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Evaluation of Obstetric Gestures: An Approach Based on the Curvature of 3-D Positions

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***Abstract*— This paper presents a method to evaluate a gesture carried out by a resident obstetrician doctors by comparing it to a gesture carried out by an expert obstetrician doctors. The studied gesture is the forceps blade placement. Residents were recorded on a childbirth simulator while placing forceps blades. Their paths were compared in order to evaluate how similar they are to a reference path defined by an expert. The comparison method is developed with respect to expert requests: time independence and in considering the whole set of data and not only particular points. In order to respect these requests, the developed method lies on the correlation coefficient between the path curvatures. Residents have been trained on a simulator and their gestures were evaluated by comparing their path curvatures to reference path curvatures. Quantitative results confirm the qualitative analysis, residents become more similar to the reference while training on simulator.**

I. Introduction

Most of the time, medical gestures are learned by experience. Experts have to transmit their knowledge to residents during real cases and they have to check if the knowledge and the know how is correctly transmitted by let them practicing in real. When problems occurred, it is difficult to evaluate if it comes from the knowledge transmission or from the checking of the know how. Especially if the gesture occurs inside the patient, it is difficult to learn, to teach, and to check.

The study of medical gesture rests on the expert technique and the movement measurement according to several parameters. These parameters can rely on video analysis of the gesture as it is the case in the study of the laparoscopic gesture by Cao [1].The study can also rely on sensors placed on the medical instrument (force and/or position sensors) which allows to describe the gesture as in Rosen [2] study of an endoscopic gesture or Pierrot [3] study of the gesture of a dermatologist and Al Bassit [4] who studies the displacements of an ultrasonic probe. However, all these studies describe the gesture but do not allow to compare those gesture with another one in order to evaluate operators efficiently.

In the case of obstetric gestures and in particular the forceps blade placement, the gesture occurs inside the pelvis, video analysis are thus useless. The path forceps blades describe consists in sliding between the fetal head and the pelvic muscles in order to circumvent the fetal head to take place behind the fetus ears. Forceps blades are thus constantly in contact with the fetal head and the pelvic muscles, there is thus a continuous risk to injure either the mother either the fetus. The aim of the forceps blade path study is to evaluate the gesture compared to a reference path defined by an expert. Expert doctors who have the instructor role want to quantify how similar two paths are.

The main goal of this paper is to describe a new method we developed in order to evaluate how similar two paths are. This method relies on the correlation coefficient between the curvature paths. This paper is divided into three parts, the first part presents the childbirth simulator used to record path and the setting of the experimental protocol. The second part is devoted to the evaluation of an obstetric gesture realized by residents with the simulator. Finally, the last part will discuss these results and presents the works in progress and future research.

II. Tools and Methods

A. The BirthSIM Simulator and Its Instrumented Forceps

The BirthSIM simulator [5] has been used to allow residents to train to place the forceps blades. This simulator consists of three components (figure 1):

- A mechanical component which reproduces accurately the maternal pelvis and the fetal head with most of their anatomical landmarks;
- An electro-pneumatic component which ensures the head displacement in order to reproduce different kind of childbirth using a rotary system and a pneumatic actuator;
- A visual component which allows residents to be submerged inside the maternal pelvis and to see the instrumented forceps displacement around the fetal head.

A forceps has been instrumented with two (one in each blade) electromagnetic six degree of freedom sensors [6], [7] in order to record forceps blade paths in order to analyze and compare them.

B. Experimental Protocol

In collaboration with the Hospices Civils de Lyon (HCL) three residents were trained on the BirthSIM simulator. The simulator training is supervised under the authority of an obstetrician expert who is the instructor. An obstetrician expert is defined as having had ten year of experience, and using forceps in more than 80% of his interventions. The fetal head is positioned according to the ACOG (American College of Obstetrics and Gynecology) classification [8]. The

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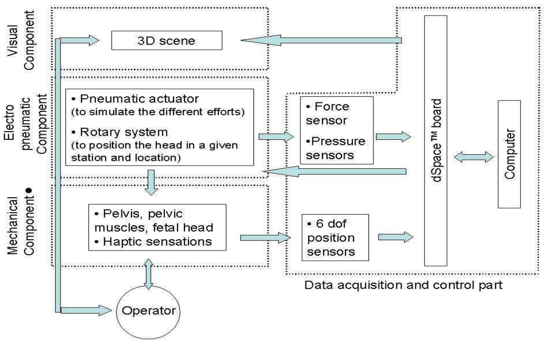

Fig. 1. Block diagram of the BirthSIM simulator

presentation is cephalic, that is to say the head comes in first and corresponds to a station and location OA+2 (Occiput Anterior location and station +2cm from the ischial spines plan). This forceps blade placement is reputed to be quite difficult. Station +2cm means that forceps have to be placed deep inside the maternal pelvis, this is the difficult part. Location OA means that forceps have to be placed in a symmetrical way, both blades have similar paths.

