A Novel Childbirth Simulator for Real-Time Monitoring of Fetal Head During the Active Phase of the Labor

L. Morchi, *Member, IEEE*, Selene Tognarelli, *Member, IEEE*, and Arianna Menciassi, *Senior Member, IEEE*

***Abstract*—A correct evaluation of the fetus progress into the birth canal during labor is often a complicated task, but it is of fundamental importance for a proper delivery management. Indeed, incorrect assessment of fetal presentation, position and station could lead to severe complications for both the fetus and the mother. Currently, fetus progress assessment during the delivery phase is still performed in the same way of last centuries, namely with a manual vaginal exploration assessed only using two fingers (index and medium fingers). This evaluation is therefore strongly subjective and dependent on clinical experience of the medical doctor; thus, reproducibility is very limited. In this framework, simulation-based training is a valuable instrument for obstetrics and gynecologists learning process, thus for evaluating and improving their abilities. In this work, we introduce a novel integrated childbirth platform which offers a real-time monitoring of fetal head during the active phase of labor. A real-time evaluation of fetal head presentation, position and station is provided, along with a 3D virtual visualization of the childbirth simulation. This kind of platform was conceived as a valid instrument for gynecological teaching and training. Preliminary results demonstrated its usefulness as an instrument for training in obstetrics and gynecology.**

***Index Terms*—Sensorized platform, simulation in obstetrics and gynecology, training.**

I. INTRODUCTION

LABOR is defined as the set of phenomena that aim to get the fetus and his/her annex out of the mother's body [1]. A correct assessment of the labor progress and of the fetus descent into the birth canal are fundamental as they allow to promptly identify dangerous situations for both the newborn and the mother (e.g., when the labor progresses slowly or stops completely, the most common dangers to the fetus are oxygen deprivation, permanent injury and trauma). Usually, the evaluation of labor and delivery is mainly digitally performed, i.e., vaginal examination. The physician assesses the progression of labor by manually evaluating fetal head presentation, position, station and cervical effacement (i.e., cervix thinning and stretching) and dilation: by inserting the forefinger and the middle finger into the vagina and recognizing fetal head markers, the physician can estimate fetus position with respect to the mother's pelvis and evaluate the structural changes of cervix, *e.g.*, length, softness, and dilation.

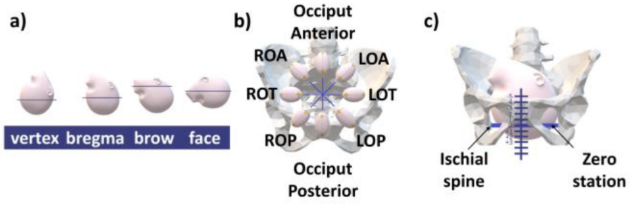

Fig. 1. a) Fetal head presentation - the horizontal line indicates the mother's pelvis superior aperture. b) Fetal head position - occiput posterior (OP), left occiput posterior (LOP), left occiput transverse (LOT), left occiput anterior (LOA), occiput anterior (OA), right occiput anterior (ROA), right occiput transverse (ROT), right occiput posterior (ROP). c) Fetal head station - it is measured in centimeters, ranging from −5 cm to +5 cm (blue bars).

Fetal presentation (Fig. 1a – vertex, bregma, brow or face, depending on head flexion) indicates which fetal part is in relation with the mother's pelvic superior aperture. Fetal head position (Fig. 1b) indicates the relationship between the fetal occiput and the maternal pelvis, based on the identification of fetal head sutures and fontanelles. Finally, fetal head station (Fig. 1c) is used for evaluating the level of the presenting part (i.e., the head) with respect to the maternal ischial spines: it is measured in centimeters, ranging from −5 cm to +5 cm; head at the ischial spines level means zero station, while it becomes negative when the presenting part is above the ischial spines and positive when it is below and going towards the delivery [2].

Looking at these premises, it emerges that the current clinical investigation of fetal head station, presentation and position through vaginal examination is highly dependent on the clinicians' experience. Studies reported an overall high rate of error (76%) in transvaginal digital determination of fetal head position during active labor and a high rate of error (65%) in transvaginal digital determination of fetal head position during the second stage of labor [3]–[5] For this reason, specific education programs are required for training gynecologists and midwives in order to provide them with the adequate practical knowledge and experiences to deal also with difficult

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The authors are with the BioRobotics Institute and the Department of Excellence in Robotics & AI, Scuola Superiore Sant'Anna, 56025 Pisa, Italy (e-mail: laura.morchi@santannapisa.it; selene.tognarelli@santannapisa.it; arianna.menciassi@santannapisa.it).

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Fig. 2. Example of (left) low-fidelity simulator - Forceps/Vacuum Delivery OB Manikin (image taken from https://simulaids.co.uk) and Fetal Head Simulator (image taken from www.gtsimulators.com/products/fetal-head-simulator-espzkk422p), and (right) a high-fidelity simulator - SimMom (image taken from https://laerdal.com).

