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Detecting Accuracy of Accelerometer and Gyroscope Wearable Shimmer Sensors using Linear Regression

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***Abstract:** Smart Wearable can measures physical activities by analyzing the user's body movements which requires existing sensors such as accelerometer and gyroscope in order to secure perilous data so that it should not go missing at the point of high speed rotation or high impact. Accelerometer is a sensor that has been generally recognized as suitable and practical in smart wearable devices to measure and assess human physical activities. Wearable accelerometer sensor affords easily moveable systems that stream real-time data. The gyroscope sensor track human movement and activity and improves its accuracy. In this paper, we are comparative analyzing the commercially available SHIMMER3 wearable 3rd generation sensors raw data of age under 71-80+ people from two different sensors i.e. accelerometer and gyroscope and modeling it with machine learning approach of linear regression.*

***Keywords:** Sensors, Wearable, Accelerometer, Gyroscope*

I. INTRODUCTION

Smart Wearable are now widely use in monitoring healthcare (1).Wearable sensors are next to exterior sensing. They are attached to the Silicon-on-Insulator's (SOI) body, excluding the space constraint levied by exterior sensing. Further, wearable sensors are usually cheaper than external sensors (2).The basic sensors for instance are gyroscope, PPG, Accelerometer, pressure sensors and magnetometer are essential for wearables to deliver facilities. They are economical and can be wearing on different body parts. They are commonly integrated in other wearable devices for example shoes, watches, textiles, etc. With the help of this single sensor maximum of the SOI's motion features can be extracted. Several different sensory devices are cast-off to regulate the object's position and orientation. The commonly used of these sensors are gyroscope and accelerometer. However related in purpose, they measure different things. They are broadly used sensors and measures physical activities in any of clinical or laboratory settings or free-living environments. Smart wearable use accelerometers combine with other sensors to determine user's sleep quality and step count. By measuring the speed of body motion it assists the smart wearable to inform that user is taking a step or merely shaking wrist. It also able to determine user's movements stopped completely for a long period of time and concludes that user is asleep. Gyroscope sensors armed smart wearables tracked motions, permitting smart wearables such as the commercially available Jawbone or Fitbit to identify different types of movements, for example distinguishing among cycling and running (3).In General, each daily life activity for example walking, getting up from a chair and sitting on, standing still have a distinctive pattern. The episodic patterns length varies with physical activity, but also varies with person to person such as; the periodic walk activity length for three persons will be different. These sensor nodes capture the physical activity factors and send the data to connected computational device which compute the given data. In this paper, data retrieve from third-generation wearable sensor technology SHIMMER3 manufactured by SHIMMER sensor Ireland (4) is used to analyze. It affords a supple platform in the form of various different kits suitable for numerous applications.

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A. Accelorometer

Accelerometers can be defined as a sensor (5) enables to measure the objects in motion accelerations along reference axes as shown in fig 1. Assessing users Physical Activity using accelerometer sensor is chosen as acceleration is relative to external force and therefore can frequency of human movement and reflects intensity. Its data can be used to derive velocity and dislocation information by embedding accelerometer sensor data with respect to time (6).Few of the accelerometers can answer to gravity to determine slant sensing with respect to orientation planes when accelerometers revolve with entities. The subsequent data inclination can be used to categorize body postures. These accelerometer features, is skilled to provide enough information for measuring physical activity and also variety of human activities (7). It uses microscopic crystals that go under stress when vibrations happen, and from that stress a voltage is produced to build a reading on any acceleration. Accelerometer sensors are vital components to smart devices that track lifestyle, fitness and other measurements in the computed self-movement.

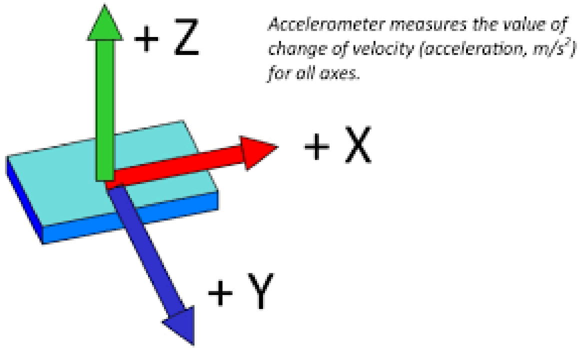

Fig 1 Accelerometer axis

B. Gyroscope

The gyroscope sensor enables to measure effective rotation rate around a specific axis. When measuring the rotation rate for instance around the aircraft's roll axis, it detects a real value up to the state object stabilizes. It sense rotational motion and changes in orientation as shown in figure 2. These are also those movements which are difficult for humans to sense. With the fundamental principles of angular momentum, the gyroscope sensor makes assistance to mark orientation. Gyroscope also called as gyro sensors, angular velocity sensors or angular rate sensors are devices that are used to sense angular velocity and effectively augment human motion (5).

