Real-time electromagnetic tracking of orthopaedic pins for robot-assisted fracture surgery

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INTRODUCTION

Traumatic fractures often involve large incisions where broken bone fragments are manually aligned and secured together using a metallic plate and screws, or intramedullary nails, leading to long stays in hospitals and place a burden on the National Health Service (NHS) [1]. To reduce recovery time and risk of infection, percutaneous techniques, using 2D intra-operative medical imaging, have been developed which allow the surgeon to manipulate the fractured fragments using pins, through small incisions in patient's flesh [2].

Robotic assistance and image guidance could have a positive impact on fracture reduction accuracy and pre- and intra-operative 3D imaging. Robot-assisted fracture surgery (RAFS) system is under research at Bristol Robotics Laboratory [2] with the aim to perform fracture reduction surgeries that involve joints using orthopaedic pins attached to the bone fragments which have to be tracked in real-time. The current RAFS system (Fig.1) consists of: 1) two *Robotic Fracture Manipulator (RFM), 2) Two Carrier Platform (CP), 3) one External Robot (ER), and 4) one System Workstation (SW).*

The system workstation supports the surgeon to operate RAFS and provides real-time navigation using an optical tracking system (Polaris Spectra, NDI Inc.) which tracks pins' pose in real time and allows accurate repositioning of fracture fragments. It consists of a graphical user interface (GUI) that enables the surgeon to interact with the robotic system and allows manipulation of the 3D models of the broken bones generated by the pre-operative CT data. The optical tracker also provides intra-operative image guidance by updating, in real time, the position of the 3D models of the bones during the surgery, through optical tools placed on the orthopaedic pins inserted into the bones. The tracking system requires line of sight between the optical tracker and the optical tools at any time [3]. Unfortunately, given the complexity of the robotic system an the procedure, this is not always achievable, thus representing one of the main limitations of this tracking methodology.

OBJECTIVES

Tracking devices are an essential component in image guided surgery particularly when precise treatment or implant positioning are required. In this paper we explore the use of an electromagnetic tracking device (Polaris Aurora, NDI Inc.) as an alternative to the optical tracking system within the RAFS platform. The proposed solution includes:

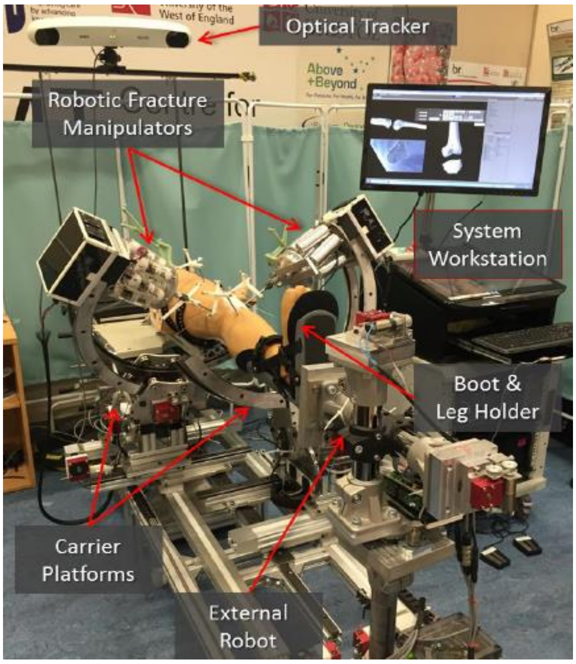

Figure 1 RAFS surgical system [3]

1. Development of a software to calculate the actual pose (position and rotation) of the pin in the workspace;
2. Design and development of a novel orthopaedic manipulation pin with an embedded electromagnetic tracking sensor;
3. Comparison of the performance of the two tracking systems in RAFS context.

METHODOLOGY

A graphical user interface (GUI) for NDI Aurora was created in LabView. The first step involved analysing a simplified version of the existing LabVIEW user - interface for Polaris Spectra, NDI.

To verify Aurora's volume, measurements were made in the cube and dome mode (i.e in the different volume modes of Aurora's data acquisition) with both the reference sensor (Aurora 6DOF Reference) and the measurement sensor (Aurora 6DOF Cable Tool).

Measurements were carried out on a flat table, away from ferromagnetic metals as much as possible.

To create a new orthopaedic pin with embedded electromagnetic sensor, an existing orthopaedic pin (please refer to the pin described in [3]) was modified.

In order to insert the sensor in the pin's distal tip, to facilitate alignment with the optical tool, a thin cavity was created inside the pin's body. As a result, the sensor was aligned with the longitudinal axis of the pin and placed as closest as possible to the end of its threaded section (Fig. 2).

