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Evaluation of Obstetric Gestures: An Approach Based on the Curvature of Quaternions

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***Abstract*— This paper presents a method to evaluate a gesture carried out by a resident obstetrician by comparing it to a gesture carried out by an expert obstetrician. The studied gesture is the forceps blade placement. Resident paths were recorded on a childbirth simulator while placing forceps blades instrumented with six degrees of freedom sensors. The path is characterized by the positions and the orientations. In this paper we particularly focus on the orientations. Forceps orientations are expressed in the quaternion unit space and the curvature of quaternion path is compared by correlation to a reference defined by an expert. Residents have been trained on a simulator and their gestures are evaluated by comparing their orientation 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

A simulator training is a solution to acquire experience for gestures learned by experience. It also allows to evaluate if a gesture is correctly acquired. Medical gesture training occurs generally in real cases and is not compulsory preceded by a simulator training like in aeronautics for example.

To evaluate the forceps blade placement, paths are analyzed with respect to these criteria defined by obstetricians:

1) **Data have to be analyzed independently of time**. In an emergency procedure, delivery has to be as fast as possible. However a recent study showed that a forceps extraction is twice faster than a cesarean procedure [1]. Moreover the gesture dynamic while placing forceps blade is about ten seconds. The duration of the placement gesture does not have to be taken into account.
2) **The whole gesture have to be studied**, not only some particular points. Forceps are placed inside the maternal pelvis and have to circumvent the fetal head to take their final position behind the fetus ear. They are thus always in contact with the pelvic muscle and the fetal head. There is a continuous risk to injure either the mother or the fetus therefore all the points of the path have to be taken into account.

To respect the obstetrician requests a method has been developed based on the curvature of the paths [2]. In order to guarantee the time independence, position data are first expressed according to their cumulated arc length. Then their curvature are compared by correlation. However, as the forceps are instrumented with electromagnetic sensors with the ability to measure six degrees of freedom, forceps orientations can also be analyzed.

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In this paper we present the adaptation of the method developed in [2] to study the forceps orientations during their placement. This paper is divided in three parts. The first one presents the BirthSIM simulator which allows to record and analyze obstetrician gestures. Then a brief definition of the quaternions is realized. The second part is devoted to the developed method to analyze gesture orientations. It is based on the curvature of the orientations expressed in the unit norm quaternion space. Then the results are presented in the third part which consists in the study of the novice obstetrician progression while training on the BirthSIM simulator. Finally, the last part will discuss these results and presents the works in progress and future research.

II. Tools

A. The BirthSIM Simulator and Its Instrumented Forceps

The BirthSIM simulator [3] has been used to allow residents to train to place the forceps blades. The simulator consists of a realistic manikin to reproduce accurately the maternal pelvis and the fetal head. This manikin is instrumented with an electro-pneumatic component to simulate the dynamic process of a childbirth and a visualization interface to submerge residents inside the maternal pelvis.

A forceps has been instrumented with two (one in each blade) electromagnetic sensors with the ability to measure six degree of freedom [4]. With such instrumentation, it is possible to record forceps blade paths in order to analyze and compare them.

B. Orientation data expressed in the unit norm quaternion space

1) Transformation of the Orientation Data in the Unit Norm Quaternion:
A special subset of the quaternion space, denoted $\mathbb{H}$, is defined when $\|q\| = 1$, then q is called an unit norm quaternion and the unit quaternion space is denoted $\mathbb{H}_1$. This particular subset is of special interest since it allows the characterization of orientation trajectories. The temporal orientation trajectories are studied in the unit norm quaternion space $\mathbb{H}_1 \subset \mathbb{H}$ [5]. The sensors yield continuous angular values with three degrees of freedom. The aeronautical convention for yaw, pitch, and roll is followed. φ represents the rotation about the $\overrightarrow{z}$-axis or yaw; θ represents the rotation about the

$\overrightarrow{y}$-axis or pitch; and finally, ψ represents the rotation about $\overrightarrow{x}$-axis or roll.

