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Angular Velocity and Elevation Angle: The Proposed Human Model Scalable Tracking Model using Linear Regression

(Halaju Sudut dan Sudut Ketinggian: Cadangan Model Manusia dengan Model Pengesanan Berskala menggunakan Regresi Linear)

CHING YEE YONG*, RUBITA SUDIRMAN & KIM MEY CHEW

ABSTRACT

A scalable tracking human model was proposed for recognizing human jogging and walking activities. The model aims to detect and track a particular subject by using wearable sensor. Data collected are in accelerometer readings in three axes and gyroscope readings in three axes. The development of proposed human model is based on the moderating effects on human movements. Two moderators were proposed as the moderating factors of human motion and they are angular velocity and elevation angle. Linear regression is used to investigate the relationship among inputs, moderators and outputs of the model. The result of this study showed that the angular velocity and elevation angle moderators are affecting the relation of research output. Acceleration in x-axis (A_x) and angular velocity in y-axis (G_y) are the two main components in directing a motion. Classification between jogging and walking motions was done by measuring the magnitude of angular velocity and elevation angle. Jogging motion was classified and identified with larger angular velocity and elevation angle. The two proposed hypotheses were supported and proved by research output. The result is expected to be beneficial and able to assist researcher in investigating human motions.

Keywords: Angular velocity; elevation angle; moderator; motion

ABSTRAK

Sebuah model pengesanan manusia berskala telah dicadangkan untuk mengenalpasti aktiviti manusia semasa berjoging dan berjalan. Model ini bertujuan untuk mengesan dan menjejaki sesuatu subjek dengan menggunakan sensor dipakai pada badan. Data yang dikumpul adalah bacaan pecutan tiga paksi dan bacaan giroskop tiga paksi. Pembangunan model manusia ini adalah berdasarkan kepada kesan penyederhanaan terhadap pergerakan manusia. Dua moderator telah dicadangkan sebagai faktor sederhana gerakan manusia dan mereka adalah sudut halaju dan sudut ketinggian. Regresi linear digunakan untuk mengkaji hubungan antara input, moderator dan output model. Hasil kajian ini menunjukkan bahawa sudut halaju dan sudut ketinggian moderator memberi kesan kepada hubungan output penyelidikan. Pecutan dalam x-paksi (Ax) dan sudut halaju dalam paksi y-(Gy) adalah dua komponen utama dalam mengarahkan usul. Pengelasan antara berjoging dan berjalan dilakukan dengan mengukur magnitud sudut halaju dan sudut ketinggian. Gerakan berjoging diklasifikasikan dan dikenal pasti dengan sudut halaju dan sudut ketinggian yang lebih besar. Kedua-dua hipotesis yang dicadangkan disokong dan dibuktikan oleh hasil penyelidikan. Hasil kajian dijangka memberi manfaat dan dapat membantu penyelidik dalam mengkaji usul manusia.

Kata kunci: Moderator; pergerakan; sudut halaju; sudut ketinggian

INTRODUCTION

Human motion analysis requires lot of data and algorithms computation. Instead of using classifier and image streams analysis, a human motion model was proposed in this study to classify human movements.

A recognition model with two moderators was proposed in this study. The two moderators were analyzed to discover their effects to the success rate of motion pattern classification. Six features (linear acceleration in x, y, z axes, angular velocity in x, y, and z axes) were introduced to the model as inputs. Angular velocity and elevation angle are the two moderating components proposed in the model to investigate the angular velocity in y direction on arm and elevation angle (leaping angle) in x direction.

The proposed model aimed to investigate the relation of angular velocity and elevation angle to the human motion activities. Hypotheses were addressed in the next section to identify the proposed model.

RESEARCH BACKGROUND

There are many ways to capture human motion in digital domain; the common ways are using mechanical, electro-magnetic, optical and video-based. Human motion identification can be done just by focusing on a set of dots on a motion (Johansson 1973). Gypsy and Physilog systems are commercial motion capture systems using mechanical way to capture human motion. Liberty mocap system from Polhemus, Cabled Flock of Birds system from Ascension, wireless electro-magnetic mocap system Motion Star from Ascension and the motion capture for Lara Craft movie performed by Motion Star are using the electro-magnetic motion capture system. Optical motion capture system uses optical markers as human model for motion estimation. The previous systems were very expensive and thus two techniques were proposed to capture the human motion using wearable sensor and single vision based camera. The most challenging issues of the techniques were poor imaging or occlusion and the need of large samples for all possible poses.

PROBLEM FORMULATION

Several imperatives were identified to be addressed by the proposed model: To improve the fit of the model, since the main effect alone may not provide sufficient accuracy in prediction; Implication on theory which is to discover the moderating factor (mean of angular velocity (AV) and mean of elevation angle (EA)) in relationship between sensor inputs and human actions output; and To provide information on the motion boundary conditions for the relationship.

The effectiveness of moderator impacted on the model was presented. A moderated relationship provides more details than main effect and therefore, provides more fine-tuned picture of reality (Amery & Bruno 2008; Chen et al. 2013; Keshavarz 2005; Ojolo et al. 2012; Preston 1980; Reuben & David 1986; Song et al. 2013).

