LOCALIZED TRACKING SYSTEM FOR HUGO-RAS SURGICAL ARM SETUP

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1 About

The following report presents a technical overview of work done by the author at Medtronic Engineering and Innovation Centre, Hyderabad under Medical Surgical portfolio during the association period as an Intern. The report contains synopsis of the problem statements and their significance in medical sector and corresponding techniques & technologies explored in direction to propose/develop the final output. However, the solutions have not been elaborated since they remain proprietary information belonging solely to Medtronic.

2 Introduction

Globally, more than 300 million surgeries are performed every year [1]. In recent years, laparoscopic surgeries are becoming preferred method over the open surgeries because they are minimally invasive and offer several advantages, such as avoiding large open wounds or incisions and thus of decreasing blood loss, pain or discomfort [2] alongside reduced chances of internal infection. According to a survey, nearly 15 million laparoscopic surgeries are performed annually in United States alone [3], thereby highlighting the growing importance of laparoscopic surgery. This makes the task of performing laparoscopic surgeries efficiently and need for constant evaluation & updates of existing techniques quintessential.

2.1 Problem Statement 1 (PS1)

Robotic Surgery (RS) technology has been on the rise in recent times, for example: more than 644k robot-assisted surgical procedures have been performed in United States in the year 2017 itself [4] and the percentage of such procedures has risen to 15.1% by 2018 [5]. However, a survey reveals more than 8k device malfunctions leading to 144 deaths in a 13-year period [6]. Such events prove to limit trusts on RS technology worldwide and lays an emphasis on need of surgeons trained to operate involved interfaces with better mechanisms. The need for efficient robotic arm systems being used to perform surgeries becomes imperative as adverse events can prove fatal for the patient and (or) cause damage to the instruments in action. Collision amongst instruments is a major concern and surgeon operating the interface cannot view or visualize the positions of the arms instantaneously in certain systems. Therefore, the work involved study of existing real-time localization techniques and proposing an appropriate design of multi-sensor fusion for the purpose, which can be utilized for collision avoidance and other potential mis happenings such as deadlock condition.

2.2 Problem Statement 2 (PS2)

The average surgery time of a laparoscopic surgery is estimated around 77 min [7], however certain variations even take more than 130 minutes [8]. It has been shown that audio-video recording during laparoscopic surgery reduces irrelevant conversations between surgeons. This in turn, helps improving intraoperative safety and surgical outcome. Majority of respondents of a survey suggest added value of intraoperative video recording [9], however there is slight reluctance due to possibility of involved infringement of privacy. Therefore, eliminating possibilities of confidentiality losses is an exigent task, and is helpful for safety of both patient and healthcare workers. Certain medical devices such as Medtronic's DS1 used in Operation Theatres (OTs) record the entire video scene of the surgery and are processed thereafter to remove any potential confidential information. This makes the processing task tedious with higher computational and storage requirements since the videos are uploaded to cloud servers and require greater amount of bandwidth consumptions, which add as cost to the organization. Therefore, a real-time confidentiality masking system for laparoscopic surgery is an exigent task for achieving improved results in laparoscopy.

3 Review of existing technology

3.1 Problem Statement 1 (PS1)

The problem can be split into three steps as shown in *Figure 1*. The key idea is to reduce the number of sensor technology involved in the solution since attaching additional sensors to robotic arm setup such as Medtronic's Hugo RAS or da Vinci systems would add up cost to the product and redundant information, thereby limiting cost-wise strata of hospitals benefitting from such robotics surgical systems. However, this strategy varies with degrees of freedom aligned to the system and the following exploration and design has been done keeping Hugo RAS for reference.

