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# Performance and Usability Evaluation of an Extended Reality Platform to Monitor Patient's Health During Surgical Procedures

Pasquale Arpaia<sup>1,2</sup> <sup>\*</sup>, Egidio De Benedetto<sup>1,2</sup> , Lucio De Paolis<sup>3</sup> , Giovanni D'Errico<sup>4</sup> , Nicola Donato<sup>5</sup> , and Luigi Duraccio<sup>6</sup> 

- <sup>1</sup> University of Naples Federico II - Interdepartmental Research Center in Health Management and Innovation in Healthcare (CIRMIS), Naples, Italy; pasquale.arpaia@unina.it  
<sup>2</sup> University of Naples Federico II - Department of Information Technology and Electrical Engineering - Augmented Reality for Health Monitoring Laboratory (ARHeMLAB), Naples, Italy  
<sup>3</sup> University of Salento - Department of Engineering for Innovation, Lecce, Italy  
<sup>4</sup> Polytechnic University of Turin - Department of Applied Science and Technology, Turin, Italy  
<sup>5</sup> University of Messina - Department of Engineering, Messina, Italy  
<sup>6</sup> Polytechnic University of Turin - Department of Electronics and Telecommunications, Turin, Italy  
<sup>\*</sup> Correspondence: pasquale.arpaia@unina.it

**Abstract:** An extended-reality (XR) platform for real-time monitoring of patients' health during surgical procedures is proposed. The proposed system provides real-time access to a comprehensive set of patients' information, which are made promptly available to the surgical team in the Operating Room (OR). In particular, the XR platform supports the medical staff by automatically acquiring the patient's vitals from the operating room instrumentation, and displaying them in real time directly on a XR headset. Furthermore, information regarding the patient clinical record are also shown on request. Finally, the XR-based monitoring platform also allows to display in XR the video streaming coming directly from the endoscope. The innovative aspect of the proposed XR-based monitoring platform lies in the comprehensiveness of the available information, in its modularity and flexibility (in terms of adaption to different sources of data), ease of use and, most importantly, in a reliable communication, which are critical requirements for the healthcare field. To validate the proposed system, experimental tests were conducted using instrumentation typically available in the operating room (i.e., a respiratory ventilator, a patient monitor for intensive care, and an endoscope). The overall results showed (i) an accuracy of the data communication greater than 99 %, along with (ii) an average time response below the ms, and (iii) satisfying feedback from the SUS questionnaires filled by the physicians after an intensive use.

**Keywords:** Augmented Reality, Extended Reality, Healthcare, Hololens 2, Surgery, Real-time Monitoring, Health 4.0, Medical equipment, Remote monitoring, uncertainty, XR

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## 1. Introduction

The *Fourth Industrial Revolution* has brought several benefits to different application fields, including healthcare [1]. In fact, 4.0 technologies are pervading the medical sector, such as internet of things (IoT) [2–4], artificial intelligence [5], machine and deep learning [6–8], cloud computing [9], additive manufacturing [10–12], wearable sensors [13–16], and augmented and virtual realities (AR and VR) [17–19].

With regard to AR and VR, these two technologies are often referred to with an umbrella term, namely *Extended Reality* (XR) [20], which encompasses the entire reality–virtuality continuum and, therefore, all possible variations and compositions of real and virtual objects. In particular, relevant uses of XR in healthcare can be found in medical training [21] and surgical procedures [22–27]. An important application of XR in surgery is the overlay of digital medical images on the patients while the surgical procedure is being carried out [28]. Instead, in [29], a patient-specific hybrid simulator for orthopaedic open surgery was presented, focusing on the details for the

33 implementation of wearable XR functionalities using Microsoft HoloLens, which has  
34 become the most successful commercial OST-HMD thanks to its advantages in contrast  
35 perception and computational effort [30]. More recently, its upgraded version (Microsoft  
36 HoloLens 2) was used to assist surgeons in completing distal interlocking [30]. Several  
37 benefits, including no radiation exposure, stereoscopic in-situ visualizations, and less  
38 time consumption, were achieved with respect to conventional approaches.