Two hypotheses are proposed in the study: Human jogging and walking motions are moderated by angular velocity in y-axis; and human jogging and walking motions are moderated by elevation angle in x-axis.

Angular velocity (G_y) is defined as the velocity of the swinging arm in half-circular form while elevation angle (A_x) is defined as the angle computed from the resultant of airborne. Figure 1 shows the mechanism of moderator development. The hypothesized functions aimed to deliver useful information with connection to the theory and the result of proposed model.

STUDY REVIEW

One form of locomotion in land by human is walking and this activity can be distinguished from another one, which is jogging by comparing the amount of ground touching by foot at a time, speed of arm swinging and elevation of runner from the ground (Novacheck 1998).

As shown in Figure 2(a), walking is done using a 4-phase strategy: contact, recoil, passing and high-point. In the forward walking motion, both feet are involved in a coordinated motion by leaving only one foot always fully contact with the ground and the other is rising. One foot firstly strikes the ground from heel and roll to toe until fully contacted to the ground. This is the first phase of walking cycle. The second phase called recoil and it happened when the other raises and begins to leave the ground. The foot is leaving the ground and slowly passing the one that contacting the ground is called passing, the third phase of a walking cycle. A full walking cycle is completed when the foot leaves the ground and reaches the highest point, then contacts with the ground again (Yong et al. 2013a).

On the other side, jogging motion is more complicated with an extra phase called airborne. Refer to Figure 2(b), in the forward jogging motion, a runner need to leap and at this moment, both feet are rising and leave no foot contacts on the ground. Due to this situation, the gap of the runner from the ground is larger than the walking motion. Hence, two components were proposed into the model for motion classification and they are angular velocity and elevation angle. Angular velocity was used to calculate

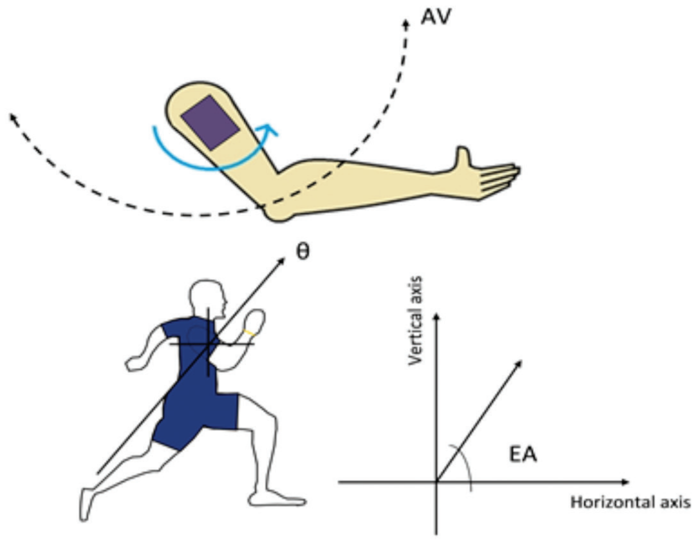
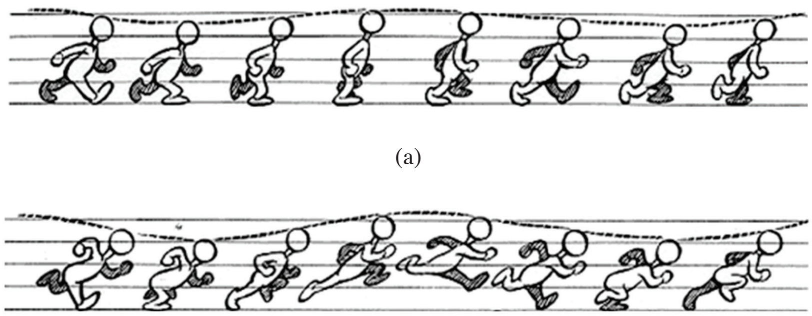


FIGURE 1. Computation of AV and EA



(a)

(b)

FIGURE 2. (a) Walking and (b) jogging

the speed of swinging arm of runner and elevation angle is the measurement of vertical gap between the runner and ground (Rajamanickam & Balusamy 2008; Sumrit et al. 2013; Yong et al. 2013b).

METHODS

In this study, a model was proposed regarding the effect of angular velocity and elevation angle on the accelerometer and gyroscope inputs features to the recognition of human jogging and walking motions patterns.

In Figure 3, the proposed model was built up with 6 input features: accelerometer in x, y and z axes, two moderating effects: mean of angular velocity (AV) and elevation angle (EA) and two respectively outputs: jogging and walking motions.

RESEARCH MODEL

A research model was proposed to investigate the effect of mean of angular velocity (AV) and elevation angle (EA) to human jogging and walking motion. Moderators were discovered to investigate the effects while performing the activities. Coefficients as shown in Table 3 were computed and regression equations as shown in Table 4 were derived to calculate the moderating effects.

