Methodology for Obtaining Static Alignment Model

Lely A. Luengas, Pedro R. Vizcaya, Giovanni Sánchez

Abstract**—**In this paper, a methodology is presented to obtain the Static Alignment Model for any transtibial amputee person. The proposed methodology starts from experimental data collected on the Hospital Militar Central, Bogotá, Colombia. The effects of transtibial prosthesis malalignment on amputees were measured in terms of joint angles, center of pressure (COP) and weight distribution. Some statistical tools are used to obtain the model parameters. Mathematical predictive models of prosthetic alignment were created. The proposed models are validated in amputees and finding promising results for the prosthesis Static Alignment. Static alignment process is unique to each subject; nevertheless the proposed methodology can be used in each transtibial amputee.

Keywords**—**Information theory, prediction model, prosthetic alignment, transtibial prosthesis.

I. Introduction

PROSTHESIS or artificial limb is a main way to recover the activity and appearance for amputees. Prosthesis acceptability depends on several factors including cosmesis (outer aesthetic covering of a limb prosthesis), mass properties of the prosthesis, comfort, and function. The performance of the prosthesis influences the level of rehabilitation for the below-knee amputees. Comfort and function are directly dependent on alignment; this is a key factor that influences the standing posture of the amputee, the gait, the interface pressure on the stump and the energy consumption during walking. So, the quality of rehabilitation of transtibial amputees with prostheses is influenced by at least four important inter-related factors: the prosthetic socket, the type of the prosthetic foot selected, prosthetic alignment and the integration of the prosthesis into the amputee's motor activity. As the static standing status is a main and basic activity of the amputee’s daily life, it is important to study how much the alignment influences the static standing biomechanics. During standing, alignment has a direct effect on biomechanical parameters: joint angles, COP and weight distribution. But, at the moment, static alignment models of transtibial prostheses do not exist [1]–[4].

To model the process of static alignment of transtibial prosthesis, principle of information theory (IT) presented by Shannon [5] was used. IT measure the amount of information contained in the data, noise and equivocation. This allows an analysis where the relations between variables are observed, besides showing the explanation or prediction of the behavior of these variables. IT does not assume any type of relationship in the information contained in the data, is a great advantage because no data group is discarded.

The aim of this study was to demonstrate a methodology that was developed for obtaining Static Alignment Model for transtibial prosthesis based on a stochastic model and IT. Section II describes the methodology propose. Section III shows a validation of the methodology. Section IV explains the results. And Section V summarizes the main conclusions.

II. Materials and Methods

A. Subjects

In order to assess the influence of prosthesis alignment on biomechanical parameters of joint angles, COP and weight distribution in static standing position in amputees subjects, seven volunteers (all males, aged 33,29 ± 3,77 years; weight 71,43 ± 4,58 kg; height 1,71 ± 0,054 m) were recruited for this pilot study (Fig. 1). All the subjects had energy storage and return prostheses (Flex-foot), total surface bearing and pin suspension. Prosthesis alignment was established clinically. All participants were independent community ambulators; none used assistive devices, with no history of neurological, cognitive, or other diagnoses or medications affecting measurements. They read and signed an informed consent form revealing the procedure of the experimental protocol, which had been approved by the Hospital Militar Central, Ethical Review Committee.

B. Apparatus

A pressure distribution measuring system for monitoring local loads between the foot and the shoe (Pedar® system, Novel, Germany) with 99 capacitive sensors on each sole and a sampling frequency of 50 Hz was used to collect COP and weight distribution during static standing, using Pedar® data acquisition software to measure these variables [6]. Seven electrogoniometers were used to measure the joint angles (Biometrics) [7]; the goniometers were placed on the socket, (prosthetic) ankle, (prosthetic) knee and hip of both limbs; the Biometrics Analysis Software was using for measure the angles. The system (Pedar and Biometrics) was mounted in the Servicio de Amputados, Hospital Militar Central, Bogotá, Colombia, with constant access to the complete experimental setup: a computer, and the guides, Fig. 1. The recordings during standing were made with the 2D guide of the markers on the floor, feet in the same position, heel midpoints approximately 150 mm apart.

