Compact, Accurate Motion Detection for Racket Sports

Introduction

With the proliferation of wearables and hearables, end consumers have increasingly demanding requirements for domain-specificity, portability, and low power consumption when capturing motion. Fitness trackers have come to dominate this domain, consisting of 72% of wearables and hearables on the market today[6]. Solutions for motition detection include absolute orientation sensors, inertial motion units (IMUs), accelerometers, gyroscopes, and domain-specific products that leverage a combination of the discussed technology. This paper reviews compact, accurate motion detection for racket sports and specifically, the implementation of the technology in Tennis.

Commercial Applications of Compact, Accurate Motion Detection

Commercial applications of the technology consist of general sensors for motion detection and domain-specific products for racket sports. The NexGen I2M SXT2 sensor made by NexGen Ergonomics is a general solution to human motion capture that is used in biomechanics research, gait analysis, ergonomics, neurology, virtual reality, robotics, and sports [11]. The product costs $200 for an individual sensor and the kits, which include 6 sensors and a docking station, cost $1250[11]. The SXT2 weighs 25g and its dimensions are 43.7x39.7x13.7mm[11]. This is larger than the alternative solutions and can cause an intrusive experience for the end-user. The device is a wrist wearable that transmits information wirelessly to its docking station.

A more domain-specific design is seen in the miPod2. The miPod2 was created by the Digital Sports Group in Erlangen, Germany as a hardware platform for embedded, real-time processing in fitness[4]. Though not sold as a product yet, the device was designed with the Bosch Sensortec BMX 055 absolute orientation sensor and the Analog Devices ADXL375-EP accelerometer for motion capture[4]. The Bosch Sensortec absolute orientation sensor costs $25.64 and the Analog Devices Sensor costs $30 [3][12]. The dimensions of the device are 35x25x8 mm as it is designed to fit the Adidas miCoach SPEED_CELL cavities and can therefore be integrated into clothes, shoes, and equipment[4]. This ensures an unintrusive end-user experience.

The Zepp2 provides a motion capture technology specifically for tennis. This product is made by Zepp Tennis and costs $220[9]. The device attaches to the bottom of a tennis racket on select rackets and can be mounted to all rackets via the Flex Mount[9]. It communicates data to the Zepp application on the user's smartphone and post-processes the data offline to retrieve metrics specific to tennis: sweet spot, ball speed, ball spin speed, and shot type. It measures 25.4x25.4x12.3mm and weight 0.22 oz[9]. This also provides an unintrusive experience for the user.

Technology of Motion Sensors

Functionality

The NexGen sensor does not have datasheets listed nor is it mentioned which sensors the inertial measurement unit (IMU) is based on. It is mentioned that the IMU uses two tri-axial accelerometers, one in the ± 16g range to measure smaller accelerations and the other in the ± 200g range to measure high-impact accelerations[11]. The device also uses a tri-axial gyroscope configured to ± 2000 °/s to measure angular momentum and velocity[11]. Furthermore, gyroscopic measurements can be significantly impacted by the relative magnetic field, air pressure, and tempurature[7]. To compensate for this, the device also includes a tri-axial magnetometer configured to ± 8 Gauss, a tri-axial barometer that ranges from 300-1100 hPa, and a temperature sensor configured to ± 0.5 K[11]. The device samples from 12 Hz to 2000 Hz and a sufficient sample rate for swing sports is proven to be 128 Hz[7][11][13]. Power specifications are not mentioned. When compared to the precise measurements of an Optical Video System(OSM), the SXT2 sensor produced a correlation coefficient of 0.96[7]. This suggests the IMU is highly efficient.

