Mobile Telesurgery Platform in Mixed Reality

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Goal

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).

Background and Significance

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 [1]. 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

We propose to use 2-3 IMUs that are strapped onto the upper arm, forearm, and (possibly) wrist and to compute joint angles of surgeons with any arm dimensions. In turn, the joint angles will be used to compute the end effector (palm) position and orientation in 3D cartesian coordinate, which will be used to control state-of-the-art robots, such as UR3 or dVRK.

In detail, the project consists of 4 main components/steps:

Kinematics Algorithm

The most crucial step of this project is to develop the algorithm that can compute the joint angles of the surgeon wearing the system from the data obtained from the IMU. Upon getting joint angle measurements, the algorithm should also compute the position and orientation of the end effector (palm) of the surgeon.

Potential challenges are skin artifact and mild torso movement, since we assume that the IMU does not move relative to the surgeon’s arm, and the surgeon’s torso will remain perpendicular to the ground.

Sensor Fusion Algorithm

This is a step that is dependent on the IMU output, mainly its noise and drift. If the noise and drift is too large and significantly impacts the kinematic computations of the position and orientation of the end effector (palm), sensor fusion algorithms might become necessary to address the issue.

Rules of Engagement Protocol

One important aspect of the mobile telesurgery is to come up with a protocol to engage and disengage the system when needed, which is analogous to the foot clutch pedal on the current da Vinci Surgeon Console. This protocol should be intuitive and should not jeopardize the mobile and wearable element of the system.

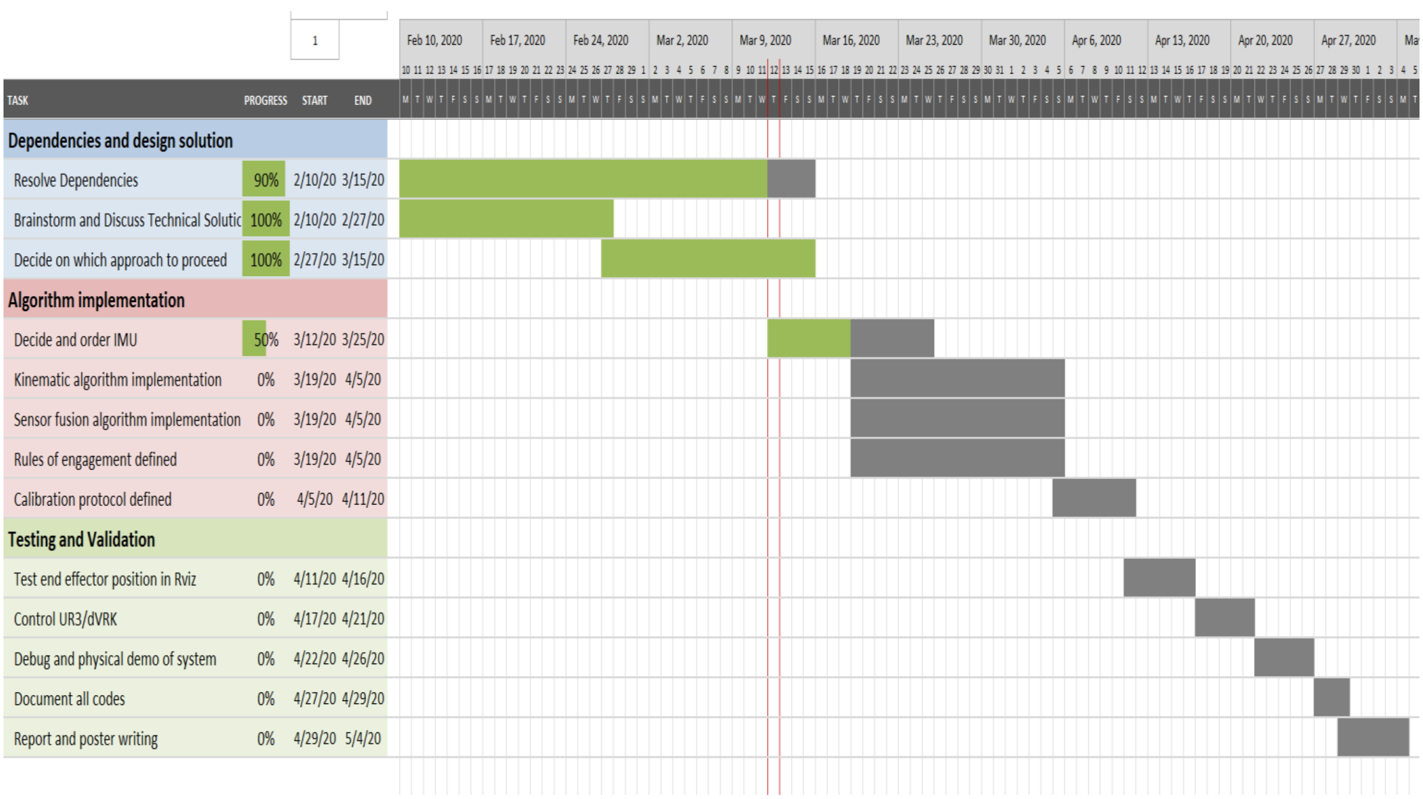
Calibration Protocol

This is a necessary step to ensure that the proposed system remains fully functional to users with different arm dimensions. Because it is impossible to place the IMUs on different people with the exact relative position and orientation, a standardized calibration protocol must be defined to ensure that the kinematic algorithm works properly to output the position and orientation of the end effector (palm).