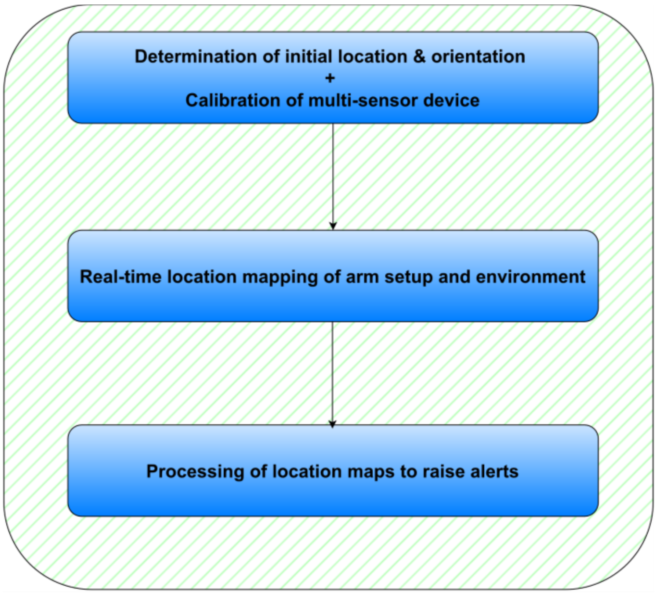

Figure 1. Workflow for localized tracking system of Hugo RAS surgical setup

Real-Time Location Systems (RTLS) techniques have been explored and appropriate choice is made keeping Step 1 and 2 in mind. Among the popular RTLS techniques: Bluetooth Low Energy (BLE), WiFi, Ultra-Wideband (UWB), Chirp Spread Spectrum (CSS), Infrared (IR), RFID and Ultrasound, since the range of system is of the orders of size of OTs and accuracy of higher orders is expected for precise tracking with low latency in such critical environments. UWB, CSS and WiFi satiate the requirement as they have the above-desired attributes [10].

One of the RTLS technology can be chosen and corresponding anchors & tags placed at appropriate positions in arm setups to measure initial distance between the arms. There are several RTLS positioning techniques with Received Signal Strength Indicator (RSSI) in most used due to low-cost, however it does not deliver high degree of positional accuracy and is prone to signal interference and attenuation. Time Difference of Arrival (TDoA) and Two-Way Ranging (TWR) are superlative choices for indoor positioning with greater levels of accuracy and real-time performance. TDoA works on concept of delay in time of arrival of signal at pair of distinct, synchronized points and the source location is determined by intersection of hyperbolas with the pair points as foci. On the other hand, TWR uses two-way communication between two devices using multiple transferred signals & does not need synchronization. The discussed mechanisms are as shown in *Figure 2*.

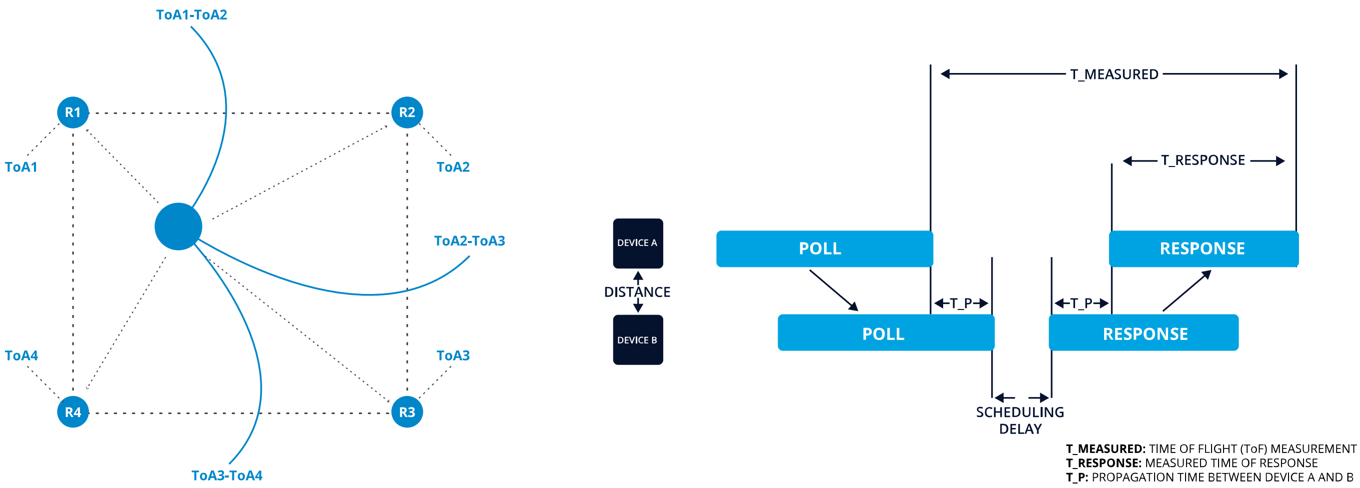

Figure 2. Diagram for (a) Time-Difference-of-Arrival (TDoA)   (b) Two-Way Ranginng (TWR) [10]

In addition, the system requires orientation detection and real-time distance measurements which can be done using LiDAR placed at specific location and vision-based SLAMs to map the other end of the setup which is unmapped since LiDAR captures distance information of only nearest surface and cannot map beyond that. The concept of utilizing VSLAM to map features has been in action in autonomous vacuum cleaner iRobot Roomba. To construct a working model, an 8K sparse point-cloud 2D LiDAR has been used to represent objects inside a distance and angle range to reconstruct the scene objects as shown in *Figure 3*.

