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Virtual Tour Using Telepresence Robot and MQTT Protocol

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***Abstract* – We often face obstacles to visit certain places, facilities, and institutions. This was especially noticeable during the COVID-19 pandemic. In this period telepresence applications were of exceptional importance. They supported communications and provided social interactions, enriching our lives during isolation. In this paper, we propose a solution for telepresence using Padbot U1 robot and the MQTT protocol. The idea is to use this solution for virtual tours in museums, art galleries, historical sites, etc. We have developed two different applications. One is a client application used by the visitor, for controlling the robot remotely. The other application is for the mobile device (tablet) attached to the robot, which is used to enable telepresence and to forward control commands to the robot. By scanning the QR codes placed on the objects, visitors can also get specific information about each of objects. Communication between applications (sending commands and receiving information for objects) is realized with the MQTT protocol. For the developed solution, we also conducted experiments to evaluate some basic criteria for VTs.**

***Keywords* – Virtual tour (VT), robot telepresence, MQTT protocol.**

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1. Introduction

In a rapidly changing world, continuous learning is key. The knowledge and skills that we have should be constantly upgraded. Therefore, we must be proactive in seeking opportunities to learn and acquire new skills. This can involve attending workshops, joining professional networks, or traveling to long distant places. Unfortunately, these activities are often time-consuming and expensive. Sometimes, we are prevented from realizing them due to objective reasons or medical restriction (as was case during the COVID-19 pandemic). In this case, virtual tours (VTs) can be used to enable sightseeing - to visit museums, art galleries, historical sites etc. VT provides the possibility of visiting a remote place, almost reaching the feeling of being physically there. Visitors can investigate a realistic digital environment from their laptops or mobile phones, from anywhere in the world.

VT are provided through variety of telepresence systems and technologies. Researchers are using them in various fields [1]: medicine [2], [3], [4], healthcare [5], [6], [7], [8], education [9], [10], [11], [12], [13], rehabilitation [14], [15], entertainment [16], [17] etc. However, there are some essential features that need to be satisfied for using telepresence robots [18].

Regarding the virtual tours, there are also several criteria according to which VTs can be evaluated [19]:

- *Imageability:* This feature is defined as the quality of a physical object that affects the overall view of the observer. According to this, the color, shape, and arrangement of objects are important to obtain structured, vivid, and positive mental images of the environment. This is really important especially for the telepresence VT.
- *Interactivity with the objects:* The general view scalability and the zoom tools are the base of this feature. Interactivity is also important for obtaining more detailed information about them.

- *Navigability:* This feature refers to the implementation of navigation elements in the telepresence application. Applications should offer effective and efficient interactivity to the users.

Spielmann and Mantonakis in [20] show how user-driven interaction in telepresence application can lead to positive attitudes towards the viewed object.

- *Virtual spatiality:* In context of telepresence VT, the spatiality is related to providing enough space to move around and explore the environment.
- *Narration:* This feature is represented by embedding additional audio/video into the VT, in the form of augmented reality, which will provide a more detailed description of the given object.

The use of telepresence robots in VT represents a new way of delivering services and offers a unique user experience. However, the use of robots for VT, in museums and art galleries, is not common. Various researchers are working on this problem.

Germak *et al.* in [21] propose a new robotic solution for cultural heritage. The developed telepresence robot is designed as a tool to explore inaccessible areas in a royal castle. The robot is controlled by museum guides and helps them in their work.

In [22] Pang *et al.* present the idea of using two social robots in a heritage museum for guiding tours and for learning languages and cultures. One of the robots act as a museum guide, while the other is a humanoid robot used for bilingualism.

In [23] Gisela Reyes-Cruz *et al.* present the Augmented Robotic Telepresence (ART) that provides remote access to visitors. The prototype was evaluated in museum settings, and the needs and requirements of the users were identified.

In [24] Burgard *et al.* presents techniques that facilitate mobile robots to be deployed as interactive agents in populated environments, such as museum exhibitions.

In [25] Kabassi *et al.* present exact steps for evaluation of museum virtual tours. In this paper they present the implementation of an evaluation experiment that combines two multi-criteria decision making theories: analytic hierarchy process (AHP) and fuzzy technique for order of preference by similarity to ideal solution (TOPSIS).