39 Another important application of XR is the real-time monitoring of patient's health  
40 in the operating room (OR). Patient's vitals, along with additional information on the  
41 electronic clinical medical records, may be displayed directly on wearable XR headset  
42 worn by the operators. The key idea is to use XR technology to allow the surgical team  
43 to effectively monitor the patient's health status in real time, even at a distance from the  
44 electromedical equipment. This aims to improve the efficiency of procedures by easing  
45 the burden of constantly looking at OR equipment; in this way, the surgical team can  
46 focus its attention on the patient and the task at hand, being ready to promptly act in  
47 case of aggravating conditions [31–35]. In [31], for example, the number of times the  
48 anesthetist had to shift attention from the patient to the equipment was investigated.  
49 As a result, a significant decrease of more than a third through an XR head-mounted  
50 display (HMD) was observed.

51 Nevertheless, at the state of the art, only the usability of such systems has been ex-  
52 plored, without an assessment of their performance. The need of a usability assessment  
53 was claimed in [36], when a systematic review of 10 years of AR usability studies was  
54 provided. With regards to healthcare, it emerged that most of the medical-related AR  
55 papers were published in medical journals, and scarce qualitative data were captured  
56 from users regarding how they felt after using the system. More recently, in [37], the  
57 usability and ergonomics of Microsoft HoloLens and Meta 2 AR devices for applications  
58 in visceral surgery was investigated by using the System Usability Scale (SUS) question-  
59 naire [38], a method successfully used for AR-based application in Education [39] and  
60 Industry 4.0 [40].

61 The aforementioned works, however, are strictly limited to the usability assessment. On  
62 the other hand, also the need of a performance assessment of the real-time monitoring  
63 system of patient's undergoing surgical procedures is evident, since it is of the utmost  
64 importance to guarantee that the information is transmitted correctly and timely dis-  
65 played in XR. For example, in [41,42] the key requirements regarding real-time wireless  
66 data transmission were explored, such as the transmission bandwidth, the number of  
67 interruptions per time unit, the mean duration of the stops, the monitoring delay, the  
68 energy efficiency, and the reliability. In particular, it appears that any video/audio  
69 delay greater than 300 ms should be avoided, to ensure proper interaction between the  
70 user and the system. Furthermore, fault tolerance techniques are generally included  
71 in the network to avoid network failures (which can range from small outages to large  
72 life-threatening scenarios).

73 Based on these considerations, in this work, an integrated monitoring platform  
74 that employs XR to assist the medical staff during surgical procedures is presented. The  
75 proposed system employs different functionalities (selectable by the intended user) to  
76 support the surgeon, the assistant surgeons, nurses and anaesthetists by displaying in  
77 real-time a comprehensive set of information regarding the patient's health status. The  
78 chosen XR headset (Microsoft HoloLens 2) receives the data from the electromedical  
79 instruments available in the OR (e.g., respiratory ventilator, patient monitor, laparoscopic  
80 camera) and displays them in real time [43]. Additionally, the information regarding  
81 the patient electronic clinical records are also made available upon operator's request.  
82 Finally, also the video streaming from the laparoscopic camera can be rendered through  
83 the platform. It should be mentioned that, in spite of the high cost of the Microsoft  
84 HoloLens 2 (approximately 3500 \$), its unique specifications currently makes it the most  
85 suitable device to be used to satisfy the healthcare requirements. The innovative aspect  
86 of the proposed monitoring platform lies in the comprehensiveness of the available

87 information, in its modularity and flexibility (in terms of adaption to different sources of  
 88 data), ease of use and, most importantly, a reliable communication, which are critical  
 89 requirements for healthcare field; to this aim, an evaluation of the system performance  
 90 in terms of data transmission, and overall usability (by means of a SUS questionnaire),  
 91 is addressed. While the obtained results in terms of data transmission outcomes and  
 92 performance are crucial for medical applications, they can be readily applied also to  
 93 other contexts such as for industrial or civil applications.

94 The paper is organized as follows. In Section 2, the concept design of the platform is  
 95 presented, along with the general architecture, and the communication with the adopted  
 96 hardware. Section 3 describes the operation of the monitoring platform. Section 4  
 97 summarizes the experimental tests of carried out at the University Hospital Federico II  
 98 (Naples, Italy). Finally, in Section 5, conclusions are drawn.