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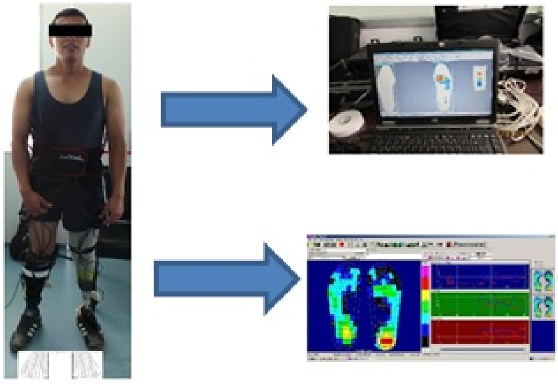

Fig. 1 Procedure to assess the joint angles, COP and weight distribution

C. Procedure

Alignment of each subject's transtibial prosthesis was dynamically tuned by a prosthetist. From this nominally aligned condition, controlled angle perturbations of 2°, 4°, 6° (flexion, extension) were induced. Including the nominally aligned condition, there were put seven alignment conditions measured for each subject. Joint angles, COP and weight distribution were recorded. Three test sessions were conducted with each subject, one to three days apart, at approximately the same time of day.

The data files were post-processed with custom software. Mean and standard deviation of measurements per subject were calculated.

D. Statistical Analysis

To verify the equality of intra-subject and inter-subject data statistical tests were performed. First, the statistical analysis of the measurements with box plot. Second, the Levene statistical test was performed and the equality of the variances for each variable in the three measurement moments was evaluated. Third, the Kruskal-Wallis H test was performed, this nonparametric method is used for testing whether samples originate from the same distribution. Statistical significance was set to an alpha = 0.05.

III. Results

To assess homogeneity, the Levene's test for equality of variances was used. Large intersubject differences in variables were found. Levene's test showed that variances in biomechanical parameters were not equal.

The body weight was similar on both limb, 50% Isakov et al. [8] and Viton et al. [9], but variability weight distribution between the limbs occurs while the subject is standing (SD 7,28%). The body weight was minimum affected by the alignment perturbations in sagittal plane (SD ± 9%). The effect of sagittal alignment perturbations on COP position was sensitive in angle perturbations. Joint angles limb showed variations. Knee variation in the prosthetic limb was lower than in the non-affected. Hip variation in the non-affected limb was lower than in the prosthetic [4]. The effect of sagittal alignment perturbations on joint angles was sensitive.

Considering these results, a methodology for Obtaining Static Alignment Model was proposed. The methodology requires the steps shows in Fig. 2.

Data are the recollected measurements, it is necessary to clean data, a low pass filter is used (f=60 Hz). Standard statistical methods are then applied. The central tendency and dispersion measures, the histogram and the scatter plot of each variable are obtained.

Discretization is a technique to partition continuous attributes into a finite set of adjacent intervals in order to generate attributes with a small number of distinct values [10]. Discretization based on IT is used.

At the end, the decision rules are obtained. This algorithm use statistical tests to construct decision rules.

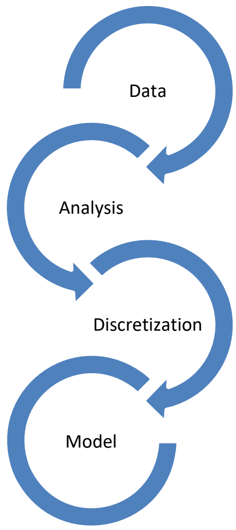

Fig. 2 Methodology for Obtaining Static Alignment Model

Data of amputee subject were used to verify the methodology. Table I shows the statistical analysis. Fig. 3 shows the central tendency and dispersion measures calculated using the data collected on the histogram. The graphs of the histogram show that no variable has a normal distribution, they are multimodal distributions, which imply that a linear regression model cannot be applied to observe the relation between the variables.

To use IT in the analysis of a system the variables must be categorical, since a finite number of values must be obtained [5], [10]. Variables of this study are numerical then a process of discretization must be done. The Least Information Loss (LIL) method was selected. The data transformation generated partitions (BINS) in each data group, is shown in Table II. The number of BINS of each variable is related to the amount of information that the input carries with respect to the output [11], [12].

