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Analysis of Shalat Gait

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Abstract

This study was done to analyze the pattern of shalat gait in comparison to walking gait. Force plate system records ground reaction forces when reading walking gait. It produces distinct curves that have profiles of an M-liked shape. This curve exhibits the behaviour of walking gait in term of ground reaction force as a function time. Instead of using force plate system, this work used heuristic method of argument by exploiting the advantages found in graph theory and algebraic representations. The 'M' profile was succesfully created using the method proposed. The method was then tested on shalat gait through responses from seventeen subjects who participated in the exercise. At the conclusion of the study it was suspected that shalat routine was similar to walking activity.

Keywords: *Shalat, Gait, Walking Gait, Graph, Ground Reaction Force, Foot, Vertex, Edge.*

1 Introduction

We have not found studies either on shalat gait postures or studies that: explain the relationship between the ground reaction forces (GRF) and the points on barefoot; dictate the specific location of these points and therefore, specify their numbers. There is, however, in [1] where a multilayer neural network is used to detect foot-contact on force plate. Nevertheless, there are numerous studies on foot biomechanics such as in [2], on walking gait analysis in [3], [4], [5], [6], [7], [8], [9], [10], and in [11] for healthy children.

By inspection human foot has twenty-seven bones arranged in cramped manner. It has five digits known as phalanges. Their function is to minimise the drop-off experience—the experience at the end of walking gait cycle. Absence of the digits would hamper, for example, sprinting. On the other hand, force plate system records ground reaction forces when measuring and reading gait. It produces a distinct curve that has a profile of an M-liked shape.

Calcaneus works somewhat like a peg that initiates the gait. It bears body weight upon heel strike. It is the largest bone. Navicular and cuboid bear distributed body weight upon foot flat. At the end of walking gait—the toe-off, the last phalanx or the toe would bear the body weight.

The objective of this paper are to: identify walking gait norm, model walking gait, evaluate the walking gait model with data from force plate system, and to asses the model by testing on shalat gait. Shalat is daily prayers scheduled at five different times. It consists of a fix number of stances and variable number of cycles.

Instead of using force plate system, this work uses a heuristic method of argument. In creating the profiles, it exploits the advantages found in graph theory and the general methods in mathematics.

2 Background

Figure 1 shows the application of a single force plate system. The subject walk towards the instrument and step on while walking. This approach, however, does not read walking gait. Instead it reads climbing gait. To overcome this shortcoming, the application of a double force plates as shown in Figure 2 is necessary.

Figure 1. Application of a single force plate to test basic walking gait.

The curve shown in Figure 2 has a distinct M-liked shape. The two peaks explain that foot is experiencing maximum body weight during heel strike—the first peak, and during toe-off. The valley indicates the gait is at midstance where the foot is aligned to the body's centre of gravity.

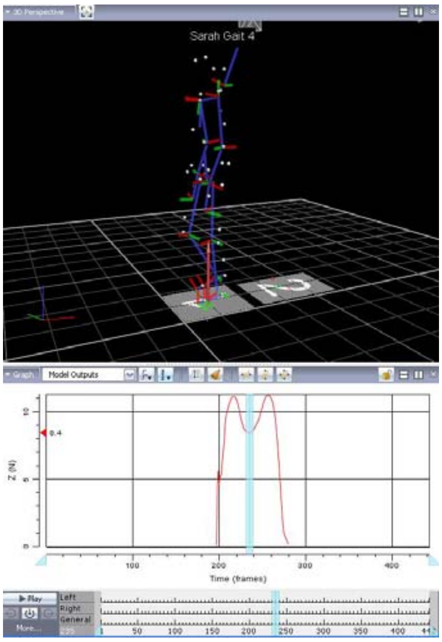

Figure 2. The above picture shows the application of two force plates to measure complete walking gait. In the curve GRF is assigned to *y*-axis, time to *x*-axis. The middle section of the curve explains midstance position, which is now aligned to the body's centre of gravity.

Definition 3.1. Suppose that a bone is represented by vertex, v and a joint by edge, e. Based on graph in Figure 3 calcaneus is v_3, talus is v_1, and e_{13} links them.