## 99 2. Materials and Methods

100 This section addresses the design and the implementation of the proposed XR-based  
 101 monitoring platform. Particular attention was dedicated to the conceptual design of  
 102 the integrated system in order to ensure modularity and flexibility (i.e., capability of  
 103 connecting different medical equipment and of receiving data from different sources).

### 104 2.1. Design of the Monitoring Platform

105 The designed platform is conceived to help nurses, anesthetists, and/or surgeons  
 106 to monitor the patients' health status by simply wearing an XR headset. In this way, they  
 107 do not have to turn to the monitoring equipment, thus being ready to promptly act in  
 108 case of aggravating conditions for the patients. Figure 1 shows the different blocks of  
 the integrated XR monitoring platform.

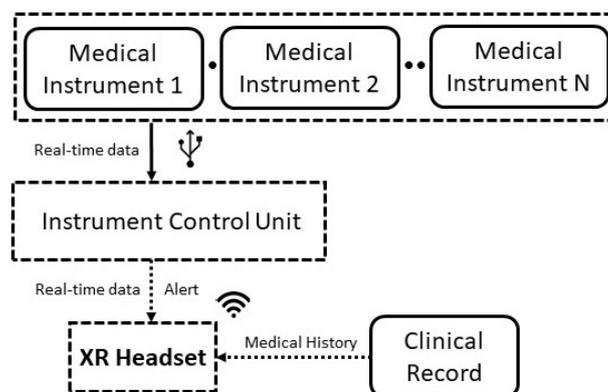


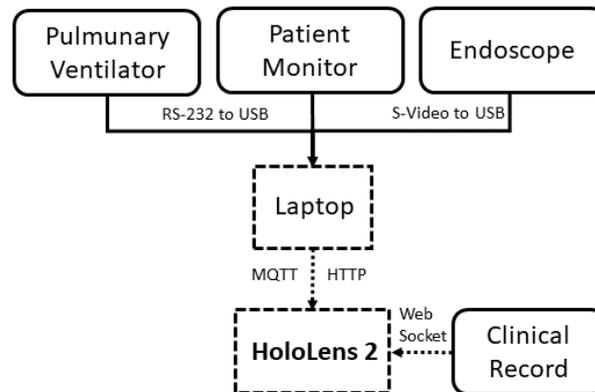
Figure 1. Conceptual architecture of the proposed XR-based monitoring platform.

109 Basically, a set of *Medical Instruments* are connected via cable to an *Instrument*  
 110 *Control Unit (ICU)*, which sends in real time the data to the *XR Headset* worn by the user,  
 111 providing, at the same time, an alert if the acquired parameters (e.g., patient's vitals)  
 112 exceed the standard values. Additionally, the *XR Headset* receives also information  
 113 about the *Clinical Record* of the selected patient, in order to obtain a comprehensive set of  
 114 information of his/her health on request. The design choices were made to adhere to the  
 115 stringent requirements of the healthcare sector, especially in terms of communication  
 116 latency between the generation and visualization of the patient's data.  
 117

### 118 2.2. Hardware

119 Figure 2 shows the block diagram of the hardware and communication modalities  
 120 used to implement the proposed monitoring platform. As a case study, the considered  
 121 medical equipment includes instrumentation typically available in operating room,  
 122 such as (i) a pulmonary ventilator, (ii) a patient monitor, and (iii) an endoscope for

123 laparoscopic surgery. A Laptop acts as an ICU and acquires in real time the data from  
 124 the instrumentation. Finally, it sends them to the XR Headset, which, in turn, receives  
 125 information on the patient from the electronic clinical record. A detailed description is  
 126 provided in the following.



**Figure 2.** Implementation of the proposed XR-based monitoring platform.

### 127 2.2.1. Operating Room Equipment

128 The OR equipment used in this work includes (i) a pulmonary ventilator, (ii) a  
 129 patient monitor, and (iii) an endoscope, as shown in Figure 3.

