Development of Hybrid System for Minimally Invasive Surgeries.

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ABSTRACT

- Minimally Invasive Surgery(MIS), although advantageous compared to open cavity surgery in many aspects, is not widely accepted by surgeons for clinical application. This is due to cost and required complex training requirement of the currently practiced technology.
- As a first step in making MIS affordable and easy to use, quality images inside the patient body as well as accurate position of surgical tool should be provided in real time. Furthermore, It is necessary to have flexible surgical arm capable of following curved paths to avoid damaging patient organs when moving the surgical tools inside the body.
- In this work, three asynchronous sensors were calibrated and information were fused together in real-time spatially and temporally in such a way that the fused information will be useful to perform successful MIS. Furthermore, A complete design of flexible surgical arm system is proposed. It is believed that the result of this work will have practical impacts in advancement of MIS and the use of flexible surgical arm in minimally invasive surgeries.

INTRODUCTION

- MIS does not require opening the patient body to perform surgical procedure.
  - Advantages: faster recovery, shorter hospital stays, less pain, decreased scarring
  - Limitations: restricted visualization of operative site, minimal accessibility, and reduced dexterity.
  - Requires practical MIS system with flexible surgical arm.
- Da Vinci surgical robot [1]
  - First Surgical Robot Approved by FDA for commercial use
  - High procurement cost and special training requirement for operating surgeon; Rigid surgical arm.

PROPOSED SYSTEM

- Online Calibration using three heterogeneous sensors, Fig. 1.
  - Laser Range Scanner (LRS): Emulates Preoperative CT/MRI
  - Videoscope: Provides real-time images inside patient body (62frames/sec).
  - Electromagnetic Tracking System(EMTS): Provides positional information inside patient body (40 Hz).
- Flexible Surgical Arm System

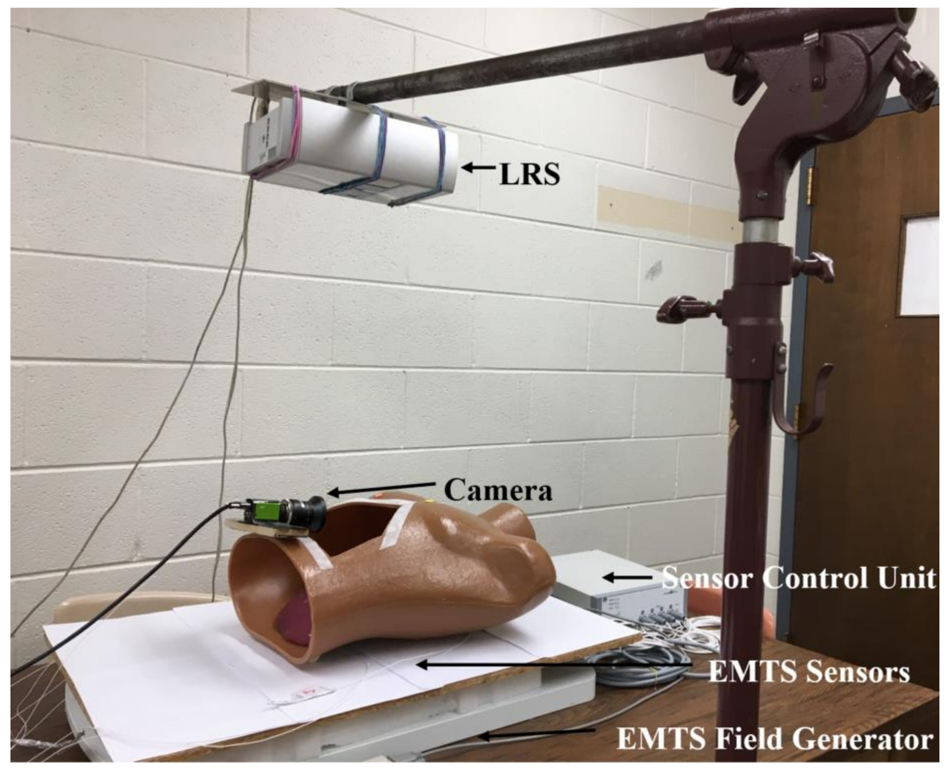

Fig. 1: Proposed Hybrid System

ONLINE CALIBRATION

- Sensors operate with reference to different coordinate frames and report measurements in different data rate based on different clocks. [2]
- Combination of online Spatial and Temporal Calibration
- Prerequisite- Offline Spatial Calibration, Fig. 2.
- Offline Spatial Calibration (Sensors Stationary)
  - Determination of spatial transformation parameters among coordinate frames.
  - Transfer all sensor data in LRS coordinate frame: Absolute Coordinate Frame.