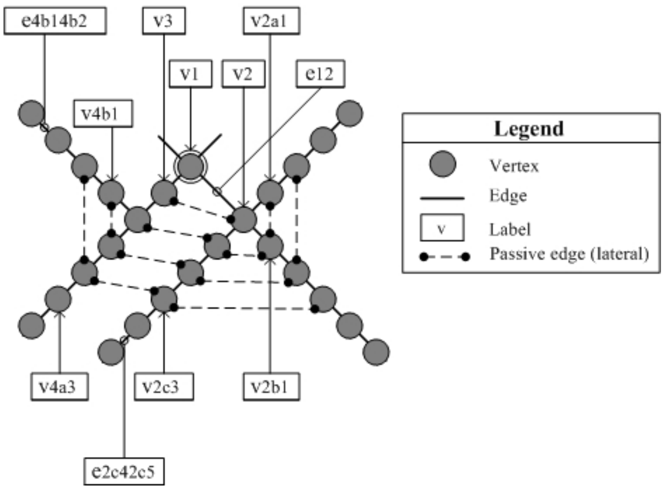

Figure 3. A vertex is represented by a solid circle, solid lines represent joints. The dashed lines, on the other hand, represent passive edges. These lateral edges are ignored in this work.

Definition 3.2. Suppose that a walk from the origin, v_1 is made by connecting vertices through edges. There are at most five walks defined by Eqs. (1) to (5) define these walks.

$$S_{\mathrm{W1}} = \langle v_1, e_{13}, v_3, e_{34}, e_{44\mathrm{b1}}, v_{4\mathrm{b1}}, e_{4\mathrm{b14b2}}, v_{4\mathrm{b2}}, e_{4\mathrm{b24b3}}, v_{4\mathrm{b3}}, e_{4\mathrm{b34b4}}, v_{4\mathrm{b4}} \rangle \quad (1)$$

$$S_{\mathrm{W2}} = \langle v_1, e_{13}, v_3, e_{34}, e_{44\mathrm{a1}}, v_{4\mathrm{a1}}, e_{4\mathrm{a14a2}}, v_{4\mathrm{a2}}, e_{4\mathrm{a24a3}}, v_{4\mathrm{a3}}, e_{4\mathrm{a34a4}}, v_{4\mathrm{a4}} \rangle \quad (2)$$

$$S_{\mathrm{W3}} = \langle v_1, e_{12}, v_2, e_{22\mathrm{c1}}, v_{2\mathrm{c1}}, e_{2\mathrm{c12c2}}, v_{2\mathrm{c2}}, e_{2\mathrm{c22c3}}, v_{2\mathrm{c3}}, e_{2\mathrm{c32c4}}, v_{2\mathrm{c4}}, e_{2\mathrm{c42c5}}, v_{2\mathrm{c5}} \rangle \quad (3)$$

$$S_{\mathrm{W4}} = \langle v_1, e_{12}, v_2, e_{22\mathrm{b1}}, v_{2\mathrm{b1}}, e_{2\mathrm{b12b2}}, v_{2\mathrm{b2}}, e_{2\mathrm{b22b3}}, v_{2\mathrm{b3}}, e_{2\mathrm{b32b4}}, v_{2\mathrm{b4}}, e_{2\mathrm{b42b5}}, v_{2\mathrm{b5}} \rangle \quad (4)$$

$$S_{\mathrm{W5}} = \langle v_1, e_{12}, v_2, e_{22\mathrm{a1}}, v_{2\mathrm{a1}}, e_{2\mathrm{a12a2}}, v_{2\mathrm{a2}}, e_{2\mathrm{a22a3}}, v_{2\mathrm{a3}}, e_{2\mathrm{a32a4}}, v_{2\mathrm{a4}} \rangle \quad (5)$$

Walk-1, S_{w1} begins from talus and ends at the first digit. Similarly, Walk-5 begins from the talus and end at the fifth digit—the thumb. Walk-2 and Walk-3 have thirteen elements, Walk-1 has eleven, and Walk-4 and Walk-5 have eleven elements. Based on Figure 3, it is realistic that Walk-1 and Walk-2 be grouped in a sub graph, and Walk-3, Walk-4, and Walk-5 in another. It is assumed that a walk can only take one route.Though actually only a trail can function as such.

In completing walking gait, foot undergoes a number of sequences. These sequences are related to the fourteen points shown in Figure 4a. The point-of-contact 0 (POC-0) is the initial point that is located somewhere prior to heel strike. The POC-1 is the point where calcaneus experiences initial impulse upon heel strike. The sequences in walking gait begins from POC-0 and ends at POC-13. This is explained in Figure 4b and Figure 4c. Figure 4d shows the relationship between these sequences and the POCs in the ambulatory path.