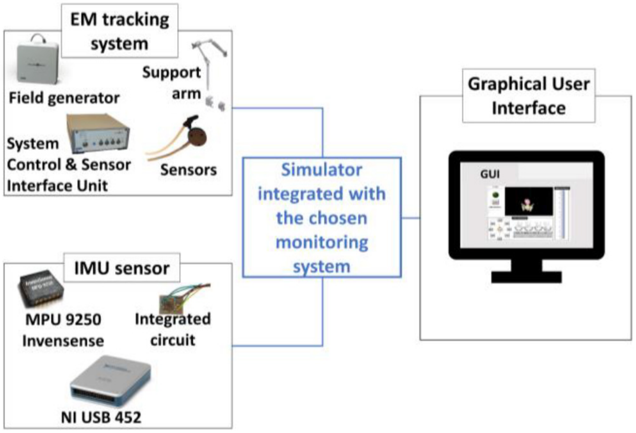

Fig. 3. Childbirth platform components: either the electromagnetic tracking system or the IMU sensor are valid options for fetal head monitoring. An integrated user interface allows real-time data visualization throughout the simulation.

situations. To do this, simulation plays an important role. To date, simulation-based training is widely used in various fields, where rapidly and correctly acting in unusual and risky scenarios is fundamental, e.g., army, aviation and medicine, in which physics and engineering can give a great contribution for its improvement [6]–[8]. Obstetrical simulation has been defined as "the technique of re-enacting or replicating routine or critical clinical events involving a woman who is pregnant or recently delivered and her fetus or new-born for task-oriented, technical and/behavioral skills training, practice, evaluation or research" [9]. With simulation, the learners can practice new hands-on abilities in a safe environment without any risk for the patient, thus acquiring confidence and capability to manage routine and emergencies events.

To date, both low- and high-fidelity simulators are available for preparing students/clinicians to the management of several obstetric events. Low-fidelity simulators replicate a body part upon which to practice a clinical procedure: they are typically cheap and portable but the learning method is limited: since this kind of simulators is totally passive, no objective feedback is provided during the simulation procedure [10], [11].

High-fidelity simulators consist in life-size mannequins that anatomically and physiologically resemble to a human being for medical procedures. They are usually provided with motor-driven mechanisms that move the mannequin of the fetus through the birth canal thus replicating the childbirth process. The most technologically advanced models are equipped with wireless computer-based software for remote control, virtual reality visualization purposes and debriefing stage [9].

From the market analysis of the available simulators for birth delivery, it emerges that low-fidelity simulators are fully passive systems, thus no feedback or monitoring of the simulation is provided (e.g., Forceps and Vacuum Delivery Obstetric Mannikin, Simulaids, Coalville, Leicestershire, Fig. 2 on the left); while high-fidelity simulators are provided with preprogrammed delivery scenarios which allow the visualization of the progression of the fetus into the birth canal, by using predefined trajectory already stored in the simulator software, but without guaranteeing any real-time fetal head monitoring (e.g., NOELLE Maternal and Neonatal Birthing Simulator, Gaumard® Scientific, Florida, United States, or SimMom simulator, Laerdal Medical, Stavanger, Norway, Fig. 2 on the right). Finally, scientific research on high-fidelity simulators mainly concerns pelvic examination procedures [12] and operative deliveries (i.e., utilizing forceps or vacuum extractors) [13]–[19].

In this framework, the present study intends to design and develop a childbirth simulator platform, which allows a real-time monitoring of fetal head during the active phase of labor. This platform was conceived as a valid instrument for gynecological teaching and training. It consists of a device, provided by specific sensors, integrated on a commercial high-fidelity childbirth simulator for tracking both the fetal head position and orientation. A pre-clinical validation of the proposed platform was conducted with clinical experts, aiming at demonstrating the teaching and training value of the proposed system.

II. MATERIALS AND METHODS

Two different solutions were evaluated for monitoring the location of the fetus inside the mother's uterus, namely an electromagnetic (EM) tracking system and an Inertial Measurement Unit (IMU) system (Fig. 3). The EM tracking system can evaluate, at the same time, fetal presentation, position and station (Fig. 1) in a childbirth simulator by sensorizing the head of the fetus mannequin. The IMU, instead, can measure both fetal head presentation (Fig. 1a) and fetal position (Fig. 1b). Since non negligible errors occur when computing the location from the IMU data, because it comes from the double integration of the acceleration values, the information on fetal head station is not provided with the IMU sensor. Thus, the IMU can be applied in situations where the information about fetal head station is not relevant to the clinical staff or when simple low-fidelity fetal head simulators are employed (Fig. 2 left).

Finally, the platform is equipped with an intuitive Graphical User Interface (GUI), allowing the 3D real-time visualization of the data recorded during the childbirth simulation, with the chosen monitoring system (either EM or IMU).

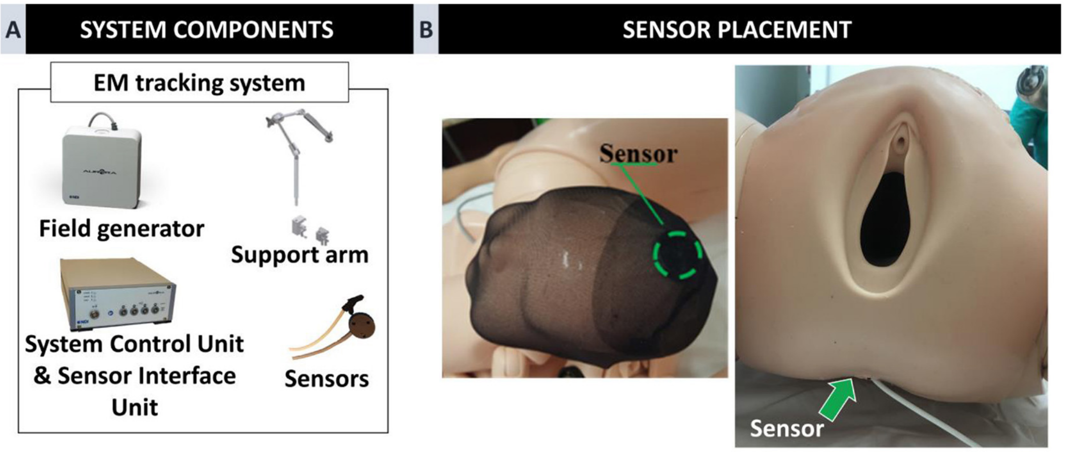

Fig. 4. (A) EM tracking system components; (B) Sensor placement: one sensor is positioned on the mannequin fetal head and one sensor is placed in correspondence of the pelvis of the simulator.

