**Real-Time Position Tracking of Wireless Medical Devices by analyzing Changes in a Magnetic Field at Pre-Determined Points**

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# 1 Background

As the demand for increasingly advanced invasive medical procedures rises with the average age of the population, it also becomes increasingly compelling to facilitate and extend the spatial awareness and dexterity of surgeons, both human and robotic. One may accomplish this by tracking an object digitally and representing its motion in a virtual representation of the area around the incision. Several groups across a diverse range of academia and industry have competed to develop better and better methods of digitally tracking objects [CITATION HERE]. In the entertainment industry in particular, object tracking is a fundamental way of bringing life-like motion to an object represented in virtual space. The generally accepted approach is to use large, complicated, and expensive computer vision (CV) systems to yield real-time tracking [CITATION HERE]. However, this approach is not suited for medical applications; CV is limited by a strict field of view. Accurately tracking surgical instruments inside of organic tissues must then be done another way.

Of the methods investigated by others [CITATION medical context as magnetic field sensing. Human tissues are permeable to magnetic flux, and magnetic fields are well characterized. Upon this motivation, we have constructed an inexpensive device from off-the-shelf parts that enables the tracking of a permanent magnet on a complex surface to serve as a foundation for future work in this field.

# 2 Methods

Electromagnetic fields are well characterized by fundamental principles. Given a magnetic dipole, its magnetic induction can be expressed as:

|  |  |
| --- | --- |
|  | (1) |

Whereby the relationship is dependent on the orientation of the magnet and the strength of its magnetic moment, given by , as well as the location of the arbitrary point of interest with respect to the center of the magnet, represented by . Equation (1) can be modified to express the strength of the magnetic field **,** which is what an observing magnetometer would perceive; which may further be broken into a more convenient polar component form:

|  |  |
| --- | --- |
|  | (2) |
|  | (3) |

Equation (2) refers to the tangential component of the total magnetic field vector perceived by a magnetometer. Equation (3) refers to the radial component. From a similar approach one may also arrive at vector components in any Euclidean space.

Based on the work of, [DIRECT CITATION], expressing the location of the center of the magnet with respect to the magnetic field vectors observed of three sensors in predefined relative positions satisfies this system of equations:

|  |  |
| --- | --- |
|  | (4) |
|  | (5) |
|  | (6) |
|  | (7) |
|  | (8) |
|  | (9) |

However, one must maintain certain minimum assumptions for the solutions to numerically converge.

1. An origin must be defined.
2. The constant value of the magnetic field strength constant K of an arbitrary magnet has been ascertained to within [INSERT TOLERANCE].
3. A constant magnetic field source of perceivable threshold exists within [RANGE] distance from at least 3 sensors in the sensor array.

In addition, to refine accuracy, certain physical restrictions facilitate these conditions.

1. Ambient magnetic fields must be mitigated; or the signal must be otherwise overcome.
2. The magnet’s physical factor is minimized to yield closer adherence to mathematical principles.

Achieving these conditions, we presupposed the sensor in the bottom left corner of our array to be the origin. The [INSERT MODEL] IMU sensors have manufactured-set axis orientations on the breakout; in the array they are aligned with each other.

Calculating the value for K can be done procedurally. A proof of concept was completed by hand. We have done this precisely using a CNC machine. As follows:

1. [MOE]
2. [KNOWS]
3. [HOW]
4. [BECAUSE]
5. [HE’S]
6. [SMART]

[INSERT PICTURE OF ARRAY]

The first device consisted of a pair of IMUs across from each other calculating the distance to the magnet and triangulating a location from there. Additional sensors were added to enable limited 3D tracking and extend the range. It is comprised of 6 [INSERT MODEL] IMUs arranged in a circular pattern around a central area. They are switched to by a [INSERT MODEL] multiplexer, and data is driven through the core [INSERT MODEL] Arduino via I2C. This information is then lightly manipulated and output, line by line, through Serial Bus to a capable Python script on a PC.