Deliverables

- Minimum Deliverable:
    - Joint measuring system that captures full motion of single human arm (3/4 DOF) using only 2 IMU.
    - Virtual demo in Rviz of a simulated robot, such as UR3, to move around according to the user's arm motion.
- Expected Deliverable:
    - Physical demo of the system with 2 IMUs using UR3 or dVRK, with rules of engagement clearly working.
- Maximum Deliverable
    - Achieve 6 DOF motion capture of human arm with 3 IMUs.

Timeline



For clearer image, please view at:
https://docs.google.com/drawings/d/10uCvZVav7OgJeBezgqyTRXf6u2UDfBBxBF97Bg2ol_s/edit?usp=sharing

Key Dates/Milestones

Milestones	Complete Date	Overall Status
Design Solution Decision Made	3/15/2020	Completed
Algorithm Implemented	4/5/2020	
Calibration protocols defined	4/10/2020	
Kinematic Measurement Validated	4/16/2020	Minimum Deliverable
Successful Physical Demo	4/26/2020	Expected Deliverable
6 DOF w/ extra IMU Implemented	4/28/2020	Maximum Deliverable
Complete Documentation	5/4/2020	

Dependencies

Dependency	Solutions	Deadline	Backup Plan	Affect what	Status
Lab Access	Contact Dr. Kazanzides to sign paperwork	2/15	Ask mentors to open doors to the lab when needed	UR3 and dVRK Access	Completed

Software License	Use WSE Solidworks license	2/11	Use older version on my personal PC	Whole project	Completed
UR3 Access	Contact Dr. Kazanzides	3/15	Use dVRK	System validation and testing	Completed
dVRK Access	Contact Anton	3/15	N/A	System validation and testing	Not started
Algorithm Implementation	ROS on personal PC	3/25	Contact mentors to use lab machines	System realization	Completed
Parts Delivered	Contact Dr. Kazanzides	3/31	None	System realization	Not Started

Management Plan

- Bi-weekly meeting with mentors
- Budget: ~$500

Reading List

1. P. Kazanzides, E. Azimi, Intuitive Surgical - Technology Research Grant Proposal
2. Surgical Asepsis and the Principles of Sterile Technique, https://opentextbc.ca/clinicalskills/chapter/surgical-asepsis/
3. L. Qian, A. Deguet, Z. Wang, Y. Liu and P. Kazanzides, "Augmented Reality Assisted Instrument Insertion and Tool Manipulation for the First Assistant in Robotic Surgery," 2019 International Conference on Robotics and Automation (ICRA), Montreal, QC, Canada, 2019, pp. 5173-5179.
4. Sabatini AM. Estimating three-dimensional orientation of human body parts by inertial/magnetic sensing. Sensors (Basel). 2011;11(2):1489–1525. doi:10.3390/s110201489
5. Determine Orientation Using Inertial Sensors, MATLAB, https://www.mathworks.com/help/fusion/gs/determine-orientation-through-sensor-fusion.html
6. Jarrassé, N., & Morel, G. (2011). On the kinematic design of exoskeletons and their fixations with a human member. Robotics: Science and Systems, 6, 113–120. https://doi.org/10.7551/mitpress/9123.003.0019
7. D-H parameters https://robotacademy.net.au/lesson/denavit-hartenberg-notation/
8. D-H paratmeters http://www.aeromech.usyd.edu.au/MTRX4700/Course_Documents/material/lectures/L2_Kinematics_Dynamics_2013.pdf
9. IMU lecture https://stanford.edu/class/ee267/lectures/lecture9.pdf
10. 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
11. 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
12. Wong, C., Zhang, Z. Q., Lo, B., & Yang, G. Z. (2015). Wearable Sensing for Solid Biomechanics: A Review. IEEE Sensors Journal, 15(5), 2747–2760. https://doi.org/10.1109/JSEN.2015.2393883
13. Lopez-Nava, I. H., & Angelica, M. M. (2016). Wearable Inertial Sensors for Human Motion Analysis: A review. IEEE Sensors Journal, PP(99), 7821–7834. https://doi.org/10.1109/JSEN.2016.2609392
14. Steidle, F., Tobergte, A., & Albu-Schäffer, A. (2016). Optical-inertial tracking of an input device for real-time robot control. Proceedings - IEEE International Conference on Robotics and Automation, 2016-June, 742–749. https://doi.org/10.1109/ICRA.2016.7487202
15. Kim, Y., Leonard, S., Shademan, A., Krieger, A., & Kim, P. C. W. (2014). Kinect technology for hand tracking control of surgical robots: Technical and surgical skill comparison to current robotic masters. Surgical Endoscopy, 28(6), 1993–2000. https://doi.org/10.1007/s00464-013-3383-8
16. Tobergte, A., Pomarlan, M., Passig, G., & Hirzinger, G. (2011). An approach to ulta-tightly coupled data fusion for handheld input devices in robotic surgery. Proceedings - IEEE International Conference on Robotics and Automation, 2424–2430. https://doi.org/10.1109/ICRA.2011.5980120