DextRoS: Affordable Mobile-based Robotic Surgery Simulator

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I. INTRODUCTION

Technological advances in surgical robotics now can help realise the full potential of minimally invasive techniques (MIS) with improved consistency, safety and accuracy [1]. However, their adoption is fundamentally dependent on the access to training facilities and extensive surgical training [2], [3]. Robotic instruments and the necessary dexterity skills are unique and different from open or laparoscopic surgery. Surgeons need to attend extended training courses to become accustomed to a particular system. This could be a significant time and resource burden for different robotic systems. Additionally, even though the importance of hands-on experience is significant in surgical training, the availability of robotic systems for training purposes represents additional operational costs for the hospitals. Therefore, significant financial and technical barriers related to surgical training are created for surgeons and hospitals that are a barrier to the adoption of the technology.

Currently, the state-of-the-art robotic MIS (RMIS) system is the da Vinci® surgical system (Intuitive Surgical, Sunnyvale, CA), introduced in 2000 for general use in minimally invasive procedures. As interest for the system has increased, a variety of surgical simulators for the da Vinci have appeared attempting to minimise the learning curve associated with the new paradigm shift in surgical practice. They offer a computer-generated reproduction of real-world surgical procedures and surgical tasks for different levels of expertise. These platforms are mainly stand-alone and do not compromise patient's safety for training. However, they are associated with the following constraints: cost (tens of thousands of dollars); lack of support for other surgical systems as they are developed specifically for the commercially available da Vinci systems; and lack of portability, *i.e.* they should be used in dedicated training spaces. While historically similar limitations appeared in laparoscopic surgical training tools, nowadays low cost alternatives exist for the performance of basic surgical tasks with full performance analytics and support of generic laparoscopic instruments with cost of less than \$1000. These simulators are often called 'take-home' simulators where users can use anywhere and present a great potential solution to scale surgical training to developing countries where surgical training tools are limited.

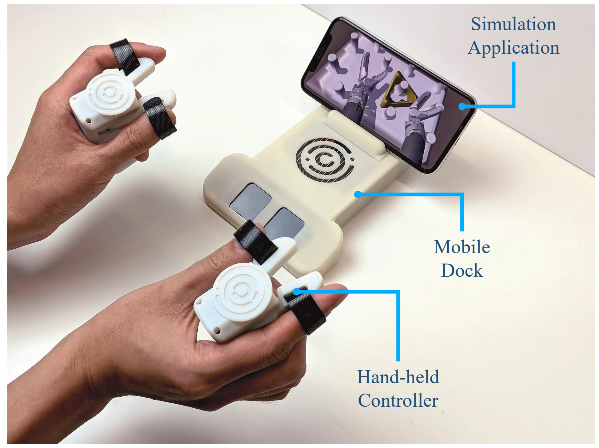

Fig. 1. Prototype demonstration of the portable surgical simulator.

In this work, we present a low-cost, fully wireless, and portable solution to train basic dexterity skills for introductory-level robotic surgery. The idea is that certain sub-tasks and acclimatisation to controlling surgical tools can be performed using a portable equipment. Its portability allows users to practise and improve their performance without space or storage limitations. To our knowledge, this is the first attempt to demonstrate such a system for RMIS.

II. MATERIALS AND METHODS

Our mobile simulator system is a compact wireless system consisting of three core components, as shown in Fig. 1, a pair of wireless hand-held master controllers with haptic and tactile feedback, a portable dock, and a smartphone or tablet that run the simulation software. The smartphone can also be housed inside a virtual reality (VR) headset for 3D visualisation. The architecture diagram of the simulator system is presented in Fig. 2. The material cost to build this system is approximately \$500, which is significantly lower than existing commercial simulation solutions.

The user operates the simulation interface with a pair of hand-held fully wireless controllers that provide 6 Degrees-of-Freedom position and orientation tracking. The platform presented in this work combines the advantages of inertial measurement unit (IMU) and an infrared (IR) tracking system for the development of a low-cost portable system to provide a low cost alternative to expensive commercial tracking solutions, *e.g.* electromagnetic tracking. The IMU is used only for the orientation tracking as the integration errors hinder its use for position estimation. The position

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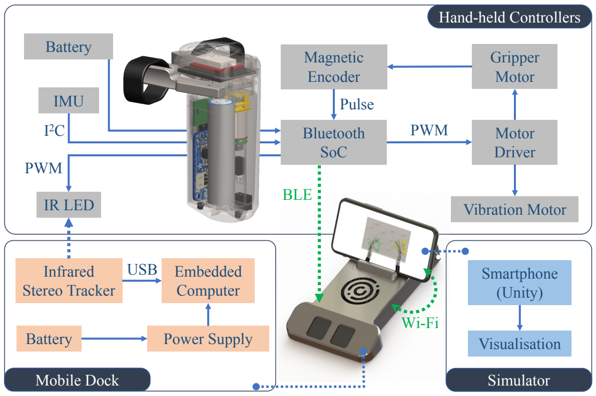

