A Framework for Computer Based Training to In Vitro Fertilization (IVF) Techniques

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***Abstract* - This paper presents a visual-haptic framework for the simulated training to some key procedures of the In Vitro Fertilization techniques which are become very popular to address several infertility conditions. Two of the most crucial procedures typically involved in the fertilization process, the Intra Cytoplasmic Sperm Injection (ICSI) and the Embryo Transfer (ET) are integrated in the system proposed. The aim is simulating them both at the visual and kinesthetic level by means of a specifically developed virtual environment. This environment includes the human egg, the selected sperm and the micro needles required during the ICSI as well as the catheter, the womb and the embryo involved in ET. The proposed approach exploits a two hand-based haptic devices mimicking the force feedback of the actual manipulation gear and a visual-haptic engine simulating the shape and the dynamic behavior of the main components involved in the two aforementioned stages of the artificial fertilization process.**

Keywords: visual-haptic interface; 3D object manipulation; virtual training

I. INTRODUCTION

Today, haptic devices providing realistic force feedback to the manipulation of virtual objects [1] allow the users of virtual simulators not only to practice at a visual level but also to develop the haptic-knowledge required to perform hand-based tasks [2]. Medical/surgical training applications [3] may particularly benefit from a visual-haptic approach, since they are inherently dependent on physical interaction [4] [5]. In this study the aforementioned interaction paradigm is exploited for the simulated training of two key techniques commonly required for In-Vitro Fertilization (IVF): the (Intra Cytoplasmic Sperm Injection) typically known as ICSI and the Embryo Transfer (ET) which are briefly explained in the following lines.

The term ICSI refers to the injection of a sperm directly into the cytoplasm of the egg. This procedure by-passes all the natural barriers that the sperm has to encounter. The ICSI procedure begins by drawing out the previously immobilized sperm into a tiny micro-needle, carefully maintaining it at its tip. The micro-injection needle is manipulated using a micro-manipulator which has extremely fine control capabilities. The egg itself is held onto another micro-tool by gentle suction to keep it firmly positioned. The micro-needle containing the sperm is pushed gently up against the outer shell (pellucida zone) and carefully injected through the shell, through the outer membrane of the egg and directly into the centre of the egg itself, i.e., the egg's cytoplasm (Figure 1a). At the end of the injection procedure the micro-injection needle is carefully withdrawn and suction on the egg is released.

After subsequent culture procedures, in case of fertilization, the Embryo Transfer (ET) procedure is performed by placing the embryos back in the uterus by means of a specific flexible catheter (Figure 1b), where they will hopefully implant and develop to result in a live birth. The ET procedure is a critically important procedure, and the physician can ruin everything with a carelessly performed embryo transfer. The entire IVF cycle depends on delicate placement of the embryos at the proper location near the middle of the endometrial cavity with as little trauma and manipulation as possible. To our best knowledge, this is the first proposal of an integrated ICSI/ET virtual training system, while there are only very few works addressing the ICSI simulation through virtual/augmented reality techniques. Banerjee et alii [6] propose a cellular micro-manipulation simulator based on the *Immersive Toucht*™ VR system including a high-resolution display coupled with a haptic device providing force feedback during the simulated cell injection procedure, while the main limit reported about this approach is the lack of hand-eye coordination. Mizokami et al. [7] suggest a system to simulate the ICSI procedure by means of a Sensable's Phantom stylus-based haptic device, which is however limited to simulate only the interaction with the micro-needle manipulator. According to the embryologists involved in this research a useful training system should realistically simulate procedures which often involves both hands, therefore we decided to implement a two-hand based interaction approach to perform the tasks required.

II. SYSTEM'S ARCHITECTURE

Though the VR-related issues may seem to be prevailing in this proposal, the main challenges are represented by the two-hand interaction and by the realism of the visual-haptic perceptions to be provided during the

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simulated manipulation procedure. Indeed, for such a virtual training system to be effective and useful, the perceptual level of the simulation is more important than the exact agreement with the underlying physic laws. According to objectives mentioned in the introduction, a couple of CyberForce® hand-based force-feedback devices by Cyberglove Systems have been adopted in order to provide the user with haptic sensations while performing simulated ICSI and ET. The CyberForce device is made up by an articulated exoskeleton anchored to the back of the user's hand which is devoted to the recovery of grounded forces to the user's arm-hand-fingers system within its operative volume. The overall architecture of the Virtual-ICSI simulator is schematically shown in Figure 2, with its main components.

