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Benchmarking of a Proposed Augmented-Reality System Architecture

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1-INTRODUCTION

The last decade has seen an increased adoption of robotic-assisted procedures in orthopaedic surgeries due to reduced rates of undesirable phenomena including implant revision and aseptic loosening[1]. Systems such as the NAVIO™ (Smith & Nephew) have illustrated significantly improved operating performance, reducing angular error from (4.1°-6.3°) to (1.7-2.5°) by introducing robotic-assistance[2].

An important component of surgical robotics is the delivery-mechanism for visual feedback, or surgical workflow. The advent of head-mounted devices and augmented reality (AR) within surgery has allowed for continual innovation of the delivery of visual feedback. As described by Sielhorst et al[3], utilising a 'virtual-display' provides multiple benefits in operating-theatres including reduced setup times due to an increased level of control over information, as well as eliminating the need for operating physical displays.

A key milestone of moving towards a more mixed-reality experience in theatres is the back-end infrastructure tasked with interfacing surgical robotics with head-mounted displays. Thus, this project sought to create a system architecture capable of communicating data between a server PC and a HoloLens™ allowing for transmission of data associated with surgical navigation and optical-tracking such as medical-images and coordinate-transformation matrices. A crucial aspect of such an architecture is its latency, as in order to better bridge the human-machine interface, it should aim to be as close to 'real-time' as possible. Several definitions of this parameter exist, however, from examining literature detailing real-time communication in an augmented-reality environment, it was determined that a system frequency between 10-30 Hz was desirable[4].

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The remainder of the paper is structured as follows; Section 2 introduces the proposed system framework and its mechanisms of operation. Section 3 presents a benchmark test carried out on the system, with the results and discussion of this test included in Section 4. Finally, Section 5 concludes the paper and explores potential future areas of work.

2-PROPOSED SYSTEM-FRAMEWORK

A system architecture was constructed following the real-time criteria outlined in Section 1, composed of a client-HoloLens communicating wirelessly via Wi-Fi protocols with a server-PC as shown in Figure 1a, with a potential virtual-workflow shown in Figure 1b.

User-Datagram Protocol (UDP) was chosen as the communication protocol to maximise streamlining of the communication framework. This was due to its low latency in communication in comparison to another commonly used protocol, Transmission-Control Protocol (TCP), which requires a ‘two-way handshake’[5], capable of slowing down communication. Whilst UDP is more vulnerable to artefacts such as packet-loss, the targeted refresh rate (>10Hz) meant that speed was the priority, and the system design was additionally optimised to minimise impact of individual packet losses.

On the server, a program written in C# formatted data into data-packets to be sent to the HoloLens™ via a UDP port. Literature indicated a packet size of 4KB[6] was optimal to balance the effects of potential packet-loss with acceptable transmission speeds. On the client-HoloLens, an app was coded in C# and deployed via Unity (Unity Technologies, USA), which received and reassembled packets of data transmitted to a UDP port on the HoloLens™.

