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ComTec

IMPROVING MOVEMENT DIRECTION OF A ROAD USER USING MOBILE SENSOR DATA

Project Work Report

Submitted by

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Abstract

Smartphones can provide a lot of useful information using sensors such as accelerometers, magnetometers, gyroscopes embedded in them. For applications like pedestrian collision avoidance, the need for movement direction estimation of pedestrians is important to avoid the collision between a car and a pedestrian. Currently, Global Positioning System (GPS) based movement direction estimation is the most used approach for heading estimation. Because of the unavailability and interference of the Global Navigation Satellite System (GNSS), movement direction detection is difficult to work well and particularly in the case of the urban environment, the presence of tall buildings makes it unreliable for GPS positioning. Alternatively, another approach uses the virtual Orientation sensor from the android operating system to get the orientation of the device and implements the Smartphone Orientation and Movement Direction Alignment (SOMDA) to get the movement direction of a smartphone user. However, starting from Android 4.4W (API level 20), this orientation sensor has become deprecated. In this project, an alternative approach is presented by sensor fusing of accelerometer, magnetometer, and gyroscope for getting the orientation of the device and a

detailed comparison of the fusion approach with the SOMDA approach is presented.

Acknowledgments

I would like to express my gratitude and appreciation to my **Prof. Dr.-Ing. Klaus David**, Chair for Communication Technology of University of Kassel for giving me an opportunity to do the project work.

I would like to pay my deep respect to my supervisor **Mr. Johann Götz**, for his kind direction and proper guidance throughout the project. I am extremely thankful for his advice, time, and support on the project to come out successfully. ~~With this, I declare that the present Project Report was made by myself. Prohibited means were not used and only the aids specified in the Project Report were applied. All parts which are taken over word-to-word or analogous from literature and other publications are quoted and identified.~~

~~Kassel, 24.04.2022~~

~~Vineela Pulagura~~

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Chapter 1

Introduction

1.1 ~~Introduction~~

In recent years, smartphone usage has been tremendously increased all over the world. As of March 2022, the number of smartphone users reached 6.64 billion [1]. With the development of sensor technology in smartphones and with the low cost, small size, and portability characteristics, several applications have been emerged exploiting these features [2]. In general, these smartphones are embedded with different types of sensors such as accelerometer, gyroscope, compass bearing, GPS, etc. Each sensor is of particular importance for each application like human activity recognition, augmented reality, indoor navigation, pedestrian collision avoidance, etc. [2–4].

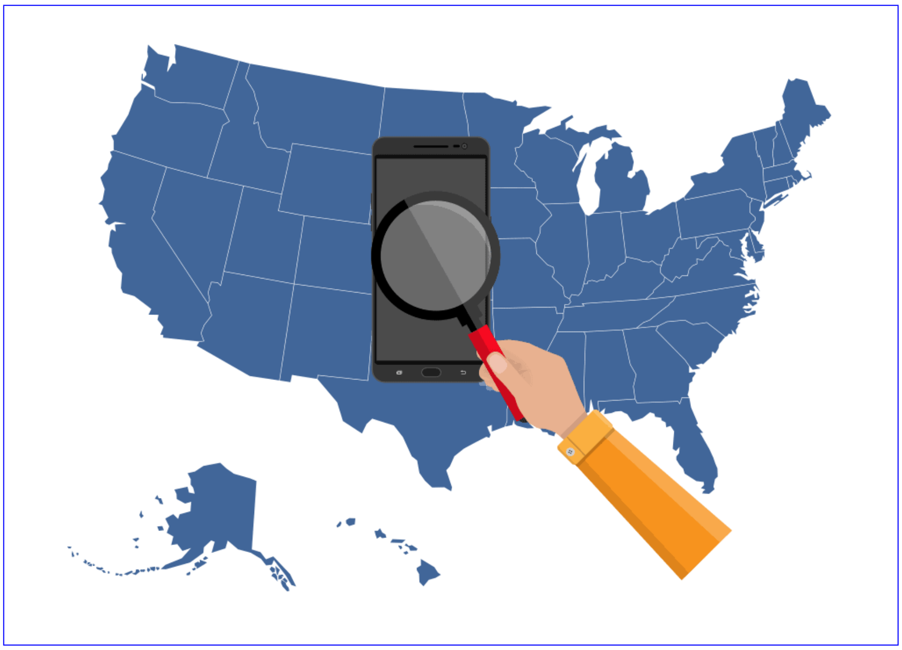


Figure 1.1: Smartphones in the world [1]

1.1 Problem Statement

For applications like pedestrian collision avoidance, the determination of user movement direction is important to avoid the collision. For example, a car is traveling on a road and a user, holding a smartphone, is approaching a car. The user might overlook the surroundings and continue to walk. If the user continues to walk, a collision could happen if the movement direction of a user is not known to the car driver. If there is a possibility that the smartphone communicates with the car driver that the user is approaching, then the collision can be avoided. A collision could happen even if there is a little deviation in the user movement direction.

Figure 1.2: Pedestrian Collision

Most of the time, smartphones are often carried in trouser pockets, shirt pockets, bags, and holding in hand. Because of the placement nad orientation of the smartphone, direction estimation has become a key challenge for pedestrian navigation. From the reference coordinate system of the smartphone, the direction of the user is different from the smartphone's direction due to the orientation of the smartphone. Therefore, the data measured from the smartphone is not aligned with the user movement direction [4]. The virtual orientation sensor from the android operating system provides the device orientation of the smartphone but starting from the Android 4.4W (API level 20), this type of sensor has become deprecated due to the default orientation of the device in either landscape or portrait mode and the sensor is consistent only when the roll angle is 0. Hence, this type of sensor is no longer available in the future, and the need for finding an alternative approach for getting the orientation of the device is essential.

1.2 Objective

The main objective of this work is to develop a simple android application using the sensors from smartphones: accelerometer, magnetometer, gyroscope, and virtual orientation sensor. The orientation details of the device are obtained in two approaches: The existing approach uses the virtual orientation sensor to get the orientation of the device and the other uses the fusion approach with the fusion of accelerometer, magnetometer, and gyroscope sensors by implementing a complementary filter. The Smartphone Orientation and Movement Direction Alignment (SOMDA) algorithm [**4**] is implemented on these two approaches by carrying the smartphone in trouser pocket, shirt pocket and in hand and compared the results of the two approaches.

1.3 Related Works

There exists a lot of research regarding the Pedestrian Dead Reckoning (PDR) systems based on the sensors like accelerometer, gyroscope, compass, etc. Yan et al. [5] implemented an indoor pedestrian dead reckoning system by using visual tracking and map information. They implemented a hybrid system using cameras, smartphone sensors, and an indoor map for movement direction estimation. This study has proven to show better results compared to a single smartphone-based PDR, particularly in the indoor environment. However, they require a map of buildings to predict the accurate direction and it's not often possible.

Chunhakam et al. [6] implemented a positioning system using GPS and compass sensors. The system operates in two types where the first type receives position data normally from the GPS and fed to the Kalman Filter for improving the position and the second type is used when the vehicle loses the position data where the last GPS position is fed as an input to Kalman Filter to predict the next position. This process repeats until a good GPS signal is obtained. Another approach by Matsumoto et al. [7] proposed a method for the estimation of movement direction when the pedestrian is swinging his arms by applying the Inertial Measurement Unit (IMU) and Principal Component Analysis (PCA) to the data obtained from the smartwatch sensors. The implemented approach is based on the stronger acceleration produced by the swinging arm to give the movement direction.

Kusber et al. [4] proposed an algorithm called SOMDA for the trouser pocket position to align the smartphone and user orientations and to determine the movement direction of the user. This approach depends on the orientation sensor from the android operating system for getting the orientation of the device but this sensor has become deprecated from the android operating system.

Chapter 2

Application Requirements

With the increase in mobile hardware technologies, a lot of mobile applications are being developed every year. Since there are a lot of android operating systems users compared to other competitors like iOS or palm OS, the development of an application in android can easily reach the public. The android mobile applications grow faster due to its open platform and easily available Integrated Development Environment (IDE) like Eclipse and Android Studio [8]. An android application required for this project is developed in the IDE ”Android Studio” using Java programming language. The main objective of this mobile application is to collect the data from the sensors and obtain the user’s location and navigation direction details.

