JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

# Mobile Telesurgery Platform in Mixed Reality

# Final Report

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# Background

The current da Vinci surgeon console is stationary in the Operating Room (OR) and is placed in the non-sterile field of the room. This means that the surgeon performing the teleoperation surgery is not able to perform any operation on the patient bed, which consequently mandates another surgeon or first assistant to be present at bedside to assist changing instruments of the da Vinci patient cart and any other necessary operations for the surgery. From Intuitive Surgical's feedback upon the original technical proposal submitted by the mentors listed in this project, it is clear that they desire a system that the current surgeon console cannot achieve, one benefit of which being able to perform solo surgery. Economically, the surgeon console is costly to manufacture. Lowering the cost of the capital equipment required to deliver the robotic instruments to the patient would benefit both hospitals, by reducing the up-front cost of the system, and Intuitive Surgical, by enabling the company to focus on the instruments [6]. Likewise, for any other similar telesurgery robotic systems, the master surgeon consoles are typically immobile and expensive to manufacture.

The goal of the project is to develop a human arm joint angle measuring system that captures up to 6 DOF which serves as a portable alternative to the master surgeon console in teleoperation surgery, for example, the Master Tool Manipulator (MTM) of Intuitive Surgical's da Vinci system. In particular, the system must be fully wearable, have similar workspace as the MTM, and recognize the surgeon's intention to engage/disengage with the system (referred to as rules of engagement below). In short, the goal of this project is to develop a mobile telesurgery interface with the da Vinci Patient Side Manipulator (PSM).

Apart from the proposed system described in the previous section, the mentors mentioned in this proposal had a large amount of research on a well-developed Head Mounted Display (HMD) system that can display the endoscopic image, being an alternative to the stereoscopic display located on the surgeon console. The grand goal of this project is to develop a novel surgeon console that can be sterile, mobile and lower cost than the current surgeon console, which will provide the benefit of solo surgery, surgery collaboration between more than 2 surgeons, and easier introduction of the system to hospitals worldwide.

# Technical Approach

## Overview

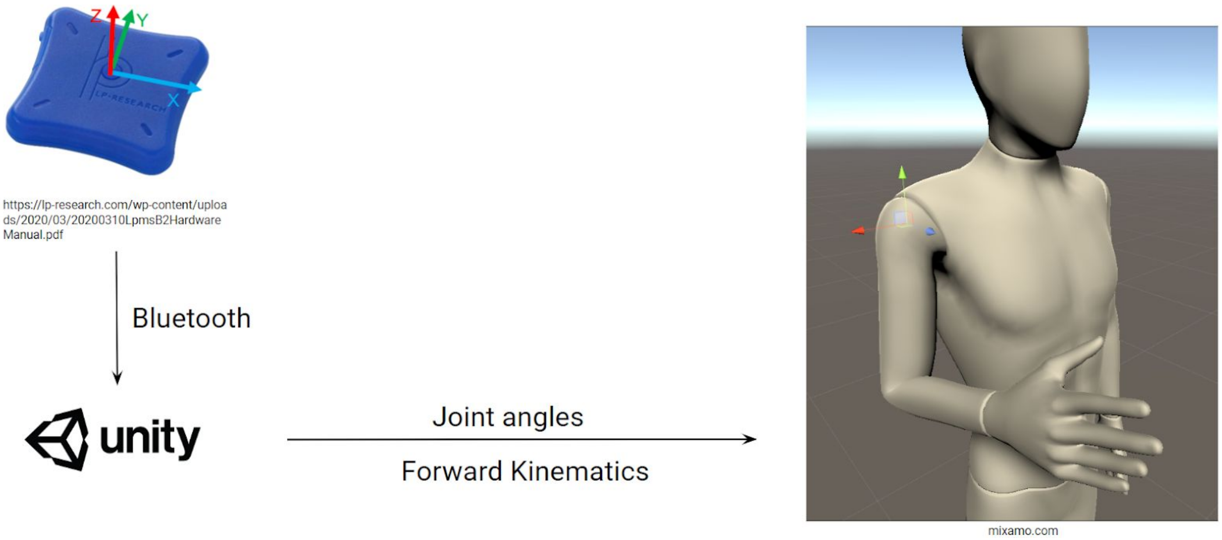

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Fig 1. System Diagram

The project system diagram is shown in Figure 1, which consists of hardware and software. The communication between hardware and software components are by standard class 2 Bluetooth host interface [1]. Once the software receives real-time (100Hz) IMU data, the kinematics algorithm developed by me calculates the joint angles and the forward kinematics, then controls a fully rigged avatar, as shown in the right of Figure 1. The joint angles computed by the algorithm is translated to the avatar's joint angle, which fairly represents the motion that the system user is making, thus achieves joint space control; the forward kinematics computed by the algorithm controls a sphere in the Unity scene that represents the end effector global position and orientation, which gives the system the capability to achieve cartesian space control.

