April 28, 2015

ActiGraph White Paper

What is the Utility of Inertial Motion Unit (IMU) Data?

I. Introduction

ActiGraph has recently released the ActiGraph GT9X Link, which contains an Inertial Measurement Unit (IMU). The IMU sensors and data output units of measure are listed in Table 1 below.

Sensor Type	Units of Measure
3 axis accelerometer (+/- 16g)	G's
3 axis gyroscope	Degrees/second
3 axis magnetometer	microTeslas (µT)
Temperature sensor	Celsius - ^{0}C

Table 1: IMU sensors and units of measure

IMU data are sampled and stored at a 100 Hertz rate. The CSV file in Table 2 below provides an example of how these data are displayed.

------------ Data File Created By ActiGraph Link IMU 9DOF Sensor ActiLife v6.11.6 Firmware v1.2.1 date format M/d/yyyy at 100 Hz -----------										
Serial Number: TAS1C32140400										
Start Time 13:12:00										
Start Date 4/1/2015										
Epoch Period (hh:mm:ss) 00:00:00										
Download Time 13:12:50										
Download Date 4/1/2015										
Current Memory Address: 0										
Current Battery Voltage: 4.17 Mode = 12										
--										
Timestamp	Acceleron	Acceleron	Acceleron	Temperat	Gyroscope	Gyroscope	Gyroscope	Magneton	Magneton	Magnetometer Z
2015-04-01T13:12:00.0000000	-0.80273	-0.09961	0.598145	32.51346	0.854492	0.305176	-5.06592	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0100000	-0.82471	-0.10645	0.621094	32.52544	3.234863	-3.84522	-4.57764	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0200000	-0.86621	-0.11719	0.632324	32.52844	8.666993	-7.8125	-1.70898	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0300000	-0.85791	-0.11865	0.632813	32.51945	16.11328	-14.7095	5.187989	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0400000	-0.78125	-0.11865	0.592285	32.53743	10.43701	-8.54492	7.385254	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0500000	-0.79688	-0.09229	0.539063	32.54342	11.29151	-4.69971	7.873536	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0600000	-0.78809	-0.09375	0.554199	32.54042	5.371094	1.037598	8.483887	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0700000	-0.79834	-0.08984	0.568359	32.53144	3.66211	-0.79346	7.995606	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0800000	-0.80273	-0.08789	0.57959	32.54641	3.051758	-1.64795	7.019043	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.0900000	-0.79785	-0.08496	0.606445	32.54641	1.220703	0.549316	5.920411	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.1000000	-0.83594	-0.09619	0.618164	32.57337	0.366211	6.225586	5.371094	-2.92969	27.53906	13.76953
2015-04-01T13:12:00.1100000	-0.81543	-0.08594	0.620117	32.57936	0.244141	9.094239	6.286621	-2.92969	27.53906	13.76953

[1]

Table 2: IMU data sample, each sensor has a 3-axis output (X, Y, Z) in orde

II. Magnetometer

The magnetometer sensor can be used to determine direction via the Earth's magnetic field.[1] During an initial evaluation of the magnetometer, the ActiGraph Link was laid flat on a table top with its top pointing north (see Figure 1 below). The device was then rotated 360 degrees clockwise. Figure 2 shows the graphed output data.