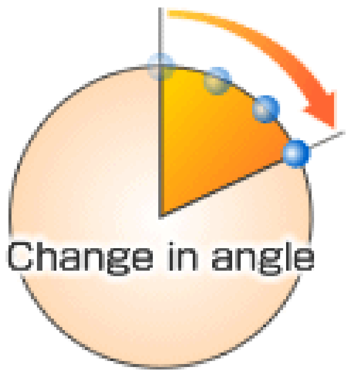

Fig 2 Gyroscope orientation

C. Accelerometer Vs Gyroscope

The classic two-axis accelerometer provides users a gravity route in a smartphone, air-jets, car or any other devices. In the view of comparison, a gyroscope sensor is anticipated to regulate an angular point grounded on the code of space rigidity and the accelerometer sensor used to measures linear acceleration grounded on vibration. The intentional device usage eventually impacts their practicality in every used platform. Various devices get advantage from the use of both sensors (5). Data to be collected on information type (acceleration or orientation) of each device will provide different outcomes.

Paper Organization

Section II glimpses the work carried out with accelerometer and gyroscope in various fields. Section III discusses about the Shimmer Wearable Device setup and functioning. Section IV performs evaluation into datasets with python data visualization and machine learning model.

Rectification in the final paper but after the final submission to the journal, rectification is not possible.

II. PROCEDURE FOR PAPER SUBMISSION

Submission of the paper

Author (s) can send paper in the given email address of the journal. There are two email address. It is compulsory to send paper in both email address.

Plagiarism Check

Good quality plagiarism software/ tool (Turnitin / iThenticate) will be used to check similarity that would not be more than 20% including reference section. In the case of exclusion of references, it should be less than 5%.

Quality Check

All submitted paper should be cutting edge, result oriented, original paper and under the scope of the journal that should belong to the engineering and technology area. In the paper title, there should not be word 'Overview/brief/ Introduction, Review, Case study/ Study, Survey, Approach, Comparative, Analysis, Comparative Investigation, Investigation'.

Paper Submission Criteria

Any one author cannot submit more than 05 papers for the same volume/issue. The authors of the accepted manuscripts will be given a copyright form and the form should accompany your final submission. It is noted that:

- Each author profile along with photo (min 100 word) has been included in the final paper.
- Final paper is prepared as per journal the template.
- Contents of the paper are fine and satisfactory. Author (s) can make rectification in the final paper but after the final submission to the journal, rectification is not possible.

III. RELATED WORK

Physical activity (PA) term can be defined as motion of body generated by human skeletal muscles which consequences in energy expenditure (8). It has been considered in epidemiological research for examining human whereabouts and the relationship to health status, specifically in the cardiovascular diseases area, obesity and diabetes mellitus. Smart Wearable use objective method or human body-fixed movement sensors, which start from actometers, switches, accelerometers, pedometers, goniometers, and gyroscopes, for physical activity assessment. Physical activity measurement by accelerometer is chosen as acceleration is proportional to external force and therefore can reflect intensity and frequency of motion. Accelerometer sensor data can be used to derive rate and movement information by integrating accelerometer numbers with respect to time (9). Accelerometers equip wearable systems skills are used to measure Movement and Posture Classification, Energy Estimation Outlay, Balance Control Evaluation and Fall Detection. Smart wearable sensors grounded fall detection systems (10), recommended system based on a basic tri-axial accelerometer sensor and gyroscope integrated in a sensor node placed on the body's neck in the form of smart wearable necklace.