In order to implement the system and achieve joint space control, an algorithm of transforming IMU reading to human joint angles is implemented, as well as a calibration protocol for IMU rotation. In order to achieve cartesian space control, a forward kinematics algorithm is implemented, as well as a calibration protocol to find the arm lengths.

## Hardware

The hardware component consists of two 9-axis Bluetooth IMU, LPMS-B2 by LP-RESEARCH Inc.. The IMU has integrated Kalman Filter sensor fusion algorithm that fuses data from the 3-axis gyroscope, 3-axis accelerometer and 3-axis magnetometer. Users have the freedom to choose from Gyroscope only, Gyroscope + accelerometer, and Gyroscope + accelerometer + magnetometer modes[1]. In this system setup, I chose the Gyroscope + accelerometer Kalman Filter, since the magnetic field disturbance is high in my particular workspace, thus making the Yaw-axis drift much more significant than what is desired.

## Hardware setup

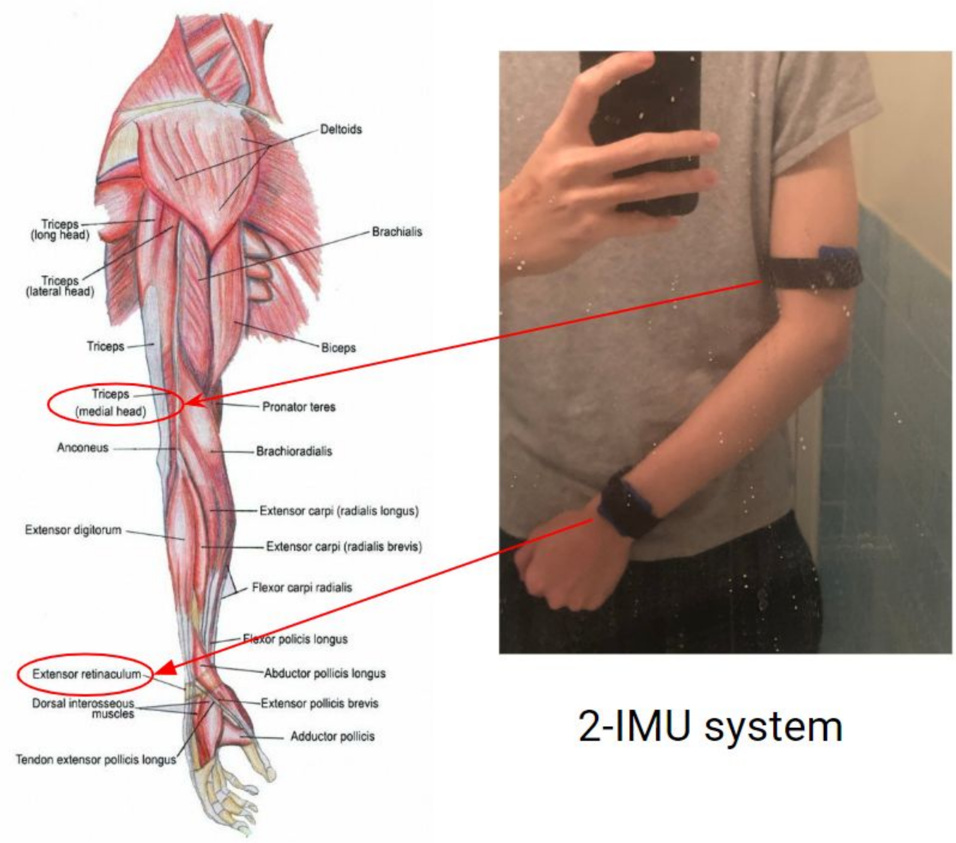

Fig 2. Hardware setup diagram

In the system setup, the 2 IMUs are placed strategically on the user's arm, to ensure a good correlation factor from the IMU reading and the actual user joint angles. The first IMU is placed on the upper arm, medial head side of the tricep; the second IMU is placed on the extensor retinaculum.