Any general three-dimensional rotation can be transform into an unit norm quaternion $q \in \mathbb{H}_1$. Such transformation is the product of the individual quaternions for each of the rotation axes. Here the symbol $\times$ denotes the quaternion product operator in $\mathbb{H}_1$ and $q_{\hat{x}}$, $q_{\hat{y}}$, and $q_{\hat{z}}$ are the quaternion values for each individual axis:

$$q_{\hat{x}} = \left[\cos\left(\frac{\psi}{2}\right), (\sin\left(\frac{\psi}{2}\right), 0, 0)\right] \quad (1)$$

$$q_{\hat{y}} = \left[\cos\left(\frac{\theta}{2}\right), (0, \sin\left(\frac{\theta}{2}\right), 0)\right] \quad (2)$$

$$q_{\hat{z}} = \left[\cos\left(\frac{\varphi}{2}\right), (0, 0, \sin\left(\frac{\varphi}{2}\right))\right] \quad (3)$$

$$q = q_{\hat{z}} \times q_{\hat{y}} \times q_{\hat{x}} \quad (4)$$

2) Visualization of the Quaternions:
Considering quaternions as a function of two angles (elevation β and azimuth α), they can be represented on a sphere using spherical coordinate system :

$$\left\{ \begin{array}{l} x = r\cos(\alpha) \\ y = r\sin(\alpha)\cos(\beta) \\ z = r\cos(\alpha)\sin(\beta) \end{array} \right. \text{with} \left\{ \begin{array}{c} r = 1(\text{unitsphere}) \\ \alpha \in [0, 2\pi] \\ \beta \in [0, \pi] \end{array} \right. \quad (5)$$

The orientation path of the studied gesture can then be visualized on a four-dimensional unit sphere. Fig. 1 represents the orientation path used as a reference.

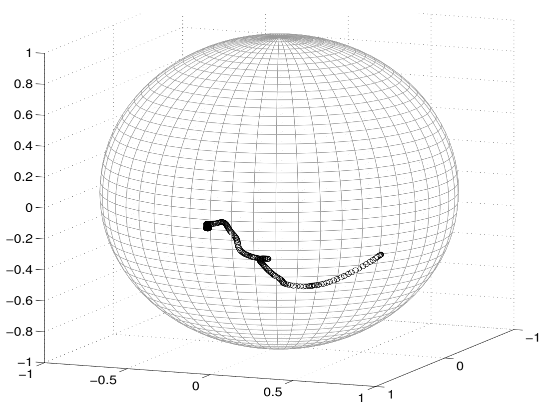

Fig. 1. Expert orientation path for its left forceps blade in the quaternion unit space used as a reference

III. Methods

A. Evaluation of medical gestures

Medical gestures have often been analyzed in order to validate new tools and techniques. Concerning obstetric gestures, the evaluation criteria are not the same. To analyze them, Sielhorst *et al.* [6] propose a method based on *Dynamic Time Warping* to synchronize two forceps blade placement on their visualization interface. This method gives only qualitative results and do not take into account the orientations of the gesture. The method we propose in this paper allows to study the gesture orientation compared to a reference gesture defined by an expert.

B. Method of Analysis

1) Calculation of the Cumulated Arc Length:
Data are first expressed according to their cumulated arc length in order to calculate the curvature. The distance between two adjacent quaternions (q and q') is defined as the minimum arc length on the geodesic great circle that crosses both quaternion values:

$$d(q, q') = \arccos\left(\frac{\|q'\| \cdot \|q\|}{\|q'\| \, \|q\|}\right) \quad (6)$$

where the operator $\cdot$ denotes the quaternion dot product. For small displacements on surface of the unit four dimensional sphere, the inter-quaternion distance (6) can be simplified to

$$d(q', q) = \|q' - q\| \quad (7)$$

Once aligner-quaternion distance is known, data can be expressed according to their cumulated arc length l (sum of their Euclidian distance), with d_1 corresponding to the first inter-quaternion distance and d_{n-1} the last one:

$$l = \begin{bmatrix} 0 & d_1 & d_1 + d_2 & \ldots & \sum_{i=2}^{i=n} d_{i-1} \end{bmatrix}^T \quad (8)$$

The orientation data along the $\overrightarrow{x}$-axis, $\overrightarrow{y}$-axis, and the $\overrightarrow{z}$-axis are given in a matrix form with respect to the cumulated arc length: $R(l) = \left[\overrightarrow{r_\psi(l)} \ \overrightarrow{r_\theta(l)} \ \overrightarrow{r_\varphi(l)}\right]$.