- *Human-Machine Interface*: receives as input the positional/rotational user's info from the haptic sub-system and outputs the user's activity data to the Physics Engine. The HMI enables to explicitly (by vocal commands) or implicitly (by hand activity) modify the simulation evolution.

- *Visual Rendering Engine*: integrates the tracking data and the current state of the physical simulation, transforming the polygonal geometry according to the camera viewpoint and rasterizing the scene in frames to be sent to the Head Mounted Display. It also checks for collision arising between the interacting objects, outputting a vector representation of any collision event, which is employed by the Haptic Rendering Engine which simulates contact forces. The VE is built on the Quest3D graphics programming environment [8] based on the DirectX API.

- *Haptic Rendering Engine*: is responsible for reproducing the haptic behaviour of all the objects involved in the interaction by means of specific haptic models. HRE depends on the Visual Rendering Engine and directly controls the Haptic Sub-System to exert contact and feedback forces. It outputs force-relevant data consisting in one force value for each finger plus the three-component force vector to be actuated by the hand back force transmission arm by applying a non-linear transfer function. The penetration of objects into other objects is therefore prevented by the combined action of the collision detection and the resulting force actuation by the force feedback device.

Contact forces are simulated by measuring them in terms of the depth of penetration of the virtual hand model into the grasped object.

- *Haptic Sub-System*: is made by left and right exoskeletons and it translates the output of the haptic rendering in terms of force feedback, also acting as an alternative input interface to select and activate the available functions.

- *Tracking System*: captures the user's hands position and orientation to enable coherent visualization by the visual engine.

- *Physical Engine*: simulates the dynamic behaviour of any object involved in the virtual simulation and represented in the 3D Dataset. The representation complies with an approximation of a subset of the physics laws appropriate to the simulation, by means of a set of physical parameters as mass, static/dynamic friction, and stiffness/elasticity. Rigid body dynamics is accomplished by means of the Newton Dynamics API [9] which is based on a deterministic solver instead of a more common solver based on linear complementary problem (LCP) or iterative methods, resulting in a more accurate and stable solution~~s~~. Soft body dynamics, which is required to realistically simulate the effect of the egg-needle and egg-pipette interaction, would be very compelling to render in real-time on a purely physical base, therefore it has been approached by pre-calculated 3D morphing.

- *Auxiliary Vocal Interface*: allows the user to control the system by (context dependent) vocal commands together to the haptic sub-system which represents the main user interface. This additional interface level is required since often during operations the user typically has both hands engaged in the manipulation.

- *3D Dataset*: is the source of every virtual content which is represented with polygonal geometry, textures, shadiness, physical properties and processed by the Visual Rendering Engine and the Physical Engine.

- *Head Mounted Display*: allows the user to experience an immersive simulation from a viewpoint resembling the microscope ocular.

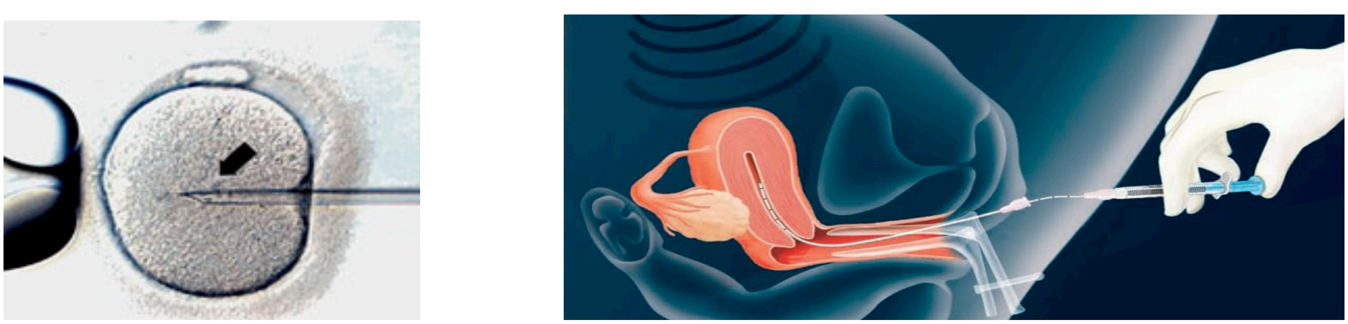

Figure 1. (a) The micro-needle penetrates the egg's zone-pellucida and reaches cytoplasm during ICSI. (b) A pictorial view of the embryo transfer procedure. The embryologist carefully insert the catheter through the cervix until the target site is reached and the fertilized embryos are gently released.