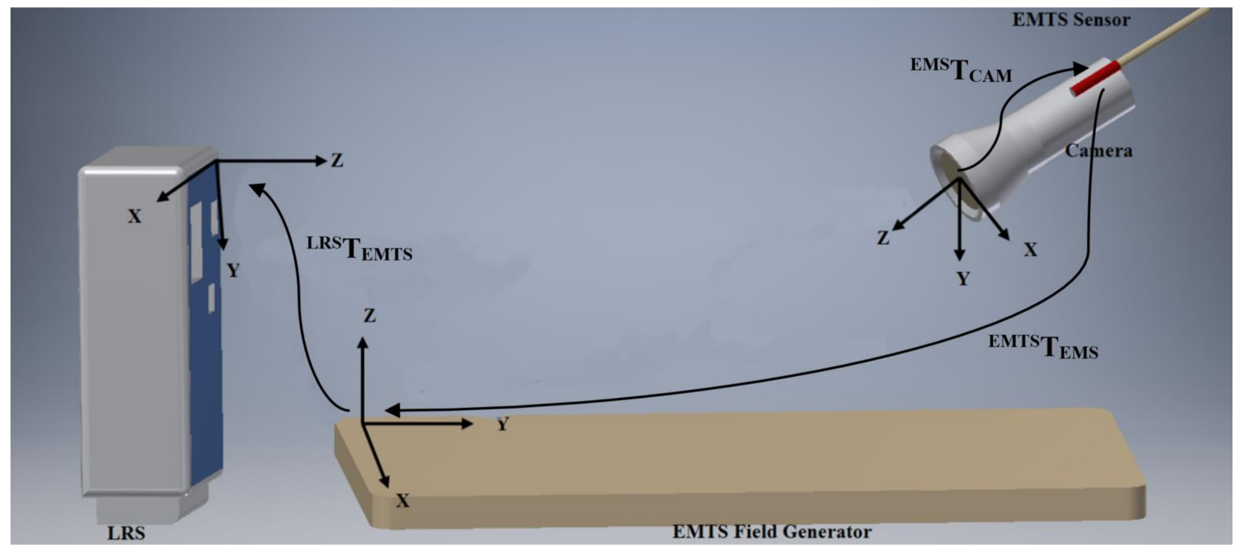

Fig. 2: Spatial Calibration Among Sensors

- Online Spatial Calibration (Sensors in Motion)
  - One Electromagnetic Sensor (EMS) attached to camera body to accommodate changing Camera-LRS, Camera-EMTS transformation, Fig. 2.
- Temporal Calibration
  - Time Synchronization of spatial data from multiple asynchronous sensors.
  - Timestamp sensor data with reference to computer: Absolute Time Reference.

FLEXIBLE SURGICAL ARM

- Internal actuators, simplified control, low cost, minimum training.
- Motion control: can be achieved using multivariable to control each joint.
- Three major sections: Flexible Arm, Off Body Drive Mechanism, Inner Body Control, Fig. 3.