DATA COLLECTION FRAMEWORK

The data for the research were collected through 3 space sensor which consists of accelerometer, gyroscope and compass sensors. Sensor was attached on subject's arm while requested to perform jogging and walking activities. 100 samples data from accelerometer and gyroscope for the respective activities were collected for investigation. Figure 4 shows the process of collecting data. The sensor is attached firmly on the arm as shown in Figure 5 with a specially designated holder to stick firmly on the arm. The data collection was performed by three subjects. They were jogging and walking activities on a treadmill for 100 meters by repeating 100 times.

SPSS was used to compute all descriptive statistics, coefficients tables and regression equations. There are three assumptions to be introduced in order to verify the collected data which are common when working with real world computation.

The three assumptions are listed as follows:

Assumption 1 The inputs of the model should be in continuous form. The variables are measured at the interval or ratio level. A_x, A_y, A_z were the accelerometer data measured in m/s^2 while G_x, G_y and G_z data were gyroscope data measured in rad/s.

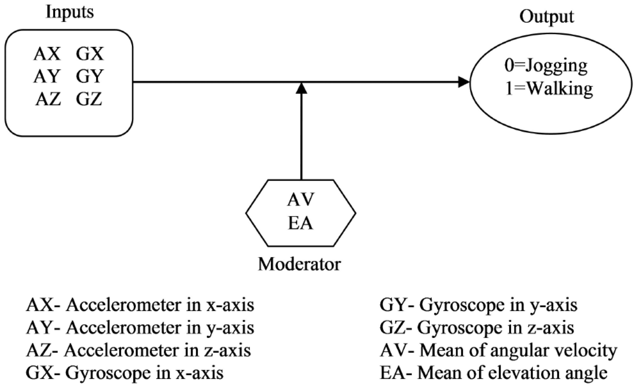


FIGURE 3. Proposed research model overview

Assumption 2 Linear relationship should exist between the variables. Scatter plot was plotted to inspect the linearity. Transformation will be performed if the inputs were not linear with each other.

Assumption 3 No significant outlier is allowed. Outlier defined as the particular data point that does not follow the usual pattern. The outlier normally exists out of the plotting variation boundary. Scatter plot is used to investigate any outlier. Elimination outlier is essential in order not to affect the computation accuracy.

The sensor was calibrated according to the manufacturer's manual, by zeroing all the readings in three axes. This procedure was executed using the manufacturer's software.

RESULT

Table 1 shows the descriptive statistics of the collected data, i.e. mean and standard deviation of every input features, moderators, product features (interaction between input features and moderators) and output.

Table 2 shows the proposed summary model of the research. All significant F change were 0.000 for both AV and EA proposed models and this implies that AV and EA do exist as moderators and therefore affect the relationships between sensor input features and human motion patterns. Table 3 shows the moderating coefficients values for AV and EA moderators. The coefficients values were used to derive the regression equations in order to produce graphical plots. Regression equations were derived in Table 4 using coefficients values in Table 3. The equations were derived

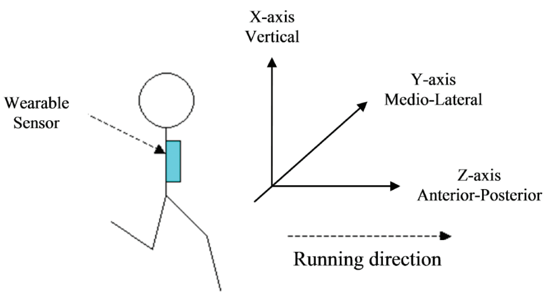


FIGURE 4. Sensor attachment on subject's arm during performing activities

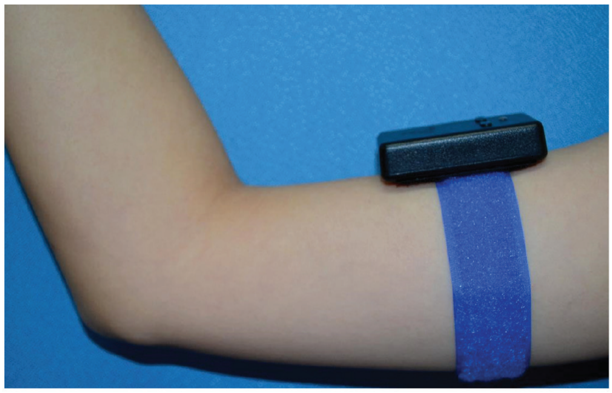


FIGURE 5. Sensor attachment on subject's arm

TABLE 1. Descriptive statistics for input features, moderators and output

Feature	Mean	Std Deviation	N
OUTPUT	0.500	0.503	100
G_x	-0.067	0.685	100
G_y	-1.364	3.365	100
G_z	0.189	1.670	100
A_x	0.142	0.411	100
A_y	0.004	0.180	100
A_z	-0.776	0.409	100
Mean_AV	2.310	0.832	100
$A_x \times$ AV	0.415	1.215	100
$A_y \times$ AV	-0.006	0.512	100
$A_z \times$ AV	-1.684	1.156	100
$G_x \times$ AV	-0.260	1.833	100
$G_y \times$ AV	-0.162	4.006	100
$G_z \times$ AV	0.181	4.908	100
Mean_EA	30.435	20.856	100
$A_x \times$ EA	6.677	20.320	100
$A_y \times$ EA	-0.179	8.525	100
$A_z \times$ EA	-20.255	21.581	100
$G_x \times$ EA	-4.450	29.486	100
$G_y \times$ EA	-4.660	65.983	100
$G_z \times$ EA	-0.050	82.364	100