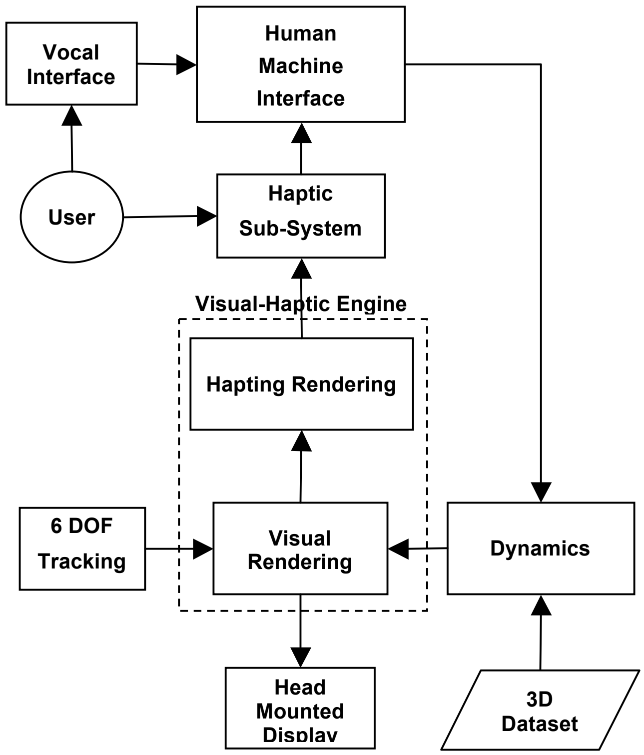

Figure 2. Schematic view of the system's architecture.

The egg model is based on concentric geodetic spheroids replicating the different cell's membranes, and its topology allows an ideal shape deformation when in touch with the micro-needle. The flexible catheter controlled by the user during the ET is approximated as a cinematic chain where each link's rotational values affect the previous links according to the distance in the chain and to a parametric decay function. The approach to render the contact between the catheter and soft organic tissues, like the cervix or the endometrium, exploits deformability/stiffness mapping. By means of this technique, texture mapping (typically simulating visual properties such as color, transparency, roughness, shininess, etc.) can be used to associate local deformability data to 3D geometry instead of relying on object-level properties.

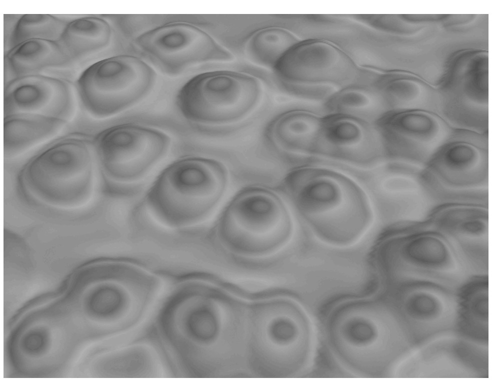

Figure 3. An example of deformability map representing the local stiffness of the simulated endometrium respectively by means of an 8 bit texture.

The deformability map is associated to mesh vertices through mapping coordinates in the form (u, v), previously projected onto the surface. The additional info can be represented through each pixel's RGB channels in a color texture or even in a grayscale bitmap, according to different arrangements offering a great flexibility of use (Figure 3). In its simplest form an 8 or 16 bit grayscale image may encode the local stiffness parameters required to compute the reaction force at a texel level, thus providing a range of 256 or 65536 stiffness levels with a spatial granularity only depending by image's resolution. A specific pixel shader processes the frames to provide a "ultrasound like" appearance to the rendered images reproducing the look of the diagnostic imagery to enhance the realism of the simulated intervention.