Proposition 3.1. Let there be a number of sequences for an ambulating foot. The sequence, Q follows POC. Therefore, the ambulatory path is created. Every sequence has at least one POC and a GRF— f_k except for Q_0 and Q_{13}.

By observation, there should be at most twelve POCs that have immediate contact with the ground surface on foot flat. These points and their respective locations are shown in Figure 4b. It is common sense that POC-0 does not experience any reaction prior to touching the ground at Q_0. In this sequence, none of the POC has contact with the ground. This is also true for the last sequence. However, upon heel strike POC-1 bears maximum body load.

Proposition 3.2. On foot flat the amount of weight that body exerts on the foot should equal to the summation of GRFs.

At standing posture the body weight acts downwards due to gravitational pull. At the same time, the reaction forces act in opposite direction equal the weight so that equilibrium is achieved.

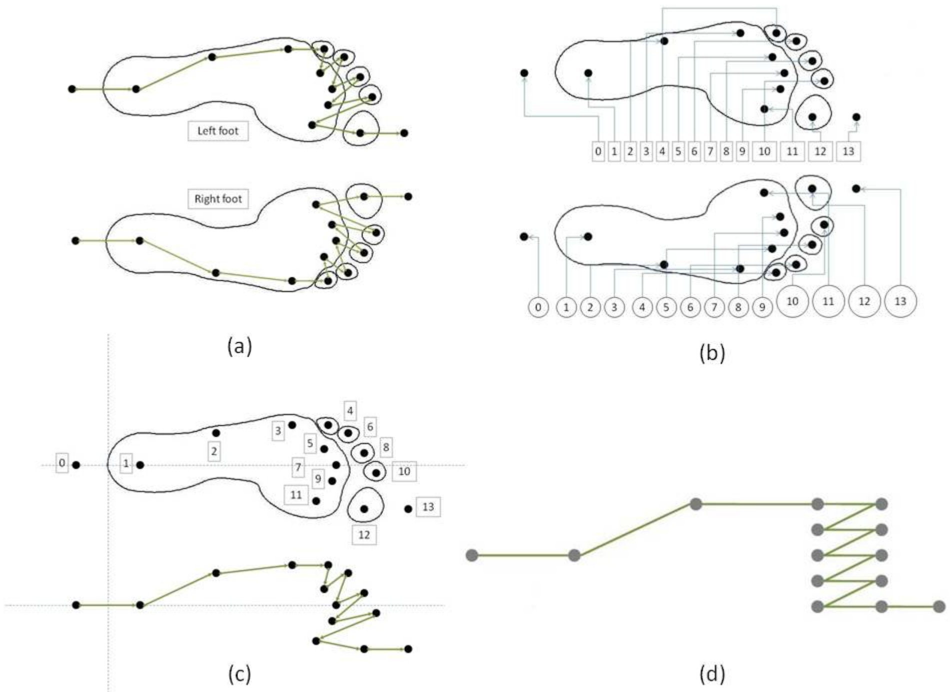

Figure 4. (a) There are at most twelve points on the footprint. (b) The location of the POCs. (c) The ambulatory path. (d) The simplified ambulatory path.

Proposition 3.3. Suppose the relationship between Q and POC with respect to f_k can be shown through Eq. (6). The degree of the relationship between Q and POC with respect to f_k and $h_{i,j}$ are represented by membership functions, Ψ. The degree 'V' means very large, 'L' large, 'M' medium, 'S' small, and 'A' absent. Elements in $\mathbf{H}$, for ideal ambulation, should result Eq. (7).

$$\mathbf{H} = \left\{ \left[h_{i,j}, Q_i \times P_j \right] \;\middle|\; h_{i,j} = \begin{cases} \text{V} \\ \text{L} \\ \text{M}, \; if \;\; \exists f_k; i = 0,1,2,3...,14; \; j = 0,1,2,3,...,13 \\ \text{S} \\ \text{A} \end{cases} \right\} \tag{6}$$