Table III shows ratio between position of socket and each variable.

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TABLE I
JOINT ANGLES, COP AND WEIGHT DISTRIBUTION OF SUBJECT 1, WHEN SOCKET WAS IN EXTENSION AND FLEXION

SOCKET (°) / VARIABLE	EXTENSION					
	6		4		2	
	X	S	X	S	X	S
CNA (°)	-1,3	0,11	1.8	0.09	2.4	0.13
RNA (°)	3,8	0,12	3.3	0.12	2.1	0.13
TNA (°)	6,3	0,1	2.6	0.16	3	0.15
CA (°)	1,2	0,07	-0.7	0.09	-2.2	0.05
RA (°)	-1,4	0,1	-1.5	0.1	-0.8	0.1
TA (°)	-0,3	0,07	-1.1	0.09	-0.7	0.2
PNA (°)	46	0,5	48.7	0.54	43.8	1.04
PA (°)	53,9	0,8	51.3	0.55	56.2	1.04
XNA (mm)	57,7	0,6	55.6	0.44	59.2	0.6
YNA (mm)	70,6	1,38	77.4	2.8	95.5	5.3
XA (mm)	32,1	0,44	28	0.56	27.1	0.34
YA (mm)	149,3	1,01	158.3	0.75	147.2	0.75
	FLEXION					
CNA (°)	-0.4	0.1	-1.9	0.08	-1	0.1
RNA (°)	1.1	0.12	2.2	0.11	1.4	0.11
TNA (°)	3.6	0.1	4.9	0.12	2.2	0.1
CA (°)	-2.7	0.07	-0.3	0.07	0	0.6
RA (°)	7.2	0.1	8.2	0.09	3.8	0.11
TA (°)	0.4	0.07	1.3	0.09	0.7	0.11
PNA (°)	47.7	0.5	52.5	0.66	51.1	0.8
PA (°)	52.4	0.8	47.5	0.7	48.9	0.5
XNA (mm)	53.6	0.6	54.5	0.47	55	0.5
YNA (mm)	128.1	1.38	84.4	3.97	103.3	2.36
XA (mm)	29.8	0.44	28.2	0.29	28.2	0.25
YA (mm)	122.8	1.01	116.3	1.27	132.7	0.81

X is Average and S Standard Deviation.

TABLE II
BINS OF EACH VARIABLE

N	VARIABLE	BINS
1	ANGULO	7
2	CNA	5
3	RNA	6
4	TNA	6
5	CA	3
6	RA	6
7	TA	3
8	PNA	10
9	PA	10
10	X NA	10
11	Y NA	10
12	X A	8
13	Y A	10

TABLE III
RATIO BETWEEN POSITION OF SOCKET AND EACH VARIABLE. ANGULAR POSITION OF THE SOCKET STRONGLY AFFECTS THE JOINT RANGES, SINCE THE RELATIONSHIP BETWEEN THESE VARIABLES IS ABOVE 84%.

VARIABLE	RATIO
CNA (%)	85
RNA (%)	84
TNA (%)	91
CA (%)	100
RA (%)	95
TA (%)	92
PNA (%)	55.73
XNA (%)	51.2
YNA (%)	72
XA (%)	61.4
YA (%)	84