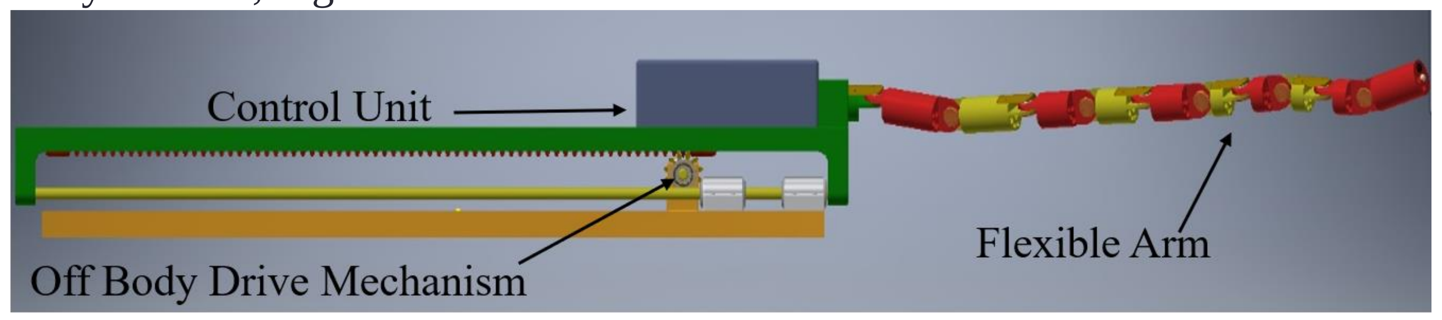

Fig. 3 Proposed Flexible Surgical Arm

- Flexible Arm
  - Multi-micromotor mechanisms with embedded encoders, Fig. 4.
  - Varying length discrete rigid links: nearly continuum behavior near organ of interest while simplifying control by limiting number of micro-motors.
  - Dedicated channels for exchange of surgical instruments.
- Off Body Drive Mechanism: One-DOF configuration
- Inner Body Control
  - Piezoelectric micro-motor for actuation.
  - Embedded optical encoders at each joint for feedback, EMS for tip tracking, Fig. 5
  - Real-time images from camera for further validation by surgeon.

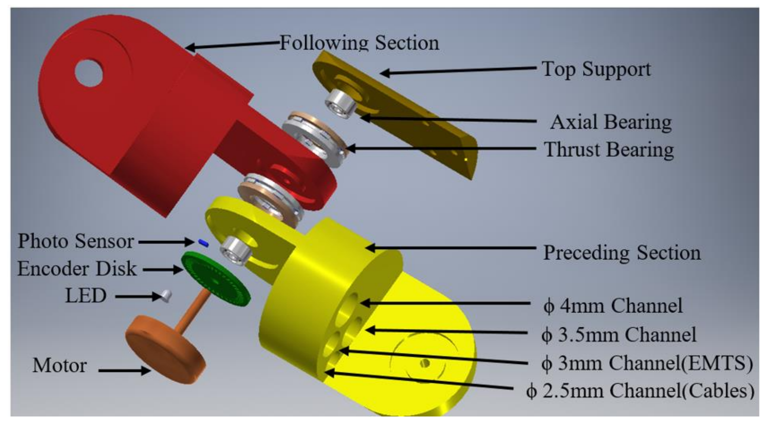

Fig. 4 Disassembly of Single Joint

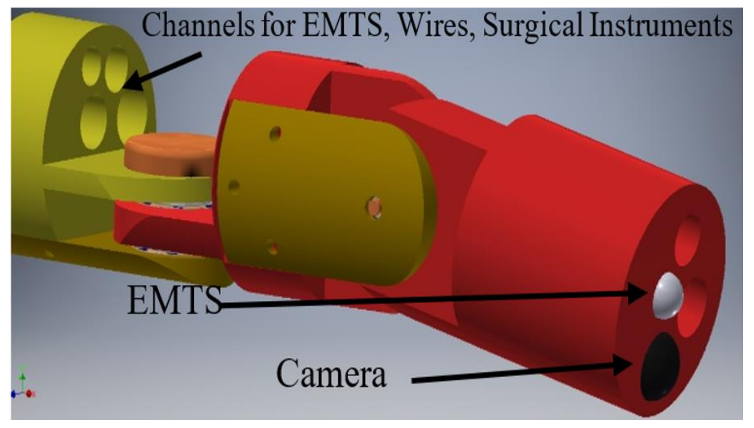

Fig. 5 Final Section of Flexible Arm

EXPERIMENTAL RESULTS

- Accuracy Evaluation
  - Based on data transformation from LRS-EMTS-2D Camera image.
  - LRS to EMTS: 1.3511±0.9321mm,2.6019±1.5239 mm, 1.1325±0.9285 mm along x, y, and z axis respectively.
  - EMTS to Camera: 0.1081±0.0606 mm, 0.0872 ±0.0298 mm along x, and y axis respectively.
- Realtime Guidance System
  - Guides surgeon in real-time to reach to the destination in LRS coordinate frame by avoiding obstacles with real-time feedback from camera and EMTS, Fig. 6.