TABLE 2. Model summary of AV/EA moderator

Model	R	R Square	Adjusted R Square	Std. Error of Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig.F Change
1	0.937[a]	0.878	0.871	0.181	0.878	111.963	6	93	0.000
2	0.980[b]	0.960	0.957	0.104	0.082	187.212	1	92	0.000
3	0.990[c]	0.981	0.978	0.074	0.021	15.807	6	86	0.000
4	0.937[d]	0.878	0.871	0.181	0.878	111.963	6	93	0.000
5	0.984[e]	0.968	0.966	0.093	0.090	260.023	1	92	0.000
6	0.992[f]	0.985	0.983	0.066	0.017	15.962	6	86	0.000

a. Predictors (AV): (Constant), A_z, G_y, A_x, G_x, A_y, G_z
b. Predictors (AV): (Constant), A_z, G_y, A_x, G_x, A_y, G_z, Mean_AV
c. Predictors (AV): (Constant), A_z, G_y, A_x, G_x, A_y, G_z, Mean_AV, $G_x \times$ AV, $A_z \times$ AV, $A_x \times$ AV, $G_z \times$ AV, $A_y \times$ AV, $G_y \times$ AV
d. Predictors (EA): (Constant), A_z, G_y, A_x, G_x, A_y, G_z
e. Predictors (EA): (Constant), A_z, G_y, A_x, G_x, A_y, G_z, Mean_EA
f. Predictors (EA): (Constant), A_z, G_y, A_x, G_x, A_y, G_z, Mean_EA, $G_x \times$ EA, $A_z \times$ EA, $A_x \times$ EA, $A_y \times$ EA, $G_y \times$ EA, $G_z \times$ EA

Sig. F Change (p) indicates the significance of the model regression. For model (p) < 0.05, the model with proposed moderators is accepted.

Output = Constant + Input + Moderator + Product Term …(1)

TABLE 3a. Coefficients table for AV moderator

Model (AV)	Unstandardized	Coefficients
	B	Std. Error
(Constant)	-0.655	0.132
G_x	1.113	0.220
G_y	-0.651	0.221
G_z	-0.418	0.165
A_x	3.519	0.340
A_y	-1.777	1.192
A_z	-0.293	0.158
Mean_AV	0.512	0.051
$A_x \times$ AV	-0.976	0.112
$A_y \times$ AV	0.883	0.444
$A_z \times$ AV	0.153	0.068
$G_x \times$ AV	-0.405	0.099
$G_y \times$ AV	0.202	0.074
$G_z \times$ AV	0.082	0.064

TABLE 3b. Coefficients table for EA moderator

Model (EA)	Unstandardized	Coefficients
	B	Std. Error
(Constant)	-0.327	0.090
G_x	0.696	0.116
G_y	-0.472	0.139
G_z	-0.341	0.101
A_x	2.727	0.285
A_y	-0.479	0.621
A_z	-0.377	0.103
Mean_AV	0.024	0.002
$A_x \times$ AV	-0.044	0.005
$A_y \times$ AV	0.022	0.015
$A_z \times$ AV	0.011	0.003
$G_x \times$ AV	-0.020	0.003
$G_y \times$ AV	0.009	0.003
$G_z \times$ AV	0.006	0.002

TABLE 4. Computation of regression equations

Output	Constant	Input	Moderator	Product term
OUTPUT_AV	= -0.655	$+ 3.519A_x$	+ 0.512AV	$- 0.976A_x \times$ AV
OUTPUT_AV	= -0.655	$- 0.651G_y$	+ 0.512AV	$+ 0.202G_y \times$ AV
OUTPUT_EA	= -0.327	$+ 2.727A_x$	+ 0.024EA	$- 0.044A_x \times$ EA
OUTPUT_EA	= -0.327	$- 0.472G_y$	+ 0.024EA	$+ 0.009G_y \times$ EA
OUTPUT_AV	= -0.655	$- 1.777A_y$	+ 0.512AV	$+ 0.883A_y \times$ AV
OUTPUT_AV	= -0.655	$- 0.293A_z$	+ 0.512AV	$+ 0.153A_z \times$ AV
OUTPUT_AV	= -0.655	$+ 1.113G_x$	+ 0.512AV	$- 0.405G_x \times$ AV
OUTPUT_AV	= -0.655	$- 0.418G_z$	+ 0.512AV	$+ 0.082G_z \times$ AV
OUTPUT_EA	= -0.327	$- 0.479A_y$	+ 0.024EA	$+ 0.022A_y \times$ EA
OUTPUT_EA	= -0.327	$- 0.377A_z$	+ 0.024EA	$+ 0.011A_z \times$ EA
OUTPUT_EA	= -0.327	$+ 0.696G_x$	+ 0.024EA	$- 0.020G_x \times$ EA
OUTPUT_EA	= -0.327	$- 0.341G_z$	+ 0.024EA	$+ 0.006G_z \times$ EA