A. *Electromagnetic Tracking System*

The electromagnetic tracking Aurora System (NDI Medical, Canada) was evaluated as a possible solution, because it allows a precise measurement despite its small sensors size, thus avoiding obstructing the passage of the fetus mannequin inside the mother simulated birth canal. The system is composed of a Planar Field Generator, sensors, a Sensor Interface Units (SIUs) and a System Control Unit (SCU) (Fig. 4A).

Two 6 degrees-of-freedom (DOFs) sensors were placed on the head of the fetus mannequin and in correspondence of the pelvis of the simulator for tracking their position and orientation, respectively (Fig. 4B). Small currents are induced by the varying electromagnetic field produced by the Planar Field Generator. The characteristics of these electrical signals are dependent on the distance and angle between the sensor and the Planar Field Generator. The accuracy of the sensors is 0.88 mm for the position and 0.48° for the orientation [20]. The Aurora System output for each sensor consists in the x-y-z coordinates and quaternions for indicating the position and the orientation, respectively. Data were read out through a Visual C++ program and then transmitted to the Labview (National Instruments, USA) application using the User Datagram Protocol (UDP), for real-time communication. Once the data were converted, the position of the two sensors was used to compute the fetal head station; the orientation of the sensor linked to the fetal head was used to compute both fetal head position and fetal head presentation. Finally, the position and orientation of the two sensors were used to obtain a real-time 3D tracking of both fetal head and mother pelvis. In order to compute fetal head station, the difference between the position of the sensor associated with the fetal head and the position of the sensor linked to the mother pelvis along the direction of the fetal descent was computed.

For the computation of both fetal head position and presentation, the orientation - in terms of quaternions - of the sensor linked to the fetal head was used. Firstly, quaternions were converted into yaw pitch and roll angles through (1)-(3). From (1)-(3), the obtained angles are further converted from radians to degrees.

$$Yaw = atan2\left(2q_y q_w - 2q_x q_z; 1 - 2{q_y}^2 - 2{q_z}^2\right) \tag{1}$$

$$Pitch = asin\left(2q_x q_y + 2q_z q_w\right) \tag{2}$$

$$Roll = atan2\left(2q_x q_w - 2q_y q_z; 1 - 2{q_x}^2 - 2{q_z}^2\right) \tag{3}$$

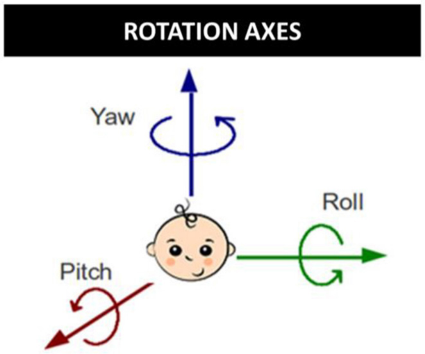

Fig. 5. Fetal head and rotation axes.

The angle associated with fetal head position, i.e., the orientation of the fetus with respect to the mother pelvis, is the Yaw angle (Fig. 5). To assign the obtained value to one of the eight possible fetal head positions (b), i.e., Occiput Anterior (OA), Left Occiput Anterior (LOA), Left Occiput Transverse (LOT), Left Occiput Posterior (LOP), Occiput Posterior (OP), Right Occiput Posterior (ROP), Right Occiput Transverse (ROT), Right Occiput Anterior (ROA) each position was mapped to an interval of 45° as in [21]. Intervals associated with each fetal position are summarized in Table I. The angle associated with fetal head presentation is the Roll angle (Fig. 5). To correctly associate vertex, bregma, brow and face presentation with the obtained angle, each presentation was assigned to a range of angular values, starting from the fact that when the fetus is in complete face presentation, there is an angle of 90° between the head and the axis of the body [1]. Since, to the best of our knowledge, in the literature there is no association

TABLE I
FETAL OCCIPUT POSITIONS AND ASSOCIATED ANGLE INTERVALS

FETAL OCCIPUT POSITION	INTERVAL [°]
OA	337.5-22.5
LOA	22.5-67.5
LOT	67.5-112.5
LOP	112.5-157.5
OP	157.5-202.5
ROP	202.5-247.5
ROT	247.5-292.5
ROA	292.5-337.5

TABLE II
FETAL PRESENTATIONS (A) AND ASSOCIATED ANGLE INTERVALS

FETUS PRESENTATION	INTERVAL [°]
Vertex	270-330
Bregma	330-10
Brow	10-55
Face	55-100

between head presentation and the angle of head flexion, each specific interval was set together with expert gynecologists. Intervals associated to each fetal presentation are summarized in Table II.

A first on-bench validation was carried out to verify if the association between fetal head position and yaw angle and between fetal presentation and roll angle was correct. The 6 DOFs sensor was positioned on the vertex of a simulated fetal head. Fetal head position was varied by moving the simulated head. Data were recorded and analyzed to verify if the head movement caused changes only in the yaw angle, while pitch and roll remained almost constant. The same procedure was repeated for fetal head presentation. Secondly, the goodness of the proposed solution was validated directly on a commercial simulator (SimMom simulator, Laerdal Medical, Stavanger, Norway). The Aurora flexible support arm was mounted on the operating table in a specific position which guarantees to cover the birth canal with the Planar Field Generator workspace. To obtain a correct axes alignment, a level was placed over the Planar Field Generator and the support arm was positioned in such a way that the bubble was centered, thus guaranteeing the correctness of the orientation of the coordinate reference system.