In this paper we propose the solution for using a telepresence robot system for virtual tours in museums, art galleries, historical sites, etc. Using the telepresence robot, the visitors will be able to view the exhibits without leaving their home. They can move the robot remotely, using a developed mobile application. Each of the object, in the exhibition, will have a QR code that will contain information about it. By scanning the QR codes, the users will be able to get information about the exhibits.

2. Methodology

The general architecture of our telepresence robot solution is presented in Figure 1.

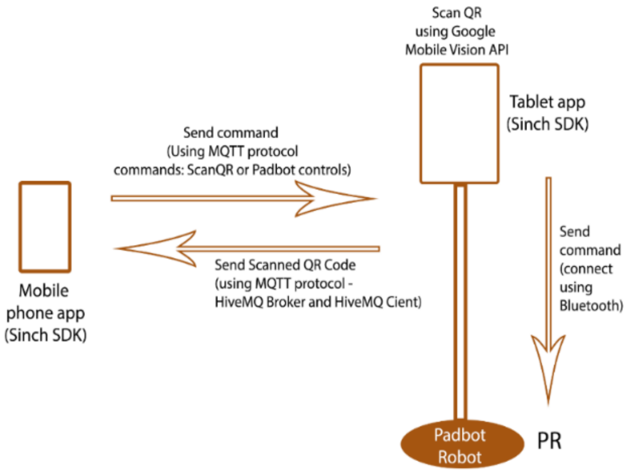

Figure 1. General architecture of the telepresence robot solution

All communication takes place between two separate parties. On one side there is a mobile device (mobile phone), while on the other side the Padbot robot to which a tablet is attached. Following this architecture, we developed two applications for Android operating system: mobile (client) application, and tablet (robot) application. These are two different applications. The mobile application is used for visual presentation of the remote environment, and for sending commands to the tablet application. The commands that are implemented in the mobile application on the client side are:

- *Commands for connecting and disconnecting the robot*
- *Robot movement commands*
- *Command for scanning QR codes*

The developed user interface on the client side supports a live stream of the environment where a robot is located. In this way, the user can explore the remote environment by moving the robot to a specific object of interest. Each of the objects has a QR code which can be scanned to obtain additional information about it. The Padbot robot is connected to the tablet via Bluetooth connection. The commands for connecting, disconnecting, and moving the robot, sent by the mobile application, are forwarded to the robot via the tablet application. By sending a command to scan QR codes, the tablet starts locating and determining the content of the QR code. After this the content is sent to the client application and displayed to the user.

3. Technology Used

The key technologies that we have used are:

- *Sinch SDK1[1] (for real-time video calls) Robot movement commands*
- *Message Queuing Telemetry Transport (MQTT) protocol[2](for sending commands and receiving QR code content)*
- *HiveMQ client[3] and Hive MQ broker[4] (for sending and receiving messages)*
- *Google Mobile Vision API[5] (For QR code scanning)*

For developing the client and robot application we have used Android Studio v.4.0.

MQTT is an application layer protocol in the Internet of Things (IoT) protocol stack [26], [28]. Actually, it is a publish-subscribe protocol (Fig.2), with two types of clients in the communication: publishers and subscribers. The clients do not communicate directly with each other. A central component called broker is used to enable the communication. Publishers send messages on a particular topic to the broker. The broker determines the topic on which the messages were sent, and then forwards the messages to all subscribers who were subscribed to that topic.

In MQTT, the topic is a hierarchically structured UTF-8 string which is used by the broker to forward messages sent by publishers to all subscribed clients. The topic can consist of one or more levels. If the topic is multilevel then each level is separated by a forward slash character. Once the broker receives a given message, it filters the message according to the topic and sends it only to the clients subscribed to that topic. The average latency between sending time and receiving time is below 300ms. This is suitable for real-time applications and is one of the reasons why we have decided to use MQTT protocol in our research.