The training lasted three days at the rate of one hour a day. During the training, the expert explained how to correctly place the forceps using the mechanical and the visual components of the BirthSIM simulator. The trainees did ten forceps placement per training day. Their gestures were recorded progressively throughout their training which enabled their evolution to be followed. Three gestures per day were recorded and analyzed to see their evolution in time. The three recorded placements were carried out at the end of the training day because an operator will have acquired a better gesture at the end of the training day than at the beginning of the following one (except for the first day to evaluate their skill before the training). At the end of the training nine measurements for each novice were obtained. With the method of evaluation we developed it is possible to quantify the resident progression according to their training day.

C. Method of Analysis

1) Previous Developed Methods:
Previous methods have been developed to study this gesture. They have been presented in [9] and the results in [10]. Two methods were developed, one allows to compare repeatability of an operator and the second one to calculate the error between the studied path and a reference path. The first method allows to analyze the paths independently of the gesture duration. Unfortunately this technique does not take into account the whole path but only particular points. It consists in calculating the smallest distance between particular points of various paths. On the other hand, the second method takes into account the whole path but the duration becomes an analysis parameter. Paths have to be normalized according to a reference time defined by an expert and by calculating an integral of the error is obtained.

According to our expert the path analysis have to respect these two requests at the same time: independence to time and every points have to be considered. We thus developed a new method based on the curvature of the paths. In order to guarantee the time independence, data are first expressed according to their cumulated arc length.

2) Expression of Data with Respect to Arc Length:
Before being processed, data are filtered using a sliding gaussian filter window to reduce measurements noise.

Let the arc length s_i be defined as the Euclidean distance between two consecutive points where i is from 1 to $n-1$ where n is the size of sampled data.

Let the distance in each direction be defined by:
$\Delta(x_i) = (x_{i+1} - x_i)$;
$\Delta(y_i) = (y_{i+1} - y_i)$;
$\Delta(z_i) = (z_{i+1} - z_i)$;
Where x_i, y_i, and z_i are the i^{th} components of the forceps positions.

$$s_i = \sqrt{\Delta(x_i)^2 + \Delta(y_i)^2 + \Delta(z_i)^2} \tag{1}$$

Let the cumulated arc length l be defined as:

$$l = \begin{bmatrix} 0 & s_1 & s_1 + s_2 & \dots & \sum_{i=2}^{i=n} s_{i-1} \end{bmatrix}^T \tag{2}$$

The positions along the $\overrightarrow{x}$-axis, $\overrightarrow{y}$-axis, and the $\overrightarrow{z}$-axis are respectively given in a vector form with respect to the cumulated arc length: $\overrightarrow{r_x(l)}$, $\overrightarrow{r_y(l)}$, and $\overrightarrow{r_z(l)}$.

3) The Sliding Gaussian Filter Window:
Data are now expressed according to their cumulated arc length and not time. Each data vectors are then filtered using the formula (3) for k from 1 to n and $f_k(l)$ corresponds to the k^{th} filtered data line:

$$f_k(l) = \frac{\sum_{i=k-m}^{i=k+m} r_i(l) e^{\frac{-d^2(P_i P_k)}{2\sigma^2}}}{\sum_{i=k-m}^{i=k+m} e^{\frac{-d^2(P_i P_k)}{2\sigma^2}}} \tag{3}$$

where $d(P_i P_k)$ is the cumulated arc length between P_i point and the central point of the filter window denoted P_k;
the setting of the cut-off frequency σ and the size of the half filter window m are developed in the subsection II-C.6.

