of control commands, in augmented reality glasses when controlling the UAV.

In order to simulate the operation of an entire network and introduce degrading effects into the grid when transferring data between the DR device and the UAV, an additional server was added to the system under study, on which the free NetDisturb software was installed. NetDisturb software has a wide range of functions that introduces various interference into the network. Namely increases the delay and can set multiple laws of delay formation, change the level of losses and their frequency, the number of duplicated packets, and change the value of jitter. To intercept and analyze traffic, software was developed that can also assess the impact of changes in the quality of network service indicators towards deterioration on the quality of perception, i.e., display of video data and transmission of control commands, in augmented reality glasses when controlling the UAV.

Specialized software intercepts traffic travelling between the quadcopter and the DR goggles. Also, the analysis of the main characteristics of the intercepted traffic is carried out. Namely, the time of receiving the packet and the packet's size is taken into account. Based on the data obtained, the Hurst parameter is calculated, which estimates the degree of self-similarity and has a relationship with subjective assessments of the quality of perception. The Hurst parameter decreases if the delay between a pair of identical changes in time series values increases. As mentioned earlier, a flow is considered self-similar if the value of the Hurst parameter $K_{Hurst} > 0.5$. Suppose the value lies in the range $0 < K_{Hurst} < 0.5$, then such a flow is ant persistent. It is more likely to change the direction of deflection, i.e., high deviation values follow low ones and vice versa.

The property of self-similar traffic is that it looks the same at all-time scales. In other words, the probability that the traffic in the next step will deviate from the average value in the same direction as in the previous step is as great as the Hurst parameter is close to one.

During the experiments, it was determined that for more accurate estimates of the Hurst parameter, it is necessary to intercept packets within one minute. To estimate the Hurst parameter, the normalized range method was used. First, the variance is calculated for a time series of 1 minute.

$$M\left[\left(\frac{R}{S}\right)_{t}\right] \sim cn^{H} \quad When \ n \to \infty$$
 (1)

where (R/S) t is the normalized estimate of the span,

- c Constant,
- n The size of the studied block of observations

H - is the Hurst parameter, i.e., the degree of self-similarity of the process under study.

For a given finite time series X = X1, X2, ..., Xn, to calculate the average value of m:

$$m = \frac{1}{n} \cdot \sum_{i=1}^{n} X_i \tag{2}$$

Then we calculate the time series of deviations from the mean Y:

$$Y_t = X_t - m, t = 1, 2, ..., n$$
 (3)

Let's calculate the number of deviations Z:

$$Z_t = \sum_{i=1}^t Y_i, t = 1, 2, \dots, n \tag{4}$$

Let us calculate the range of ranges R:

$$R_t = \max(Z_1, Z_2, \dots, Z_t) - \min(Z_1, Z_2, \dots, Z_t), t = 1, 2, \dots, n$$
(5)

Let's calculate a number of standard deviations S:

$$S_t = \sqrt{\frac{1}{t} \sum_{i=1}^t (X_i - u)^2}, t = 1, 2, ..., n$$
 (6)

where u is the average value of the values of the series from X_1 to Xt. Let's calculate a number of normalized ranges (R / S):

$$(R/S)_t = \frac{R_t}{S_t}, t = 1, 2, ..., n$$
 (7)

Next, the series (R/S) t should be averaged over the regions [X1, Xt] for different values of t in the interval from 1 to n. usually, not all n points are taken, but some sufficient population is uniformly distributed over the entire interval from 1 to n.

The obtained averaged values M[(R/S)] t and the corresponding averaging block length t must be displayed in logarithmic axes. Then the obtained points are approximated by a linear function constructed using the least-squares

method. The slope (the tangent of the angle of inclination to the positive direction of the abscissa axis) of the obtained line will, in accordance with formula (4.61), be an estimate of the Hurst parameter of the initial time series.

In this study, the Hurst parameter is used to determine the relationship between objective assessments of the quality of service and subjective assessments of the quality of perception in AR systems when controlling a UAV.

5. Experimenting on UAV control using AR and analyzing the results

The expert is wearing augmented reality glasses, which display the video stream from the camera located on the quadcopter. The expert turns his head in different directions, including up and down, thereby changing the direction of the camera position. Thus, the viewing angle changes and another video information is displayed.

The expert's task is to subjectively assess the response of the quadcopter and the quality of the modified video image in the AR glasses. Three scenarios of the experiment were implemented, in which the influence of changes in network characteristics, such as latency, loss and decrease in bandwidth. The quality of perception was investigated. For each scenario, 20 experiments were performed. To obtain adequate estimates, the experts were shown a reference case in which no degrading effects on the network were introduced, i.e., as close as possible to ideal data transmission conditions.

