Evaluation Form – Technical Background Review

Student Name: Jonathan Park

Project Advisor: Dr. Jennifer Hasler

Team Name: A novel detection method for mTBI

Team Members: Sean Kim, John Tarasidis, Joo Won Lee, Brian Sang

_____ / 30   Technical Content
- Current state-of-the-art and commercial products
- Underlying technology
- Implementation of the technology
- Overall quality of the technical summary

_____ / 30   Use of Technical Reference Sources
- Appropriate number of sources (at least six)
- Sufficient number of source types (at least four)
- Quality of the sources
- Appropriate citations in body of text
- Reference list in proper format

_____ / 40   Effectiveness of Writing, Organization, and Development of Content
- Introductory paragraph
- Clear flow of information
- Organization
- Grammar, spelling, punctuation
- Style, readability, audience appropriateness, conformance to standards

_____ / 100   **Total - Technical Review Paper**

Inertial Measurement Unit as Low-Power Wearable Sensor

Introduction

To conserve power, many devices will only wake from a low-power state if triggered by a particular external event that is relevant to the necessary processing task. Inertial measurement units (IMUs) can accomplish this functionality by capturing acceleration and rotation disturbances as triggers for computational methods that are dependent upon large collisions or specific gestures. This paper reviews IMUs that are commercially available for wearables, the important technology features of IMUs, and implementation considerations for an effective IMU sensor in a wearable application.

Commercial Applications of IMUs

Many personal electronic devices require the ability to track bodily movement in a low-power and cost-efficient manner. Due to their multi-axis sensing capabilities, IMUs are utilized today in wearables, such as smart watches and fitness trackers, augmented reality glasses, and video game controllers [1]. In these wearable and controller applications, the IMU can detect specific body or hand gestures, such as walking up a set of stairs [2]. While the cost of the finished consumer product varies based upon the complexity of other hardware components, IMUs can also be purchased as standalone units. Sparkfun sells a breakout board that is geared toward individual use and breadboard prototyping for $15.95 with an ST LSM9DS1 IMU mounted onto a printed circuit board (PCB) [3]. The on-board chip supports nine degrees of freedom (three for each of acceleration, angular rotation, and magnetic force) and both I2C and SPI interfaces. Because of these features, the Sparkfun product is sufficient for rapid prototyping and academic applications, but with its 1.9 mA minimum current draw and a form factor similar in size to a quarter, it is ill-suited for products that require hard power, size, or cost constraints [4].

Bosch Sensortec manufactures low-power 6-axis IMUs that sell for $5.58 [5]. The Bosch Sensortec BMI270 is capable of reducing current draw to 3.5 μA during low-power operation, which is three orders of magnitude less than the 1.9 mA drawn by the Sparkfun board during its low-power mode [1], [4]. The BMI270 also has built-in registers to support significant motion and wrist gesture detection. The lack of a magnetometer on the BMI270 limits its dead reckoning and error correction ability, but since collisions do not necessarily influence directional heading, this is not a large drawback for a collision detection sensor [1].

Technology Features of IMUs

The IMU is a sensor that combines the functionality of an accelerometer, which measures linear acceleration along three axes, and a gyroscope, which measures angular velocity along three axes, into a single unit; this allows the IMU to measure up to six degrees of freedom [3]. The IMU may also contain a

magnetometer, which would allow the IMU to sense up to nine degrees of freedom [6]. Many low-cost IMUs today utilize microelectromechanical systems (MEMS) technology, which allows for much smaller and cheaper technology than traditional sensors [7]. The MEMS accelerometer is manufactured by connecting a small, movable mass to a supporting stator with springs. The stator and mass are capacitively coupled through electrodes. Movement of the mass produces changes in the capacitance, which, along with the elastic forces on the springs, can be sensed to determine linear acceleration data [8]. The MEMS gyroscope contains two movable masses that are capacitively coupled to a stator. One mass functions as a driver with constant oscillation, and the other mass rotates about the stator. The rotational movements of the two masses subjects each of them to a Coriolis force, which reveals angular velocity of the system through calculation [6], [8].