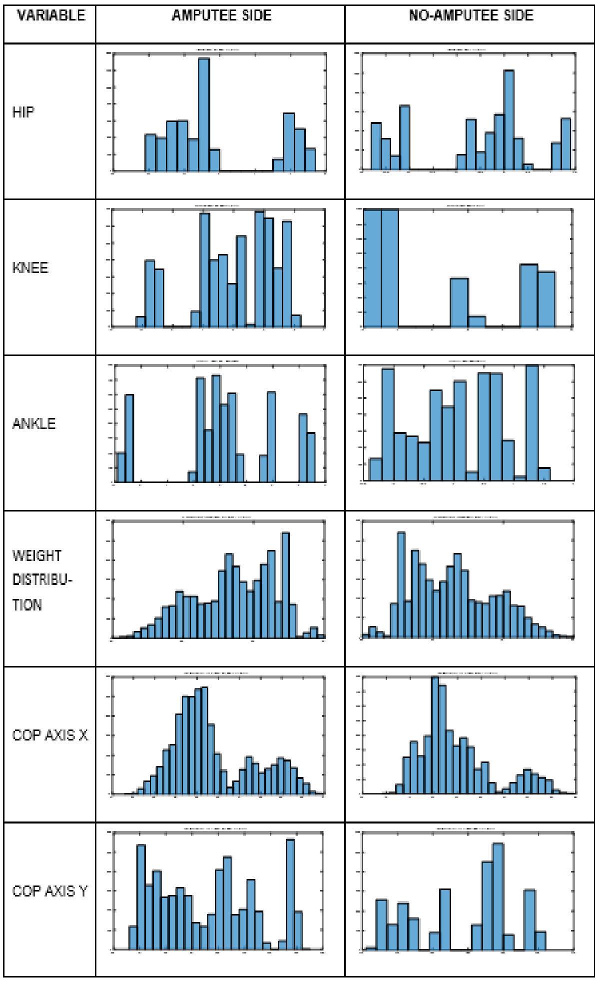

Fig. 3 Histograms show history representation of the distribution of numerical data of subject

Prediction of the behavior of the system was made from the attributes of the data and obtaining relationships of these data, decision rules were used. Model data compared to those measured at the three times were plotted, as shown in Fig 4. To calculate model error, Kolmogorov-Smirnov (KS) was used [13], [14]. Accuracy to the model was above 88%.

Methodology in all subjects to obtain model for each of them was used. The behavior of the models was similar to subject one. Accuracy to all models was above 80%.

IV. CONCLUSION

Alignment data are not equal in all subjects; each one shows specific parameters [15].

The derived model of Methodology for Obtaining Static Alignment Model demonstrates clearly that it is possible to predict the nature and magnitude of prosthetic alignment from kinetic and kinematic data.

The performance of the model was above 88% in subject one, in the other subjects was above 80%, all predicted values were within the expected range and with the expected sign of the actual alignment conditions (flexion or extension). The models exhibited self-selected pertinent variables that make sense from a clinical point of view and are very similar to those selected for the best model highlighted in Table I. The non-linear solutions had the best numerical accuracy in predicting the actual alignments.

Using models to describe the prosthesis behavior could to derive in design of instrument to help prosthetists optimize alignment.

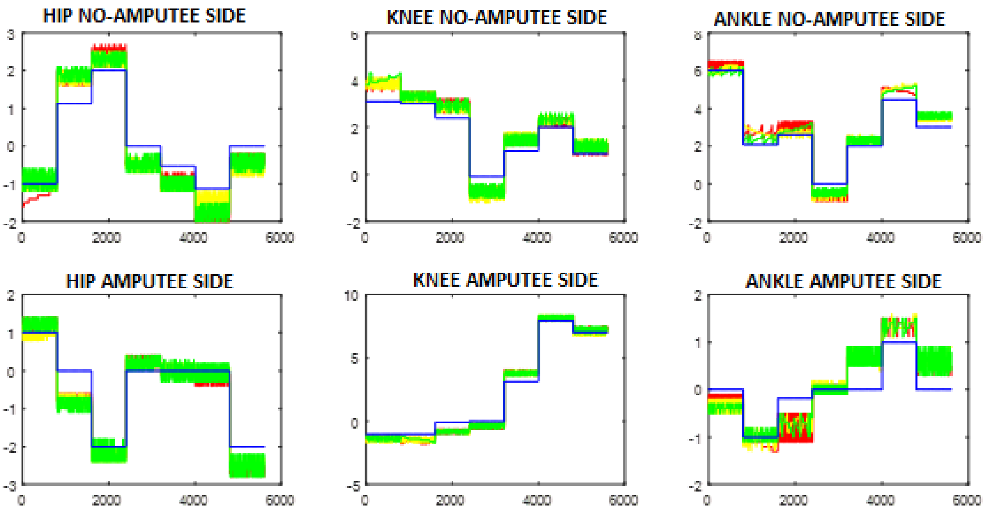

Fig. 4 Graphs show the data of model compared to measurements. The blue line is the model prediction, the red measurement 1, the yellow measurement 2 and the green measurement 3

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