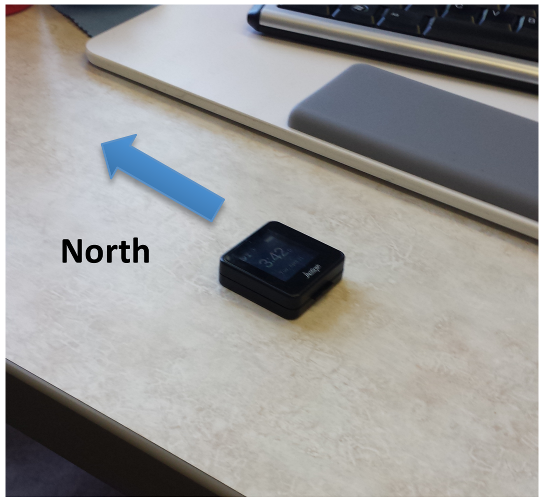

Figure 1. Link tabletop test

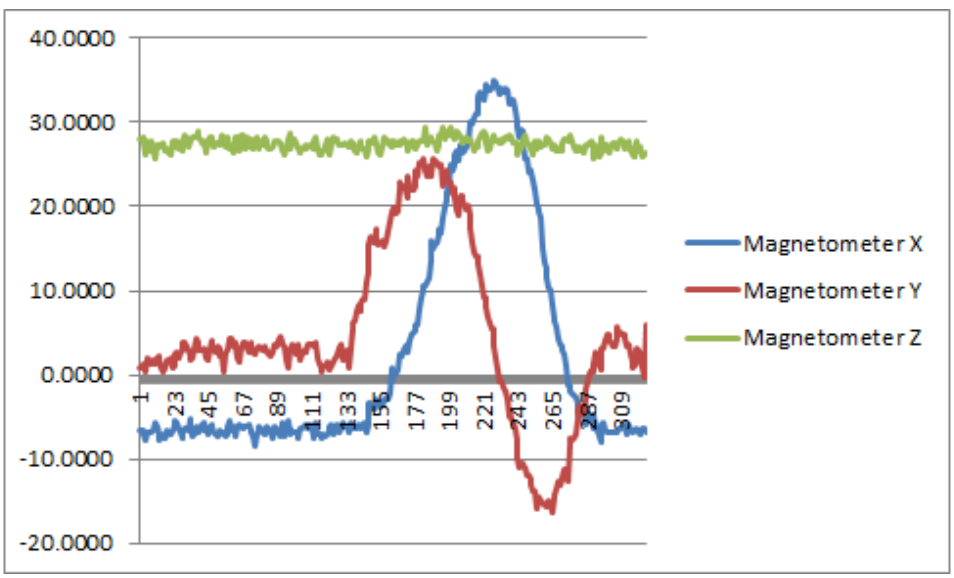

Figure 2. Graphed magnetometer data

1. For best results magnetometer data should be coupled with acceleration data in order to eliminate effects from non-zero elevation and bank angle values.

In Figure 2, the X-axis data (shown in blue) has a minimum level of approximately -6 µT (micro Tesla), which corresponds with north. As it is rotated, the blue line peaks at approximately 34 µT, pointing south.

As expected, the Y-axis demonstrated a similar peak to peak deflection of 40 µT (-15 µT to 25 µT), but lagging by 90 degrees (starting orientation was east). The Z-axis data did not change significantly during the rotation, indicating that this axis was oriented perpendicular to the tabletop (elevation and bank angles ~ 0^o). Repeating the measurement with a handheld Link device with non-zero elevation and bank angles resulted in variations in the Z-axis output.

These data were used to set up the compass table in Figure 3. Because the X-axis goes from low to high as it rotated from north to south, the Y-axis data is necessary to determine if it is facing east or west while it is between its max and min. Therefore, in this simple experiment, if the Y-axis is above 4 µT, the ActiGraph Link is facing east, and if it falls below this value, it would be facing west.

An initial review produced the table below.

	magX		magY
N	<-6		>4
NNE	-6.00	-0.29	>4
NE	-0.29	5.43	>4
ENE	5.43	11.14	>4
E	11.14	16.86	>4
ESE	16.86	22.57	>4
SE	22.57	28.29	>4
SSE	28.29	34.00	>4
S		>34	
SSW	34.00	28.29	<4
SW	28.29	22.57	<4
WSW	22.57	16.86	<4
W	16.86	11.14	<4
WNW	11.14	5.43	<4
NW	5.43	-0.29	<4
NNW	-0.29	-6.00	<4
N	<-6		<4

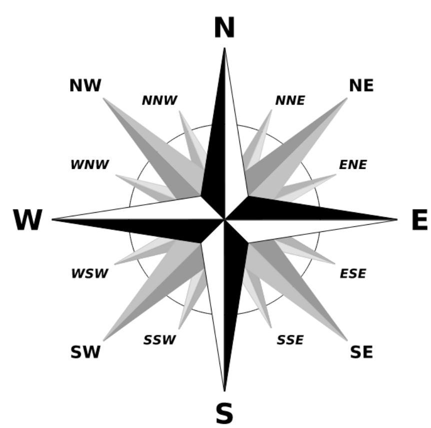

Figure 3. Magnetometer compass table

A second test examined the ActiGraph Link in the vertical position (simulating a hip worn device), with the top up and the face northward. The ActiGraph Link was then rotated twice (see Figure 4 below).