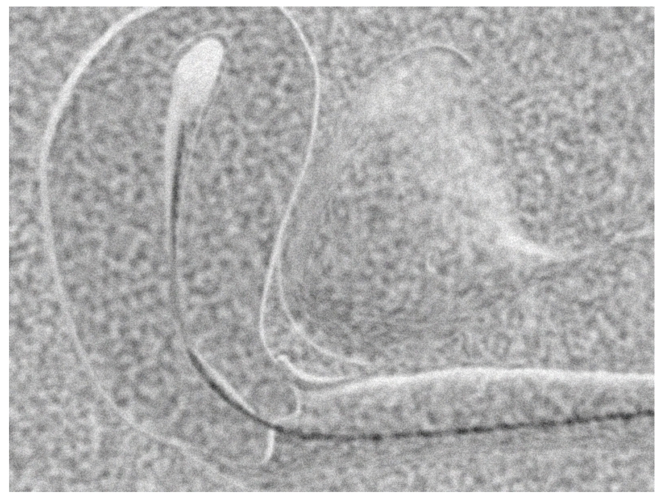

Figure 4. A rendering showing the simulated Embryo Transfer

III. First Experiences with the System

We performed some preliminary experiments on the framework described above, to verify the subjective response of the expert and trainees embryologists to the virtual training. The test bed hardware included a dual quad-core Intel Xeon processor based on a Mac Pro workstation from Apple Inc., equipped with 8 Gigabytes of RAM and an Nvidia Quadro 5600 graphics board with 1,5 Gigabytes of VRAM. Five embryologists have been involved in the experimental sessions after a brief training on the usage of the HMD (a Cybermind Visette Pro SXGA) and of the haptic devices (Figure. 5). Each operator participated to 6 different sessions (3 for ICSI and 3 for ET) for a total of 30 sessions. After each session, each operator had to fill a questionnaire, assigning a vote in the integer range 1-10 (the higher the better) to seven subjective aspects of the simulated intervention and precisely: A. Realism of Visual Simulation; B. Realism of Haptic Perceptions; C. Accuracy of Simulated Manipulation; D. Visual-Haptic Coherence; E. HMD Alignment; F. Haptic System Fatigue; G. Simulator Usefulness.

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A. Measures the overall visual realism of the simulation in terms of its training efficacy. This value is therefore affected not only by the graphics quality delivered by the system (the level of detail in the 3D anatomy, the frame rate, etc.) but also by how credible are the visual aspects of the dynamic simulation.

B. Measures the realism of the haptic sensations provided during the virtual experience. This value is therefore influenced by the limits of the haptic device in terms of force intensity and degree of freedom (for instance the Cyberforce cannot convey torque on wrist and arm joints) but also by the quality of the haptic-rendering algorithms adopted to simulate the contact forces during collision between solid and deformable bodies.

C. Measures the effectiveness of the visual-haptic manipulation, including grasping, releasing and exertion of forces on the virtual objects during the manual intervention.

E. Measures the subjective perception of spatial and temporal coherence between visual and haptic stimula provided by the system during the simulation. Therefore this value measures the quality of the perceptual illusion generated during simulation.

F. Measures comfort level experienced by users wearing the Head Mounted Display. The values reported in this experiment are clearly dependent on the particular HMD solution adopted, and on the device's technical specs, particularly the field of view, the resolution and the display's corner-to-corner sharpness, so they may considerably change if other devices are chosen. Negative issues related to the immersive stereoscopic visualization may have an impact on this value as well.

G. Measures the accretion of abilities and, consequently, the reduction of human stress related to a tricky medical scenario.

While these Figures are subjective and the number of users involved in these first trials is small, the overall evaluation has been positive so far.

Figure 5. Two exoskeletons during a simulated manipulation.

TABLE 1. Subjective evalutions resulting from the resume form

Features	Min	Avg.	Max
(A) Realism of Visual Simulation	6	7.1	9
(B) Realism of Haptic Perceptions	5	6.3	8
(C) Accuracy of Sim. Manipulation	6	7.2	8
(D) Visual-Haptic Coherence	6	6.8	7
(E) HMD Sickness	4	5.4	7
(F) Haptic System Fatigue	4	5.8	6
(G) Simulator Usefulness	6	7.3	8

IV. CONCLUSIONS

A framework for the visual-haptic simulation of In Vitro Fertilization procedures has been presented in this paper. The main visual and haptic aspects of the simulated procedure have been positively evaluated during our preliminary tests, while the main concern is related to the overall fatigue involved in wearing the articulated exoskeletons and the head mounted display. Anyway our work is at an early stage and we are in the process to set up and perform more polished and accurate experiments to measure the advantages and the limits of this framework for IVF practice.

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