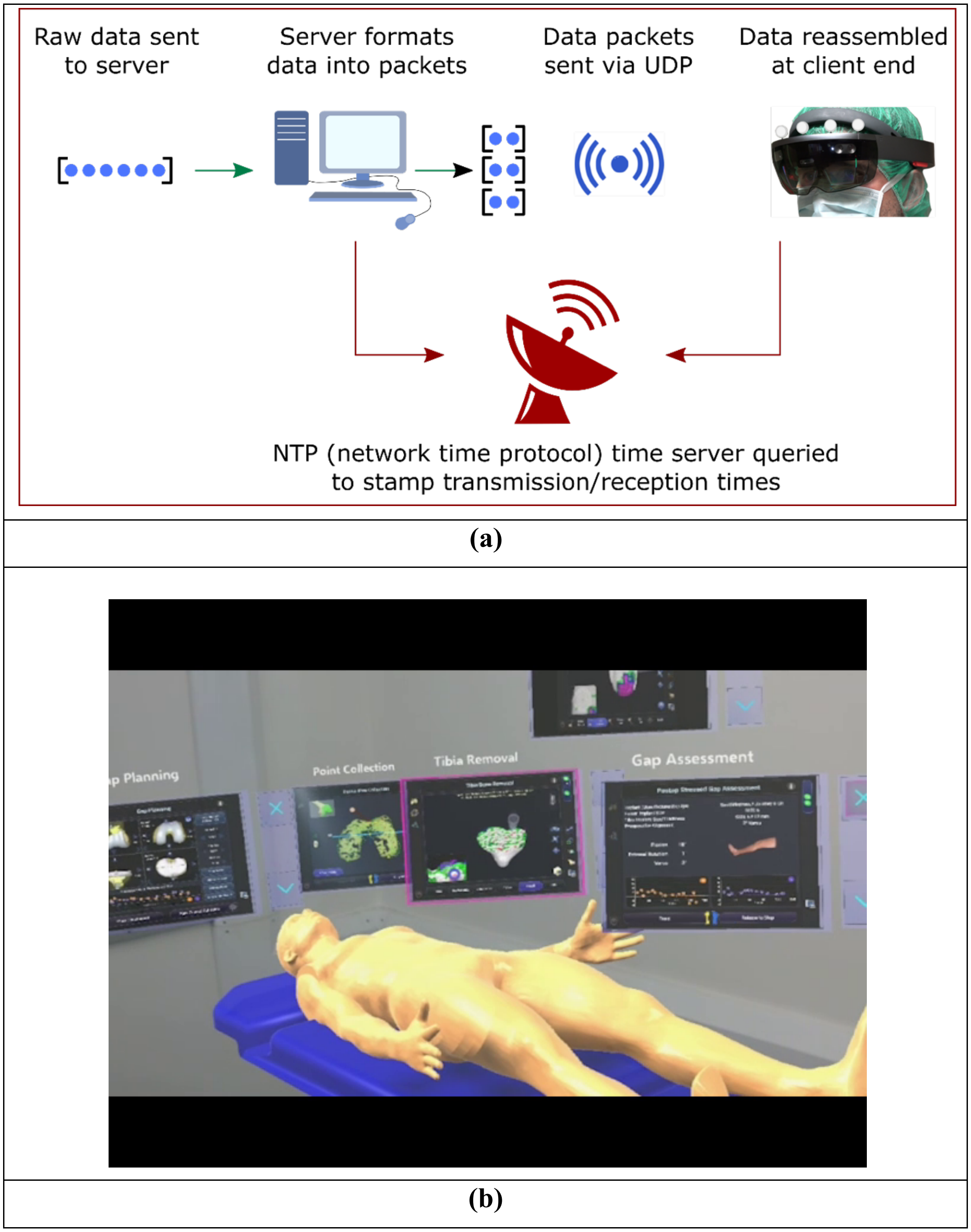


Figure 1 (a) - Proposed system architecture (b) – Potential virtual workflow environment using static imagery

3-BENCHMARK TEST

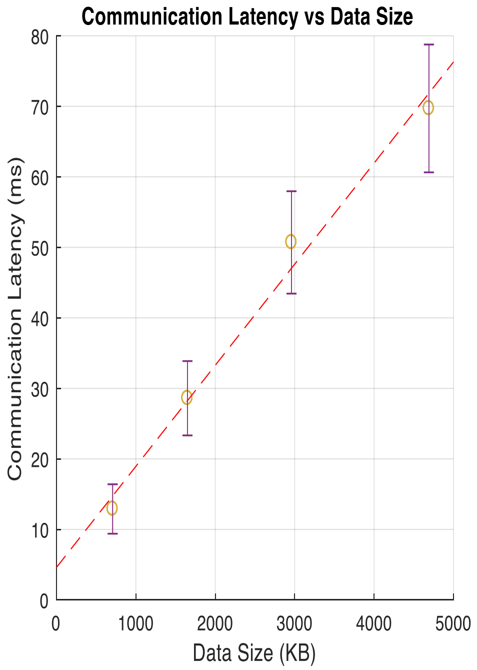
The constructed system was tested to explore its capability of supporting real-time communication. It was envisioned 2 types of information would be transferred using this architecture; a 4x4 coordinate-transformation matrix, and high-resolution video frames (potentially obtained from surgical robotic workflows).