## Human Arm Kinematics

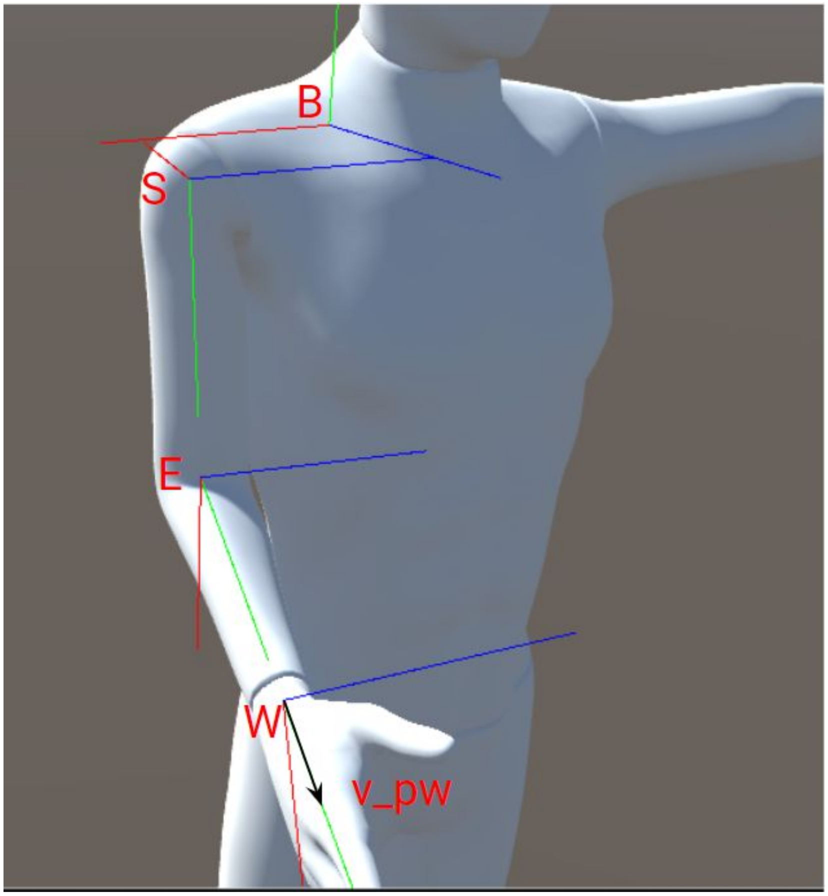

Fig 3. Human arm kinematics

$$T_S^B = [R, 0] \quad (1)$$

The translation of this homogeneous is 0 because in the system setup, the shoulder frame is at the origin of the world frame. The R here is the rotation matrix of the shoulder joint.

$$T_E^S = [Rz, p] \quad (2)$$

The translation vector p here is $[0,\ lu,\ 0]^T$, where lu is the length of the upper arm. The Rz here is the rotation matrix around z-axis and z-axis only.

$$T_W^E = [Ry, p] \quad (3)$$

The translation vector p here is $[0,\ lf,\ 0]^T$, where lf is the length of the forearm. The Ry here is the rotation matrix around y-axis and y-axis only.

$$v_P^W = [0, lp, 0]^T \quad (4)$$

This is a vector which indicates the local coordinate of the middle of the palm wrt the wrist local frame.

In order to know the world coordinate of the middle of the palm $v_p$ (end effector), simply multiply (1) through (4):

$$v_p = T^B_S * T^S_E * T^E_W * v^W_P \quad (5)$$

## Calibration protocol

- Rotation calibration

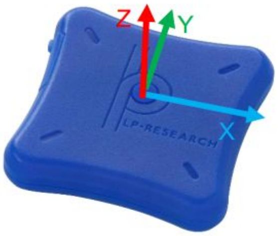

Fig 4. IMU's body-fixed frame diagram [1]

IMU's internal +y should be perpendicular to the workspace(screen).
IMU's internal -z should be pointing toward the ground.
If IMU drifts during operation, perform "heading reset" [1].