2.1 Application Specifications

The application is developed in android operating system with android version 12. The application is developed in the Google Pixel 4a smartphone with android version 12. The application specifications for this project are shown in the Table 2.1.

Feature	**Specification**
Model	Google Pixel 4a
Operating System	Android
Android Version	12

Table 2.1: System Specifications

2.2 Hardware Specifications

Accelerometer/Gyroscope: The Google Pixel 4a has an integrated chipset LSM6DSR IMU manufactured by STMicro. The sensors accelerometer, gyroscope, and temperature are embedded in this block. This sensor block measures the linear acceleration and angular velocity in the X, Y, and Z axes.

Magnetometer: A tri-axial digital magnetic sensor chipset is embedded in the Google Pixel 4a manufactured by STMicro that measures the magnetic field in microtesla along the X, Y, and Z axes.

Orientation Sensor: It is a virtual sensor that uses gravity and geomagnetic field to provide the orientation of the device.

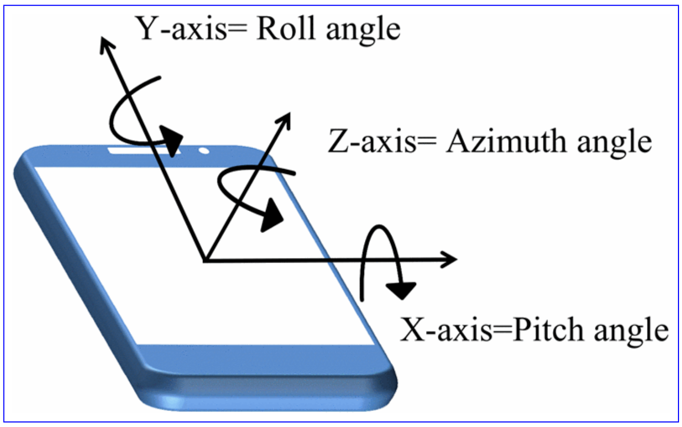


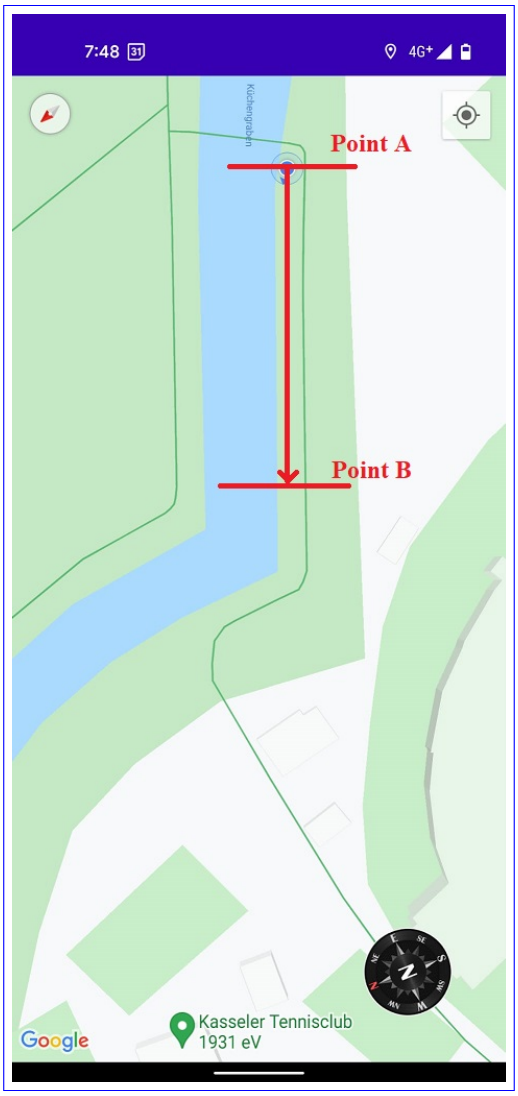
Figure 2.1: Orientation angles of the Smartphone [7]

The device orientation is measured through pitch (rotation around the X-axis or horizontal plane), roll (rotation around the Y-axis or vertical plane), and azimuth (rotation around the axes which is opposite to the face of the screen) angles which are measured in degrees as shown in Figure 2.1 [4], [9].

Chapter 3

Raw Measurements

The measurements were carried out in an outdoor location in the Auepark, near Auestadion, Hessen, Germany. For the actual movement direction, a navigation magnetic compass that is free from the external magnetic influence is considered. The ground truth angle measured from the magnetic compass in the considered location and movement direction is around 290 degrees. The details of the location and the ground truth angle measured from the magnetic compass are shown in Figure 3.1.



(a) Location

(b) Ground Truth measured from the Magnetic Compass

Figure 3.1: Location and Ground Truth

Before taking the measurements, the smartphone is calibrated first by moving the smartphone in the infinity (∞) symbol direction twice. The smartphone is placed in different positions trouser pocket, shirt pocket, and in hand, as shown in Figure 3.2. These are the mostly used positions for carrying the smartphones by most of the smartphone users.

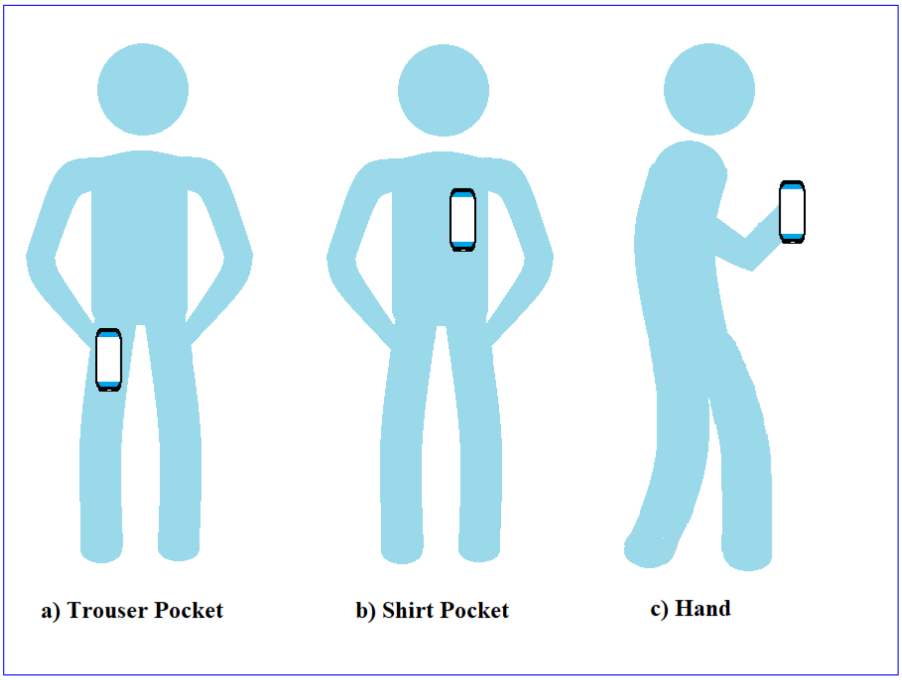


Figure 3.2: Smartphone Positions

The most feasible orientations in the shirt pocket and trouser pocket are shown in the Figure 3.3. They are the smartphone placed inside the trouser pocket facing the screen towards the user (O1), facing the screen towards the user and standing upside down (O2), facing the screen away from the user (O3), and facing the screen away from the user and standing upside down (O4) as shown in the Table 3.1.