The sensor related to the fetal head was placed in correspondence of the vertex of the head of the fetus mannequin, while the sensor associated with the pelvis was placed in correspondence of the anus of the mother simulator. To check for the correctness of fetal head station measurements, the set-up reported in Fig. 6 (left) was used. The fetal head was consecutively manually moved in the birth canal from -5 cm to $+5$ cm; a measuring tape properly included in the set-up as an external reference was assessed periodically, while data from the Aurora sensors were simultaneously recorded. Ten repetitions were performed; for each repetition, the error between the data recorded from the Aurora sensors and those ones read from the measuring tape was computed. Results showed a mean error lower than 3 mm (Fig. 6 right). An intuitive GUI was developed utilizing Labview system-design platform (Fig. 7). Head presentation was depicted by using a horizontal progress bar (Fig. 7, bottom-right): a LED indicator (green) of each fetal head presentation is turned on as the corresponding presentation is reached. Head position was represented by using a clock-like model (Fig. 7, bottom-left): a Led indicator of each fetal head position is turned on as the position is reached. Head station was represented with a vertical bar that is progressively filled as the station passes from -5 to $+5$ (Fig. 7, right). Moreover, a 3D virtual scene of the simulation is included in the GUI by utilizing two CAD models, for the fetal head and the mother pelvis respectively (Fig. 7, center). The position and orientation of the two models reflect those ones of the fetal head and mother pelvis of the childbirth simulator.

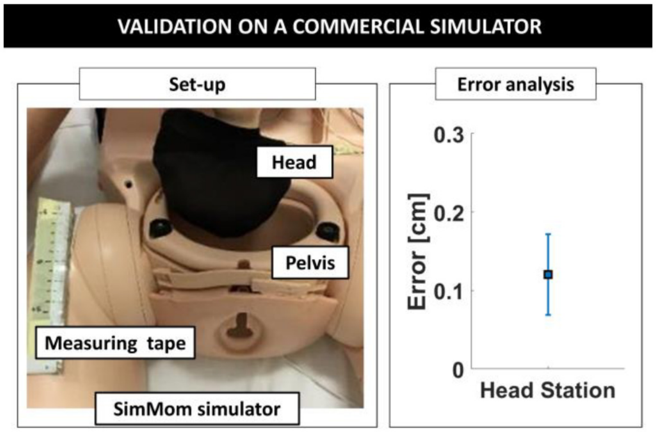

Fig. 6. (Left) fetal head station validation set-up; (Right) validation of fetal head station measurements. The blue square represents the mean error between the Aurora data and the value read from the measuring tape; the blue bar indicates the associated standard deviation.

B. Inertial Measurement Unit (IMU)

Since the IMU device does not provide the information on fetal head station, it can be used in case of limited working conditions, when the available simulator does not allow the measurement of fetal head station, due to the absence of the mannequin part representing the mother pelvis (e.g., Fetal Head Simulator, Educational and Scientific Products Ltd., West Sussex, U.K. – Fig. 2 left), or when the information on fetal head station is not relevant to the clinical staff during simulations. In addition, the IMU device represents a valid low-cost alternative to the EM tracking system, thus providing a cost-effective and affordable version of the childbirth platform. Specifically, a 9-axis 3x3x1 mm IMU sensor (MPU-9250, Invensense, San Jose, California, United States), composed of accelerometers, gyroscopes and magnetometers, was programmed to provide an accurate estimation of fetal head presentation and position. The operating circuit [22] was realized and successively miniaturized in order not to obstruct the passage of the fetus through the birth canal during childbirth simulation. The MPU-9250 was interfaced with the Host PC through the NI USB-8452 by I2C communication (Fig. 8). A calibration step for the MPU-9250 sensor was performed to