The Quality of Service (QoS) feature in MQTT is used for reliable message delivery. It is an agreement between the publisher and the subscriber that guarantees the delivery of a given message. MQTT has 3 QoS levels:

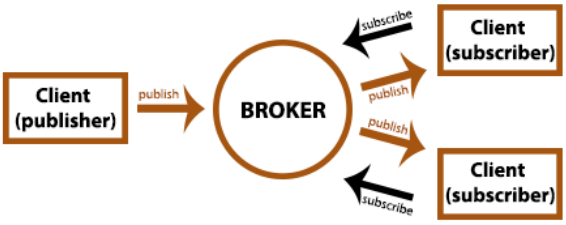

Figure 2. MQTT publish/subscribe model

- QoS 0 – At most once, means that the message could be delivered once or not at all.
- *QoS 1* – At least once, means that the message will be delivered to the receiver at least once.
- *QoS 2* – Exactly once, means that the message will be delivered exactly once.

Two cases of QoS should be considered for message delivery:

- *Message delivery from the publisher to the broker*
- *Message delivery from the broker to the subscriber*

The publisher that sends the message to the broker defines the QoS level of the message. On the other hand, when the broker sends the message to the subscribers, QoS is defined during the subscription. Because MQTT guarantees message delivery, QoS facilitates communication in unreliable networks. According to [27], for wired network, the end-to-end delay for different payloads is below 0.14 sec. For messages smaller than 4000 bytes, the end-to-end delay of QoS 2 level messages is around 0.1 sec, for QoS 1 is around 0.05 sec and for QoS 0 is around 0.03 sec. For messages with greater payloads, these values for the delay are quite higher, but in our case, we do not have very large messages to send. QoS 2 is the most effective, but it has complex 4-way handshake and longer end-to-end delay. QoS 0 does not guarantee that messages will reach the receiving site. For the purposes of our research, we used QoS 1 which has low end-to-end delay while offering a guarantee of message arrival.

Clients must be connected before they can send or receive data. The connection between clients is never direct but is made through a broker (Fig.3).

In order to connect to the broker, the client sends the CONNECT control packet. The broker responds with CONNACK control packet and a status code. The connection is kept until the client sends a DISCONNECT control packet or the connection is terminated unexpectedly.

The PUBLISH control packet is used for sending messages, while the subscription to a certain topic is made with the SUBSCRIBE control packet.

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[1] Sinch SDK, https://developers.sinch.com/

[2] MQTT v.5.0 specification, https://docs.oasis-open.org/mqtt/mqtt/v5.0/mqtt-v5.0.html