The daily life activities executed by different persons are Lying, Sitting in the chair, Standing, Sitting on the floor, Go upstairs, Walking, Running, Go downstairs, Bending and some fall types are also simulated which are Fall backward (BF), Fall forward (FF), Fall leftward (LF), Fall rightward (RF), Fall on the stairs. The human body fall is identified using the threshold algorithm grounded on posture angle, angular velocity, and the acceleration. If the values of accelerometer and gyroscope sensor are surpassed from pre-defined threshold value, then fall incident was spotted.

IV. WEARABLE SHIMMER SENSOR

A. Hardware Setup

Wearable SHIMMER kit is very minute, lean and supreme robust Bluetooth based wireless sensor produced to date as shown in figure 3. It recommends a wireless flexible sensor platform with varied kind of applications, control over data capturing, and technically trustworthy interpretation data. It has range of sensing skills such as physiological, kinematic, and ambient sensing. Besides it consents to develop software in different kinds of tools for example languages C#, MATLAB, Android and LabVIEW. SHIMMER based tri-axial accelerometer data is used to analyze. Figure 1 displays available Shimmer3 sensor device that designed to comfortably fit the wearer, and be effortlessly attuned to ideal size with a strap.

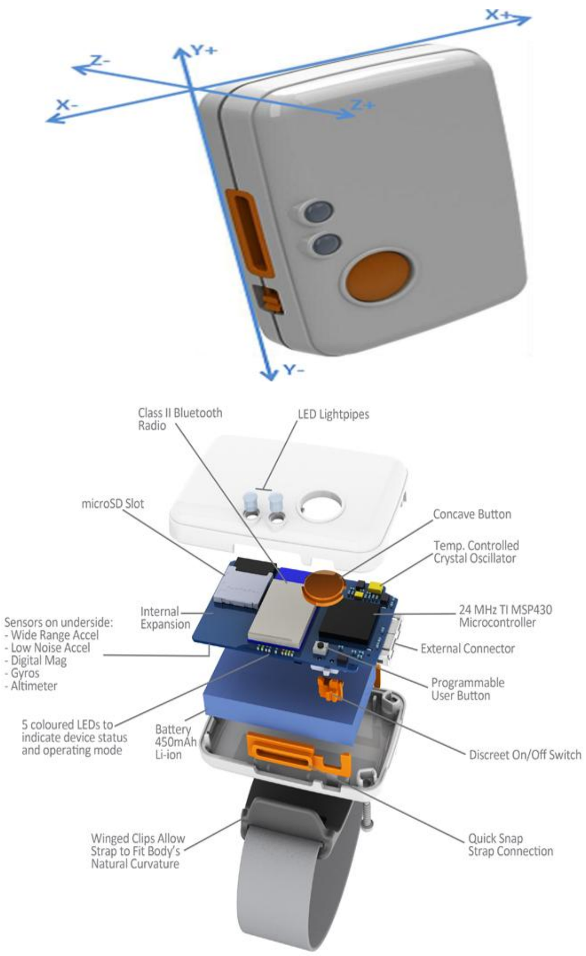

Figure 3 Wearable Shimmer Sensor

Source: Wearable Tech Specifications | shimmersensing.com

B. Equipment

Tri-axial accelerometer acquire data from wearable SHIMMER sensor which was positioned on the waist of human body using flexible elastic strap (11, 12–14) to achieve best results. Human body's waist is the area closest to the gravity's center of the body as shown in figure 4. Hence, the data recordings of the human body's waist fixed accelerometer will not be affected much by uninvited signal components such as noise in data reading by interpersonal fluctuations in the movement of body which subjects' to enables better performance (15).

V. EXPERIMENTAL SETUP

Shimmer3 wearable sensors were used for the data readings. The numerous sensors usage allows measuring the movement skilled by varied body parts, such as the acceleration, the turn rate; consequently improve fetching body dynamics. The physical activities were gathered in an out environment of lab without any constraints on the way to be executed, with the exclusion that the subject must try their best efforts when implementing them.

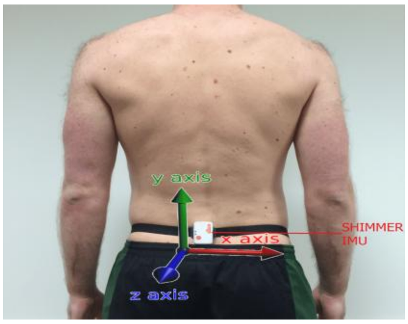

Figure 4 Shimmer Wearable body position

D.Data acquisition

Daily life's three activities, such as walking, standing still, and sitting on chair or getting up from chair were nominated. For data acquirement, the research was conducted on 114 fit candidates in both raw and calibrated methods. The acquired data was from tri-axial sensors which are low noise accelerometer, gyroscope, wide range accelerometer and magnetometer. Candidates conducting walking activity were requested to walk on a smoothed surface for around 5 to 6 meter. The triaxial accelerometry and gyroscope raw data of walking pattern can be seen in Fig. 10.