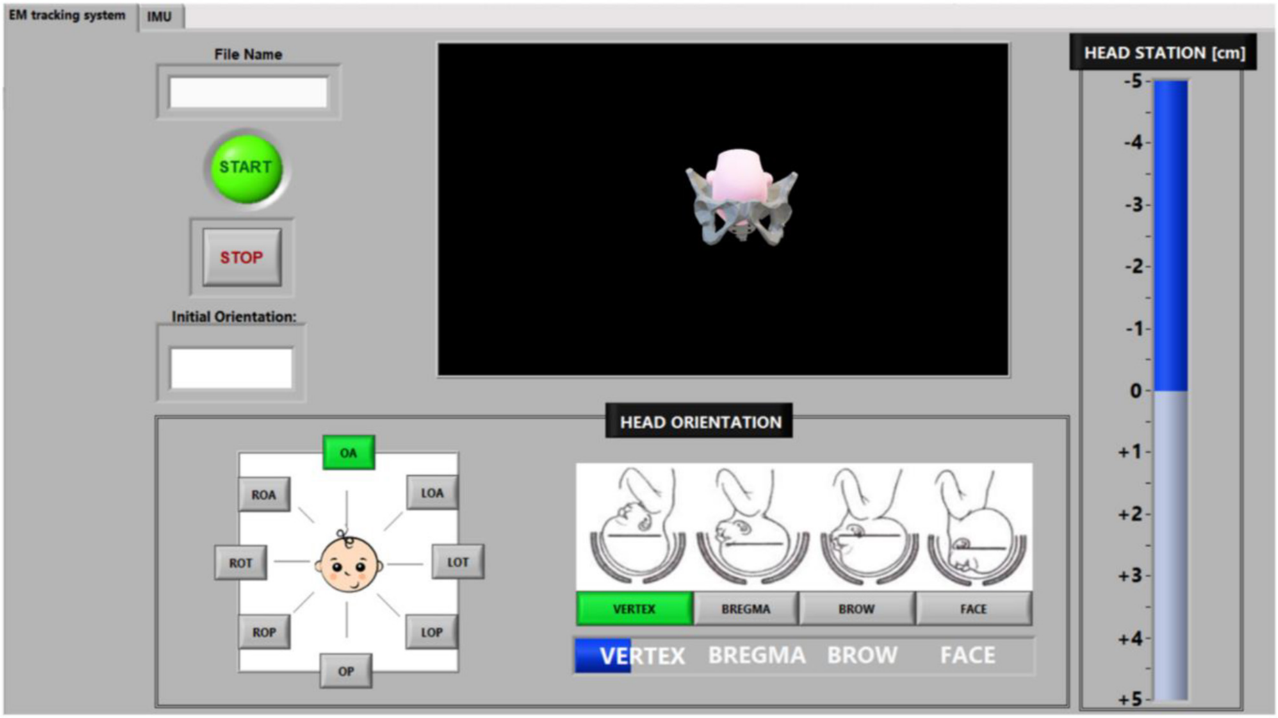

Fig. 7. User interface for the electromagnetic tracking system.

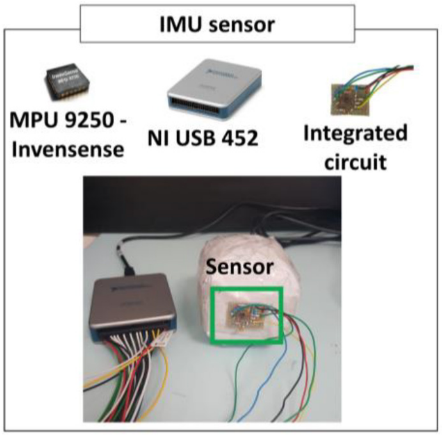

Fig. 8. System components: the IMU sensor was connected with the NI USB 452 and positioned in correspondence to the occiput of a simulated fetal head.

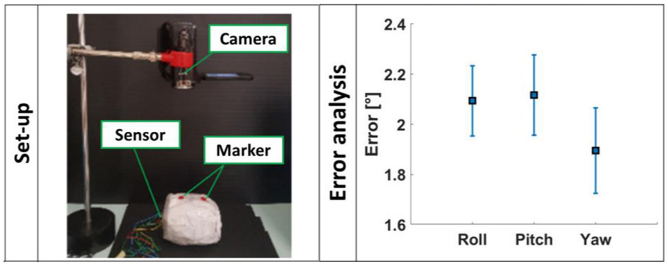

Fig. 9. Validation set-up: two markers were placed on a simulated fetal head and a camera was used for recording the movements around the roll, pitch and yaw axis; the graph on the right reports the on-bench validation of roll, pitch and yaw measurements. Blue squares represent the mean error between the angle computed using the IMU sensor and the angle calculated through video analysis; blue bars indicate the associated standard deviation.

remove both gyroscope and accelerometer offset, as well as to compensate for hard iron biases for the magnetometer [23]. Afterwards, to compute fetal head presentation and fetal head position, the Madgwick orientation filter was implemented. Such orientation filter is able to achieve a static error $< 2°$, where static indicates a state in which the corresponding angular rate is $< 5°/s$ [24]. Based on this assumption, the fetal head movement during the childbirth process can be considered static. The obtained orientation in terms of quaternion was associated to fetal head position and presentation, following the path described in Section II-A). For assessing the accuracy of the computed orientation, quaternions were converted into yaw, pitch and roll angles by means of a dedicated bench-test reported in Fig. 9 (top). The IMU was attached to a simulated fetal head, in correspondence of the fetal occiput. Two markers were positioned on the simulated fetal head, which was then moved around the yaw, pitch and roll axis respectively. An external video of the realized movements was recorded. Video analysis was carried out using MATLAB software (MathWorks, Massachusetts, USA): every 40 video frames, the coordinates of the two markers were assessed; the rotation angle with respect to the initial frame was computed. For each rotation axis, ten repetitions were performed. For each repetition, the error between yaw, pitch and roll angles and the data obtained through the video analysis was computed.

Fig. 9 (bottom) reports the obtained results for the on-bench validation of the IMU sensor: a mean error of 2.09°, 2.11° and 1.89° was obtained for yaw, pitch and roll respectively.

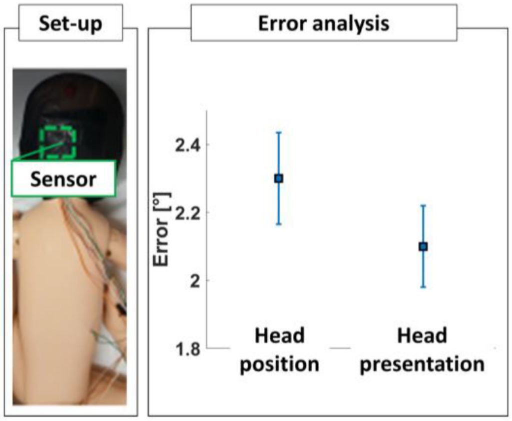

Fig. 10. Sensor placement on the fetal head of the simulator, in correspondence to the occiput; the graph reports the validation of fetal head position (yaw angle) and presentation (roll angle): the blue squares represent the mean error between the values computed using the IMU sensor and the values calculated through video analysis. Blue bar indicates the associated standard deviation.

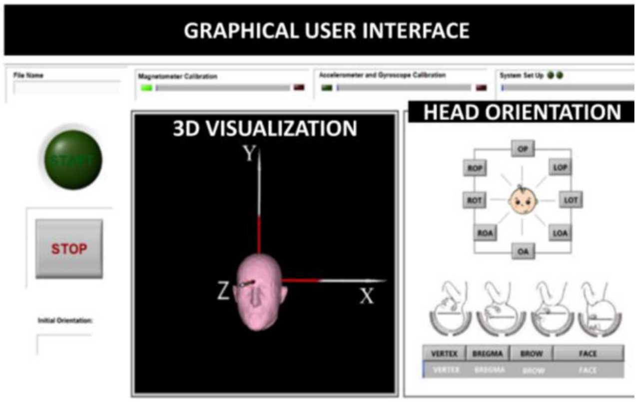

Fig. 11. Graphical user interface for the IMU system.