4) The Curvature κ:
The curvature, denoted κ, corresponds to the norm of the second derivative of the filtered data expressed according to the cumulated arc length. Derivatives are calculated with respect to the cumulated arc length by a second order central derivative approximation.

$$\kappa(l) = \left\| f''(l) \right\| \tag{4}$$

5) The Correlation Coefficient:
For each path, the curvature is calculated. Then they are compared to each other by calculating their correlation coefficient. The Pearson coefficient [11], denoted r_{pr}, allows to calculate the linear relation between two vectors $\overrightarrow{A}$ and

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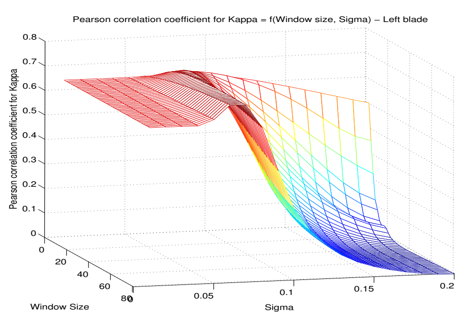
$\overrightarrow{B}$ (with $\overrightarrow{A} = (A_1, A_2, \ldots, A_n)$ and $\overrightarrow{B} = (B_1, B_2, \ldots, B_n)$).

$$r_{pr} = \frac{\sum_{i=1}^{i=n} (A_i - \overline{A_m})(B_i - \overline{B_m})}{\sqrt{\sum_{i=1}^{i=n} (A_i - \overline{A_m})^2 \sum_{i=1}^{i=n} (B_i - \overline{B_m})^2}} \quad (5)$$

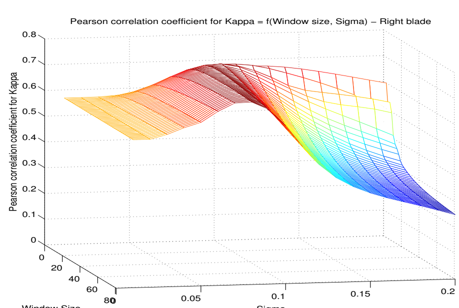
with :
A_i is the i^{th} component of the first curvature vector;
$\overline{A_m}$ is the average of the first curvature vector;
B_i is the i^{th} component of the second curvature vector;
$\overline{B_m}$ is the average of the second curvature vector.

6) Tuning Gaussian Filter Parameters:
To determine ω and σ, several values of σ are studied for a given filter window size ω. In the same way the window size take several values but has to be always odd: $\omega = 2m+1$ with $m \in \mathbb{N}$.

The figure 2 shows the behavior of r_{Pr} with respect to σ and ω. A preliminary study allowed to reduce the interval of study of σ. On figure 2, σ varies from 0.01 to 0.2 and several window sizes ω for the filter are studied (ω varies from 3 to 81). One notices that from a certain value of ω ($\omega = 11$), r_{Pr} depends above all on σ. For low values of ω ($\omega \leq 11$), the curve is nearly constant with respect to σ. Indeed the filter does not take into account enough points to calculate the gaussian of the filter. For $\omega > 11$, the curve decreases rather quickly for values of σ higher than its optimal value because the signal becomes too smoothed. The chosen couple σ and



(a) Left blade



(b) Right blade

Fig. 2. Kappa correlation in function of sigma and m to determine the appropriate filter size.

ω corresponds to the best correlation coefficient obtained by comparing two expert paths. Experimental results show that $\sigma = 0.08$ is the best results. Indeed by analyzing qualitatively two expert paths, a high quantitative result, i.e. a high correlation coefficient is expected. Therefore the gaussian filter parameters are chosen for the best results for two expert paths (one is defined as the reference and the another one is similar to the reference). For $\omega = 21$ the correlation coefficient is almost constant, the window size ω thus takes the value 21. For these values ($\sigma = 0.08$ and $\omega = 21$) the r_{Pr} is 81% and 68% for respectively the left and right blade for two expert paths. Other expert paths were compared to the reference and the quantitative results confirm the qualitative results depending on how similar the paths look like. Thus this parameters tuning seem to be sufficiently precise in our case.

III. Results

By calculating the correlation coefficient between the curvatures of the resident paths and the reference curvature during their training, it is possible to quantify their progression.

Figures 3 and 4 represent the analyzed paths with in bold the expert path which has been used as reference. The three other paths correspond to the forceps blade placement carried out by resident 2 (at the beginning of the first training day for the figure 3 and at the end of the third training day for figure 4).