in terms of output, input features (A_x, A_y, A_z, G_x, G_y, G_z), moderators (AV, EA) and product features ($A_x \times AV$, $A_y \times AV$, $A_z \times AV$, $G_x \times AV$, $G_y \times AV$, $G_z \times AV$, $A_x \times EA$, $A_y \times EA$, $A_z \times EA$, $G_x \times EA$, $G_y \times EA$, $G_z \times EA$). Product features are product terms between inputs and moderators. The product features investigate the interaction between inputs and moderators. Table 5 shows the regression codings for regression equations. The codings showed two situations of moderators: AV/EA=0 means moderators were absent and AV/EA=1 means moderators were present. The equations of these two situations were used to determine the absence and presence of moderators that may affect the output of the model.

Discussion

From the supported result, as shown in Figure 6(a), 6(b), 6(c) and 6(d) lines A and lines B were plotted, respectively, with high value (mean + standard deviation) and low value (mean – standard deviation), both regression equations were intersected with each other. The intersection means moderators do exist and affect the human motion patterns. Figure 6(e)-6(l) shows no intersection for both regression coding equations and these mean moderators do not affect A_y, A_z, G_x and G_z input features.

Figure 7 shows the directions of accelerometer and gyroscope while a subject was performing the jogging and walking activities. Subject arm was moving repeatedly in linear A_x direction and at the same time, the arm was swinging in angular G_y direction. In order to differentiate jogging and walking, the study was focusing on the runner's airborne. As the result, for jogging motion, the runner was moving faster, leaping higher and therefore the larger the elevation angle in A_x direction and angular velocity in G_y direction. The theory was supported by the proposed model and hence A_x and G_y are the main components for human in performing jogging and walking activities.

The coefficients (Table 3(a) and 3(b)) give the values to compute regression equation for Table 4. The regression equation is computed as:

Conclusion

This study attempted to raise an interest of angular velocity and elevation angle in affecting the human motion activity patterns towards its features in the signal processing field. The results from the proposed model indicated that human motion was controlled by two main components and they were acceleration in x-axis and angular swinging in y-axis by arm.

A more detailed concept of model will be more useful in the next analyzing stages. As in moderating flow algorithm, all the information was needed to be incorporated on the direction of processing. Optimization in realization is very important for an optimize solution from the beginning.

In future, upgrading by implementing more other affecting moderators will be performed to stabilize the model to provide necessary information needed to increase the reliability and effectiveness of analysis potential (Byrne et al. 2013; Chen & Shi 2012).

Potential Applications

Human can walk so much easier and naturally than robots do because a baby learns to turn over and crawling before he started to walk and run. Walking is harder for a robot than it looks because robot does not have the nature stem brain stimulation like humans were born with. The study demonstrated the basics locomotion of moving with full capabilities from the start. The results present the optimal walking and jogging cycles as the mechanics of learning process for robots.

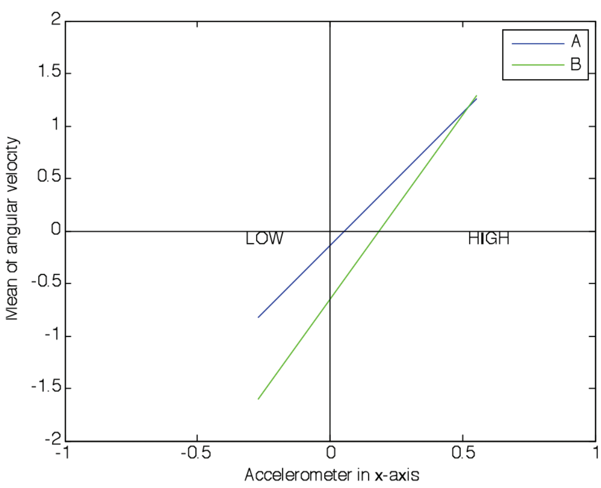
Disability is a natural factor caused by aging. Evaluation of rehabilitation therapies for disabled