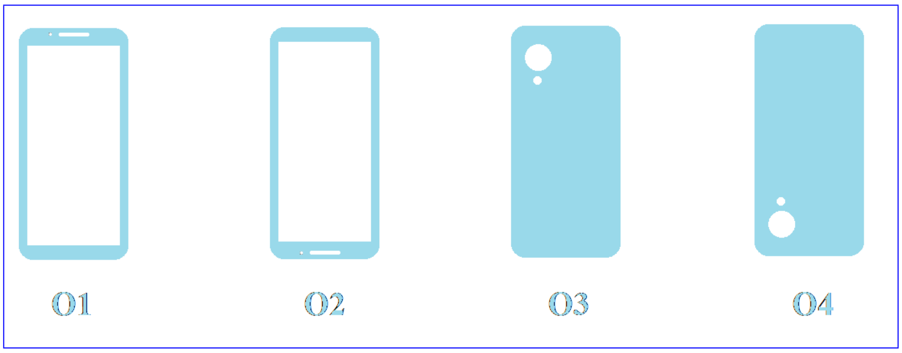


Figure 3.3: Smartphone Orientations

Orientation	**Details**
O1	facing the screen towards the user
O2	facing the screen towards the user and standing upside down
O3	facing the screen away from the user
O4	facing the screen away from the user and standing upside down

Table 3.1: Smartphone Orientations

A subject takes out the measurements carrying the smartphone in each position by walking from Point A to Point B as shown in the Figure 3.1. This process is repeated in the same direction and same path by carrying the smartphone in the each orientation. Therefore, each position gives four measurements in total. Each measurement took around 80 sec duration walk from Point A to Point B with a speed of around 1.3m/s. This process was carried out 9 times in total for each position.

3.1 Data Collection

A simple android application is developed using the sensors: accelerometer, magnetometer, gyroscope, and virtual orientation sensor. The SensorManager class available from the android sensor hardware contains the SensorEventListener interface that is used to read the data from the sensor using the abstract method onSensorChanged() [10]. To take the services from the sensor, the sensor must register for the event. During the registration of the sensor, the sampling rate must be provided. Here, a 50Hz sampling rate is considered for the project.

After registering for the sensor events with the sensors, the SensorEventListener provides a notification to the onSensorChanged() method whenever a sensor is changed. When a sensor is changed, SensorEventListener continuously throws the sensor information [10]. It contains the data of the device in the X, Y, and Z directions. A small program is developed using files class in java.io package to store the sensor information of the device in a comma-separated value format within the smartphone. This can be done by taking the external storage permission from the android. The sample format of the data is shown in the Figure 3.4.

A	B	C	D	E	F	G	H	I	J	K
Time in Seconds	Acceleration_Z	OrientSensor	OrientSensor_Pitch	OrientSensor_Roll	FusedOrientation_Azimuth	FusedOrientation_Pitch	FusedOrientation_Roll	AccelOrient_Azimuth	AccelOrient_Pitch	AccelOrient_Roll
00:04.1	6.1070814	265.93518	-18.802713	-51.180244	160.5838946	2.501055618	-11.69766286	-104.2463291	-3.556246848	45.85683141
00:04.1	6.1070814	265.93518	-18.802713	-51.180244	160.5838946	2.501055618	-11.69766286	-104.2463291	-3.556246848	45.85683141
00:04.1	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.1	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.1	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.1	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.1	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.1	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.2	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.2	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.2	5.1553364	269.58514	-17.747469	-51.770794	160.5838946	2.501055618	-11.69766286	-91.95590231	-6.99609105	48.37159436
00:04.2	4.6396832	273.1821	-17.10402	-52.68344	160.5838946	2.501055618	-11.69766286	-62.84614833	-13.8932895	57.81820019
00:04.2	4.6396832	273.1821	-17.10402	-52.68344	160.5838946	2.501055618	-11.69766286	-62.84614833	-13.8932895	57.81820019
00:04.2	4.8209395	275.772	-17.574486	-53.470016	156.1152979	2.173168972	-10.30734712	-47.07399844	-15.58997337	61.86816086
00:04.2	4.3208394	277.09076	-19.151617	-53.567722	152.0515266	1.817906501	-8.863837868	-44.35837328	-15.04270618	62.70449703
00:04.2	4.3208394	277.09076	-19.151617	-53.567722	152.0515266	1.817906501	-8.863837868	-44.35837328	-15.04270618	62.70449703
00:04.2	4.3208394	277.09076	-19.151617	-53.567722	152.0515266	1.817906501	-8.863837868	-44.35837328	-15.04270618	62.70449703
00:04.2	4.3208394	277.09076	-19.151617	-53.567722	152.0515266	1.817906501	-8.863837868	-44.35837328	-15.04270618	62.70449703
00:04.2	4.3208394	277.09076	-19.151617	-53.567722	152.0515266	1.817906501	-8.863837868	-44.35837328	-15.04270618	62.70449703
00:04.2	3.1752756	277.23538	-21.473133	-53.111706	152.0515266	1.817906501	-8.863837868	-24.36452274	-21.41248254	66.21432634
00:04.2	2.6662025	276.57532	-24.06608	-52.68088	148.5232012	1.353299211	-7.362276274	-20.14879338	-33.80112405	63.77788175
00:04.2	2.6662025	276.57532	-24.06608	-52.68088	148.5232012	1.353299211	-7.362276274	-20.14879338	-33.80112405	63.77788175
00:04.2	2.6662025	276.57532	-24.06608	-52.68088	148.5232012	1.353299211	-7.362276274	-20.14879338	-33.80112405	63.77788175
00:04.2	2.6662025	276.57532	-24.06608	-52.68088	148.5232012	1.353299211	-7.362276274	-20.14879338	-33.80112405	63.77788175
00:04.2	2.6662025	276.57532	-24.06608	-52.68088	148.5232012	1.353299211	-7.362276274	-20.14879338	-33.80112405	63.77788175
00:04.2	2.6662025	276.57532	-24.06608	-52.68088	148.5232012	1.353299211	-7.362276274	-20.14879338	-33.80112405	63.77788175
00:04.3	2.6662025	276.57532	-24.06608	-52.68088	145.1497571	0.650211491	-5.939474446	-20.14879338	-33.80112405	63.77788175
00:04.3	3.738187	275.41635	-26.778954	-52.7183	145.1497571	0.650211491	-5.939474446	-31.52136742	-32.51973958	58.65093003
00:04.3	3.738187	275.41635	-26.778954	-52.7183	145.1497571	0.650211491	-5.939474446	-31.52136742	-32.51973958	58.65093003
00:04.3	3.738187	275.41635	-26.778954	-52.7183	145.1497571	0.650211491	-5.939474446	-31.52136742	-32.51973958	58.65093003
00:04.3	3.738187	275.41635	-26.778954	-52.7183	145.1497571	0.650211491	-5.939474446	-31.52136742	-32.51973958	58.65093003

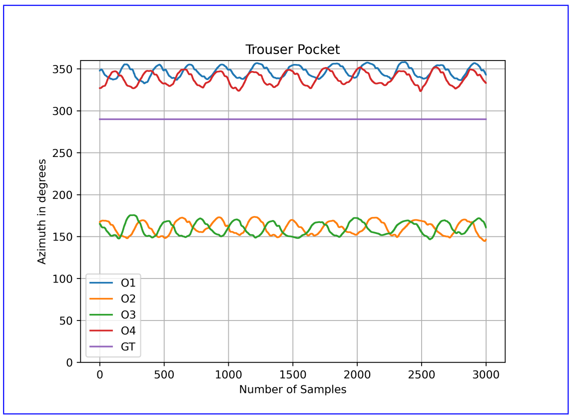
Figure 3.4: Example of the data

Chapter 4

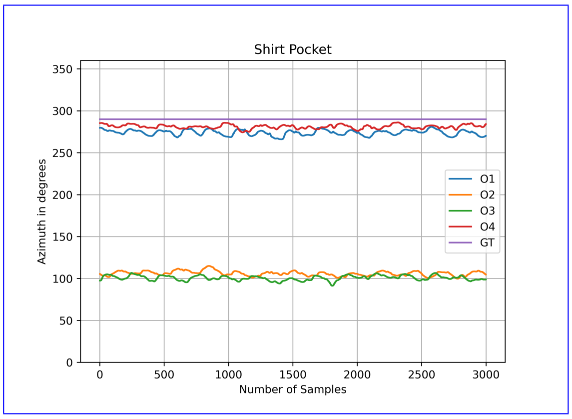
Implementation using Orientation Sensor

The orientation sensor is the virtual sensor that uses a gravity sensor and geomagnetic field sensor to give the orientation angles of the device directly without any further computations. This sensor provides orientation information of the device's pitch, roll, and azimuth angles in degrees. Since the user is moving in the same direction holding the smartphone with an angle of 290°, let's assume that the readings from the orientation sensor should also produce the same direction with each orientation.