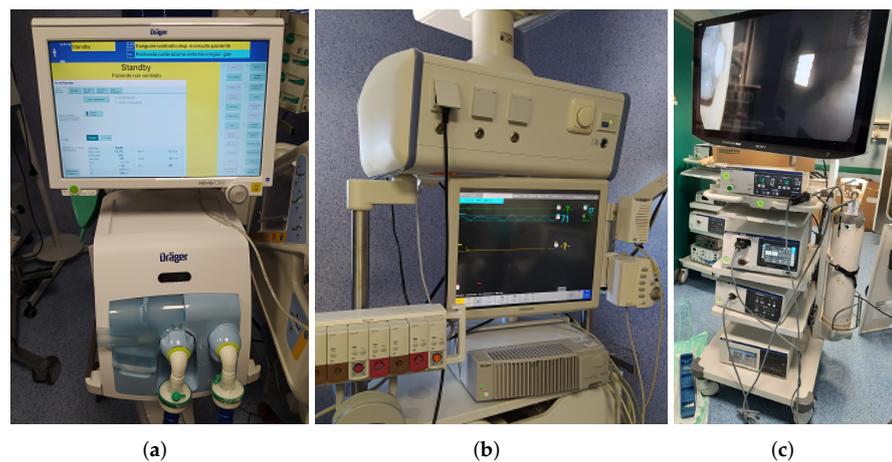
- 130 • *Pulmonary ventilator:* The adopted ventilator is the *Dräger Infinity V500*. It is used  
 131 for intensive care and to help lungs to administer an adequate amount of O<sub>2</sub> to the  
 132 patient, to eliminate the produced CO<sub>2</sub>, and to reduce the respiratory effort of a  
 133 patient due to excessive work of the lungs. The Infinity V500 ventilator is equipped  
 134 with a LAN (Local Area Network) interface, and with three RS-232 interfaces, with  
 135 the possibility to choose between MEDIBUS or MEDIBUSX protocol. Baud Rate,  
 136 Parity Bits, Stop Bits, and Terminator Character can be set by the user.
- 137 • *Patient monitor:* The *Philips IntelliVue MP90* patient monitor was adopted. It allows  
 138 to monitor more than 50 different vitals, such as oxygen saturation, compound ECG,  
 139 respiration rate, heart rate, after connecting separate ‘plug-and-play’ modules.
- 140 • *Endoscope:* The endoscope used was the *Olympus Visera Elite II*. It is an imaging  
 141 platform for general surgery, urology, gynecology, and more. It is equipped with an  
 142 S-video interface which provides the access to the camera.

### 143 2.2.2. XR Headset

144 As mentioned in Section 1, *Microsoft HoloLens 2* was used as an XR headset. This is  
 145 an OST device running *Windows 10 Holographic* and equipped with four light cameras,  
 146 two infrared cameras, depth sensor, an *Inertial Measurement Unit (IMU)*, and a 8 MP  
 147 camera. The user can interact with this device in different ways: hand gestures, eye  
 148 tracking, head tracking, and voice commands. One of the most important additional  
 149 features with respect to the previous version (HoloLens 1) is that the diagonal field of  
 150 view (FOV) is increased up to 52°. Finally, the display resolution is 2048 × 1080 pixels.  
 151 In spite of the relatively high cost of this headset, its hardware and interaction modes  
 152 make it the optimal solution to meet the stringent healthcare requirements, in terms of  
 153 communication latency and usability.

### 154 2.2.3. Laptop

155 The employed *Operating room equipment* did not have any stringent requirements to  
 156 handle the communication protocols with the Instrument Control Unit; hence, a laptop  
 157 equipped with an Intel i7-10750H processor, 16 GB RAM, Windows 10, and 3 USB 3.1



**Figure 3.** Electromedical devices used: (a) pulmonary ventilator; (b) patient monitor; (c) endoscope.

158 ports was chosen. It is connected to the pulmonary ventilator by means of an RS-232 to  
159 USB adapter. Instead, the connection with the patient monitor is established through (i)  
160 a *Medicollector* adapter, which is a particular LAN to RS-232 adapter, and (ii) a second  
161 RS-232 to USB adapter. Finally, the interfacing with the endoscope is realized by means  
162 of an S-Video to USB adapter.