As for the EM tracking system, the assembled device was further validated on a commercial childbirth simulator, for confirming the obtained on-bench results (Fig. 10 left). The IMU sensor was fixed in correspondence to the occiput of the fetus mannequin (fetus of the SimMom simulator Laerdal Medical, Stavanger, Norway). Following the same procedure described before, two external markers were positioned on the mannequin's head and the head was moved around the yaw axis while a video was recorded. Ten repetitions were performed. The same procedure was repeated for the roll axis. Fig. 10 (right) reports the results achieved for fetal head position and presentation: a mean error of 2.3° and 2.1° was obtained, respectively.

An intuitive and interactive GUI was realized within Labview environment (Fig. 11) for allowing the clinicians to easily control the system: the interface is provided with an intuitive representation of the real-time fetal head position and presentation. Moreover, a 3D virtual view of the fetal head orientation is visualized by utilizing the same CAD model described above.

TABLE III
THE THREE DIFFERENT SCENARIOS USED FOR THE SIMULATION

	Position	**Presentation**	**Station**
Scenario 1 (S1)	OA	vertex	+1
Scenario 2 (S2)	LOT	vertex	-2
Scenario 3 (S3)	ROP	bregma	-1

C. Pre-Clinical Validation

We evaluated two tracking systems, namely EM tracking system and IMU, for monitoring the progress of the fetus into the birth canal. Even though the IMU presents advantages in terms of costs and portability, its use does not allow the monitoring of the fetal head station, which is an important parameter for evaluating the progression of labor. In addition, the accuracy of the EM tracking system resulted higher with respect to that one of the IMU (namely 0.88° vs 2.03°); thus, we decided to carry out a first pre-clinical validation by integrating the EM tracking system in the PROMPT commercial simulator. Eight experienced gynecologists were involved for carrying out a first pre-clinical validation of the proposed virtual childbirth simulator platform integrated on the PROMPT Flex Birthing Simulator (Laerdal Medical, Stavanger, Norway) (Fig. 12). The choice of integrating the conceived platform in the PROMPT Simulator was made because it is equipped with the same anatomical structures of the SimMom simulator (previously used for validating the platform) which are relevant during a childbirth simulation, and at the same time it is less heavy and thus easier to transport. In view to test the realized platform in multiple clinical centers and compare the recorded data, this appeared an optimal solution.

The pre-clinical validation was conducted at the Neonatology unit of the Azienda Ospedaliero Universitaria Pisana in Pisa by involving eight expert gynecologists coming from the Azienda Nord-Ovest structures. The experiments were conducted following the recommendations of the institution and all the subjects gave written informed consent in line with the declaration of Helsinki. No ethical approval was required. The utilized experimental set-up is reported in Fig. 12: the PROMPT simulator was integrated with the proposed childbirth platform and a screen was used to show the GUI to the users. The protocol consisted in performing a gynecological examination in three different pre-established scenarios (S1, S2, S3), carried out, on the simulator only first – from now on called Test A (namely, without seeing the GUI) –, and then with the proposed childbirth platform integrated on it – from now on called Test B. Thus, each subject executed the following protocol: Test A – S1, Test B – S1, Test A – S2, Test B – S2, Test A – S3, Test B – S3. Table III reports the three different pre-established scenarios with their working parameters (namely, fetal head presentation, position and station). For each scenario, the fetal head was positioned inside the mother's uterus and the subject had to identify fetal head presentation, position and station and data were recorded. Finally, subject's timing for performing each examination were also recorded. For each