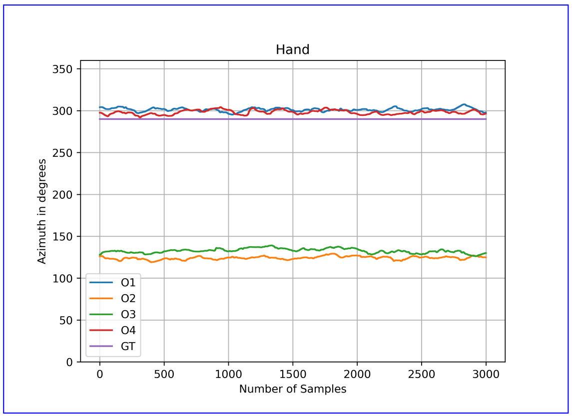
The raw measurements of the orientation sensor for each position with the four considered orientations are shown in the Figure 4.1. The X-axis shows the number of samples taken, Y-axis shows the azimuth angle from compass in degrees (0-360°) and the label ”GT” represents the ground truth angle measured manually from the magnetic compass.



(a) Trouser Pocket



(b) Shirt Pocket



(c) Hand

Figure 4.1: Influence of the Smartphone Orientation on Azimuth angle

However, the plots from the Figure 4.1, shows that the measurements are misaligned and the assumption is wrong. There is a maximum misalignment of 150° for the trouser pocket, 190° for the shirt pocket, and 170° for the hand with reference to the ground truth angle of 290°.

This is due to the rotation of 180° of the device around the X-axis for the orientations O2 and O3 when compared to O1 and O4 and the face of the screen facing either towards the user or away from the user. There is a lot of influence on the azimuth angle due to the orientation of the device. So, the actual movement direction of the smartphone user can't be detected if the orientation of the smartphone is not known.

4.1 SOMDA Algorithm

The orientation of the device is described from three angles. They are pitch, roll, and azimuth. Pitch is the angle of rotation around the X-axis which is the horizontal direction. Roll is the angle of rotation around the Y-axis or the vertical axis, and azimuth is the angle of rotation around the Z-axis. These three angles give the angle of turning with reference to the reference coordinate system. The reference coordinate system is also referred to as the Global Coordinate System or World Coordinate System [7]. It can be shown in Figure 4.2.

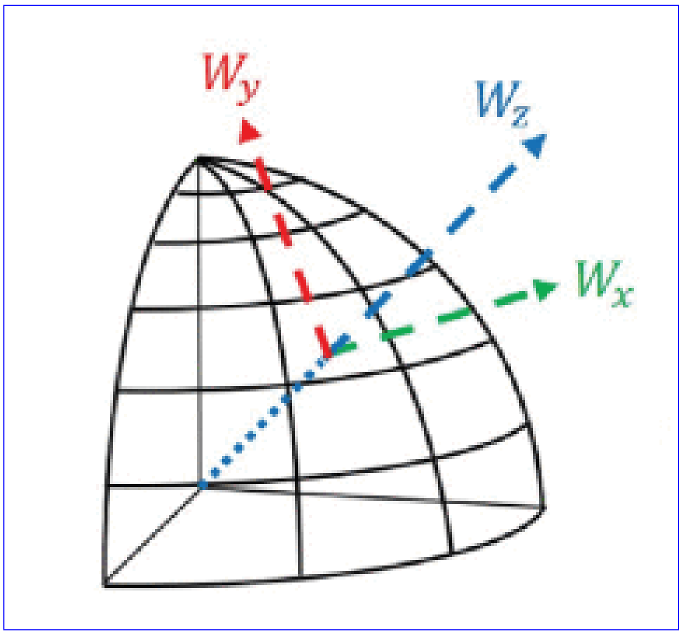


Figure 4.2: World Coordinate System [7]

Therefore, the angle of rotation around the X, Y, and Z axes for the user and the device are with reference to the World Coordinate System. When a user carries a smartphone in the trouser pocket as shown in figure 4.3, the device frame and the user frame are different. In other words, the data collected from the smartphone doesn't give information about the user orientation but its own orientation [4].

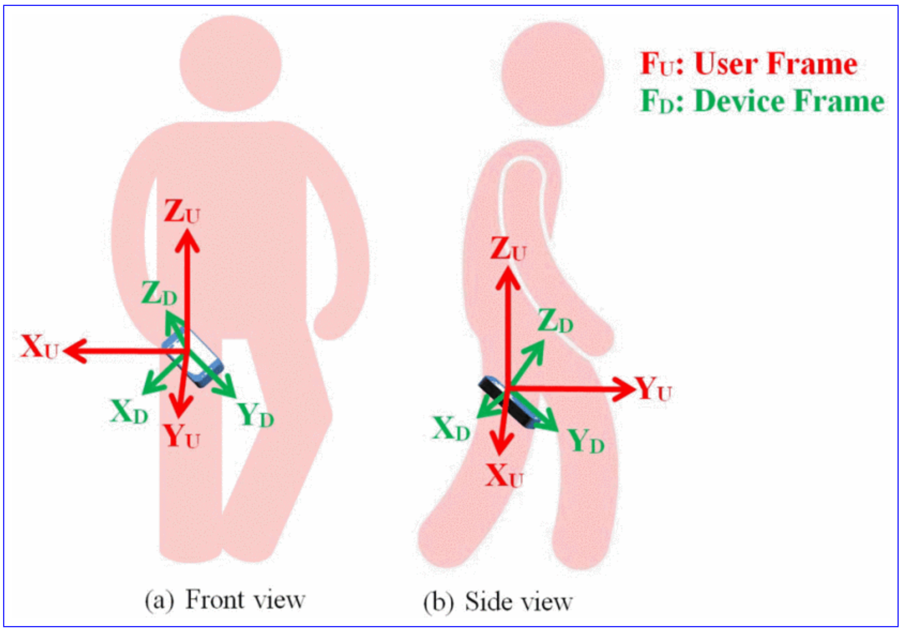


Figure 4.3: User frame and device frame [4]

To align user orientation and device orientation, the SOMDA algorithm is used on the device data. The SOMDA approach comprises of two steps as shown in Figure 4.4 [4].

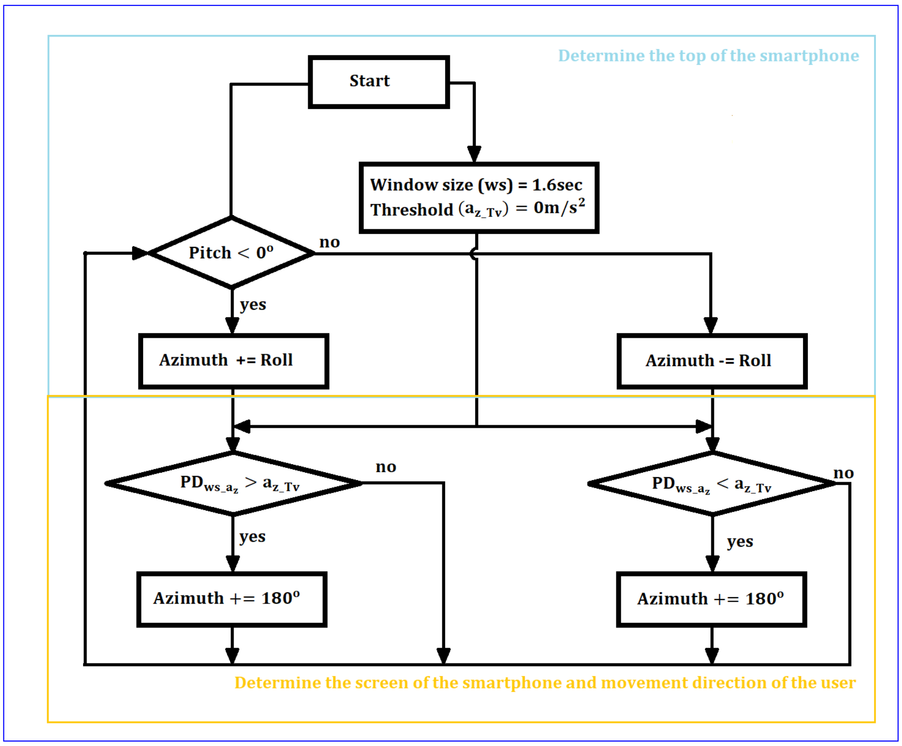


Figure 4.4: Flowchart of SOMDA [4]