$$\mathbf{H}=\begin{bmatrix} A & A & A & A & A & A & A & A & A & A & A & A & A & A \\ A & V & A & A & A & A & A & A & A & A & A & A & A & A \\ A & V & L & L & M & M & M & S & S & S & S & S & S & A \\ A & A & V & L & L & M & M & M & S & S & S & S & S & A \\ A & A & A & V & L & L & M & M & M & S & S & S & S & A \\ A & A & A & A & V & L & L & M & M & M & S & S & S & A \\ A & A & A & A & A & V & L & L & M & M & M & S & S & A \\ A & A & A & A & A & A & V & L & L & M & M & M & S & A \\ A & A & A & A & A & A & A & V & L & L & M & M & M & A \\ A & A & A & A & A & A & A & A & V & L & L & M & M & A \\ A & A & A & A & A & A & A & A & A & V & L & L & M & A \\ A & A & A & A & A & A & A & A & A & A & V & L & L & A \\ A & A & A & A & A & A & A & A & A & A & A & V & L & A \\ A & A & A & A & A & A & A & A & A & A & A & A & V & A \\ A & A & A & A & A & A & A & A & A & A & A & A & A & A \end{bmatrix} \tag{7}$$

In walking gait foot experiences GRFs all over. At the initial contact with ground, POC-1 has the largest GRF—“V”, whereas others have none—“A”. This situation is seen in row two of Eq. (7). In all instances, the first and the last POCs do not have contact with the ground. This is shown in the first and the last column. In row three, the foot flat phenomenon is occurring where POC-1 to POC-12 have immediate reaction forces with ground. The rest of the sequences follow the trend prescribed.

Proposition 3.4. Suppose Eq. (7) is transformed into equivalent third order polynomial functions with vertical axis intercept. Equation (8) estimates the membership functions.

$$\widehat{\Psi}_{P_j}\left(Q_i\right)=x_3 Q_i^{\,3}+x_2 Q_i^{\,2}+x_1 Q_i+x_0 ; \forall \widehat{\Psi}, x\in\mathbb{R}; Q, \mathrm{POC}\in\mathbb{N} \tag{8}$$

Definition 3.3. An f_k acts on a specific point shown in Fig. 4b. Having the forces embedded into Eqs. (1) to (5) will show the locations of bones and joints . Equation (10) is its general definition.

$$S_{\mathrm{W}m}\Big|_{f_k}=\left\langle v,e:\Big|_{f_k}\right\rangle \tag{10}$$

Definition 3.4. Within walks there is an assumed scale. It is the sums of the degree of GRFs that act on the POCs defined in Eq.(6). Equation (11) describes this phenomenon by showing it in term of walks. So that, all walks should experience some degree of GRFs on ideal ambulation.

$$\sum S_{\mathrm{W}m}\Big|_{f_k}:\iint \Psi_{P_j}\left(Q_i\right)dP\cdot dQ \tag{11}$$

A typical walking gait profile is shown in Figure 2. On the other hand, the profile's unique shape could also be obtained through human intelligent feedbacks. The following section will discuss the matter.

3 Analysis

This study involved seventeen respondents demographically shown in Table 1. There were ten male subjects. The youngest participant was eleven years old and the oldest was fourty-seven.

Table 1. Subject background.

Category	Gender		Age		
Sub-category	Male	Female	Minimum	Average	Maximum
Quantity	10	7	11	24	47

A survey form was constructed. Figure 5 is a snapshot of a part in the form. It instructed subjects to fill in the boxes with feedbacks following Eq. (6). There were twenty-six boxes for a sequence. There were eight shalat postures used in this study wherein there were 208 blanks that the participants responded to. In addition, they were briefed on the theoretical background found in Proposition 3.3, Eq. (6), and Eq. (7) was given earlier in layman language.

Please write one number in each box in the foot figure that corresponds to the amount of force at the respective point-of-contact.