VI. METHODOLOGY

A.. Dataset Collection:

This dataset which we are using ,the data acquisition process was completed at three different locations, Shaikh Zayed Islamic Centre, University(Karachi) [16], Darul-Sukoon (Old Age Home) [17], Edhi old age home (Sohrab Goth, Karachi)[18].

B.Python Data Visualization

Python provides many good graphics libraries having loads of different parameters. Multiple new visualization libraries are familiarized recently, for intsance folium, matplotlib, pygal, Vispy, bokeh, Seaborn, and network. The matplotlib library has appeared as the key python data visualization library. It is useful in attractive illustration and instructive statistical graphics. Matplotlib is a data visualization for python 2D plotting library to build interactive plots or graphics. With the help of matplotlib library, the python data visualization of complex and huge data becomes easy to handle.

C.Linear Regression

The linear regression model's objective is to identify relationship among independent variables (one or more features) and a uninterrupted dependent variable (target variable). When there there are multiple features, it is called *Multi*ple Linear Regression else it is called *Univariate* Linear Regression. The **regression** line is the best fit line for which the *error* between the observed and predicted values is minimum.

D.Performance of the model

RMSE (Root mean squared error) is used and Coefficient of Determination (R^2 score) is used to evaluate our model. RMSE define as the square root of the sum of the squares of residuals average.

RMSE is well-defined by R^2 score or with the coefficient of determination which clarifies about how much the dependent variable's total variance able to reduce with the help of the least square regression.

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(h(x^i) - y^i)^2}$$

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VII. INVESTIGATION

A. Dataset: Inertial Sensor Dataset

The dataset which is used in this paper designed to deal with the techniques using for human behavior analysis based on activities recorded in multimodal inertial measurement of wearable shimmer sensors (20, 21).

The dataset is downloaded from Google dataset search engine.

Data Set Characteristics:	Multivariate, Time-Series
Number of Instances:	114
Area:	Computer Applications
Attribute Characteristics:	Real
Number of Attributes:	14
Date updated	2019-4-20
Associated Tasks:	Classification, Pattern analysis
Data Set Information:	
Data is divided into five age and weight groups' categories.	

a. DATASET ACTIVITY SUMMARY:

Activities: 3
Sensor devices: 1
Subjects: varies

S. No.	Age Groups	Male	Female	Total
1	41 – 50 yrs.	3	3	6
2	51 – 60 yrs.	33	30	63
3	61 – 70 yrs.	13	6	19
4	71 – 80 yrs.	13	3	16
5	>80 yrs.	5	5	10
Total		67	47	114

Activity Set
L1: Standing still (5sec)
L4: Walking (1 min)
L11: Stand to Sitting (3 steps) (time varies)

NOTE: In brackets define are the repetitions numbers (Nx) or exercises duration (min).

B. Dataset Attributes

In this paper, the examination done on the walking activity data of the old people group under age 70-80+.

Table consists of the following attributes.
Column 1: Time stamp raw
Column 2: Time stamp in millisecond
Column 3: acceleration raw (X axis)
Column 4: Acceleration cal (X axis)
Column 5: acceleration raw (Y axis)
Column 6: Acceleration cal (Y axis)
Column 7: : acceleration raw (Z axis)
Column 8: Acceleration cal (Z axis)
Column 9: gyro raw (X axis)
Column 10: gyro cal (X axis)
Column 11: gyro raw (Y axis)
Column 12: gyro cal (Y axis)
Column 13: gyro raw (Z axis)
Column 14: gyro cal (Z axis)
*Units: Acceleration (m/s^2), gyroscope (deg/s).

C. Analysis on the following attributes

In this paper we are analyzing on the following attributes.