### 163 2.3. Software

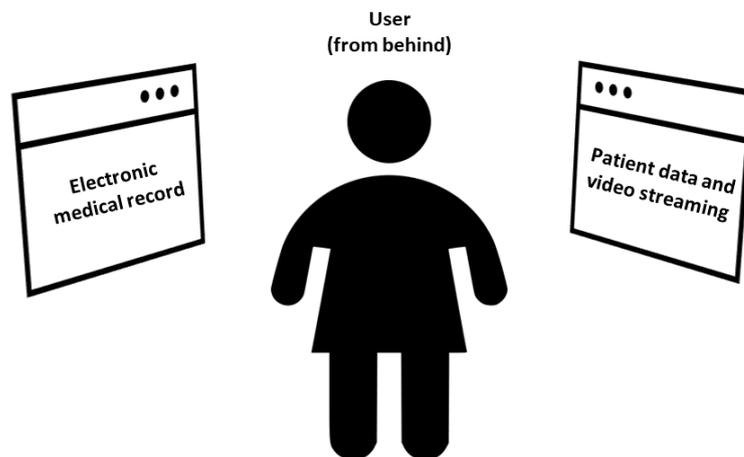
164 The XR software was developed in *Unity 3D* by using the *Windows Mixed Reality*  
165 *Toolkit (MRTK)*. A navigation menu was implemented to let the user have access in  
166 real-time to (i) the electronic clinical record, and (ii) a comprehensive set of data coming  
167 from the medical equipment. Three modalities of interaction were foreseen to select the  
168 data of interest: (i) hands gestures, (ii) vocal commands, and (iii) gaze pointing. At the  
169 start of the application, the OR operator was asked to select the patient among those  
170 available. The list of patients is updated by a *WebSocket* server, which sends it to the  
171 HoloLens on request. The XR content is provided by means of the navigation menu.

#### 172 2.3.1. Navigation Menu

173 The navigation menu was developed to guarantee that each window was at the  
174 same distance from the user (approximately 1 m), as shown in Fig. 4. This also allows  
175 avoiding sickness effects during the fruition of the XR Application. It consists of two  
176 main sections:

- 177 • Electronic Medical Record, placed originally on the left side of the menu (90°  
178 rotation of the head to the left).
- 179 • Data and video streaming from the medical equipment, placed originally on the  
180 right side of the menu (90° rotation of the head to the right).

181 Therefore, the view in front of the user is originally clear. However, the user can move  
182 and rotate the XR content through vocal commands, in order to show it frontally.



**Figure 4.** Concept of the implemented navigation menu.

### 183 2.3.2. Display of Clinical Record

184 The section dedicated to the display of data coming from the electronic clinical  
 185 record of the selected patient is divided into four categories: (i) Anamnesis, (ii) Diagnostic  
 186 Tests, (iii) Blood Tests, and (iv) Clinical Diary. These data are sent to the HoloLens by  
 187 means of *WebSocket* protocol. In particular, the *WebSocket* Server provides a database  
 188 of web pages for each patient. It is possible to access to these web pages by means of  
 189 HTTP links and a web browser. By default, Unity 3D does not foresee a browser service  
 190 to display web-pages in an XR environment. To this aim, the *PowerUi* asset was installed.  
 191 The user can select which category to monitor by means of hand gestures or gaze pointer.

### 192 2.3.3. Interfacing With Medical Equipment: for vitals signs and video streaming

193 With regards to the real-time interfacing with the medical equipment, HoloLens  
 194 receives via *Wi-Fi* the data coming from the Laptop, which, in turn, is in charge of  
 195 collecting the data from the instruments connected via cable. In particular, the Laptop  
 196 receives via *UART* (i) the data coming from the pulmonary ventilator, adopting the  
 197 *MEDIBUS* protocol, and (ii) the video streaming coming from the endoscope. Instead,  
 198 the communication between the Laptop and the patient monitor was implemented by  
 199 means of *TCP/IP* protocol via *Medicollector* adapter. Finally, these data are sent to the  
 200 HoloLens via *MQTT* (vitals) and *HTTP* (video streaming), which displays it in real  
 201 time. In this way, the OR operator can evaluate in real time if the surgical procedure in  
 202 progress is being correctly performed. Further details about the interfacing are provided  
 203 below:

- 204 • *Acquisition from the ventilator*: a code running in *MATLAB* environment implemented  
 205 the *MEDIBUS* protocol. This software protocol is intended to be used for exchanging  
 206 data between a *Dräger* medical device and external devices via *RS-232* interface.  
 207 After the initialization of the protocol, the code asks and decodes the vitals to be  
 208 acquired. Finally, it sends them to the HoloLens via *MQTT* protocol.
- 209 • *Acquisition from the patient monitor*: the code related to the data acquisition from  
 210 the patient monitor was integrated with the *MATLAB* script implemented for  
 211 the communication with the ventilator. This code is in charge of retrieving the  
 212 waveforms from the monitor via *TCP/IP* through the *Medicollector* adapter. After  
 213 acquiring the waveforms, the code sends them to the HoloLens via *MQTT* protocol.  
 214 The user can select the waveform to display by hand gestures or gaze pointer.
- 215 • *Acquisition from the endoscope*: a script running in *Python 2.7* was developed to  
 216 acquire the video streaming from the endoscope using the *Imutils.video* library.  
 217 Successively, the data are sent in real time to the HoloLens via *HTTP* protocol.

218 It was chosen to adopt HTTP protocol for the transmission of the video streaming from  
 219 the endoscope to the HoloLens because HoloLens offers native video support via the  
 220 *Media Foundation* engine, which made it easy to use HTTP as a protocol for adaptive  
 221 multimedia content streaming. Therefore, the *UnityWebRequest* class was used on the  
 222 Unity 3D side for composing and handling HTTP requests. Instead, MQTT was adopted  
 223 for the patients' vitals transmission since it is a commonly used TCP-based messaging  
 224 protocol for device-to-device communication, because it is lightweight (polling-free  
 225 compared to RESTful over HTTP), scalable, and efficient with low-performance devices  
 226 (like low-power HMDs). The data exchanged was formatted in *JavaScript Object Notation*  
 227 (JSON), a text-based format for exchanging data. On the Unity side, the *M2Mqtt* library  
 228 from the *M2MqttUnity* asset was used to implement an MQTT client on HoloLens.

### 229 3. Operation of the XR Monitoring Platform

230 Figure 5 shows the block diagram of the user's operation while employing the XR  
 231 platform.

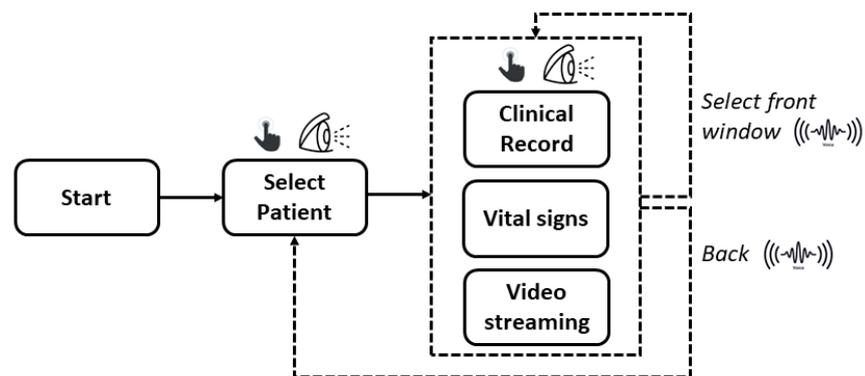


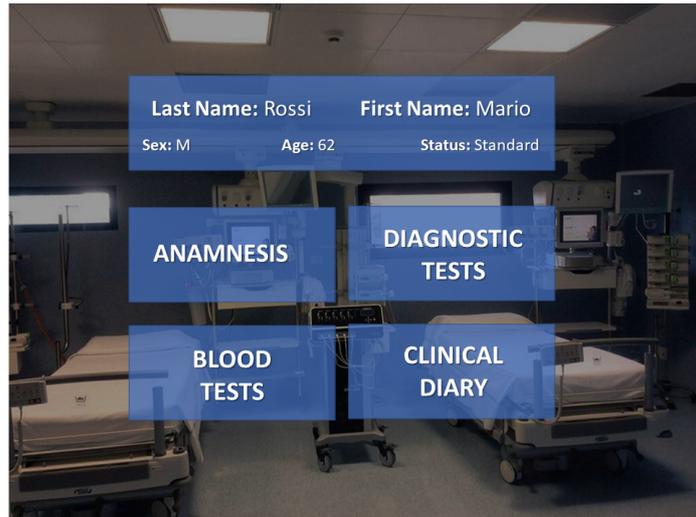
Figure 5. Block diagram of the user's operation during the fruition of the XR platform.