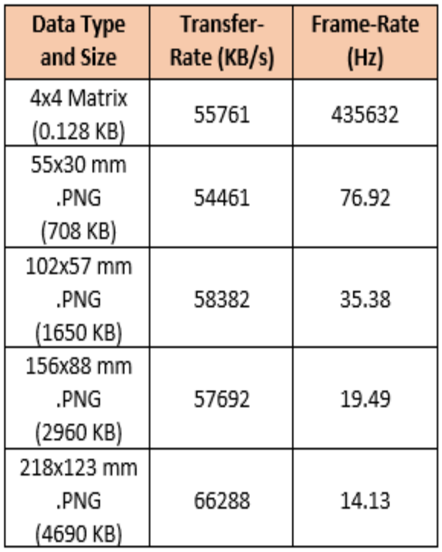
The testing procedure was carried out by utilising the system architecture to transfer the following data-types:

- 4x4 coordinate-transformation matrix, composed of 16 doubles
- 55x30 mm video frame @ 600 dpi
- 102x57 mm video frame @ 600 dpi
- 156x88 mm video frame @600 dpi
- 218x123 mm video frame @600 dpi

An external NTP-server was used to timestamp the transmission and reception times of each data-type, and thus a communication-latency time was obtained. From this, a bit-rate was calculated by taking the ratio of data size in KB and latency in seconds. Finally, the bit rate was converted into a frame-rate. The results of this process are outlined in Figure 2. Additionally, a ramp test-signal was sent during each test to detect and remove any anomalous data associated with network-issues.

4-RESULTS AND DISCUSSION





Data Type and Size	Transfer-Rate (KB/s)	Frame-Rate (Hz)
4x4 Matrix (0.128 KB)	55761	435632
55x30 mm .PNG (708 KB)	54461	76.92
102x57 mm .PNG (1650 KB)	58382	35.38
156x88 mm .PNG (2960 KB)	57692	19.49
218x123 mm .PNG (4690 KB)	66288	14.13

(a) **(b)**

Figure 2 – (a) Communication latency for increasing data-size (b) Frame-rates for increasing data-size

Figure 2a indicates an increase in communication-latency corresponding to an increase in transmitted-data size. Within this order of data-size, the latency increases linearly as indicated by the linear regression-line included in the plot. The bit-rates in Figure 2b are consistently in the order of 60,000KB/s. The known network-speed of the laboratory setup was 108,337KB/s, indicating these calculations are within the expected range. This also suggests there is room for further streamlining of the system-architecture. Finally, the obtained frame-rates in Figure 2b show that the system architecture has successfully met the criteria set in Section 1; this system would be able to support real-time communication of data-transfer in the MB range at 10Hz. As indicated by Troccaz[7], this matches existing standards of real-time communication within surgical robotics. However, if this system architecture were to integrate more complex and taxing data-streams associated with surgical robotics such as segmented CT-scans (see Pratt et al[8]), then a higher frame rate of at least 30 fps is optimal, leaving room for improvement.

5-CONCLUSION

The continued growth of AR technology will further facilitate it as a versatile tool for medical imaging and human-machine interfacing for medical robotics. A key component of moving such systems from laboratories into operating theatres is a robust back-end system capable of providing low-latency wireless communication. In order to achieve this, the system detailed in this paper utilised UDP-based communication to create a wireless data-communication network. This system architecture was shown to be capable of providing frame rates above 10Hz when transferring data in the order of megabytes, which would indicate promising potential to transmit surgical navigation workflows and co-ordinate transformation data and move towards a more virtually augmented surgical environment. Moving forward, this system will work towards interfacing additional devices associated with surgical-robotics (i.e. optical cameras, hardware-switches etc.) whilst maintaining low communication-latency.

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DISCLOSURES

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