[3] HiveMQ client, https://github.com/hivemq/hivemq-mqtt-client

[4] HiveMQ MQTT broker, https://www.hivemq.com/public-mqtt-broker/

[5] Google Mobile Vision – Barcode API overview

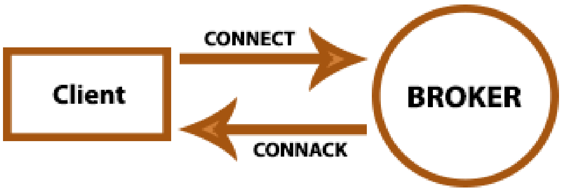

Figure 3. MQTT connection establishment

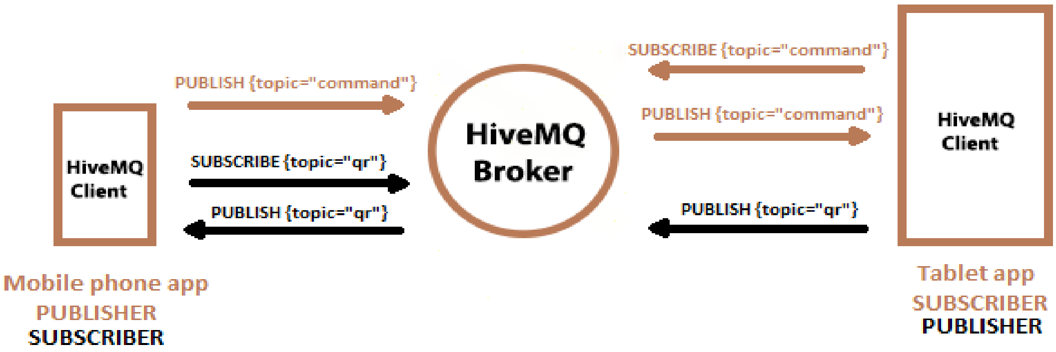

Figure 4. MQTT publish/subscribe model

Figure 4 shows the MQTT communication between the publisher, broker, and subscriber for the proposed solution. Both clients (mobile phone and robot tablet) can act as publisher or subscriber. When we send a command to move the robot, the mobile phone client is the publisher, and the robot tablet is the subscriber. The mobile client application (MA) sends the PUBLISH control packet on a topic and suitable textual command as a payload. The robot tablet application (RA) is subscribed to the same topic. Each time the MA sends a command to the broker, it forwards the message to RA with PUBLISH control packet. According to the payload of the PUBLISH packet, RA sends appropriate command to the robot to execute it.

When we send a command to scan QR code then MA and RA are both publishers and subscribers. In this case, MA first subscribes to a specific topic and RA subscribes to another topic, by sending a SUBSCRIBE packet. When the user wants to scan the QR code of an object, the MA sends a PUBLISH control packet to the RA subscribed topic. The broker forwards the PUBLISH packet to the RA and when RA receives the packet, it runs the activity for QR code scanning. When the scanning process is complete, the result is sent to the broker as a payload of a PUBLISH control packet on a MA subscribed topic. On the MA side, the QR code result is displayed in a pop-up window, displaying information about the scanned object.

We used the Google Mobile Vision Barcode API to implement the QR code scanning functionality.

The Barcode API enables real-time detection of barcodes or QR codes in any orientation.

As a robot telepresence system, we used the Padbot U1[6] robot that has a wheeled motion system and an anti-fall system. The height of the robot is 876mm. It has a stretchable fixture, as a head, that supports 7-inch or 10-inch tablet and it has the ability to tilt and rise. The tablet can be active all the time by charging it via the USB port of the robot. The robot and the tablet are connected with Bluetooth connection. Padbot U1 also has advanced obstacle detection sensors that provide protection against collisions. In this way the robot can move freely. This is especially important for spaces where we have multiple objects that can hinder the movement of the robot. The Padbot U1 robot has also an auto-answer feature that allows it to be activated remotely without the need of direct human interaction.

4. Experiments and Discussion

For experimental validation of our solution, evaluation criteria of virtual tours, described in [19] were used. These criteria include:

- *Imageability* - This criterion is not so much applicable to our solution as it is related to the arrangement of the objects and their appearance in the environment.
- *Interactivity with the objects* - Our solution enables interaction with the objects with help of the QR codes that contain information about the exhibits. The experiment was conducted to examine the relationship between the size of QR codes, and the optimal and maximum scanning distances.

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[6] Padbot U1 robot, https://www.padbot.com/padbotu1

The optimum scanning distance is the distance from which the robot can scan the QR code, while the maximum distance denotes the point beyond which the QR code remains undetectable. We used 7 QR code of different dimension, starting from 2x2cm (as min. used dimension) to 20x20cm (as max. used dimension). The other dimensions were: 35x3.5 cm, 4x4 cm, 7.5x7.5 cm, 13x13 cm. All dimensions were with 25 module per side. The QR codes were positioned at the same height as the robot's mobile device. The experiment was performed in laboratory environment (Fig. 5).

For the experiments, we used Tablet Lenovo Tab E7 TB-7104F with the following features: 7-inch display with resolution of 720 x 1280 pixels, MT8167 4 core 1.3GHz CPU, 1GB RAM, 16GB internal memory, 2MP rear camera, Android 8.1.0 OS.

Figure 5. Performing the experiments in laboratory environment

The correlation between QR codes and measured scanning distance are presented in Figure 6. The experiments were done with two runs of the robot, so the average distance of two runs for different QR code sizes was used. All the QR codes were scanned frontally under the angle of 90 degrees. During the scanning process there were no obstacles along the line of sight nor any obscuration of the QR codes. Entire process was performed in indoor environment, without any natural lightning.