TABLE 5a. Regression codings for AV/EA = 0

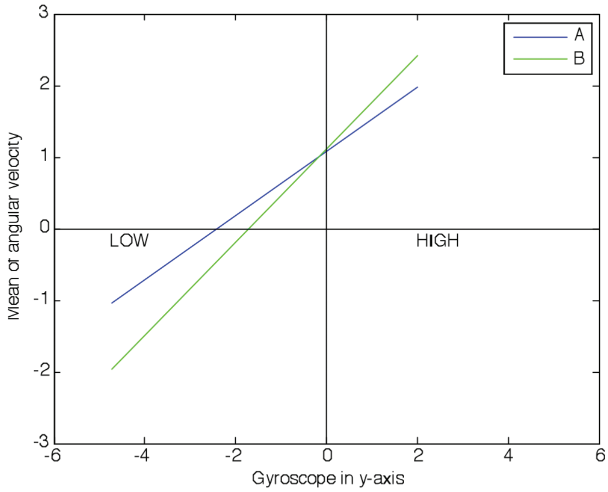
Output	Constant	Input
OUTPUT_AV	= -0.655	+ 3.519A_x (line B in Figure 6a)
OUTPUT_AV	= -0.655	– 0.651G_y (line B in Figure 6b)
OUTPUT_EA	= -0.327	+ 2.727A_x (line B in Figure 6c)
OUTPUT_EA	= -0.327	– 0.472G_y (line B in Figure 6d)
OUTPUT_AV	= -0.655	– 1.777A_y (line B in Figure 6e)
OUTPUT_AV	= -0.655	– 0.293A_z (line B in Figure 6f)
OUTPUT_AV	= -0.655	+ 1.113G_x (line B in Figure 6g)
OUTPUT_AV	= -0.655	– 0.418G_z (line B in Figure 6h)
OUTPUT_EA	= -0.327	– 0.479A_y (line B in Figure 6i)
OUTPUT_EA	= -0.327	– 0.377A_z (line B in Figure 6j)
OUTPUT_EA	= -0.327	+ 0.696G_x (line B in Figure 6k)
OUTPUT_EA	= -0.327	– 0.341G_z (line B in Figure 6l)

TABLE 5b. Regression codings for AV/EA = 1

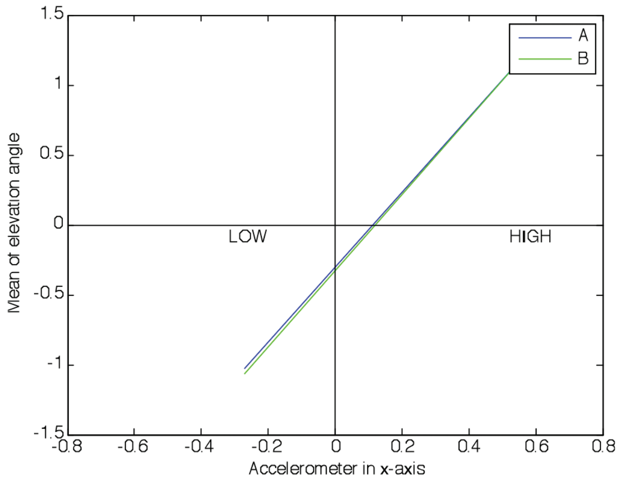
Output	Constant	Input
OUTPUT_AV	= -0.143	+ 2.543Ax (line A in Figure 6a)
OUTPUT_AV	= -0.143	– 0.449Gy (line A in Figure 6b)
OUTPUT_EA	= -0.303	+ 2.683Ax (line A in Figure 6c)
OUTPUT_EA	= -0.303	– 0.463Gy (line A in Figure 6d)
OUTPUT_AV	= -0.143	– 0.894Ay (line A in Figure 6e)
OUTPUT_AV	= -0.143	– 0.140Az (line A in Figure 6f)
OUTPUT_AV	= -0.143	+ 0.708Gx (line A in Figure 6g)
OUTPUT_AV	= -0.143	– 0.336Gz (line A in Figure 6h)
OUTPUT_EA	= -0.303	– 0.457Ay (line A in Figure 6i)
OUTPUT_EA	= -0.303	– 0.366Az (line A in Figure 6j)
OUTPUT_EA	= -0.303	+ 0.676Gx (line A in Figure 6k)
OUTPUT_EA	= -0.303	– 0.335Gz (line A in Figure 6l)