1. Determine the top of the smartphone:

The top of the smartphone is determined by the pitch angle θ_t. The pitch angle is positive when the smartphone is in downward direction in the pocket and negative if it faces upwards. If the pitch of the device is positive, roll angle ϕ_t is added to the azimuth ψ_t otherwise subtracted from the azimuth. This action is referred to as Roll Correction ψ_{RC} and it is described in the equation (4.1) With this operation, the device is always assumed to be perpendicular to the ground inside the trouser pocket [4].

$$\psi_{RC} = \begin{cases} \psi_t + \phi_t \middle| \theta_t < 0 \\ \psi_t - \phi_t \middle| \theta_t \geq 0 \end{cases} \tag{4.1}$$

2. Determine screen of the smartphone and the movement direction of the user:

The screen of the smartphone is the face of the smartphone facing either towards the user or away from the user. The screen of the smartphone and the movement direction is determined by the acceleration of the device. It can be decided by the peaks in the acceleration towards the Z direction of the device when the user walks. Normally, when a user walks the device gives a maximum value from the acceleration sensor in the Z direction.

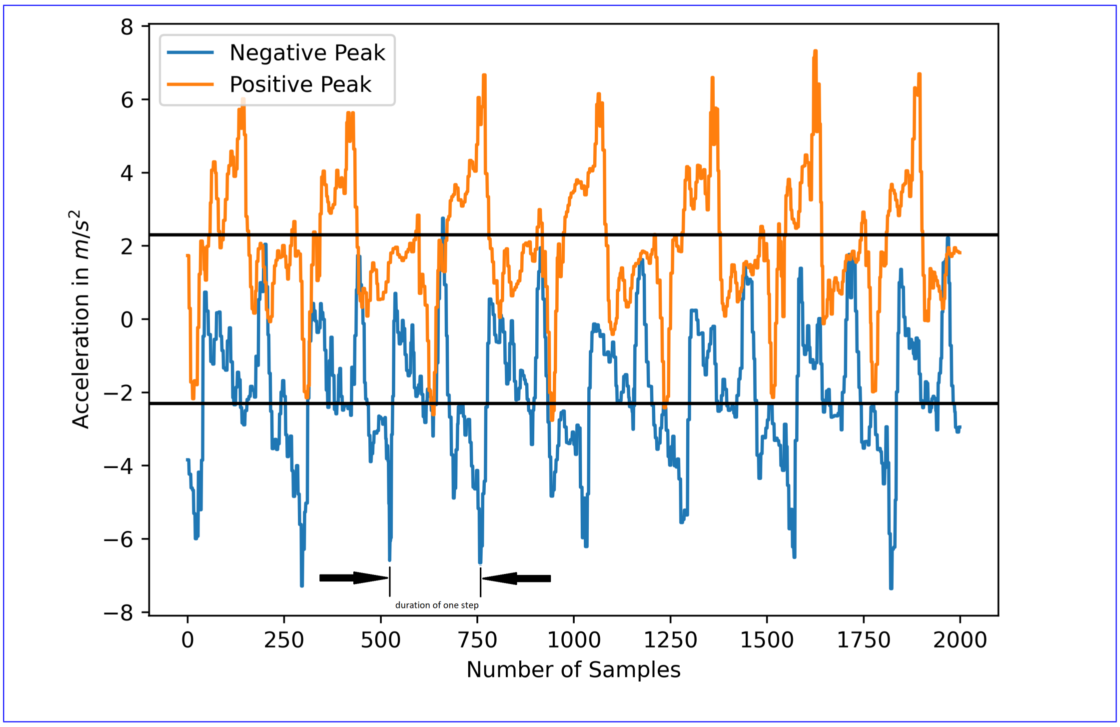


Figure 4.5: Positive and Negative Peaks

Figure 4.5 shows the positive and negative acceleration along the Z-axis of the smartphone. To detect the peaks in the accelerometer, Kusber et al. in [4] used a windowed peak detection algorithm where it detects the peaks by segmenting the acceleration data into segments and setting a threshold on the data. For this project, the mean acceleration is considered to be 1.6s which is the mean interval of 1 step and the threshold for the acceleration is $0m/s^2$. The equation (4.2) gives the result of the peak detection when the user takes steps while his/her smartphone is in the trouser pocket in one of the four orientations. $PD_{ws\_a_z}$ is the peak detection within the window size on the accelerometer data a_z where a_z is the acceleration in the Z direction of the device.

$$PD_{ws\_a_z} = \begin{cases} a_z & |a_z > a_{z\_Tv} \ or \ a_z < -a_{z\_Tv} \\ 0 & |else \end{cases} \tag{4.2}$$

The result of the peak detection on the orientations O1 and O3 is shown in Figure 4.6. The plot shows the time in seconds on X-axis and acceleration in m/s^2 on Y-axis. By setting the threshold value to $0m/s^2$, the positive peak is detected for orientation O3 and the negative peak for orientation O1 for the duration of one step (1.6s).