2) The Sliding Gaussian Filter Window:
Each data vectors are then filtered using the formula (9) for k from 1 to n where n is the number of sampled data and $R_{f_k}(l)$ corresponds to the k^{th} filtered data line:

$$R_{f_k}(l) = \frac{\sum_{i=k-m}^{i=k+m} R_i(l) e^{\frac{-l^2_{(P_i P_k)}}{2\sigma^2}}}{\sum_{i=k-m}^{i=k+m} e^{\frac{-l^2_{(P_i P_k)}}{2\sigma^2}}} \quad (9)$$

where $l_{(P_i P_k)}$ 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 detailed in [2]: from two expert paths which are similar, a high correlation coefficient is expected. The chosen couple σ and ω corresponds to the best correlation coefficient obtained by comparing two expert paths.

3) 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 the central derivative approximation.

$$\kappa(l) = \left\| f''(l) \right\| \quad (10)$$

This vector gathered the curvature of each section of path.

4) The Correlation Coefficient:

For each path, the curvature vector is calculated. Then they are compared to each other by calculating their correlation coefficient. The Pearson coefficient [7], denoted r_{pr}, allows to calculate the linear relation between two vectors $\overrightarrow{A}$ and $\overrightarrow{B}$ (with $\overrightarrow{A} = (A_1, A_2, \ldots, A_n)$ and $\overrightarrow{B} = (B_1, B_2, \ldots, B_n)$). Curvature vectors have to be first normalized in order to compute their correlation coefficient. As data were expressed according to their cumulative arc length, this normalization does not affect the results.

$$r_{pr} = \frac{\sum_{i=1}^{i=n} (A_i - \overline{A_m})(B_i - \overline{B_m})}{\sqrt{\sum_{i=1}^{i=n} (A_i - \overline{A_m})^2 \sum_{i=1}^{i=n} (B_i - \overline{B_m})^2}} \tag{11}$$

with :

A_i is the i^{th} component of the first vector;

$\overline{A_m}$ is the average of the first vector components;

B_i is the i^{th} component of the second vector;

$\overline{B_m}$ is the average of the second vector components.

To resume the method of analysis presented in this paper, the table I propose a succinct scheme with the main steps to compare gesture orientations during forceps blade placement.

TABLE I

STEP BY STEP RESUME OF THE METHODOLOGY

1	$G(t) = [\varphi(t)\ \theta(t)\ \psi(t)]$	Data from the sensors
$\Downarrow$	$\Downarrow$	$\Downarrow$
2	$q_{\hat{x}} = \left[\cos\left(\frac{\varphi}{2}\right), \left(\sin\left(\frac{\varphi}{2}\right), 0, 0\right)\right]$ $q_{\hat{y}} = \left[\cos\left(\frac{\theta}{2}\right), \left(0, \sin\left(\frac{\theta}{2}\right), 0\right)\right]$ $q_{\hat{z}} = \left[\cos\left(\frac{\psi}{2}\right), \left(0, 0, \sin\left(\frac{\psi}{2}\right)\right)\right]$ $q\ = q_{\hat{z}} \times q_{\hat{y}} \times q_{\hat{x}}$	Expression of orientation data in the quaternion space
$\Downarrow$	$\Downarrow$	$\Downarrow$
3	$x = rcos(\alpha)$ $y = rsin(\alpha)cos(\beta)$ $z = rsin(\alpha)sin(\beta)$	Quaternions are defined by two angles to express data in $\mathbb{H}_1$
$\Downarrow$	$\Downarrow$	$\Downarrow$
4	$\Delta(q_x) = (q'_x - q_x)$ $\Delta(q_y) = (q'_y - q_y)$ $\Delta(q_z) = (q'_z - q_z)$	Calculation of inter-quaternion distance l
$\Downarrow$	$\Downarrow$	$\Downarrow$
5	$Q(l) = [\varphi(l)\ \theta(l)\ \psi(l)]$	Expression of data according to l
$\Downarrow$	$\Downarrow$	$\Downarrow$
6	$R_f(l) = \left[S_{f\varphi}(l)\ S_{f\theta}(l)\ S_{f\psi}(l)\right]$	Application of the sliding gaussian filter window
$\Downarrow$	$\Downarrow$	$\Downarrow$
7	κ	Calculation of the curvature κ from the second derivative
$\Downarrow$	$\Downarrow$	$\Downarrow$
8	r_{pr}	Calculation of the Pearson correlation coefficient

C. 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 years of experience, and using forceps in more than 80% of his instrumental interventions. The fetal head is positioned according to the ACOG (American College of Obstetrics and Gynecology) classification [8]. The 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 to them how to correctly place the forceps using the mechanical and the visual components of the BirthSIM simulator. The training method is detailed in [9]. 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. 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 (from 1 to 3).