Like any real-world sensor, the IMU is not perfectly accurate. While a small error will not drastically affect a single reading, the errors compound when integrating multiple data points, causing drift [6]. The drift can be mitigated by a complementary filter that calculates a weighted average of both the acceleration and angular velocity data or a Kalman filter [6], [9]. The ability to minimize error through complementary filtering methods is an advantage of IMUs over pure accelerometers and gyroscopes, which have less degrees of freedom. Low-pass filters can eliminate high frequency noise that may be introduced by slight instability of the sensor. IMUs such as the Bosch BMI270 [1] may have a configurable low-pass filter built into the chip.

Implementation of IMUs for Wearables

The integration of an IMU into a wearable will require communication with a microcontroller over an interface such as I2C or SPI. The microcontroller can remain in a low-power state until the IMU detects an event of significant magnitude. The microcontroller will then analyze the raw data from the IMU to determine the relevance of the event detected by the IMU and take the appropriate action. Depending on the specific constraints of the product, the complementary filter approach to minimizing drift can be modified. Modifying the respective weights of the acceleration and gyroscope data will affect the speed and sensitivity of the system; increasing the weight of the accelerometer data will generate a more sensitive but unstable system [6].

A study [10] attempting to algorithmically determine collisions with acceleration data in a rugby game incorrectly identified collision events at a 45% rate. These false positives are common in sports applications due to quick acceleration changes that are not due to player-player impacts, such as jumping or falling on the ground. Results from [2] show distinct signatures in acceleration data for similar movements such as nodding off and looking up. While [10] only looked for events crossing a set threshold (3.5 g-force), [2] demonstrates that comparing patterns over time may be a more accurate

approach to determining whether a specific behavior occurred. A reliable gesture or collision detection system must be able to distinguish between events of similar magnitude.

[1]   Bosch, "6-axis, smart, low-power Inertial Measurement Unit for high-performance applications," BMI270 datasheet, Jun. 2020.

[2]   P. Li, R. Meziane, M. Otis, H. Ezzaidi, and P. Cardou, "A Smart Safety Helmet using IMU and EEG sensors for worker fatigue detection," In Proc. 2014 IEEE International Symposium on Robotic and Sensors Environments (ROSE) Proceedings, Timisoara, 2014, pp. 55-60.

[3]   Sparkfun, "SparkFun 9DoF IMU Breakout - LSM9DS1," [Online]. Available: https://www.sparkfun.com/products/13284. [Accessed Oct. 10, 2020].

[4]   ST, "iNEMO inertial module: 3D accelerometer, 3D gyroscope, 3D magnetometer," LSM9DS1 datasheet, Nov. 2014.

[5]   Mouser Electronics, "BMI270 Bosch Sensortec," 2020. [Online]. Available: https://www.mouser.com/ProductDetail/Bosch-Sensortec/BMI270?qs=u16ybLDytRYIj%252BjQEee88A==. [Accessed Oct. 9, 2020].

[6]   A. Cismas, M. Ioana, C. Vlad, and G. Casu, "Crash Detection Using IMU Sensors," In Proc. 2017 21st International Conference on Control Systems and Computer Science (CSCS), Bucharest, 2017, pp. 672-676.

[7]   ST, "MEMS (Micro-Electro-Mechanical Systems)," 2020. [Online]. Available: https://www.st.com/content/st_com/en/about/innovation---technology/mems.html. [Accessed Oct. 10, 2020].

[8]   B. Simoni and C. Valzasina, "Microelectromechanical device incorporating a gyroscope and an accelerometer," U.S. Patent 10,598,690, 9 Dec., 2015.

[9]   N. Perkins, R. McGinnis, and B. Copple, "IMU system for assessing head and torso orientation during physical motion," U.S. Patent 10,293,205, 26 Jan., 2015.

[10]   A. Clarke, J. Anson, and D. Pyne, "Proof of Concept of Automated Collision Detection Technology in Rugby Sevens," *Journal of Strength and Conditioning Research*, vol. 31, no. 4, April, 2017. [Online serial]. Available: https://journals.lww.com/nsca-

jscr/Fulltext/2017/04000/Proof_of_Concept_of_Automated_Collision_Detection.30.aspx.
[Accessed Oct. 9, 2020].