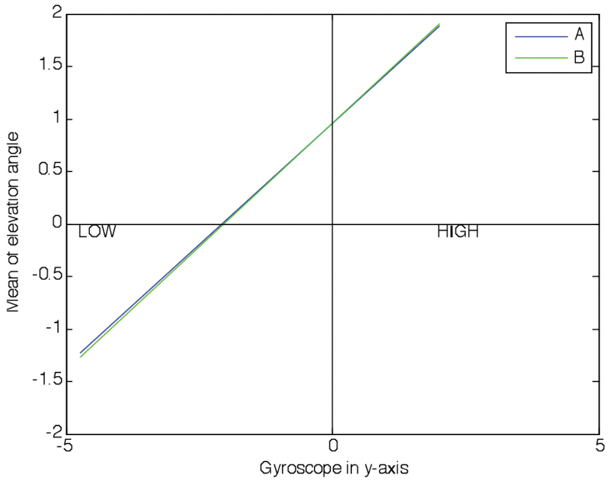
a) A_x-AV



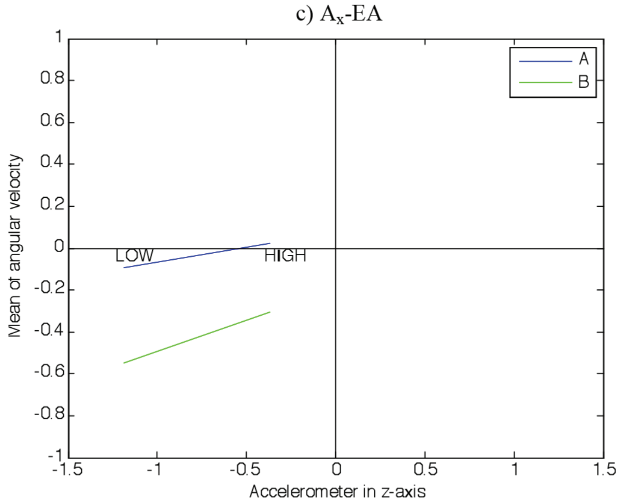
b) G_y-AV



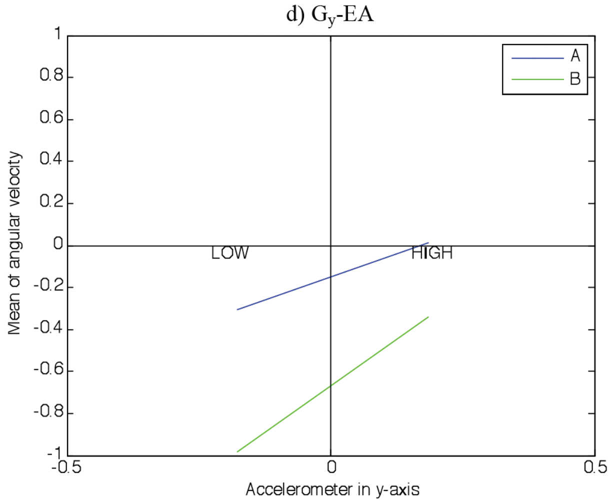
c) A_x-EA



d) G_y-EA



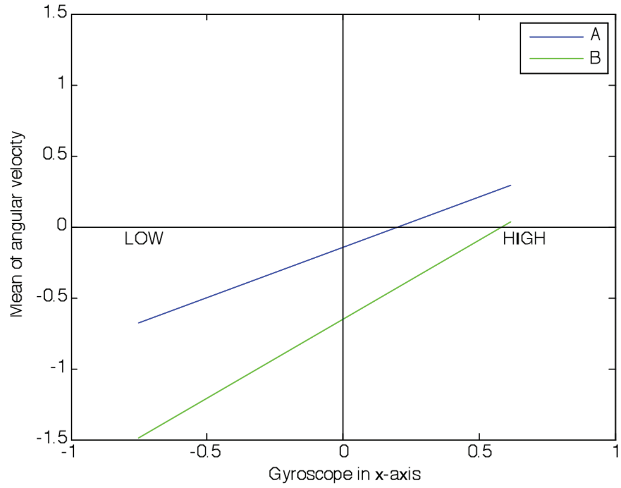
e) A_z-AV



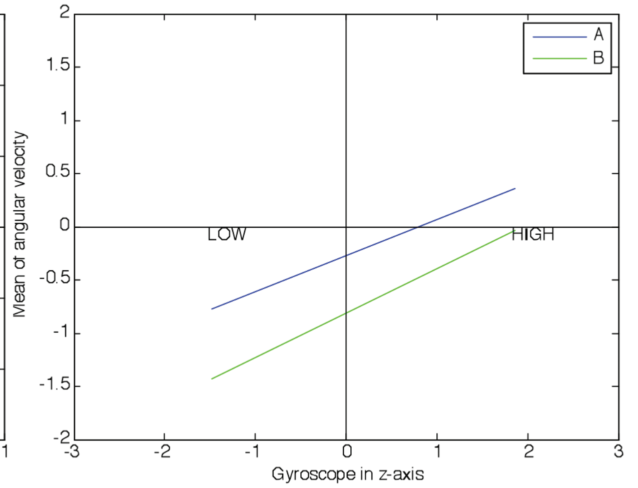
f) A_y-AV

(continue)

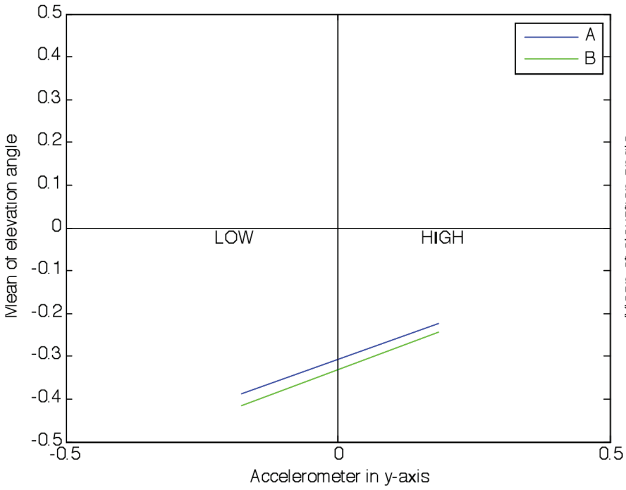
Continued (FIGURE 6)