IV. 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. Fig. 2 represents the analyzed quaternion paths during the first training day for a resident. Fig. 3 represents the last training day for the same resident. In these figures, from a

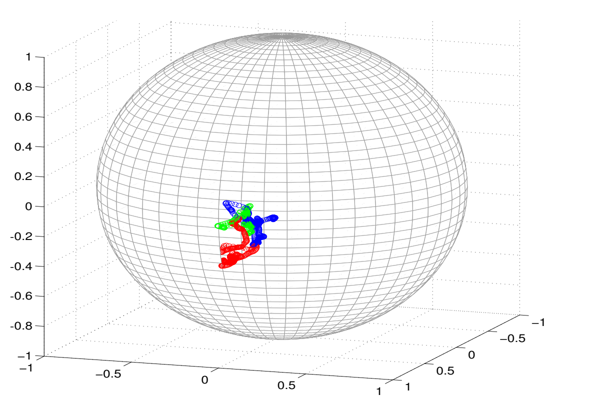

Fig. 2. Resident paths for its left forceps blade at the beginning of his training

qualitative point of view, the paths after the training are more similar to the expert one than before the training. The expert

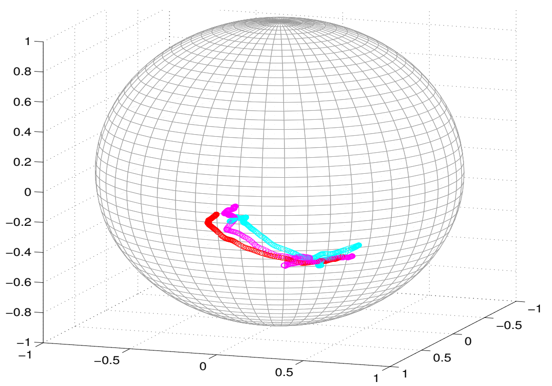

Fig. 3. Resident paths for its left forceps blade at the end of his training

orientation path used as a reference is shown on Fig. 1. The study of the correlation coefficient of the curvatures allows to quantify this similarity. Quantitative results for both residents are available in table II which gathers the results with respect to the training day. The result in percentage indicates the rate of similarity with the expert path which has been used as reference. This result corresponds to the average of the three recorded paths.

In table II LFB means Left Forceps Blade, RFB Right Forceps Blade and TD Training Day.

TABLE II

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

Presentation OA+2		Correlation coefficient r_{pr} in %		
		TD 1	TD 2	TD 3
Resident 1	LFB	4.92	7.88	30.96
	RFB	22.57	46.44	40.43
Resident 2	LFB	22.89	35.58	46.48
	RFB	27.25	33.22	61.04
Resident 3	LFB	8.69	2.66	31.99
	RFB	41.23	10.44	66.35
Average Resident	LFB	12.16	15.37	36.48
	RFB	30.35	30.03	55.94

The effect of training is to increase the gesture similarity, *i.e.* to raise the correlation coefficient to reach values beyond 40% (except for the left blade of novice 1 and 3 with respectively 31% and 32%). Concerning the expert results, the correlation coefficient is 75% and 70% of similarity respectively for the left and right forceps blade.

V. DISCUSSION AND CONCLUSION

Comparing and evaluating human gestures learned by experience and especially medical gestures allows checking of whether 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 clinically carry it out.

This paper shows the results obtained with a new method we developed. This method and the one presented in [2] are complementary; with both of them the gesture is completely compared to a reference gesture defined by an expert. This comparison allows the quantification of the path similarity with respect to expert obstetrician requests: time independence, the whole path is studied and both positions and orientations are taken into account. Using quaternion expressions allows definition of an orientation path and then the curvature of the orientation path is correlated with the expert one. These results allow the establishment of a similarity score which is convenient for obstetricians because easily understandable.

Residents still have to train in order to improve their experience and until they reach expert score (75% and 70% respectively for left and right forceps blade. With their right blade residents almost reach expert score whereas for their left blade they hardly score over 30%. They should train more their left forceps blade placement. This blade is more difficult to place beause it is hold by the left hand and it is the first to take place inside the maternal pelvis.

A new campaign of measurement should be launched soon to obtain more representative results with a larger number of novices. The training provided with the BirthSIM simulator allows novices to proceed to a risk-free forceps blade placement. Once they correctly learn how to place forceps they can complete their training while proceeding to an instrumental delivery using the electro-pneumatic component of the BirthSIM simulator [10].

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