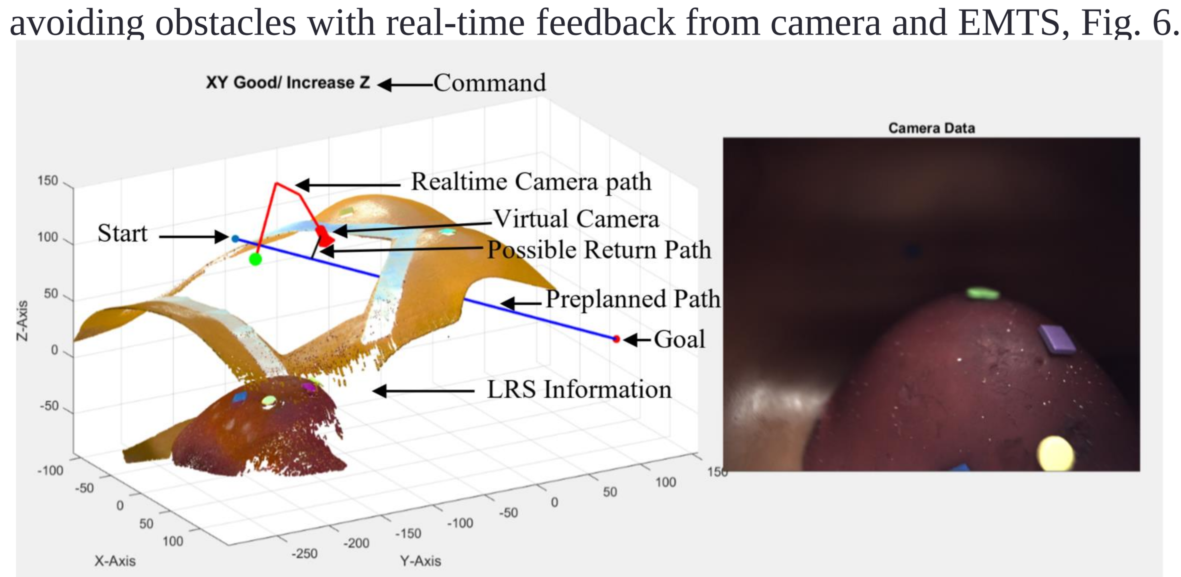

Fig. 6 Real-time Guidance System

DISCUSSIONS

- Developed a hybrid system for integrating real-time information from three heterogeneous sensors: LRS, EMTS, and camera; sufficient for conducting successful minimally invasive surgery.
- Proposed discrete rigid link flexible surgical arm to be used in minimally invasive surgeries and tested with dynamic simulation.

CONCLUSIONS & RECOMMENDATIONS

- It is believed that the result of this work will have practical impacts on making MIS more affordable, and flexible surgical arms more accurate and user friendly than existing counterparts.
- Recommendations
  - Realtime overlaying of camera image on the top of LRS/CT/MRI image.
  - Development of multivariable control algorithm for flexible arm.
  - Make current arm length adaptive in size by adding/removing joints without redesigning the arm.

REFERENCES

1.N. Ishikawa et al, "The da Vinci surgical system versus the radius surgical system". *Surgical Science*, vol. 3(7), pp. 358-361, 2012.

2. M. Feuerstein *et al*, "Magneto-optical tracking of flexible laparoscopic ultrasound: model-based online detection and correction of magnetic tracking errors," *IEEE Trans. Med. Imaging*, vol. 28, *(6)*, pp. 951-967, 2009.