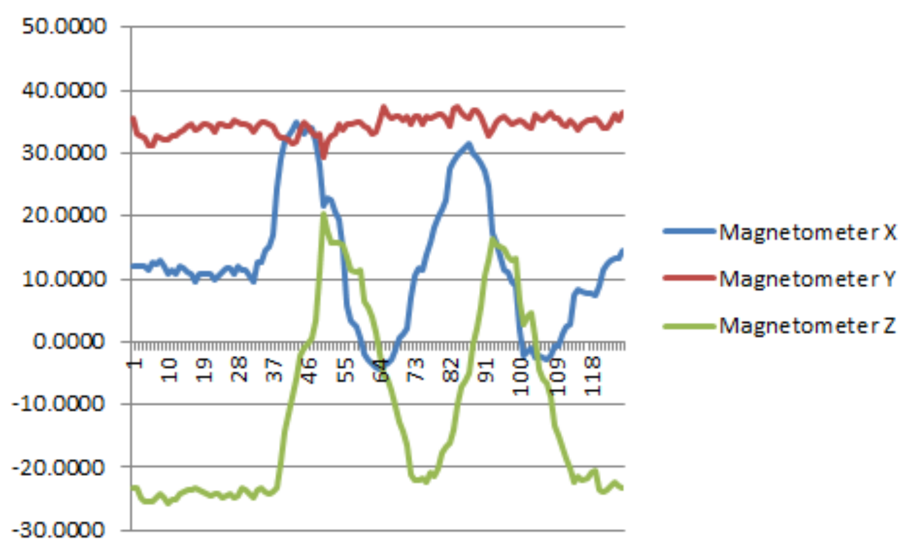

Figure 4. Graphed IMU data with Link in vertical position

Note that the axis orientation has changed with the Z-axis data serving as the north/south indicator axis and the X-axis as the east/west indicator axis. Table 3 displays the ActiGraph Link directional orientation.

	magZ =		magX
N	<-22		>22
NNE	-22.00	-16.71	>22
NE	-16.71	-11.43	>22
ENE	-11.43	-6.14	>22
E	-6.14	-0.86	>22
ESE	-0.86	4.43	>22
SE	4.43	9.71	>22
SSE	9.71	15.00	>22
S		>15	
SSW	9.71	15.00	<22
SW	4.43	9.71	<22
WSW	-0.86	4.43	<22
W	-6.14	-0.86	<22
WNW	-11.43	-6.14	<22
NW	-16.71	-11.43	<22
NNW	-22.00	-16.71	<22
N	<-22		

Table 3. Direction orientation

As noted earlier, when the ActiGraph Link was not horizontally oriented, the Z-axis value changed. When the device is worn at the hip, this becomes the Y-axis. With further study and data conditioning, these data may help determine if the individual is going up or down hill while ambulating.

A Note About the Earth's Magnetic Field:

The two apparent poles are referred to as dipolar, with a positive peak generally lying somewhat south of the true locus of the anomaly and a depression (or negative) in the magnetic field occurring to the north at mid-northern latitudes.

Magnetometry: Nature's Gift to Archaeology
Kenneth L. Kvamme chapter 9, pg 209

III. Gyroscope

The gyroscope measures rotational velocity in units of degrees per second (deg/s). Using the same data set from the initial compass test with the ActiGraph Link laid flat on the tabletop, the gyroscope data were plotted as shown in Figure 5.