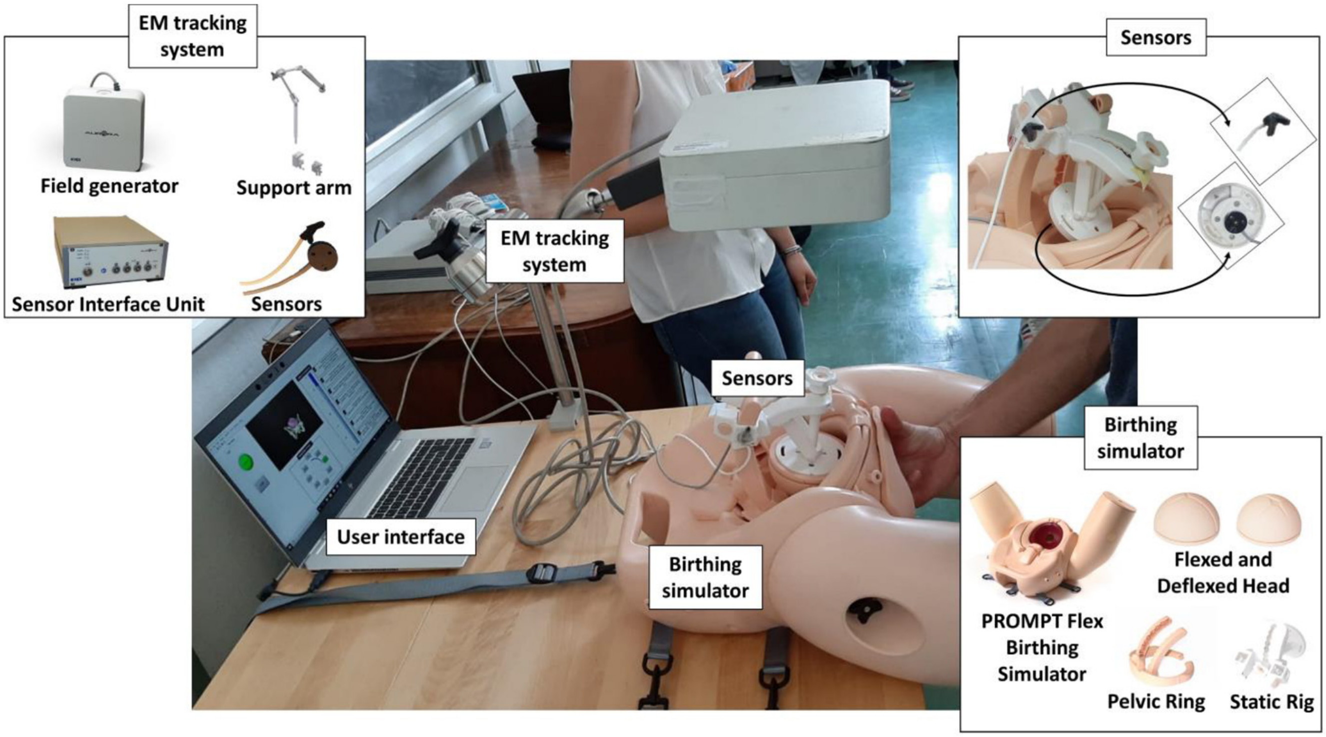

Fig. 12. Experimental set-up: the PROMPT Flex simulator mounts the Aurora sensors. The Aurora field generator is fixed over the simulation area. A screen is used to show the GUI to the users.

TABLE IV
RULES FOR SCORE ASSIGNMENT FOR THE EVALUATION OF FETAL HEAD PRESENTATION, POSITION AND STATION IN THE THREE SIMULATED SCENARIOS

Parameter	**Score**	**Rule**
Position	0	Incorrect evaluation
	2	Correct side (Left/Right), incorrect position (Transverse/Anterior/Posterior)
	4	Correct side and position
Presentation	0	Incorrect evaluation
	2	-
	4	Correct evaluation
Station	0	Incorrect evaluation
	2	Error of +/-1
	4	Correct evaluation

scenario, all the subjects performed Test A first. After all the subjects completed Test A, Test B was conducted. This execution protocol aimed to minimize the training bias, by distancing in time the two tests by the same subject. At the end of the training session, data were post-processed by following a specific protocol: for each simulation parameter, a score of 0, 2 or 4 was assigned if the answer was incorrect, partially correct or correct, respectively. Rules for score assignment are reported in Table IV. Then, subject answers were compared between Test A and Test B. Statistical analysis was performed using MATLAB routines. The normality of the data was verified by the Shapiro – Wilkinson test. Data showing a normal distribution were compared using the paired t-test. When comparing normal distributed data with non-normal distributed data as well as when comparing non-normal distributed data, the non-parametric Wilcoxon rank sum test was utilized. Three levels of statistical significance were used, namely p-value < 0.05 (marked with '*'), p-value < 0.01 (marked with '**') and p-value < 0.001 (marked with '***').

III. RESULTS AND DISCUSSION

In this section, results obtained in the pre-clinical validation are shown.

Expert gynecologists were involved in the pre-clinical validation of our platform. In this framework, the educational and training potentialities of the proposed childbirth simulator platform were confirmed by the clinicians and the implemented user interface met their approval. Indeed, the graphical indicators used for representing fetal head station, position and presentation were in line with medical representations of these three parameters. The possibility to real-time visualize the fetal location into the birth canal was considered a fundamental added value to obstetric simulation. By playing with different fetal positions and visualizing them through the user interface the teaching value of childbirth simulations is enriched, and expert clinicians reported they can better transmit their knowledge to unexperienced ones.

Fig. 13 (A-C) reports the statistical analysis between results obtained in simulation performed with the commercial simulator and simulation performed with the commercial simulator integrated with the proposed childbirth platform, for the three performed scenarios. To have a global evaluation, for each subject, single scores were summed over each parameter (i.e., fetal head presentation, position and station). A significant increase of the median value of the score in the "Integrated