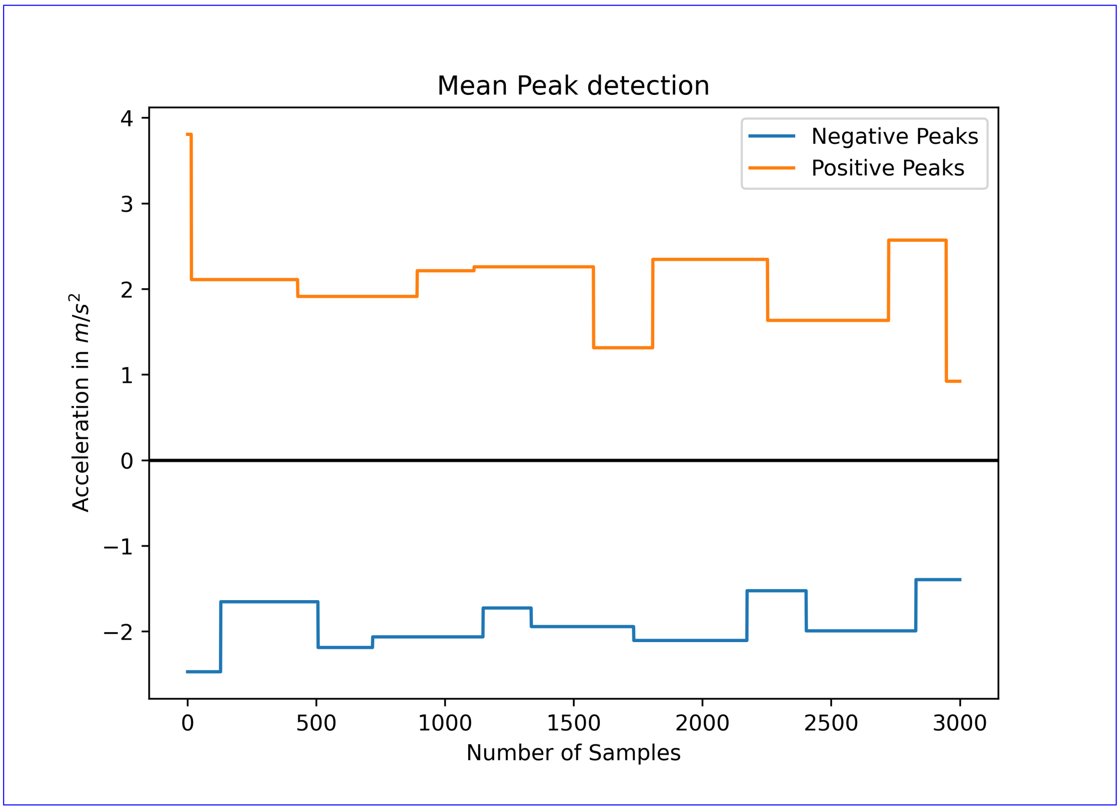


Figure 4.6: Mean acceleration with window size of 1.6s

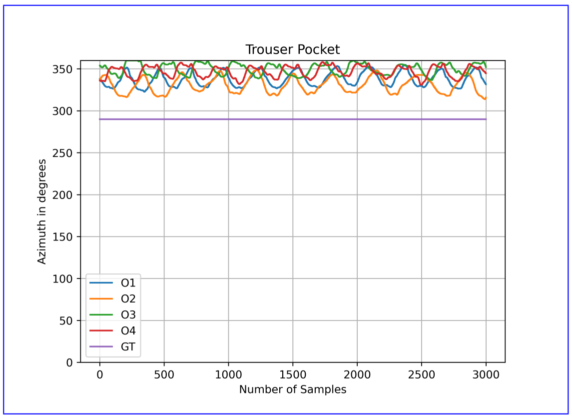
Now the information on the peak value is taken and combined with the pitch angle from the device orientation details. The screen of the smartphone is facing towards the user if the pitch angle is negative, and a negative peak is detected and in our case it's O1. If the pitch is positive and a positive peak is detected, then the smartphone screen is also facing toward the user, and in this case, it's O4.

If the pitch angle is positive and a negative peak is detected, then the smartphone screen is facing away from the user, and it is O2. The smartphone screen is also facing away from the user if the pitch angle is negative, and a positive peak is detected. In both cases, the SOMDA algorithms aligns the smartphone orientation with the user by adding 180 degrees to the azimuth angle. The equation describing the aligned movement direction and the final azimuth angle ψ_{AA} using the SOMDA algorithm is in the equation (4.3).

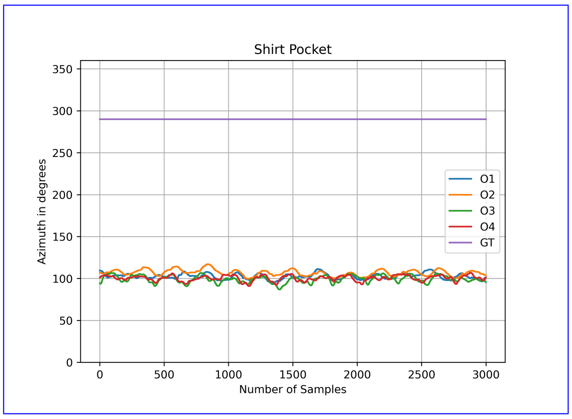
$$\psi_{AA} = \begin{cases} \psi_{RC} & |\theta_t < 0 \; and \; PD_{ws\_a_z} < 0 \\ \psi_{RC} + 180 & |\theta_t < 0 \; and \; PD_{ws\_a_z} > 0 \\ \psi_{RC} + 180 & |\theta_t > 0 \; and \; PD_{ws\_a_z} < 0 \\ \psi_{RC} & |\theta_t > 0 \; and \; PD_{ws\_a_z} > 0 \\ 0 & |else \end{cases} \tag{4.3}$$

4.2 Implementing SOMDA with the Orientation sensor

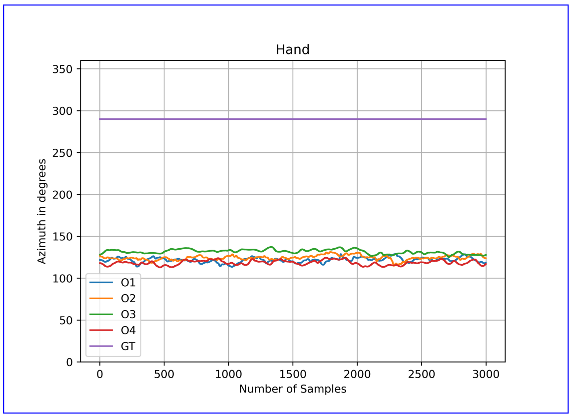
After the implementation of the SOMDA algorithm, the results of the Orientation sensor in four orientations for trouser pocket, shirt pocket and in hand are shown in Figure 4.7.



(a) Trouser Pocket



(b) Shirt Pocket



(c) Hand

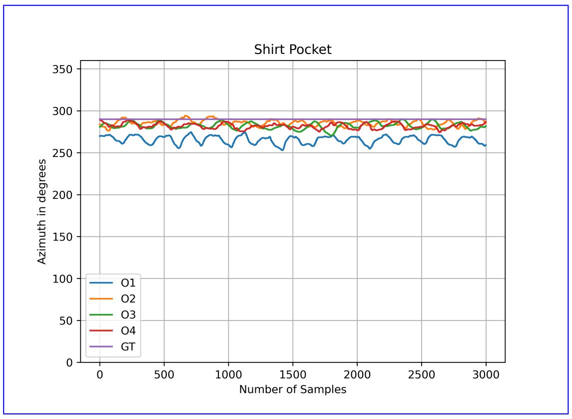
Figure 4.7: Azimuth angle after implementation of SOMDA

From the Figure 4.7, the orientations O1, O2, O3 and O4 are almost aligned for trouser pocket, shirt pocket and in hand. But the results for the shirt pocket and in hand shows a large deviation from the ground truth angle. This is due to the negative pitch angle for the shirt pocket and hand positions compared to the trouser pocket. Therefore, the SOMDA algorithm is adjusted for the shirt pocket and hand positions according to the Table 4.1.

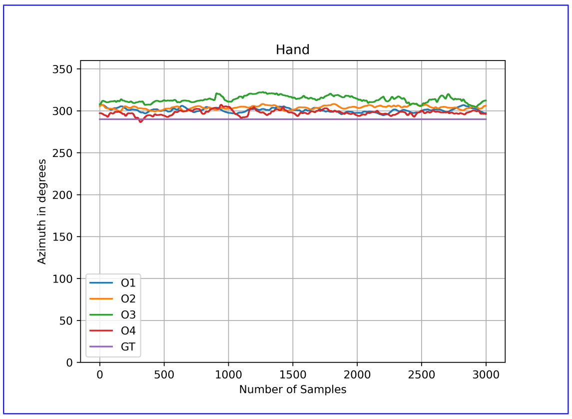
Trouser Pocket	**Shirt Pocket and Hand**
$\psi_{RC} = \begin{cases} \psi_t + \phi_t \vert \theta_t < 0 \\ \psi_t - \phi_t \vert \theta_t \geq 0 \end{cases}$	$\psi_{RC} = \begin{cases} \psi_t + \phi_t \vert \theta_t > 0 \\ \psi_t - \phi_t \vert \theta_t \leq 0 \end{cases}$

Table 4.1: Changes in the Roll correction for Shirt pocket and Hand positions

After adjusting the SOMDA algorithm, the results of the azimuth angle have been improved for shirt pocket and hand as shown in Figure 4.8.



(a) Shirt Pocket



(b) Hand

Figure 4.8: Azimuth angle after adjustment of SOMDA for Shirt Pocket and Hand positions

Table 4.2 shows the mean azimuth angle in degrees before and after implementation of SOMDA algorithm. The results show that there is a misalignment of 3°-18° for trouser pocket, 16°-19° for shirt pocket and 4°-17° for hand. In contrast to the average misalignment before applying SOMDA, the average misalignment after applying SOMDA is very small. The results shows that the measurements are successfully aligned.

Orientation	Mean Azimuth angle in degrees					
	Before Applying SOMDA			After Applying SOMDA		
	Trouser Pocket	Shirt Pocket	Hand	Trouser Pocket	Shirt Pocket	Hand
O1	345	274	301	334	266	301
O2	160	106	124	331	285	304
O3	160	101	132	349	282	314
O4	339	281	298	347	282	297
Max Misalignment	185	180	177	**18**	**19**	**17**

Table 4.2: Mean Azimuth values before and after applying SOMDA in degrees

4.3 Accuracy Evaluation

For the accuracy evaluation, the accuracy is calculated as the correctness of the data by setting a tolerance on the data. It means how much of a tolerance value for the data that is allowed to differ from the ground truth value. Here, in this project four tolerances 5, 10, 15 and 20 degrees are considered that are allowed to differ from the ground truth.