(0) Absent	(1) Small	(3) Medium	(4) Large	(5) Very large

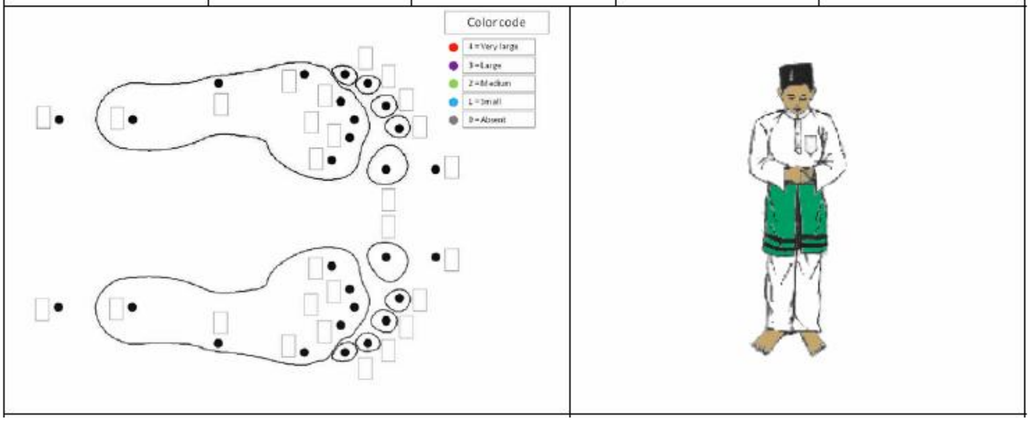

Figure 5. The snapshot of the survey. On the left-hand side are the feet with blank boxes adjacent to POCs. The respondent would have to fill these blanks with appropriate feedbacks using the membership functions defined. On the right-hand side is the shalat sequence at standing posture. This is sequence number one.

The data was computed by straightforward averaging. The manipulated data were grouped into equivalent membership functions defined in Eq. (6). For every sequence there was a distinct membership function. Figure 6 shows profiles of shalat gait in term of the relationship between the membership function and the sequence. The pictures in Figure 6 were the studied shalat stances.

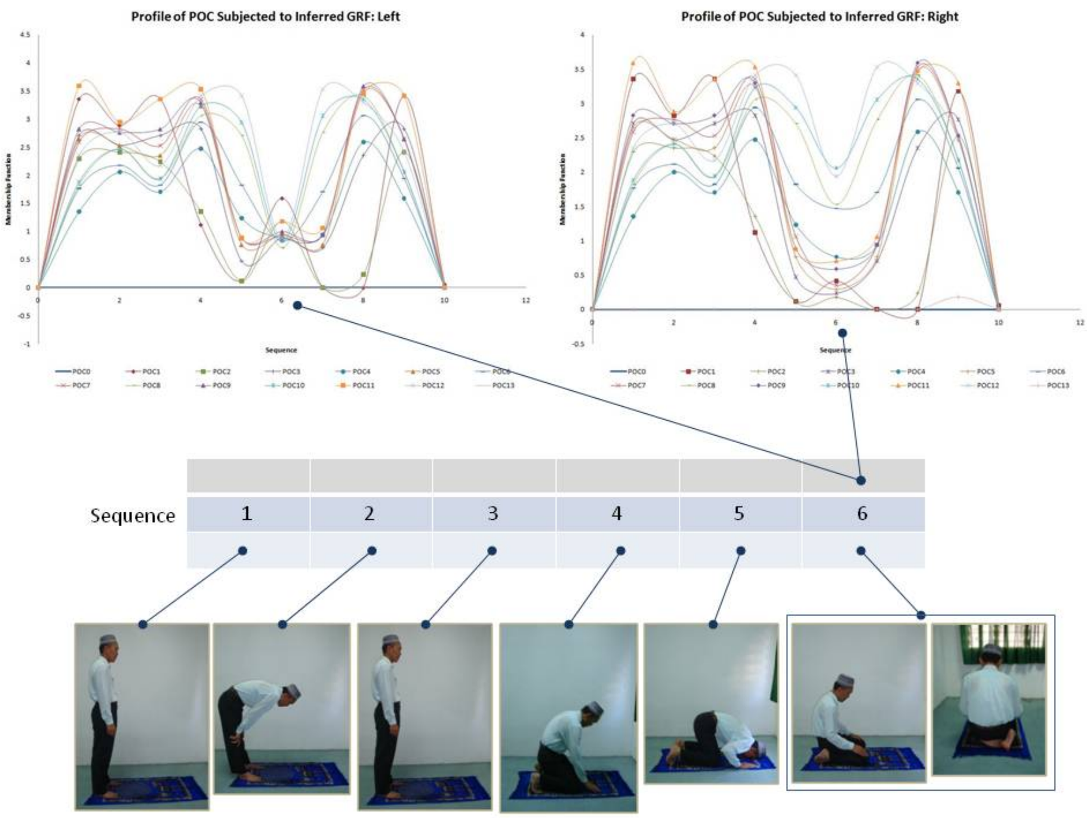

Figure 6. Profiles of shalat gait in term of the relationship between the membership function and the sequence.