232 After the user wears HoloLens 2 and starts the application, first, he/she has to select  
 233 which *patient* to monitor. This selection can be performed by means of the gaze pointer  
 234 or the hand gestures, alternatively. Therefore, the XR content appears as mentioned in  
 235 Section 2.3.1. In particular, three *windows* are available:

- 236 1. *Clinical record* of the selected patient, placed originally at the left side of the naviga-  
 237 tion menu (90° rotation of the head to the left).
- 238 2. *Vital signs*.
- 239 3. *Video streaming*, placed at the right side (90° rotation of the head to the right).

240 When the application is started, the frontal view is clear. The user can turn his/her  
 241 head sideways to see the desired XR holographic content; hence, the user can select the  
 242 information of interest by using the gaze pointer or the hand gestures. Alternatively,  
 243 the user can also decide which window to show frontally by means of vocal commands.  
 244 Finally, if he/she decides to stop the monitoring, it is possible to go back to the selection  
 245 of the next patient by vocal commands.

246 For the sake of example, Figure 6 shows a snapshot of what the user sees on the  
 247 *Clinical Record* menu.



**Figure 6.** Snapshot of the electronic clinical record window.

248 On the other hand, Figure 7 shows a snapshot of the user view when he/she selects  
 249 the *Vital Signs* category to monitor the patient's vitals. In this case, the set of waveform  
 250 coming from the monitor are: Heart Rate, Respiration Rate, ECG, and O<sub>2</sub> Saturation. On  
 251 the other hand, the monitored parameters from the ventilator are: Minimum, Mean, and  
 252 Peak Airway Pressure, Minute Volume, and Compliance.



**Figure 7.** Snapshot of the vitals monitored in real-time.

#### 253 4. Experimental Results

254 After the validation of the correct functioning of the XR platform, experiments were  
 255 carried out to address: (i) the real-time communication with the medical equipment,  
 256 and (ii) the usability of the application running on the XR headset. To this aim, two  
 257 experimental sessions were carried out, each consisting of  $N = 5$  measurement runs. A  
 258 non-self-inflating bag was plugged to the pulmonary ventilator to emulate the patient's  
 259 lungs. As for the patient monitor, it was used to monitor the vitals of a healthy volunteer.

##### 260 4.1. Performance of the real-time communication

261 With regard to the assessment of the communication with the medical equipment,  
 262 it is necessary to evaluate if the proposed integrated platform suits the stringent criteria  
 263 of healthcare field. Two figures of merit were considered: communication accuracy and  
 264 time response.

The communication accuracy is defined as the percentage of packets correctly decoded by the Instrument Control Unit. The measurement of the communication accuracy  $A$  was carried out for each run according to the following equation:

$$A = \frac{L - E}{L} \cdot 100 \quad (1)$$

Where  $L$  is the number of packets sent within a run, and  $E$  is the number of errors occurred. Then, for each session, the accuracy mean value  $\mu_A$  and the standard deviation  $\sigma_A$  were assessed. Hence, the 3-sigma type A uncertainty  $u_A$  was evaluated considering the total number of runs  $N$ , according to the following equation:

$$u_A = \frac{k \cdot \sigma_A}{\sqrt{N}} \quad (2)$$

265 with  $k = 3$ , corresponding to a 99.7 % confidence under the assumption of normal  
266 distribution.

Time response  $T$  is defined as the time interval needed by the Instrument Control Unit to send the data to the XR headset. For each run, the mean value  $\mu_{Ti}$  and the standard deviation  $\sigma_{Ti}$  among all the packets sent were evaluated. At the end of the session, the assessment of the weighted mean  $\bar{\mu}_T$  was carried out, taking into account the different number of packets  $L_i$  sent for each of the  $N$  runs, as expressed in (3).

$$\bar{\mu}_T = \frac{\sum_{i=1}^N \mu_{Ti} \cdot L_i}{\sum_{i=1}^N L_i} \quad (3)$$

With regards to the uncertainty, the 3-sigma uncertainty  $u_T$  was carried out according to the law of propagation of uncertainties, expressed in (4).

$$u_T = k \cdot \sqrt{\sum_{i=1}^N \left( \frac{\partial \bar{\mu}_T}{\partial \mu_{Ti}} \cdot u_{Ti} \right)^2} \quad (4)$$

267 Where  $u_{Ti}$  is the standard uncertainty of the time response evaluated for each run. Again,  
268  $k = 3$  corresponds to a 99.7 % confidence under the assumption of normal distribution of  
269 the data. Table 1 summarizes the details of the two experimental sessions. As visible, the  
270 measured time response was below the ms, while the communication accuracy assessed  
271 was greater than 99 %. These obtained values are compatible with the specification of  
272 healthcare field.