Inertial Navigation System (INS) coupled with IMU sensor or Direction speaker (parametric speaker) are alternatives to the above-mentioned techniques. Directional speakers use ultrasonic waves of shorter wavelength to travel to another point, which allows the sound to travel in a given direction with very little or negligible dispersion of sound. Thereby, it is often used by military and police to distress crowd or during collection of sea vessels.

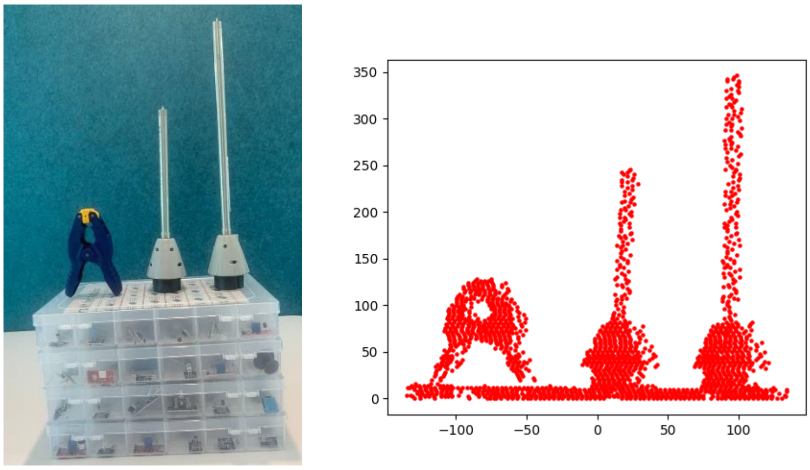

Figure 3. 2D reconstruction using LiDAR (a) Actual scene (b) Reconstructed scene in distance range

3.2 Problem Statement 2 (PS2)

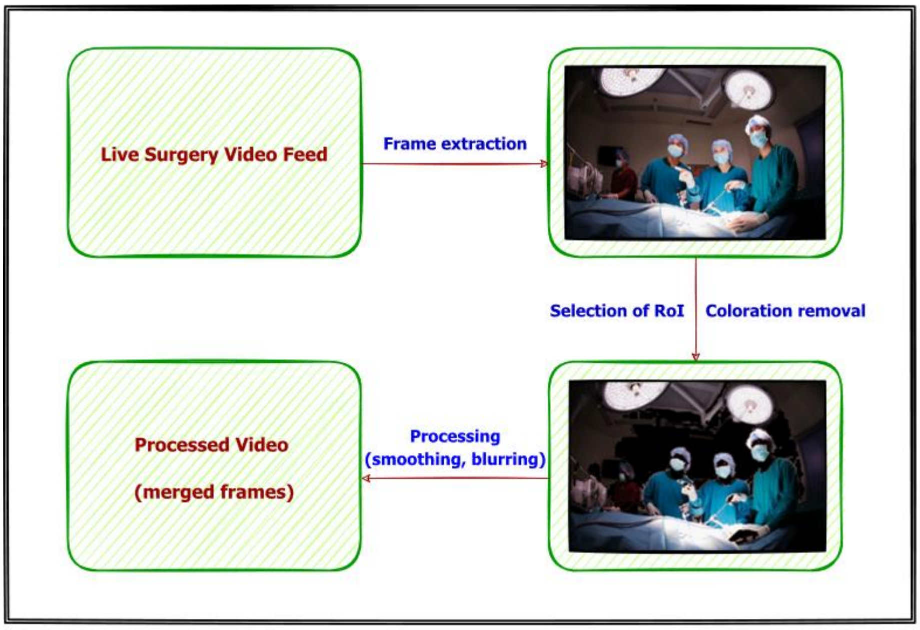

Figure 4. Workflow for Color-based filtering of laparoscopic video feed

The proposed framework for PS2 can be implemented by modifying trocar using certain electromechanical sensors that detects the relative position of the laparoscopic camera. When the camera is outside the trocar, color-based masking of the surgical scene is done based on pre-decided and (or) real-time coloration input and selected Region of Interest (RoI). This helps in real-time elimination of certain types of confidential information and can be used as a pre-processing element for DS1, thereby reducing storage and computational requirements.

4 References

The following items have had a significant contribution in shaping up this project. In addition to these, several other papers and articles have been reviewed.

1 : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7388795/
2 : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC539626/
3 : https://www.nkch.org/find-a-service/surgery/minimally-invasive-procedures/laparoscopy
4 : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7347828/
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