Orientation	Accuracy at different tolerances											
	Trouser Pocket				Shirt Pocket				Hand			
	5°	10°	15°	20°	5°	10°	15°	20°	5°	10°	15°	20°
O1	0	0	0	0	0	0	0	0.2	0	0.4	0.93	1.0
O2	0	0	0	0	0.55	0.93	1.0	1.0	0	0	0.67	1.0
O3	0	0	0	0	0.25	0.68	0.97	1	0	0	0	0.13
O4	0	0	0	0	0.17	0.72	0.99	1.0	0.2	0.8	0.98	1
Overall Accuracy (%)	0	0	0	0	24.2	58.2	74	80	5	30	64.5	78.2

Table 4.3: Accuracy evaluation with the Ground Truth 290°

From the Table 4.3, none of the orientations are aligned with the ground truth for the trouser pocket. There is an accuracy of 80% for the shirt pocket and 78.2% that are within the tolerance of 20° with reference to the ground truth. However this type of evaluation cannot give the accurate results due to the constant ground truth value considered for the evaluation and there could be some user measurement errors. Therefore, the accuracy evaluated with one of the measurements as a reference measurement gives the accurate results.

On taking O2 as a reference measurement, the results are shown in the Table 4.4.

Orientation	Accuracy at different tolerances											
	Trouser Pocket				Shirt Pocket				Hand			
	5°	10°	15°	20°	5°	10°	15°	20°	5°	10°	15°	20°
O1	0.26	0.52	0.72	0.85	0	0.04	0.21	0.53	0.62	0.98	1.0	1.0
O3	0.18	0.29	0.41	0.49	0.47	0.81	0.98	1.0	0.12	0.47	0.92	1.0
O4	0.12	0.25	0.43	0.65	0.53	0.92	1.0	1.0	0.34	0.87	0.99	1.0

Table 4.4: Accuracy evaluation with the reference measurement O2

From the Table 4.4, there is an overall average accuracy of 66.3% for trouser pocket, 84.3% for the shirt pocket and 100% that are within the tolerance of 20° with the reference measurement O2. Even though this approach performs better for the hand position, it is still not able to show better results for the trouser pocket and shirt pocket positions and needs further improvement in the movement direction detection. However, this type of orientation sensor is deprecated since Android 4.4W (API level 20) from android due to the default position of the device in either landscape or portrait in different devices such as tablets, smartphones, and some other devices that uses this type of sensor and it is only reliable when the roll angle is 0. Also, this type of sensor cannot be available in the future android versions. Therefore, an alternative approach must be presented to get the orientation of the device that can furthermore improve the movement direction detection of the user.

Chapter 5

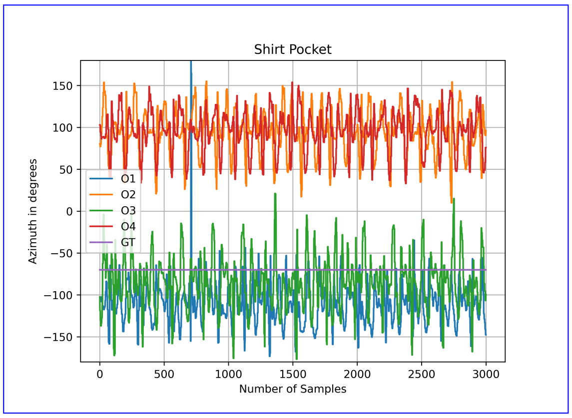
~~Implementation using~~ Fused Orientation approach

Since the orientation sensor is deprecated, the other alternative to this sensor is the rotation matrix method available form the sensor manager library that maps the device coordinate system to the world or global coordinate system in a matrix. This rotation matrix is based on the readings from the accelerometer and magnetometer. By passing this rotation matrix as an input to the getOrientation() method, it returns the orientation of the device (pitch, roll, and azimuth) in radians which can be further converted to degrees. The changes in the computed new orientation angles with respect to the orientation sensor is shown in the Table 5.1.

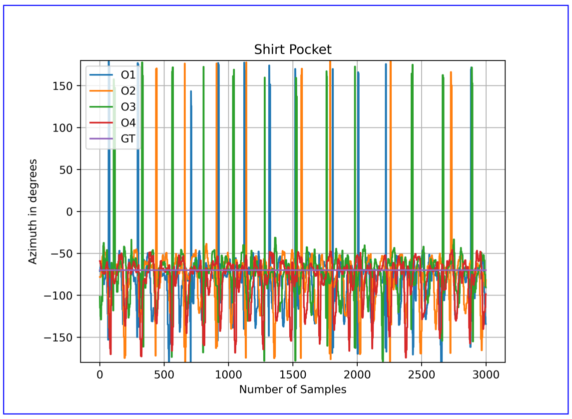
Parameter	Orientation Sensor	Orientation Method
Angles	Measured in degrees	Measured in radians
Azimuth	Ranges between $0°$ and $360°$ where North :$0°$, South :$180°$, East :$90°$, West :$270°$	Ranges between $-\pi$ and π where, North :0, South :π, East :$\pi/2$, West :$-\pi/2$
Pitch	Ranges between $-180°$ and $180°$	Ranges between $-\pi/2$ and $\pi/2$
Roll	Ranges between $-90°$ and $90°$	Ranges between $-\pi$ and π

Table 5.1: Comparison with the Orientation sensor

The results of this type of orientation before and after implementation of SOMDA algorithm for the shirt pocket is shown in Figure 5.1.



(a) Before SOMDA



(b) After SOMDA

Figure 5.1: Azimuth angle before and after implementation of SOMDA for the Shirt Pocket

Figure 5.1 shows a lot of noise from the accelerometer and compass. It requires low pass filtering mechanism to remove the noise. So, the true direction is not possible when using accelerometer and magnetometer alone.

5.1 Implementation using Fused Orientation Approach

Sensor fusion is the fusion of two or more sensors to take and advantage of one sensor and mitigate the weakness of other. The accelerometer can accurately measure the attitude of the device but it suffers from external noises and so it never gives the true direction of the device. However, the magnetometer can provide the true north of the device in the absence of magnetic interference from the surroundings [11]. The fusion of these two sensors is given in the above section. Another fusion would be to integrate gyroscope sensor with the accelerometer and magnetometer. The advantages are that gyroscope does not suffer from external noises and give quick responses, but it induces drift errors with time [11]. By continuously comparing the orientation angles with the zero drift errors produced by accelerometer and magnetometer, the drift error can be mitigated. Therefore, the fusion of these three sensors would obviously improve the orientation angles of the device [11].

A simple complementary filter is implemented to do the sensor fusion using the accelerometer, magnetometer and gyroscope sensors. The advantage of using this type of filter is that it does the high-pass filtering for the drift accumulated due to the gyroscope sensor and low-pass filtering for the noises from accelerometer and magnetometer [11]. The block diagram of the complementary filter is shown in Figure 5.2.