Column 1: Time stamp raw
Column 3: acceleration raw (X axis)
Column 5: acceleration raw (Y axis)
Column 7: acceleration raw (Z axis)
Column 9: gyro raw (X axis)
Column 11: gyro raw (Y axis)
Column 13: gyro raw (Z axis)

D. Dataset Shimmer sensor Walking

Details: age of 70-80+

VIII. PYTHON VISUALIZATION OF ACCELEROMETER AND GYROSCOPE

The equations are an exception to the prescribed pacifications of this template. Figure depicts the accelerometer analysis

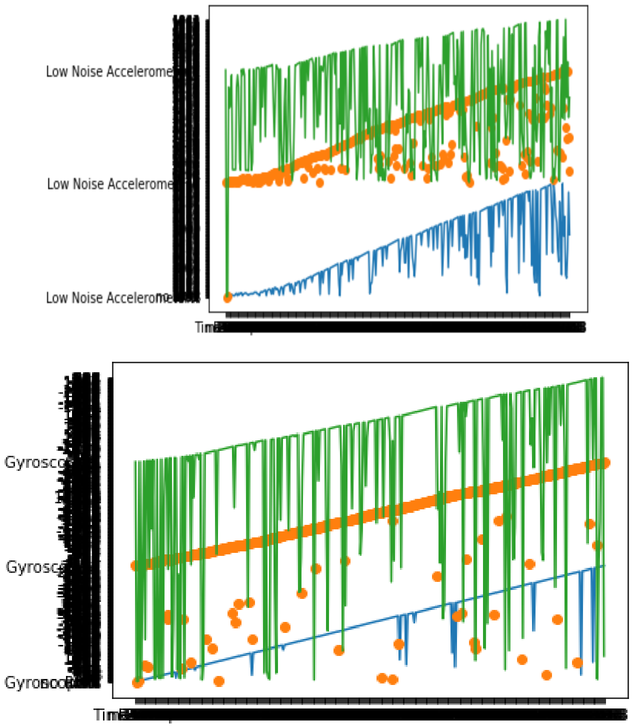

Figure 5. accelerometers and gyroscope during walking

A.Time complexity analysis

The walking data set of the person (Fig. 3) is commonly free of big transients in the output of accelerometer. Apart this, the specific motion estimation is actually different from these two sensor types. Certainly, the accelerometer accounts more activity at both levels of high and low frequencies.

As we can see from the figure the acceleration data on the side x-axis appears more 'inconsistent' in comparison to the other two y and z axes. This becomes clear in the plot of frequency domain (Figure 3). Here it can be understood that the data laterally on the x-axis (green line) is more outward in the higher frequencies instead of the y-axis leads to the less even appearance in time field.

One can observe the range of magnitude is sometimes more or less equal for every signal. Considering at the gyroscope sensor data (Figure 4) it appears that, observing at the x-axis, the track shape has slight effect on the signal but probing the other two axis it becomes obvious again. As the rotation influenced least around the lateral axis observed at these signals marks a bigger difference among the magnitudes range.

B.Comparative analysis

In comparison to gyroscope sensors the Tri-axial accelerometer sensors deliver a high measurement devotion of force along the x-y-z directions, and thus provide a view into person's motion wearing the device. Low power accelerometer sensor consumes less power and thus can be used easily in wearables.

IX. PREDICTIVE MODELLING

A. Linear Regression Model on Accelorometer Sensor

The predictive model for accelerometer sensor as shown in Fig.6 (a , b, c)for the following best fitting lines x-y-z axis observed from the following figures as x-axis and z axis provide values from high to low timestamps towards their axis values inspite y –axis values will not vary with timestamp and continue to be a straight line. Hence, it concludes that the x-z axis will be in movement with person in motion while y-axis is almost constant.