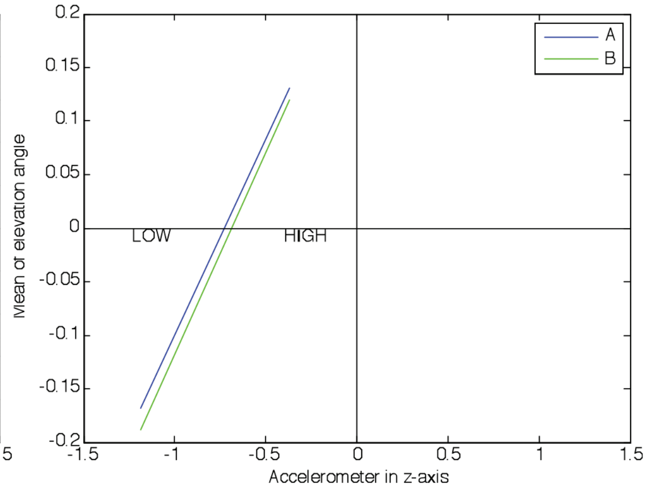
g) G_x-AV



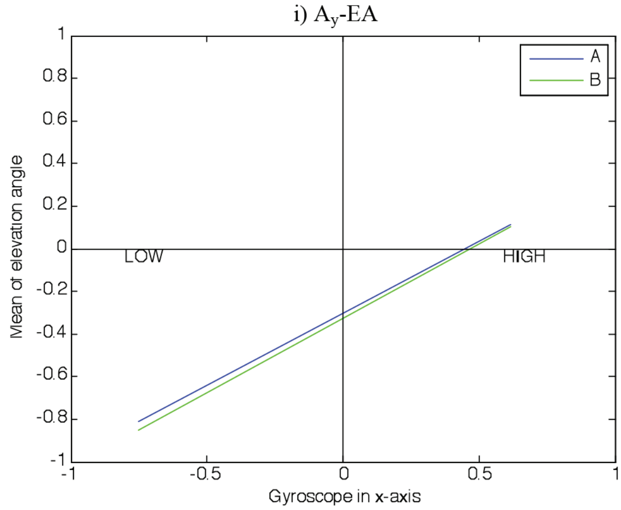
h) G_z-AV



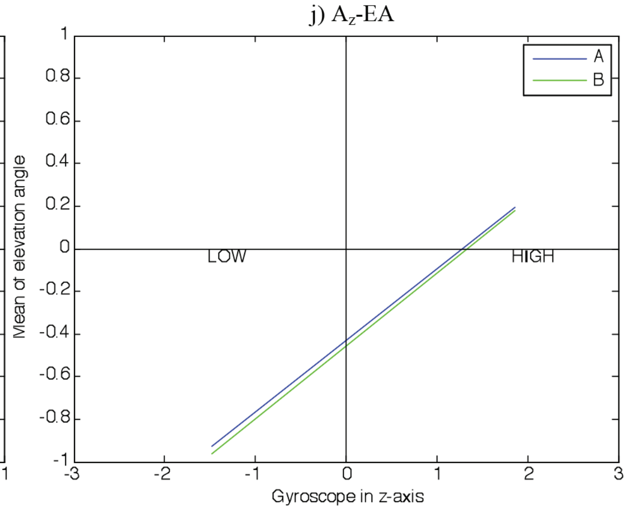
i) A_y-EA



j) A_z-EA



k) G_y-EA



l) G_z-EA

FIGURE 6. Graphical plots of regression equations

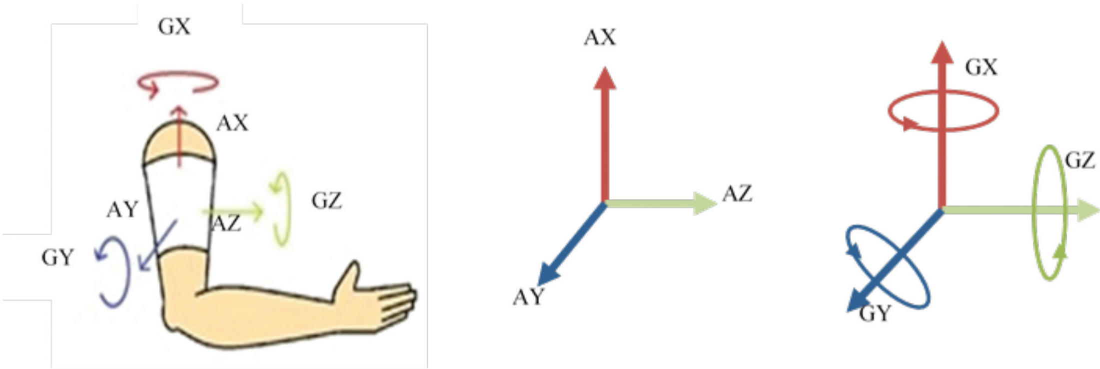


FIGURE 7. Subject's arm movement in A_x, A_y, A_z, G_x, G_y and G_z directions

individual is essential with engineering and technological solutions. The design and performance of assistive device for disabled in mobility and activities associated with independent living are often entailed in rehabilitation process. Findings from the study are highly recommended to promote good posture and mobility through assessment of progress by charting data from proper sensors worn on body of patient. The best example can be stroke rehabilitation, sports assistive training, sports performance training, arts performance training and exercise machine.

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Faculty of Electrical Engineering
Universiti Teknologi Malaysia
81310 Skudai, Johor Darul Takzim
Malaysia

*Corresponding author; email: chiyong@fkegraduate.utm.my

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