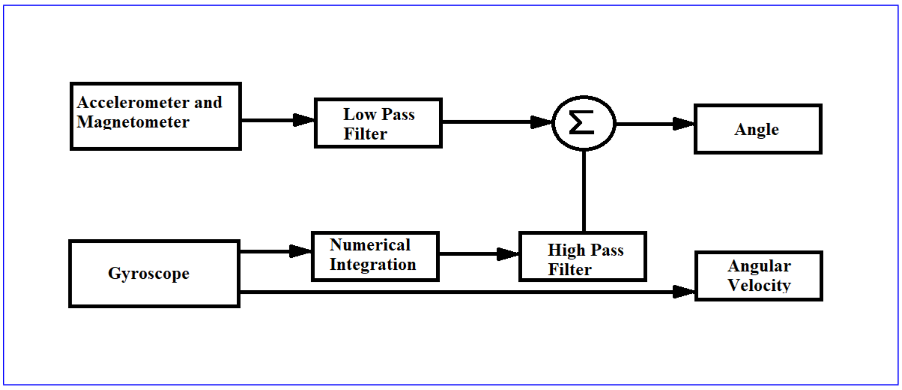
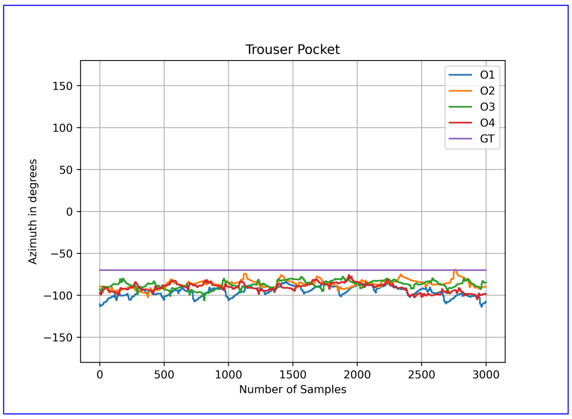


Figure 5.2: Block diagram of the Complementary Filter [11]

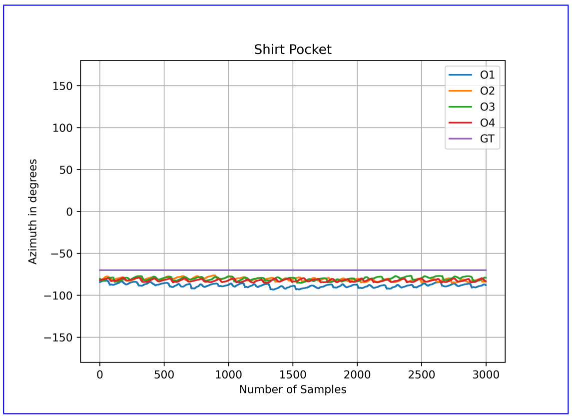
The equation (5.1) describes the complementary filtering process for the fused orientation approach where H is the filtering coefficient, newGyrovalue is the integrated gyroscopic orientation value and newAccMagValue is the orientation obtained from the accelerometer and magnetometer. The parameter H can be tuned to have a better signal quality. Here in this project, a value of 0.98 is taken for tuning the signal quality from the sensors [11].

$$FusedOrientation = (1-H) * newGyroValue + H * newAccMagValue \tag{5.1}$$

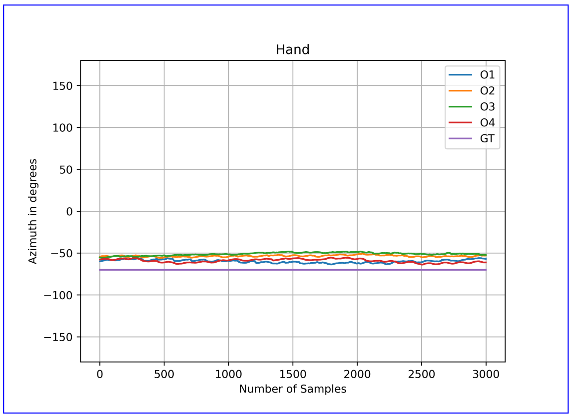
Figure 5.3 shows the results of the fused orientation approach after implementing SOMDA algorithm. The results show that the all the four orientation for each of the position are almost aligned.



(a) Trouser Pocket



(b) Shirt Pocket



(c) Hand

Figure 5.3: Azimuth angle after implementation of SOMDA

5.2 Accuracy Evaluation

Since the range of azimuth values are from $-\pi$ to π, the reference ground truth angle $290°$ in the new reference is $-70°$. The accuracy evaluated with respect to the ground truth $-70°$ at the tolerances 5°, 10°, 15°, and 20° are shown in the Table 5.2.

Orientation	Accuracy at different tolerances											
	Trouser Pocket				Shirt Pocket				Hand			
	5°	10°	15°	20°	5°	10°	15°	20°	5°	10°	15°	20°
O1	0	0	0.01	0.21	0	0	0.07	0.77	0	0.44	1.0	1.0
O2	0.02	0.09	0.35	0.75	0	0.29	0.99	1.0	0	0	0.05	1.0
O3	0	0.02	0.34	0.72	0	0.48	0.99	1.	0	0	0.02	0.67
O4	0	0.01	0.13	0.45	0	0.06	0.99	1.0	0	0.4	1.0	1.0
Overall Accuracy (%)	0.5	3	20.7	**53.2**	0	20.7	76	**94.2**	0	21	51.7	**91.7**

Table 5.2: Accuracy evaluation with the Ground Truth $-70°$

Table 5.2 shows the accuracy evaluated over 3000 samples for the tolerances 5°, 10°, 15°, and 20°. There is an overall accuracy of 53.2% for trouser pocket, 94.2% for the shirt pocket, and 91.7% for the hand position that are within the tolerance of 20° with reference to the ground truth value.

Orientation	Accuracy at different tolerances											
	Trouser Pocket				Shirt Pocket				Hand			
	5°	10°	15°	20°	5°	10°	15°	20°	5°	10°	15°	20°
O1	0.33	0.62	0.8	0.92	0.17	0.86	1.0	1.0	0.38	0.90	1.0	1.0
O3	0.54	0.85	0.97	0.99	0.87	1.0	1.0	1.0	0.97	1.0	1.0	1.0
O4	0.54	0.77	0.92	0.99	0.96	1.0	1.0	1.0	0.41	1.0	1.0	1.0

Table 5.3: Accuracy evaluation with the reference measurement O2

Table 5.3 shows the accuracy evaluation on evaluating with the reference measurement O2. The results shows an overall accuracy of 96.6% for the trouser pocket, 100% for the shirt pocket and hand positions that are within the tolerance of 20°.

Chapter 6

Experiment Results

In the previous chapter, the accuracy evaluation for the fused orientation approach is implemented. In this chapter, the results of movement direction detection for the two approaches are compared and discussed.

Table 6.1 shows the comparison of the two approaches with the accuracy evaluation at different tolerances. The results from the orientation sensor gives 66.3%, 84.3%, and 100% for the trouser pocket, shirt pocket, and hand positions whereas the fused orientation approach gives 96.6%, 100%, and 100% for the trouser pocket, shirt pocket, and hand positions that are within the tolerance of 20°. From the results, it is obvious that the fused orientation approach is performing better than the orientation sensor when accuracy evaluated at each of the allowed tolerances.

Position	Average Accuracy at different tolerances (%)							
	Orientation sensor				Fused Orientation			
	5°	10°	15°	20°	5°	10°	15°	20°
Trouser Pocket	19	35.3	51.6	66.3	47	74.6	89.6	96.6
Shirt Pocket	32.6	57.6	72.6	84.3	66.6	95.3	100	100
Hand	36	77.3	97	100	58.6	96.6	100	100

Table 6.1: Comparison of accuracy for the two approaches with the reference measurement O2

Furthermore, At a tolerance of 10°, the overall average accuracy for the smartphone carrying in hand from the fused orientation approach results 96.6% which is better compared to the shirt pocket (95.3%) and trouser pocket (74.6%) positions. Hence, the movement direction detects better when the user carries the smartphone in hand.

Chapter 7

Conclusion and Future Works

In this report, the movement direction detection of a pedestrian is estimated by implementing the SOMDA algorithm on the orientation data of the smartphone. The virtual orientation sensor in the android operating system is deprecated due to the default position of the device in either landscape or portrait. Also, this type of sensor is only reliable when the roll angle is 0. Therefore, the use of a virtual orientation sensor must be avoided.

A new orientation approach is introduced using the accelerometer, magnetometer, and gyroscope sensors for improving the movement direction detection. The SOMDA algorithm is implemented on the two approaches and compared with each other. From the results, there is an overall accuracy of 83.53% using the orientation sensor and 98.87% using the fused orientation approach that are within the tolerance of 20° for the smartphone carrying in the trouser pocket, shirt pocket and hand positions. There is an improvement of 15.34% considering all the positions in the presented approach. It is obvious that the presented approach performs better compared to the orientation sensor approach.

In this project work, the pitch angle is adjusted manually based on the position of the smartphone. In the future, the manual adjustments for the pitch angle are to be implemented dynamically by classifying the position of the device. Furthermore, the use of machine learning approaches may further improve the user movement direction detection.

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