For the reference case, the Hurst parameter was also calculated, and its value turned out to be 0.61, which indicates a self-similar structure of the transmitted traffic. To simplify the analysis of the experiment results, when transmitting the reference sequence, a subjective assessment of the quality of perception was set equal to 5 points on a five-point scale. In the first scenario, the effect of increasing latency on the quality of perception was investigated. Figure 3 present the results of the first scenario. It can be seen from Table 4.10 that with delivery delays not exceeding 100 ms, the quality of video stream perception by an expert remains at an acceptable level. However, when controlling a UAV with such a delay value, several difficulties arise. Due to the data lag, the pilot (in our case, the expert) does not understand precisely when it is necessary to change the movement or stop. Thus, the control is carried out at random without visual control.

The commands are transmitted with a delay, and, therefore, the response is returned with a delay.

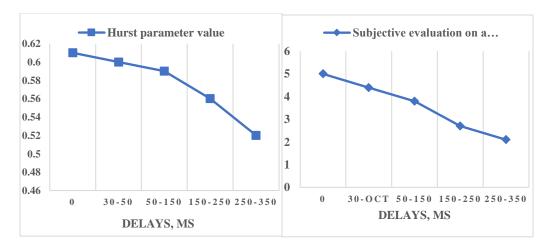


Figure 3. Experimental results with increasing delay

In this example, the Hurst parameter correctly establishes the relationship between the values of the service quality indicators and the subjective assessments of the quality of perception in the AR systems. Obviously, with delays above 150 ms, it is impossible to control the UAV using an augmented reality application.

The second scenario involved adding losses to the communication channel between the quadcopter and the augmented reality device. Figure 2 shows the results of this experiment.

As you can see from the results in Figure 4, losses significantly affect the quality of user perception when controlling a quadcopter. In addition to difficulties with control, there are also difficulties with recognizing video objects on an augmented reality device.

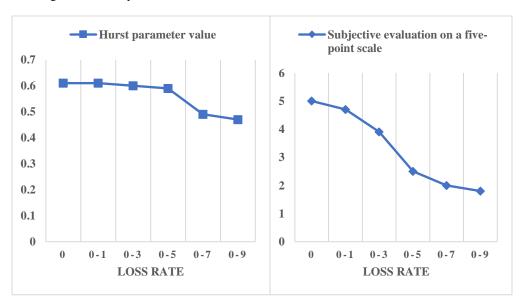


Figure 4. Experimental results with an increase in the Loss rate.

The quality of perception of the video stream significantly decreases with an increase in packet loss. It becomes difficult to disassemble the video. Moreover, the moments "drop out" from the video stream harm the UAV's control.

The third scenario investigated the impact of bandwidth limiting on the quality of control and display of a video stream. The results are shown in Figure 5.

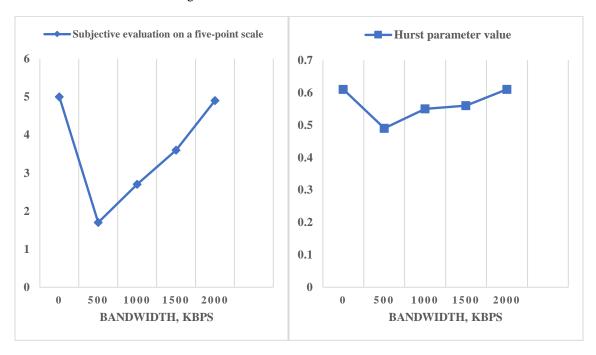


Figure 5. Experimental results with an increase in the Bandwidth.

According to the assessments of the quality of perception and the value of the Hurst parameter presented in Figure 5, a critical decrease in bandwidth affects the quality of user perception in augmented reality systems. As well as in the two previous cases, there are difficulties in controlling the quadcopter because the expert (pilot) ceases to possess up-to-date information about the movement of the UAV and the objects surrounding it. All data begins to be transmitted with long delays. Some of them are lost, an expert wearing augmented reality glasses starts to feel dizzy.

6. Conclusion

The study found that Augmented Reality applications can be used to control unmanned aerial vehicles. However, it should be borne in mind that control takes place in real-time. Therefore, it is necessary to fulfil specific requirements for the characteristics of the network to ensure timely and comfortable control of the UAV based on the current video information. This section investigated the influence of network performance indicators on the quality of

user perception in an augmented reality system when transmitting video images for control tasks from a UAV camera. Based on the results obtained, it was found that in a network with minimum delays of up to 100 ms, control of a quadcopter using an augmented reality application is possible without losing the quality of perception and control accuracy.

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