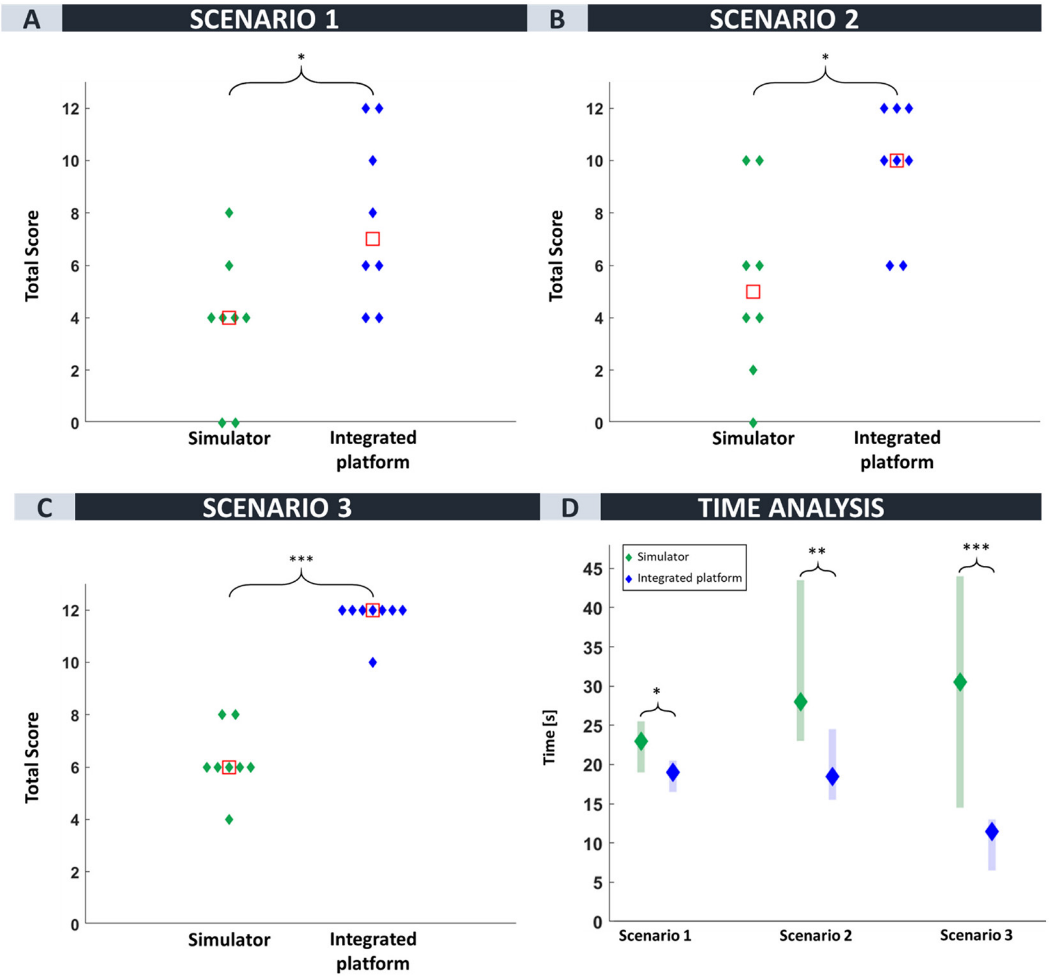

Fig. 13. (A-B-C) - Statistical comparison between simulation performed with the commercial simulator ("Simulator)" and with the simulator integrated with the childbirth platform ("Integrated platform") for the three scenarios. Green diamond and blue diamond indicate the obtained score for each subject, summed over the parameters, while red squares stand for the median values of the scores. (D) - Statistical comparison between the time spent in performing the simulation with the commercial simulator (green) and with the simulator integrated with the childbirth platform (blue) for the three scenarios. Green diamond and blue diamond indicate the median time value, while the associated vertical bars span from their 25th percentile to their 75th percentile. In A-B-C-D, The level of significance of the statistical comparison between "Simulator" and "Integrated platform" is indicated as: i) '*' for p-value < 0.05; ii) '**' for p-value < 0.01 and iii) '***' for p-value< 0.001.

platform" simulation can be appreciated for all the three scenarios, that means higher number of right answers. Fig. 13-D represents the statistical analysis of the time spent in performing the simulation in all the three scenarios of Table III, without and with the integrated childbirth platform. For all the three scenarios, a significant decrease of the median value of the time spent in the "Integrated platform" simulation can be noticed. In addition, statistical significance between "Simulator" and "Integrated platform" results increases from Scenario 1 to Scenario 3. This could indicate that the subjects improve their confidence in the use of the integrated childbirth platform.

An attempt to enrich the informative content of the proposed platform was made. To evaluate the contact points between the fetal head and the pelvis during childbirth simulation, a textile pressure matricial sensor was adopted (16 X 16 HIGHDYN Matrix Sensor Evaluation Kit, Knitronix Srl, Florence, Italy). Through an ad-hoc interface, the sensor allows the visualization and monitoring of all the contact points and exerted pressures between the fetal head and the birth canal. By visualizing which are the contact points during physiological delivery simulation, and which contacts could cause an arrest of labor progress in pathological deliveries, a better understanding of the correct fetus path into the birth canal can be achieved. However, the encumbrance of the sensor did not ensure a straightforward conduction of the childbirth simulation. A deeper investigation is necessary to optimize the integration of such a sensor in a childbirth simulator. Thus, at this moment, we have decided not to include this element in the final version of the platform.

IV. CONCLUSION

The need of simulation in obstetrics arises because labor progression evaluation is mainly conducted "by hand", therefore it is strongly subjective and based on clinician's experience, thus reproducibility is very limited. However, data reproducibility is the major limit in this field, because there is often more than one clinician taking part in the management of a single labor which usually entails several hours.

Moreover, residents have to spend many hours in the delivery room for correctly learning how to make an accurate evaluation of the labor progression, as there are no available alternatives in terms of training processes. In order to overcome this drawback, simulation is playing a fundamental role for residents learning and training. This work approaches this problem realizing an advanced virtual childbirth simulator platform both for gynecologists and midwives teaching and training purposes. In particular, the developed platform allows the real-time monitoring of the fetus's location inside the mother's uterus during childbirth simulation, giving to the user a visual 3D feedback of the scene and a graphical information of fetal head presentation, position and station. Thus, a more in depth understanding of the correct path of the fetus into the birth canal is offered, enlarging the training value of the proposed childbirth platform.

Validation tests provided a preliminary confirmation that the platform is useful as an instrument for teaching childbirth phenomenon and training in gynecological examination. The educational and training purpose of the proposed virtual childbirth simulator platform was confirmed by experienced clinicians.

In the future, integrating the proposed solutions in commercial childbirth simulators will pave the way for a new generation of interactive systems for obstetric/gynecological education and training. Clinicians can simulate both physiological and pathological deliveries, describing them to the unexperienced clinicians/students with the help of the 3D representation. The same procedure can be performed by the medical students and/or medical doctor under training exploiting the 3D graphical interface both for having a real-time feedback of the procedure (in particular for fetal head presentation, position and station) and for recording the entire trial session for debriefing process. To extensively validate the proposed platform, future works will focus on testing sessions in multiple clinical centers: by comparing results obtained using traditional simulators with those ones obtained with our integrated platform, demonstration of its teaching and training value will be provided.

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