The miPod2 uses a similar system with the absolute orientation sensor and the additional accelerometer. The BMX055 absolute orientation sensor contains a tri-axial accelerometer that can be configured from ± 2g to 16g[4]. The BMX055 also contains a tri-axial gyroscope that can be configured from ± 125°/s to ± 2000°/s[4]. The tri-axial magnetometer on the device measures ± 1300µT on the XY axis and ± 2500µT on the Z axis[14]. The device features a temperature sensor that detects ± 0.5 K and can sample from 12.5 Hz to 1600 Hz [14]. Finally, the secondary ADXL375 accelerometer, which is meant for measuring rapid accelerations, measures up to ±200 g[2]. There is no barometric sensor on the device, but the supply voltage required by the device is from 2.4V to 3.6V[14]. When the BMX0x55 and ADXL375 data was processed through six machine learning models (Na¨ıve Bayes, RandomForest, Support Vector Machine with linear kernel and radial based function kernel, and k-nearest neighbors) and compared to an OSM to classify different table tennis strokes, the data returned a mean Precision and a mean Recall of 95.7% and 98.2% respectively[4]. This suggests that when the data is post-processed effectively, highly accurate results are achieved.

The Zepp2 is described to have Dual accelerometers and dual tri-axial gyroscopes on the product website; however, the technical specifications of the product's motion detection are not publicly disclosed [9]. There is no mentioning of a temperature sensor, barometric sensor, the use of a magnetometer, or power specifications. When the Zepp2 was compared to an OSM, the data returned a stroke classification correlation coefficient of 0.61 and impact location correlation coefficient of 0.22[6]. The data suggests the Zepp2 sensors are moderately inaccurate.

Improvements

The absolute orientation sensor used on the miPod2 was recently enhanced and re-released as the BMX160. The new device is more precise in accelerometer data computation. The device now uses 16384 LSB/g in place of 1024LSB/g, 8192 LSB/g in place of 512 LSB/g, 4096 LSB/g in place of 256 LSB/g, and 2048 LSB/g in place of 128 LSB/g for the ± 2g, ± 4g, ± 8g, and ± 16g ranges respectively[1][14]. Moreover, the newer device is more compact and has reduced power requirements with a supply voltage range of 1.71V to 3.6V[1][14]. Lastly, the device now contains a FIFO buffer to mitigate data loss[1]. The literature search did not show performance metrics for the device's accuracy; however, the results from the miPod2 trials indicate that with a more accurate sensor the performance would improve.

Implementation of Motion Sensors in Tennis

When implementing motion technology in Tennis, the device needs to be compact so that it will not intrude on the player's experience. The device also must meet the power requirements to last the length of a tennis game, post-process the data to produce accurate results, and must be able to transmit motion sensor data to a processor.

The NexGen IMU is able to transmit information, has sufficient battery cycle time, and can post-process the data accurately. The IMU transmits the measurements to the docking station, though the communication protocol is not disclosed[11]. The docking station can then transfer the information to a computer via USB. The limitation, however, is that the data can only be post-processed using NexGen software. The SXT2 sensor lasts eight hours when sampling at 128Hz[11]. Finally, the design is not compact (43.7x39.7x13.7mm) nor lightweight (25g); therefore, the IMU creates an intrusive experience for the player[5].

The Zepp2 is small in size (25.4x25.4x12.3mm) and lightweight (0.22 oz) and has a battery cycle time of eight hours. This device transmits the data captured by its dual accelerometers and tri-axial gyroscopes via Bluetooth Low Energy to be post-processed through the app. There is no control over how this data is post-processed and many sources indicate that its classifications are inaccurate[6][8][10]. This implies that the Zepp2 sensors do not meet the requirement of accurate post-processing results despite meeting the power, size, and communication requirements.

The miPod2 meets all of the criteria; however, the sensors are outdated. The device is compact and fits Adidas's specifications (35x25x8 mm) to provide an unintrusive user experience. The power requirements are met as a 155mAh battery is sufficient to power the motion sensor and the system for six hours[4]. The device also communicates the raw data retrieved by the absolute orientation sensor and secondary accelerometer sensor via Bluetooth Low Energy to be post-processed offline. A robust classification algorithm ensures this data is accurate[4]. The data can also be retrieved from the sensors via I2C or SPI and the newer model of the BMX absolute orientation sensor maintains a FIFO buffer to prevent data loss. With the newer edition also being more compact (2.5 x 3.0 x 0.95mm as opposed to 3 x 4.5 x 0.95mm), this provides the potential for online processing.

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