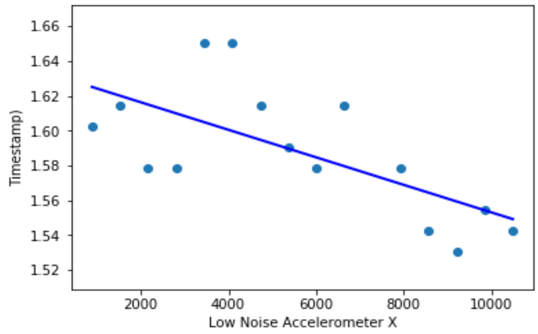

Figure 6 a

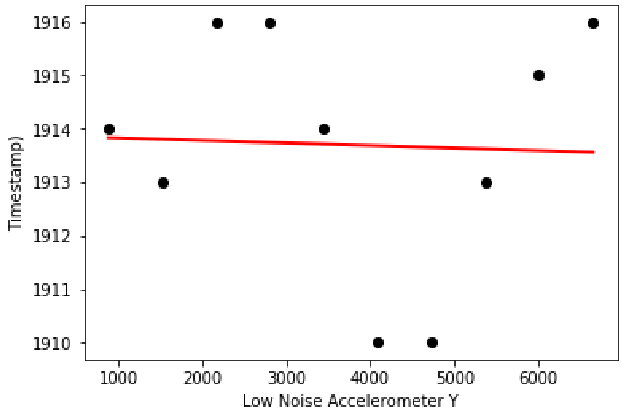

Figure 6 b

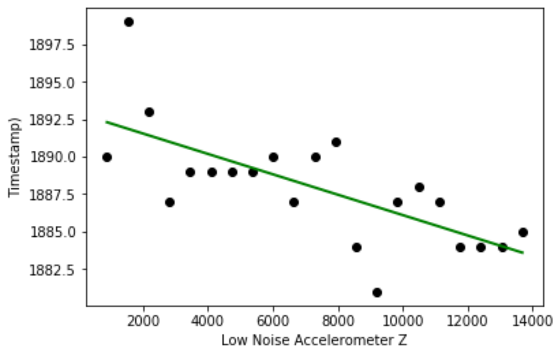

Figure 6 c

Figure 6: Machine learning Accelerometer Model of Human walking

B. Linear Regression Model on Gyroscope Sensor

The predictive model for gyroscope sensor for the following x-y-z axis best fitting lines observed from the following figures 7(a, b, c) as x-axis provides the highest variation from high to low on timestamp and y axis provide values from high to low timestamps towards their axis values inspite z –axis values will not vary much with timestamp. Hence, it concludes that the x-y-z axis will be in movement with person in motion while z –axis vary least.

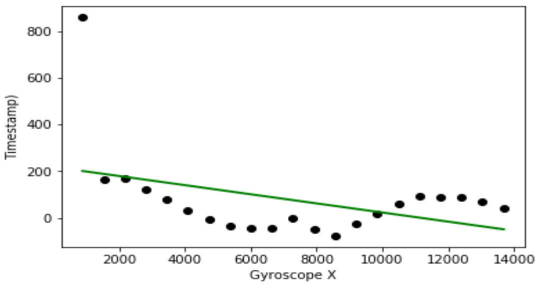

Figure 7a

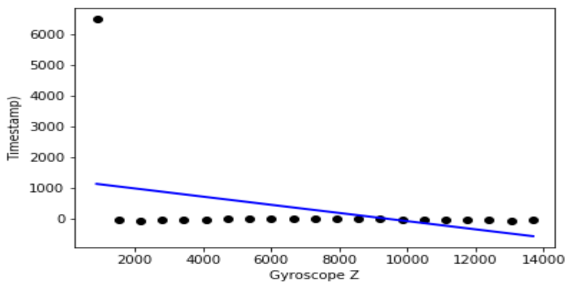

Figure 7b

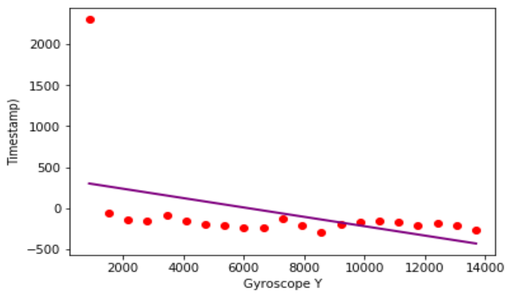

Figure 7c

Figure 7: Machine learning Accelerometer Model of Human walking

C. Model Evaluation

Regression Slope is typically articulated as an absolute value. In statistics, negative slope signifies a negative correlation amid two variables. This understood as one variable raises, the other one decreases—and vice versa.R^2 is a numerical amount about how much close the data values are fitted regression line. When interpreting the intercept in a Linear Regression Model. The intercept (sometime labeled as constant) is the anticipated mean value of timestamp(y) when all x=0. Beginning with a linear regression equation with one predictor, x. If x often equals to 0, the intercept is simply the expected mean value of timestamp (y) at that value. Root Mean Square Error (RMSE) is the regular deviation of the prediction errors. Prediction errors are a degree of how far from the linear regression line data points are. In other mean, it informs about how concentrated the data is around the line of best fit.