During Ruku' that is sequence 2, the degree of GRFs for all points seemed to converge. The GRFs were distributed almost uniformly on the foot due to body balancing. The major distinguishing element between left foot and right foot was during sequence 6 where the left foot tucked under the buttocks while the right foot was kept vertical. Right foot recorded high in the phalanges. In Figure 7, there are three curves representing left foot and right foot for shalat gait, and an ideal walking gait based on Eq. 11.

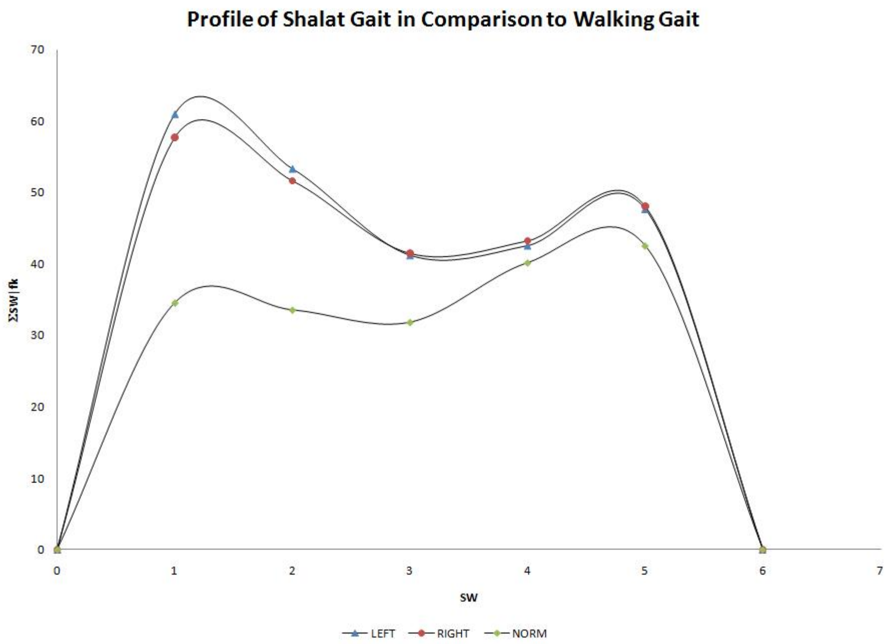

Figure 7. The ideal walking gait profile shown in the norm curve. In a normal human ambulation, it is theorized that the profile should has the outlook as the norm curve. Walk-3 is supposedly the midstance.

The profile for shalat especially for sequence 1 is higher than the norm. Sequence 1 in walking gait involves heel strike where GRF consideration is only at one point. However, for shalat it is the standing posture where GRFs do not concentrate on heel but throughout the foot. Therefore, the summation of the GRFs is more in shalat gait than in walk's. Closing to toe-off, shalat gait exhibits higher responses to GRFs. In shalat, there is no toe-off stance. There is, however, Sujud returning to standing posture. This is considered equivalent to toe-off as it is like to begin a new cycle.

4 Conclusion

If a force plate system is used in measuring and recording the shalat gait, the profile obtained will not be an M-liked shape. Instead, it records a long curve with extremums and minimums here and there, and that begin and end at zero. This is due to a pause at every sequence. During these pauses, the stances seemed to experience static GRFs for some time. It was like keeping the weight on specific points within certain time limit. Nevertheless, using the method suggested, it was found that the profile of shalat gait was almost equivalent to walking gait's but higher reaction to GRFs in shalat. It is concluded that shalat routines perform by Muslims five times a day are, in fact, static walking exercises.

5 Shalat gait open problems

Healthy Muslims enjoy performing shalat in standard postures. The disables, however, would perform shalat in exceptable postures suggested by the scholars. For those who use prosthetic foot, although they are able to walk, would find it difficult to follow the standard postures. Using ideas based on Eqs. (1) to (11), solve the following problems:

- The point of contacts have roles in that they allow human body to acquire reaction forces for balancing purposes. If left foot has lost POC-2 functionality, can one balance the standing posture?
- Human foot has twenty six bones. In addition, it has unopposable thumb. This property distinguishes it from other primates. If foot has lost its thumb, would the person be able to maintain Ruku' posture with ease?
- A person with prosthetic foot unit has it installed just below the knee. It is secured using socket onto the thigh. We can imagine how struggle the person is to do Sujud. The POC-3 to POC-12 play significant roles in this stance. Could a person with prosthetic foot perform standard shalat sequence? This is the issue that commercially available prosthetic foot products do not answer. It typically affect Muslim users.

ACKNOWLEDGEMENTS

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