Fig. 2. Overview of the system architecture along the various communications between the components.

of each wireless hand-held controller is tracked externally using a low cost IR stereo tracker (Leap Motion, USA) that is situated in the front of a docking station and an IR LED attached at the bottom of each controller. Active trackers were preferred due to their higher contrast and robustness in detection; passive markers are more prone to false positives due to flood illumination. After a simple binary thresholding scheme, the marker positions are identified using fast connected components and processed using an extended 3D Kalman filter to improve the tracking robustness in events of temporary occlusion and erroneous detection. Although each hand-held controller has three markers installed, only one is illuminated for the simplification of our tracking algorithm.

The simulation application is built using the Unity engine (Unity Technologies, USA), while the physical interactions are simulated using the built-in physics engine (Nvidia PhysX). The articulated instruments' joint angles are calculated using a commercially available inverse kinematics (IK) solver (Rootmotion). In this work, we demonstrate a simple but well-established pick and place surgical task, adapted from the Fundamentals of Laparoscopic Surgery (FLS) model training task.

Every hand-held controller has a multifunctional button. When pressed, it serves as the clutch of each surgical instrument. If the buttons on both controllers are pressed, then the user can adjust the camera view by moving both controllers in relative to each other for rotation and translation.

III. RESULTS

A preliminary user study was conducted with 4 surgeons (with experience in robotic surgery) and 9 novices (without prior surgical experience) to evaluate the usability of the simulator. The subjects were asked to perform a bi-manual peg transfer task within 3 minutes. Users were given 5 minutes to familiarise with the simulator before the task started. For each subject, three repetitions of the task were performed. The metrics measured during the experiment include: number of successful peg transfers, accidental drops, time spent per transfer, and the total distance moved. Fig. 3 and Fig. 4 summarise the results. Additionally, each surgeon was asked after completing the task to fill out our questionnaire prepared specifically for this experiment.

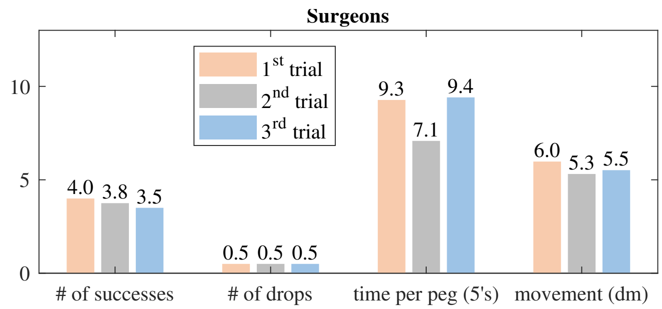

Fig. 3. Results from the usability study, comparing four performance metrics between surgeons.

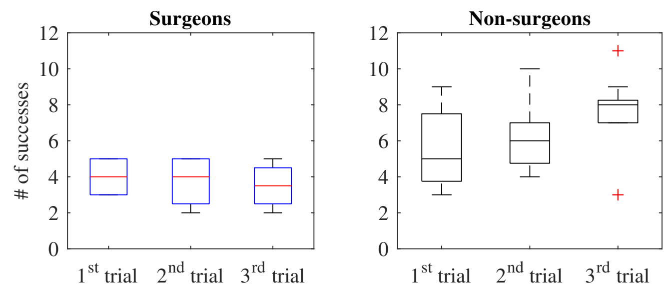

Fig. 4. Distribution of number of successful peg transfers, comparing between surgeons and non-surgeons.

IV. DISCUSSION

The user study presents that surgeons performed equally well across all three trials. In contrast, the results from the novices demonstrated improvement both in terms of the increased number of successful peg transfers and its consistency, which can be seen in Fig. 4. The latter suggests that the novice users could learn and improve their dexterity skills with the robotic simulator over a short period of time. Responses from the questionnaire indicate low-to-medium level of mental, physical, and temporal workloads for the users. They also perceived moderate level of task complexity and stress. They did not feel distracted and were confident during the experiment. One common user feedback is the lack of depth perception, which can affect the fidelity of the simulation as well as the performance. To address this limitation, future studies will incorporate a virtual reality headset providing 3D visualisation.

Indeed, from the questionnaire responses regarding the applicability of DextRoS to robotic surgery training, surgeons agreed that the device is useful for teaching basic skills required, and would like to use this simulator during their free time or at home.

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