a. Evaluating the performance of accelerometer model x-axis

The model parameters and the performance metrics of the model are given below:

Slope: [-7.90662652e-06]

Intercept: 1.6320655121482281

Root mean squared error: 0.000712246576520637

R2 score: 0.44410876207755534

b. Evaluating the performance of Gyroscope model of x-axis

Slope: [-0.04613906]

Intercept: 334.4252093749999

Root mean squared error: 29789.736866666666

R2 score: 0.39410704677966

X. Results

Table 1: Accuracy Detection of Sensors

Features	Accelerometer	Gyroscope	Observation
Location	Varies at the body location or device orientation.	Independent	In this paper we mounted the device on waist consists of both sensors.
Measurement	Measures Linear acceleration from gestures of users.	Measure of angular velocity	Observing the measurements of both the sensors in walking activity.
Reading	Blue line z-axis variate with time-stamp as the person is using steps up and down.	Blue line z-axis variate minimal as the person is experiencing less rotation.	Simple walking pattern less rotation.
	Green line x-axis is constantly varying with time stamp as the usual motion of walking activity.	Green line x-axis is highly varying with time stamp considering the angular motion of walking activity.	Simple walking and high rotation in motion.
	Orange line y-axis which is upwards is in correlation to x-axis motion.	Orange line y-axis which is upwards is in correlation to x-axis angular motion.	In correlation with X-axis.
Prediction using Linear Regression	x-axis and z axis provide values from high to low timestamps towards their axis	x-axis provides the highest variation from high to low on timestamp.	In accelerometer sensor x-z axis will be in movement with person in motion while y-axis is almost constant.
	y-axis is almost constant	y axis provide values from high to low timestamps towards their axis values	In gyroscope x-y-z axis will be in movement with person in motion while z –axis vary least.
		z –axis values will not vary much with timestamp.	
Model Evaluation (x-axis only)	Slope: [-7.90662652e-06]	Slope: [-0.04613906]	Accelerometer model slope has strong negative relationship in comparison to the gyroscope weak slope model.
	Intercept: 1.6320655121482281	Intercept: 334.4252093749999	Accelerometer intercept is most fitted.
	Root mean squared error: 0.000712246576520637	Root mean squared error: 29789.736866666666	Accelerometer low value enables better fit in model.
	R2 score:	R2 score:	44% in accelerometer

XI. DISCUSSION

The purpose of this paper was to explore tri-axial-accelerometer and tri-axial-gyroscope parameters as estimation of position and orientation which compares and analyze the available datasets of walking activity movements with the help of wearable which have in built accelerometers and gyroscopes sensors to provide an estimate of waist motion. The datasets are visualized in python which is observed and further analyzed with the help of machine learning model of linear regression. The outcomes show the two of the used sensor patterns are very different. Accelerometer and Gyroscopes sensors slope describes the predicted values along the timestamp. Although, an accelerometer sensor response is slow also sensitive to linear accelerations, and a gyroscope sensor undergoes from slow drift and unidentified initial inclination.

Hence, the presented comparative analysis and provide valuable visions into the human activity patterns.

XII. CONCLUSION

The fast progress in functional sensors of low-power ICs, and wireless communication has permitted a new generation of wireless sensor networks, which are used in various areas such as monitoring transport, agriculture, infrastructure, and healthcare. From all of these sensors accelerometer and gyroscope are so commonly used in wearable for recording daily human activities. In addition, accelerometers and gyroscopes sensors are inexpensive and can be used in practically any environment. These sensors are analyzed and compared in python language data visualization along with linear regression. Recently, inertial sensors (accelerometer and gyroscope) have experienced key growths. The measurements quality has enhanced while their cost has reduced, leading to a rise in accessibility. Also, obtainable computational resources are steadily growing. Hence, we trust that inertial sensors can be used for even more varied forthcoming applications.

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Jana Shafi is a P.hD scholar have numerous publications and authored book and chapters also serving as a reviewer in various journals also a member of prestigious associations. She attended numerous conferences and received best research award also.

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