Mid-term report

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Introduction

To effectively perform knee replacement surgery, the surgeon must balance many forces and recreate knee geometry to a high degree of precision. Currently, geometry is measured using a set of infrared cameras and reflective markers fixed to the patient, however, this approach can be cumbersome as calibration is complex and important data is hidden behind proprietary technology.

This project will develop a system to run in parallel to existing technology while fixing many of the existing limitations. Firstly, the solution space of alternative technology will be explored, then a system engineering framework will be used to develop a concept. The concepted developed will be realised into a prototype and tested.

This mid-term report will cover the fundamental design developed, literature studied, and the concept developed. This will be followed by an overview of the project so far, a discussion of issues, risks to the project and projected outcomes.

Scoping

The scope of this project includes how data is gathered using sensors, how it is transmitted and rudimentary data processing as shown in table 1.

Functions included
Data and error from sensors
Power to sensor unit
Data processing up to finding required angles
Functions excluded
Sensor mechanics and operation details
Mechanical design and attachment to patient
Use of required angles
Communication methods between subsystems

Table 1, project boundaries

Design requirements

No.	Category	Name	Description
R.1	Data	Accuracy	Measurements are sufficiently accurate
R.2	Data	Sampling rate	Sample rates are sufficiently fast
R.3	Data	Data processing	Data is processed accurately and fast enough
R.4	Setup	Setup	The system is simple, fast and easy to setup
R.5	Setup	Ease of calibration	The system is simple, fast and easy to calibrate
R.6	Operation	Size and comfort	Device does not hinder surgical procedures
R.7	Operation	Battery life	Device will last a surgical procedure
R.8	Other	Interfacing	System interfaces with other tools effectively
R.9	Other	Independence	System is not dependant on any proprietary technology

Table 2, Design requirements

Sensor domain review

To ensure a thorough exploration of the solution space, a review of relevant literature was conducted. This review mainly studied indoor localisation techniques, however, use cases are very broad and there is no universally dominant technique for measuring positions and angle. However, solutions could be categorised into five domains.

While the aim of this project is to estimate orientation of a sensor, most of these domains allow for direct measurement of orientation, but for those that do not, orientation can be inferred from estimating the position of several markers. Therefore, the problems of estimating position and estimating orientation will be considered equivalent.

- Optical
- Inertial
- Ultrasound
- Radiofrequency
- Magnetic

Optical

The system created will be designed to operate conjunction with existing optical tracking systems. Adding more optical cameras to the operating theatre will create unnecessary complexities and does not meet the aim of this project and hence will not be considered as an option. Moreover, this violates the independence (R.9) requirement.

Inertial

Inertial systems rely on the measuring apparent forces created in accelerating and rotating reference systems. A typical inertial measurement unit (IMU) consists of an accelerometer to measure linear acceleration and gravity, and gyroscope to measure angular velocity. Most systems rely on integrating these measurements in some sense to estimate position and orientation. However, in integrating these measurements, *sensor drift* is introduced into the results and need to be addressed.

One common method of eliminating sensor drift is adding a magnetic compass to directly measure orientation. A magnetic compass addressed drift in orientation estimates but not position estimates.

Since the problem being studied only requires an estimate of orientation, the combination of accelerometer, gyroscope and magnetic compass is sufficient.

Accuracies very depending on cost but a typical IMU for less than 100 AUD will have an accuracy in the order of 1 degree.

Ultrasound

Ultrasound is commonly used in medical settings; however, its main drawback is that the signal attenuates rapidly in air. Frequencies can range from 40kHz to 2MHz, choosing a low frequency will mean the signal penetrates air better and have greater range but will not be as accurate as higher frequencies. All the solutioned explored by Runge et al that transmit though have an accuracy in the order of 10cm or greater.

Radiofrequency (RF) signal positioning

Radiofrequency based positioning has by far the most literature of the options with technologies such as Wi-Fi, Bluetooth and RFID being explored. However, these mostly seem to study localisation on a greater scale, where an accuracy between 10cm to 1m is considered acceptable (Obeidat et al, 2021).

Magnetic positioning

Magnetic positioning can be classified into three sub-categories, those that rely of Earth's magnetic field, artificial AC field and artificial DC fields. Since measuring earth's ambient magnetic field is common in inertial based systems, this will be excluded from the magnetic positioning domain. Magnetic field.

A DC magnetic field can be generated from a permanent magnet. Accuracies were in the order of 1mm, and between 1-10 degrees (Pasku et al, 2017; Shirai et al, 2020).

AC magnetic fields can be generated by running an AC signal though a wire coil. Compared to a DC system an AC system is less prone to noise and has improved accuracies of 1mm or 1 degree (Pasku et al 2017).

Evaluation of sensor options

Comparing the specifications found in the review conducted primarily relate to two of design requirements (table 3). The magnetic and inertial systems both have considerable accuracy, however, the magnetic system will require more equipment and may have interference from ferrous metals.

Therefore, in conclusion, the inertial sensors are the best option for measurement concept given the results conducted in the review.

	Inertial	**Ultrasound**	**RF**	**Magnetic**
Accuracy (linear) (R.1)	-	10 cm	10 cm	1mm
Accuracy (angular) (R.1)	1 degree	-	-	1 degree
Setup (R.4)	On leg sensors	-	Array of transmitter / receivers	Coil, on leg sensors

Table 3, evaluation of sensor options

Current work and Issues

Beyond the work presented in this report I have developed the essential mathematics to process and interpret measurements. In addition to this I have developed a simple simulation to test the theory developed and begin to define some design validation procedures.

So far in the project there has been minimal significant issues.

The aim and scope of the project are still vague and are constantly being changed. This makes deciding on task priority and relevance difficult, despite this the project is still going well.

Further work and project risks

Coming up I aim to be working with physical sensors, retrieving measurements and programming data processes. Beyond this I aim to develop more tests for the system and work on define more thorough performance metrics. Finally, if there is additional time at the end of the project, I may begin broadening the scope working on wireless data transfer and mechanical housing and attachments as summaries in the list below, ordered in descending priority.

- Program a processor to retrieve measurements from sensor.
- Design and implement a data processing pipeline for measurements.
- Create definitive performance metric for the system.
- Test system against metrics, including simulations.
- Design the mechanical attachment onto leg.
- Test the system in-vivo.
- Design a wireless data transfer system.

References

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