Further optimization is necessary, especially to trim computation time to allow for a smoother refresh rate on a real-time display. We did our best to address this by constraining our possible solution space and by carefully picking initial values for numerical solvers driven by [INSERT METHOD]. The development of more efficient hardware arrangements is left as future work. For now, the

* **Outline of analytical foundations**
  + **Fundamental concepts on EMF**
  + **Identify constraints/assumptions**
  + **Deriving a value of “K” for an arbitrary magnet**
  + **Empirical approx. of K**
* **Summary of system iterations and design inspirations.**
* **Exhaustive explanation of devices and system configuration.**
  + **A nice “Fig. 1”**
* **Explanation of computational approach**
  + **Identify key libraries and modules**
  + **Newton-Raphson Method**
  + **Optimization approach**

***>>>VERY ROUGH DRAFT<<<***

The computation approach starts with the Teensy 3.2 MCU. The sketch begins by calibrating the IMUs, this process is crucial as it allows the IMUs to neglect the ambient magnetic fields due to earth’s own magnetic field and the surrounding equipment. The process requires that the permanent magnet be at least [**XYZ METERS**] away from the IMU grid. Fifty data points are then collected and averaged as a base reading. When the calibration process is done, the base reading is then subtracted from the subsequent readings; this permits the IMUs to read the magnetic field of the permanent magnet without accounting for ambient magnetic fields.

Now that the magnetic field is obtained, a Python script is responsible for pooling the data from the Teensy MCU and performing the required calculations in order to obtain the position of the permanent magnet. The system of equations that govern the calculation of the permanent magnet’s location is characterized as a system of non-linear equations and as can be observed from [**EQN #XYZ**], no closed form (analytical) solution exists, thus the need for a numerical approach arises. Due to the nature of the problem at hand, the Levenberg-Marquardt algorithm (LMA) was chosen for its robustness and speed of convergence. Furthermore, given that the LMA combines Newton-Raphson’s algorithm and Steepest Descent, LMA converges to a solution even if it starts far off. A readily available LMA is written in Python and is provided by the [**scipy.optimize**] module.

The grid of IMUs constructed consisted of six SparkFun LSM9DS1 sensors, each sensor providing one equation for a total of six coupled equations, rendering the system of equations overdetermined. The LMA provided by the [**scipy.optimize**] module is not equipped to handle overdetermined systems and thus the need for an optimization process was needed. This was done by first calculating the L2 norm of the magnetic field and then determining which sensors are closer to the magnet. Clearly, the highest three L2 norms corresponded to the sensors that are closest to the magnet, and thus the relevant equations of those sensors were fed into the LMA for obtaining the position.

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# 3 Results

* Examples of data plot
* Speed of the data
* Accuracy and precision
* Discuss permeability of materials to magnetic flux

The Results section describes the evaluation of the design or the experimental methods.

# 4 Interpretation

The Interpretation section provides an interpretation of the results and conclusions of the study.

* Limitations of the approach
  + No visualization of the orientation of the magnet, yet.
  + Only one magnetic point at a time.
* Other calibration considerations
* How to improve!
  + Optimize software.
  + Improve data sampling rate.
  + Redress fundamental principles; higher abstraction models.

# References

References follow ASME style, described in See the “Writing a Technical Paper or Brief” section, under Guidelines at the ASME Journal Tool Author Help (<http://tinyurl.com/43chze9>)

* All references need to be complete citations with ALL authors listed (As per style et al. is not allowed in the reference list.), starting page number and ending page number, doi if available, etc. **examples:**
  + Brigitte, M., Max, S., Juergen, H., Peter, M., Bernd, K., & Eckhart Georg, H. (1999). Disposable-sheath, flexible gastroscope system versus standard gastroscopes: a prospective, randomized trial. Gastrointestinal Endoscopy, 50461-467. doi:10.1016/S0016-5107(99)70066-0
  + Ma, J. and Kim, H. M., 2014, “Continuous Preference Trend Mining for Optimal Product Design With Multiple Profit Cycles,” J. Mech. Des., 136(6), 061002, doi: 10.1115/1.4026937

[FORMATTING NOTES]

* Entire paper is two to four pages. Top and bottom page margins are one inch so that total text height is 9 inches. There are two columns, with the title area being in the first column. Columns are 3.125 inches wide and the spacing between the two columns is 0.25 inches for a total text width of 6.5 inches. Columns are justified left and right.
* Font for title, headers, body text is Times. Body text is 9 point. Title is 14-point bold. Authors and affiliation are 11-point with author names in bold..
* New paragraphs are indented by 0.2 inches, no blank line between paragraphs.
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* Provide definition for all acronyms. Example: deep brain stimulation (DBS)
* When in doubt, look at an article in an ASME journal.