Finally, we have tested accuracy of the new pin on ex-vivo animal samples. Bending tests were performed using a pork leg. Furthermore, a comparison of the two tracking systems has been performed.

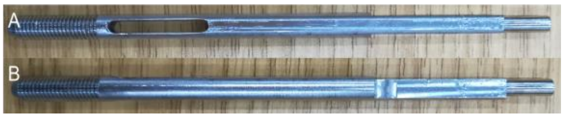

Figure 2 New orthopaedic for electromagnetic sensor. 2-A: front view with the anchoring system section and the cavity, 2-B: side view.

RESULTS

The relative pose of the Aurora sensor and the Polaris optical tool (both placed in one pin as shown in Fig.3A) was measured with respect to their references (placed on another pin with a fixed and known position as shown in Fig. 3B). A LabVIEW user interface was created to acquire actual and relative poses of the Aurora and Polaris sensors. In order to better understand the pin's dynamics, manipulation forces were measured through a load cell placed on the top end of the pin (Fig. 3A).

Before starting the data acquisition, the relative pose between the optical tool and the electromagnetic sensor was settled to zero. The orientation, represented as roll, pitch and yaw, was a way to represent an object's orientation through the angles of the principal axis, respectively. The numerical derivative of the relative difference of the Aurora pose relative to Polaris pose measurement was calculated (Fig 4).

It is observed that when forces are applied, there is an increase of the position and orientation difference, being greater in x-axis, because the hole for placing the electromagnetic sensor, which is along this direction, makes the pin more fragile, increasing the probability of bending. When force is applied to y-axis, bending is observed which can be due to the geometry of the pin. In z-axis, the peaks observed can be neglected since, in those time frames, no forces were applied in this direction.

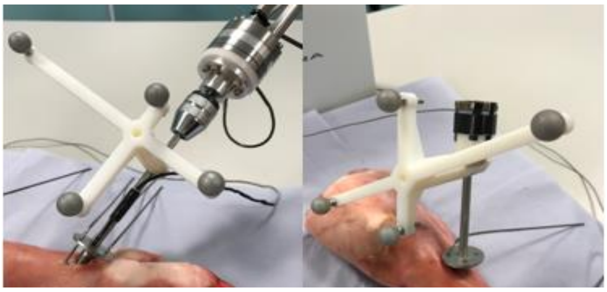

Figure 3 Attached pins. A: electromagnetic pin with embedded Aurora's sensor, Polaris' optical tool and load cell. B: reference pin, Polaris' reference optical tool and Aurora's reference sensor.

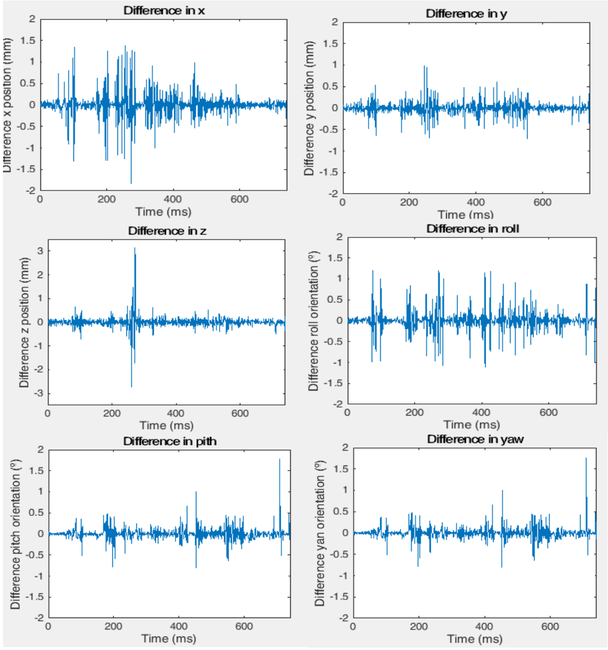

Figure 4 Relative difference of position and orientation in time

DISCUSSION AND FUTURE WORK

After the experimental tests, it was obvious that Aurora system has a smaller workspace, when compared to Polaris optical tracking system, but, despite magnetic field interferences from ferromagnetic materials, Aurora has the added advantage of not requiring a line-of-sight. The pin, however needs redesigning to avoid bending. In a clinical environment, higher forces and torques could be applied and pin bending might compromise the accuracy and safety of the surgical procedure. A prototype of a new orthopaedic pin with the space for an embedded electro-magnetic sensor is required, to include a larger section where the cavity is created.

In addition, the surgical robot will have to be modified to remove all ferromagnetic materials, in order to obviate interference with the Aurora system.

REFERENCES

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