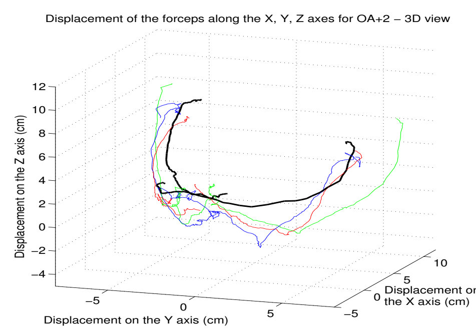


Fig. 3. Resident paths at the beginning of his training compared to the expert path (in bold).

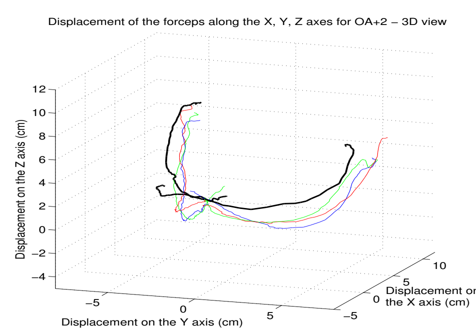


Fig. 4. Resident paths at the end of his training compared to the expert path (in bold).

In these figures, from a qualitative point of view, the paths after the training are more similar to the expert one than

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before the training, the study of the correlation coefficient of the curvatures allows to quantify this similarity. Quantitative results for residents are available in table I which gathers the results with respect to the training day. The result in percentage indicates the rate of similarity with the expert path used as reference. This result corresponds to the average of the three recorded paths at the end of the training day (except for the first day where the first forceps blade placements were recorded to know their skill before the training).

In table I LFB means Left Forceps Blade, RFB Right Forceps Blade and TD Training Day. Figure 5 represents in

TABLE I

EVOLUTION OF THE CORRELATION COEFFICIENT OF THE CURVATURE IN % FOR RESIDENTS ACCORDING TO THE TRAINING DAY

Curvature		TD 1	TD 2	TD 3
Resident 1	LFB	28%	12%	43%
	RFB	28%	26%	50%
Resident 2	LFB	17%	38%	39%
	RFB	3%	44%	33%
Resident 3	LFB	30%	16%	45%
	RFB	33%	28%	51%

a histogram form the progression of residents with respect to their training day. A significant raise of the correlation coefficient between the path curvature of the resident and the expert one during their training to reach values beyond 43% (except for novice 2: 39% and 33%). Concerning the expert results, the correlation coefficient is 81% and 68% of similarity respectively for the left and right forceps blade.

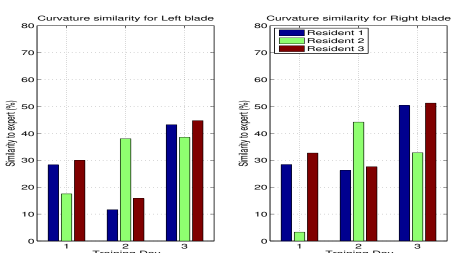

Fig. 5. Evolution of the correlation coefficient of the resident curvatures with respect to the expert one according to the training day

IV. DISCUSSION AND CONCLUSION

Comparing and evaluating human gestures learned by experience and especially medical gestures allows to check if the knowledge is transmitted without any problems and if the residents manage to correctly acquire it. They will thus be more confident when they will have to apply it in real.

This paper shows the results obtained with a new method we developed. This method allows to quantify the path similarity with respect to expert obstetrician requests: time independence and the whole path is studied. It emphasizes the progression of residents obtained in [10] while training on a childbirth simulator to place forceps blades. It lies on the calculation of the curvature and the results obtained correspond to the correlation coefficient with respect to a reference path defined by an expert. These results allow to establish a similarity score which seems to be convenient, because easily understandable for doctor instructor.

The next series of measurement carried out on the BirthSIM simulator will have to take into account more novices and with a more important follow-up of them. The objectives will be to know if a training using a simulator allows novices to acquire a first experience before carrying out forceps during a real childbirth and in the long term to show the utility of a childbirth simulator. In addition the path analysis have to be completed in studying the orientation parameters of the path. A similar method is under development to study the orientations. Moreover the electro-pneumatic part has just been validated by our expert and should lead to a new series of measurement where the novices will learn how to correctly place the forceps but also how to extract the fetus by applying minimal forces of traction so that the birth is the most possible natural. It will be then possible to follow the paths of the forceps and the fetal head in movement during the extraction.

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