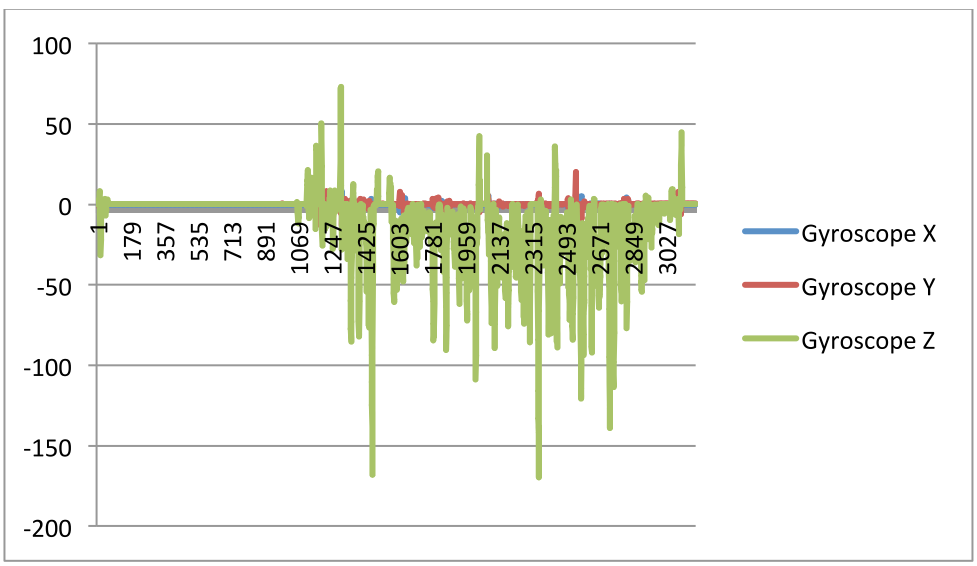

Figure 5. Plotted gyroscope data with Link flat on tabletop

The graph in Figure 5 shows that only the Z-axis responded, indicating that it was rotated in a single axis plane. The signal is negative, which corresponds to a clockwise rotation. Because the gyroscope output is in degrees per second, a column was added to the data output to display the summed degrees per epoch. These data are stored at a rate of 100 samples per second; therefore the degree displayed must be divided by 100 to match the epoch period. The summed degree column was plotted in Figure 6 below.

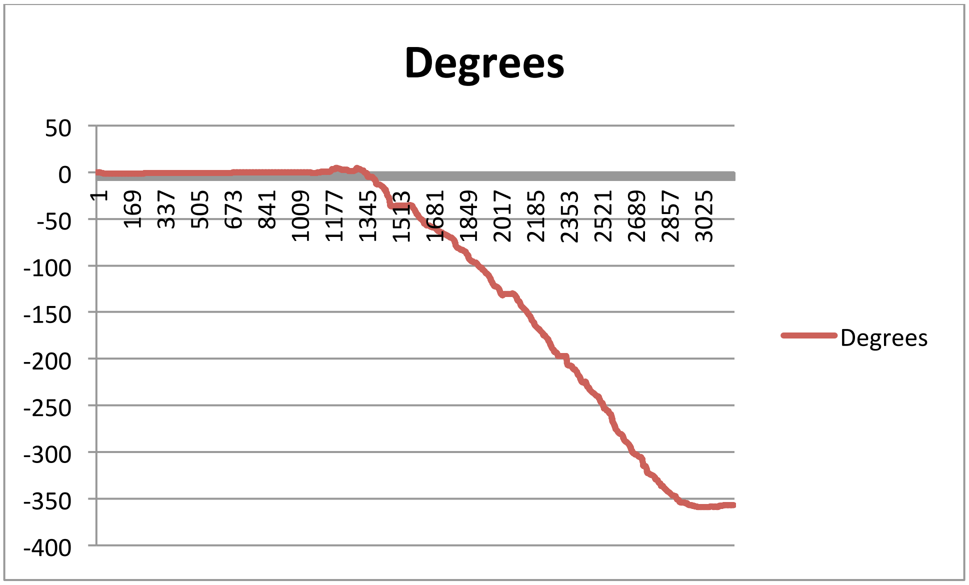

Figure 6. Summed degrees added from the gyroscope Z-axis

Figure 6 shows that the ActiGraph Link was rotated approximately a negative 360 (^{o}) degrees (measurement was 359.01^{o}). By looking at the number of epochs to rotate the full 360 degrees, the average rate of rotation can be determined. The rotation started at approximately 1000 and ended at approximately 3000, and since the sample rate is 100 per second, the 2000 epochs would be divided by 100 to equal approximately 20 seconds. This indicates the rotation took about 20 seconds and 18.0^{o} in one second (average).

IV. Conclusion

It has been shown that by monitoring the magnetometer data, directional information can be harvested. As mentioned, the inclusion of accelerometer data is needed in order to further refine and improve accuracy of this sensor endpoint. Additionally, this testing demonstrates that determining the rate of rotation and the amount of rotation is possible using the gyroscope data. Each axis would need to be evaluated independently and some type of vector magnitude algorithm would need to be applied in order to evaluate the three dimensional rotation. With further research and study there are many possible applications for these data.