- Link length calibration

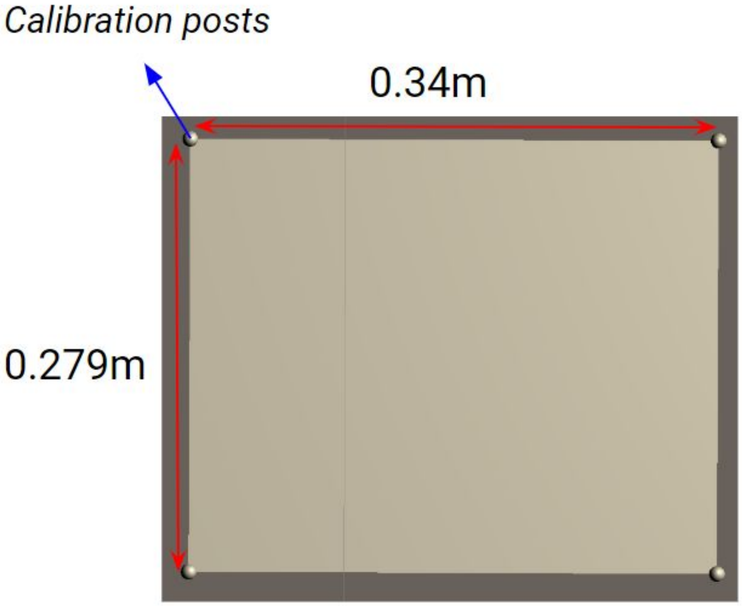

Fig 5. Link length calibration workspace

A 2D calibration object is defined. The object is placed on a level tabletop, with four calibration posts located in the four corners of the object. The dimension of the calibration object is defined in Figure 5.

A brute force calibration method is used in MATLAB (calibration.m). The math concept is as follows:

$d$ = *actual distance between calibration posts* (6)
$e$ = *distance between two end effector position when placed on two calibration posts* (7)

In order to find e, first the user needs to align his/her palm on the different calibration posts, and then record the transformation matrix outputted by the software(unity); secondly, input all the matrices into the MATLAB code, which computes the position of the palm in world space. Then, e is obtained by calculating the absolute difference between palm position.

It is important to note that, the $l_f$ and $l_u$ in the forward kinematics mentioned in Page 4 of this report are the variables to be calibrated. As a result, the brute force calibration searches for the values of these two variables that minimizes:

$$|d - e| \quad (8)$$

## Software

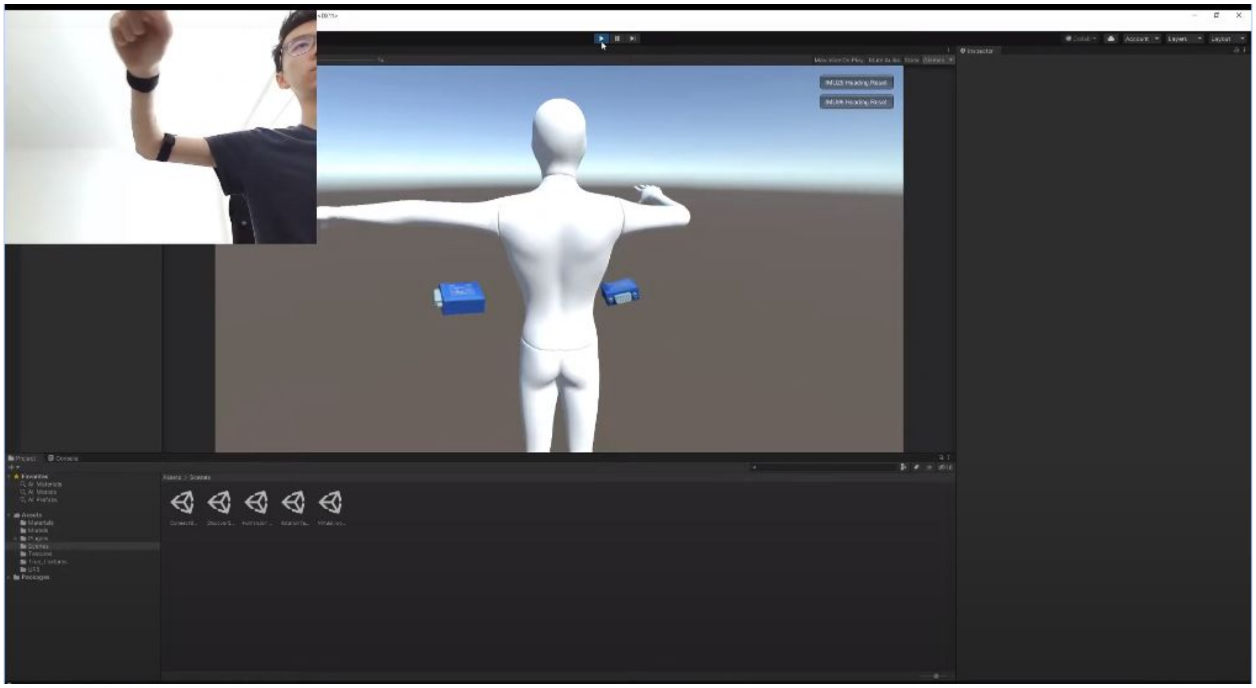

Fig 6. Unity software scene overview

A real time visualization scene is set up in Unity, where a mannequin's right arm is controlled by the 2-IMU system worn by the user.