Table 1: Details of the two experimental sessions.

First experimental session				Second experimental session			
L	$\mu_T$ (s)	$\sigma_T$ (s)	A (%)	L	$\mu_T$ (s)	$\sigma_T$ (s)	A (%)
117	$9 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	99.2	111	$9 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	99.4
122	$9 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	99.7	102	$8 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	100.0
118	$8 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	98.9	113	$17 \cdot 10^{-4}$	$6 \cdot 10^{-4}$	98.7
118	$9 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	98.9	35	$7 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	99.1
41	$8 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	99.0	117	$9 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	99.2
<b>Total</b>	$\bar{\mu}_T$	$u_T$	$\mu_A \pm u_A$	<b>Total</b>	$\bar{\mu}_T$	$u_T$	$\mu_A \pm u_A$
514	$9 \cdot 10^{-4}$	$3 \cdot 10^{-5}$	$99.1 \pm 0.4$	478	$11 \cdot 10^{-4}$	$6 \cdot 10^{-5}$	$99.3 \pm 0.6$

#### 273 4.2. System Usability

274 Another important aspect that was considered is the usability of the XR platform. To  
275 this aim, all the OR operators were asked to provide feedback after an intensive use of the  
276 application during the experimental trials. A modified version of the SUS questionnaire

277 was employed as shown in Table 2. The obtained results were re-scaled to 0-100 range.  
 278 Overall, the employed XR platform showed satisfying ergonomics (even with users  
 279 with glasses and/or long hair), no motion sickness effects during the fruition of the  
 280 application and, most importantly, ease of use. In particular, the multiple choice of data  
 281 selection (vocal commands, gestures, gaze pointers) was particularly appreciated, thus  
 282 also confirming the suitability of the Microsoft HoloLens 2 headset for the considered  
 283 platform.

Table 2: Adopted SUS questionnaire

N.	Question	Score				
		1	2	3	4	5
1	I think that I would like to use this system frequently	1	2	3	4	5
2	I found the system unnecessarily complex	1	2	3	4	5
3	I thought the system was easy to use	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5	I think the various functions in this system were well-integrated	1	2	3	4	5
6	I thought there was too much inconsistency in this system	1	2	3	4	5
7	I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8	I found the system very cumbersome to the user	1	2	3	4	5
9	I felt very confident using the system	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this system	1	2	3	4	5
11	I found the multiple choice of data selection easy to use	1	2	3	4	5
12	I felt motion sickness effects after an intensive use of the system	1	2	3	4	5

## 284 5. Conclusions

285 An integrated platform based on XR is proposed for the real-time monitoring of  
 286 the patient's health during surgical procedures. This platform focused on a practical  
 287 use-case for members of the surgical team in the OR. Nurses, anesthetists or surgeons  
 288 can wear an XR headset, which displays in real-time a comprehensive set of information,  
 289 such as (i) the patient electronic clinical record, (ii) the vitals acquired from a pulmonary  
 290 ventilator and a monitor for intensive care, and (iii) the video streaming coming from a  
 291 laparoscopic camera. This monitoring platform makes the fruition of data easier and  
 292 timely available for the user. The proposed XR platform was developed to meet the  
 293 stringent healthcare requirements, especially in terms of communication accuracy and  
 294 time response. In fact, the obtained experimental results showed that the measured  
 295 communication accuracy was higher than 97%, with a corresponding time response in  
 296 the order of milliseconds. These values fully satisfies the aforementioned requirements  
 297 of the healthcare sector. Also the usability tests through SUS questionnaires confirmed  
 298 the suitability of the proposed XR monitoring platform for prolonged use. In conclusion,  
 299 the proposed XR integrated platform has demonstrated to represent a suitable support  
 300 for OR operators in monitoring the patients' health during delicate surgical procedures.

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303 ; investigation, E.D.B., L.D.; data-curation G.D., L.D.; writing—original draft preparation, L.D.;  
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