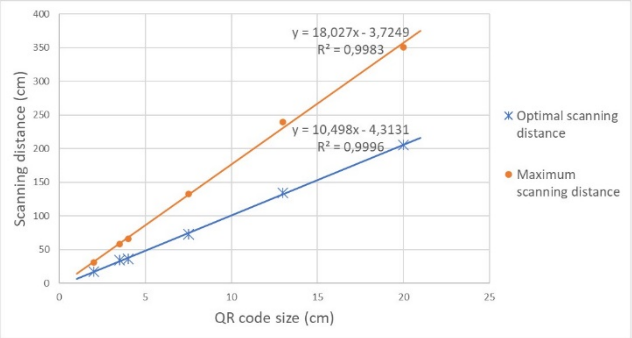

Figure 6. Correlation between QR code size and scanning distance

From the graph it can be observed the linear correlation between QR code size and max. scanning distances, which means the bigger QR code dimension, the greater maximum scanning distance.

In the real-world application scenarios, positioning the robot and scanning the QR code sticked to an object, under the angle of 90 degrees, is not always feasible. The scanning distance also depends on the scanning angle. Therefore, it is important to determine the dependency between the scanning distance and the scanning angle. For this purpose, we have selected a fix-size QR code with dimensions 7.5x7.5cm (since this dimension is most suitable for our application). In Figure 7 the dependency of the scanning distance from the scanning angle, for QR code size 7.5x7.5 cm is shown.

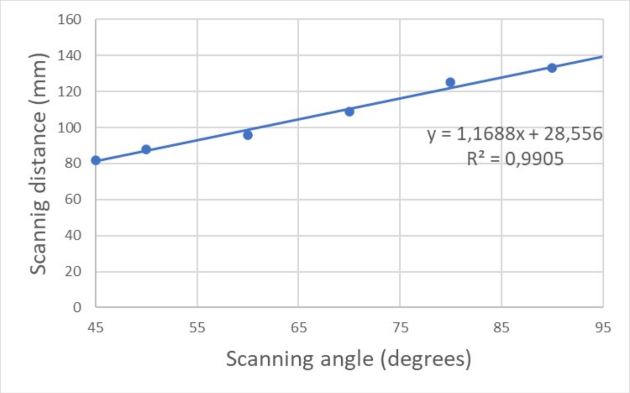

Figure 7. Correlation between scanning distance and the angle of scan

From the graph it can be observed that changing the angle of capture causes an almost linear decrease in distance. At an angle of 45 degrees, the QR code can be scanned from a distance of 80cm, which is acceptable in our situation. Angles below 45 degrees are practically unusable.

- *Navigability* - Our solution has navigation elements that are used to control the robot by sending commands.

As can be seen in Figure 8, the navigation elements are located at the bottom of the screen in the form of a circle with several bars and can be used to move the robot in all directions. In addition to that, the user can look in arbitrary directions by controlling the pan-tilt unit of the robot. Last but not least, the user can request the robot to move around an exhibit in order to view it from all possible directions.

- *Virtual spatiality* – This criterion refers to the provision of enough space for moving the robot in the environment in which it is located. The museum environment is highly dynamic and crowded with people who are constantly moving from one exhibit to another. Having in mind that there are valuable exhibits in the museum, the robot needs to move very precisely through the environment. However, the robot's dimensions (heigh:876mm, width:266mm, depth:372mm) together with the wheeled motion system, anti-fall, and obstacle detection system, allow smooth movement even in crowded and complex environments.

Figure 8. A view of the client application and navigation elements

- *Narration* - This criterion is still not met, but in the next period we plan to add audio files to the application that will enable narration for some important objects in the environment.

5. Conclusion

Robotic solutions offer new opportunities for interactive telepresence to visitors, when time, money, and geography are obstacles. VTs supported by telepresence robots, allow users to take tours in remote environments, and to be "present" on distant places, without traveling and leaving their home.

One such telepresence solution using the Padbot U1 robot is presented in this paper. We developed two separate applications for the mobile client and for the robot. The applications enable live streaming, sending and receiving commands to move the robot and scanning QR codes. In the next period, we will work on enriching the functionality and the content of the applications. We plan to use emerging technologies, such as virtual and augmented reality, in order to provide a more immersive and engaging experience.

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