### Rules of engagement protocol

Rules of engagement is the indication of the user's desire to engage or disengage with the system, analogous to the clutch pedal on da Vinci's surgeon console.
The protocol is defined as follows:
If the user rotates his wrist two times in a quick succession, the system switches from disengage to engage, or vice versa.

# Result

### Calibration result

True $l_f = 0.25m$
True $l_u = 0.26m$
Calibrated $l_f = 0.158m$
Calibrated $l_u = 0.521m$
Error e( $l_f$) = $0.261m$
Error e( $l_u$) = $0.092m$

### Error Analysis

A noticeable joint angle error is present in elbow joint calculation, which propagates through the forward kinematics which ultimately affects the accuracy of calibration.

# Future Work

- Improve elbow joint angles kinematics model, since the error greatly affects the calibration result.
- Accuracy test for angle measurement model.
- Evaluate IMU drift and determine whether further sensor fusion is needed.
- Improve Calibration Protocol.
- Extend to 3-IMU system to capture wrist 2DOF.
- Conduct comparative study with dVRK.
- Write Academic paper.

# Management Summary

## Credits and Acknowledgement

This project is funded by Dr. Peter Kazanzides, who provided the funding for the 2 IMUs in the system. While I am the only member on this team, with all the above mentioned work done by me, this project is impossible without the help of my mentors Dr. Peter Kazanzides and Ehsan Azimi, as well as Professor Hao Su from The City College of New York, who provided guidance in the first part of the design phase of this project. Last but not the least, I received help from Anton Deguet, and support staff Thomas Hauth from LP-RESEARCH Inc..

## Deliverables

- Minimum Deliverable:

Joint space control of single human arm (3/4 DOF at tool), virtual demo in Unity. (Done)

- Expected Deliverable:

Cartesian space control of the same human arm. (Done)
Rules of engagement. (Done)

- Maximum Deliverable:

Achieve wrist 3DOF using 2 IMUs from wrist to dorsal side of hand. (Work in Progress)

I met the expected deliverable and the minimum deliverable on time, however, there are still future works desired to improve the current outcome of the two deliverables. Thus, my work this semester successfully establishes a solid foundation of what is needed to further complete the project goal. The failure to accomplish the maximum deliverable are of two reasons: first is my own time management failed to predict the workload needed to setup the Unity environment, second is the hardware dependency was resolved late in the project phase (4/28/20), which was the connection issue in Unity with the IMU, that caused me to unable to read real time data in Unity from the IMU.

## Lessons Learnt

- System visualization is highly productive
- Always plan for unknowns and delays that are out of my control
- Really seek alternative ways if a dependency is unresolved and try to work around that
- There are a lot more refinement needed for this project
- Unity is fun

# Technical Appendices

All documentation and codes are archived on project wiki page, under Reports and Presentations section.
https://ciis.lcsr.jhu.edu/dokuwiki/doku.php?id=courses:456:2020:projects:456-2020-14:project-14

# Reference

1. IMU Manual
   https://lp-research.com/wp-content/uploads/2020/04/20200330LpmsUserManual.pdf
2. D-H paratmeters
   http://www.aeromech.usyd.edu.au/MTRX4700/Course_Documents/material/lectures/L2_Kinematics_Dynamics_2013.pdf
3. IMU lecture https://stanford.edu/class/ee267/notes/ee267_notes_imu.pdf
4. El-Gohary, M., & McNames, J. (2012). Shoulder and elbow joint angle tracking with inertial sensors. IEEE Transactions on Biomedical Engineering, 59(9), 2635–2641. https://doi.org/10.1109/TBME.2012.2208750
5. Naidu, D., Stopforth, R., Bright, G., & Davrajh, S. (2011). A 7 DOF exoskeleton arm: Shoulder, elbow, wrist and hand mechanism for assistance to upper limb disabled individuals. IEEE AFRICON Conference, (September), 1–6. https://doi.org/10.1109/AFRCON.2011.6072065
6. P. Kazanzides, E. Azimi, Intuitive Surgical - Technology Research Grant Proposal.