# Simulating Obstetric Forceps Delivery in an Augmented Environment

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**Abstract.** During the process of human childbirth, obstetric forceps delivery is a justified alternative to Caesarean section when normal vaginal delivery proves difficult or impossible. Currently, training of forceps interventions is done directly on patients due to the lack of realistic training facilities. The research presented in this paper demonstrates a first implementation of an obstetric forceps simulation in an augmented environment. Currently, the simulation allows an obstetrician to manipulate a real forceps whilst rotating and extracting a virtual fetus from the birth canal. Deformations of the baby's skull, as a result of the forceps manipulation, are then calculated, hence providing diagnostic information of the intervention. Further development of the simulation includes haptic feedback to turn it into a useful training tool for junior obstetricians and other medical professionals.

## 1 Introduction

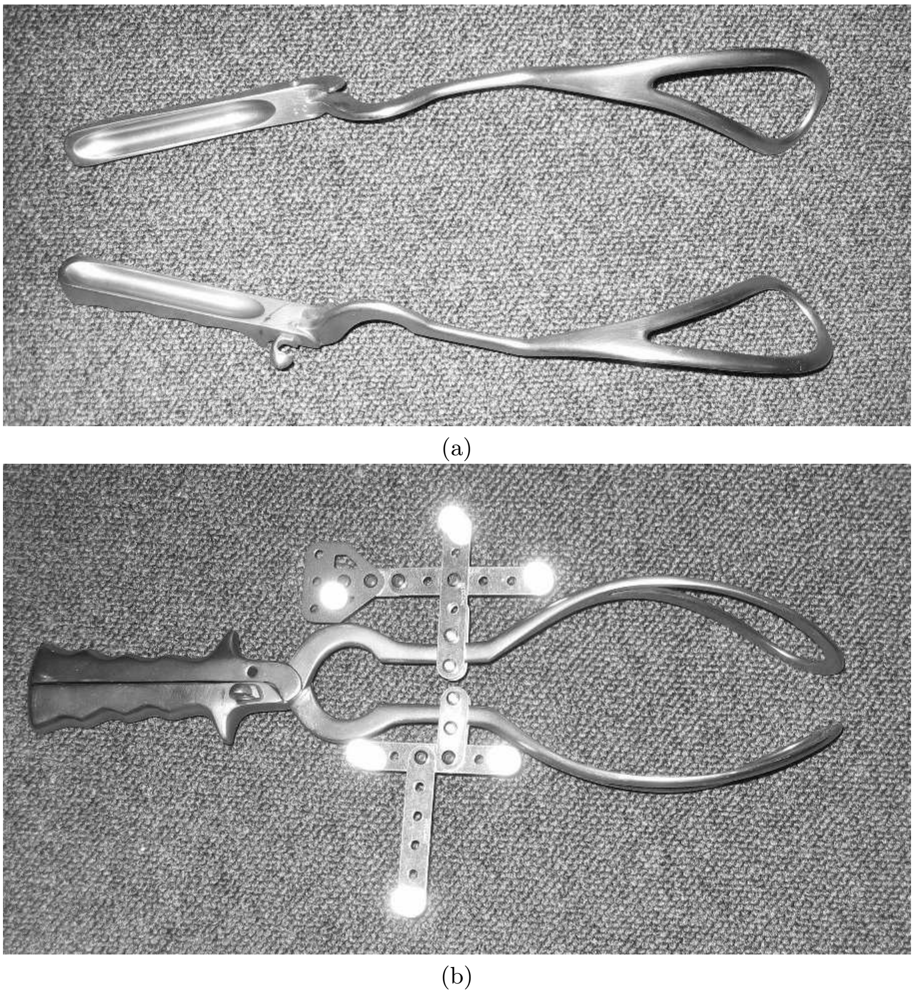
The use of obstetric forceps when a natural vaginal delivery fails to progress[1] is often a better alternative than emergency Caesarean section (ECS) as the latter quadruples the risk of severe obstetric morbidity as compared to vaginal delivery [14]. However, the use of obstetric forceps is not without risk either. A typical forceps has two blades which are initially separated - Figure 1(a). Firstly, the left blade is inserted. After ascertaining that the blade makes smooth contact with the head, the right blade is inserted and clipped over the left blade [1]. If the blades are not positioned nicely around the fetal head, local peak pressures can occur, hence jeopardising fetal well-being.

Currently there are no realistic training facilities for obstetric forceps delivery. Dummy models do exist but do not exhibit sufficient realism hence novices are forced to receive crucial training on patients. A feasible alternative to the current training procedures is the use of either virtual or augmented reality technology in combination with haptic feedback. Augmented Reality (AR) may be preferred as it preserves a sense of the real world as opposed to Virtual Reality (VR) which aims to immerse the user into a complete virtual world, which can be detrimental as communication with the instructor is indirect, even when a Collaborative

[1] Typically because the combined expulsive force of the uterine contractions and maternal bearing-down effort are insufficient to overcome the resistance to descent of the fetal head [12].

Virtual Environment (CVE) is used. Moreover, AR still allows to use dummy models wherever this may prove a better option than a virtual graphics model.

In the further course of this paper, we describe a pilot simulator which currently allows the user to impose typical forceps manipulations on a virtual fetus, i.e. rotation and traction, in an augmented environment. The forceps manipulations are recorded and subsequently applied to the diagnostic assessment on the effect of these manipulations on fetal head deformation.



(a)

(b)

**Fig. 1.** Neville-Barnes forceps - (a) left (below) and right (above) blades disassembled; (b) Assembled forceps with passive tracking balls on each blade.

## 2 Methodology

### 2.1 Geometric models

To be able to visualise 'virtual' objects in the augmented environment which can also be interacted with, polygon models are ideal as they can be used both for visualisation and simulation of mechanical interaction using Finite Element Analysis (FEA). Geometric models, crucial to a realistic and complete simulation of obstetric forceps delivery are:

- the forceps;
- the fetal head, including the skull bones and the fetal brain;
- the fetal torso and limbs;
- the bony pelvis;
- the pelvic floor muscles and ligaments;
- the uterus.

The above list is for the ideal case of an advanced simulation, though an acceptable obstetric forceps simulation can do with a fetal head/skull with torso, a bony pelvis and a forceps model. Hence, these are the models we have generated at this stage of the project using the in-house written volume rendering software, 3DView [7], which can be downloaded from: `http://www2.cmp.uea.ac.uk/~rjal/`. 3DView allows users to visualise medical image data obtained from Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and other image modalities either represented in raw or DICOM format. It also provides active watershed based segmentation [7] and mesh generation [9] and decimation [2]. Figure 2 shows a segmented fetus from MR images and the 3DView interface. Figure 3 shows a shaded polygon and wireframe model of the same fetus. Models of the bony pelvis, the fetal skull and the forceps[2] were created as well.

### 2.2 Forceps tracking

Both the real and virtual forceps are needed in the augmented environment. The former as the interaction tool, the latter to refer the former to the virtual space. Registration of both blades and subsequent tracking is currently accomplished using an NDI Polaris hybrid tracking device. Passive markers are attached to each of the two blades of the forceps - Figure 1(b). Note that each blade needs to be tracked separately to provide simulation of the placement of each blade.

### 2.3 Collision detection

Collision detection between the 'virtual' forceps blades and the fetal head is performed in three steps. The first step uses bounding boxes around the polygon models to establish that a forceps blade is in the vicinity of one side of the fetal

[2] The polygon model of the forceps was created using digitisation with an NDI Polaris pointing device.

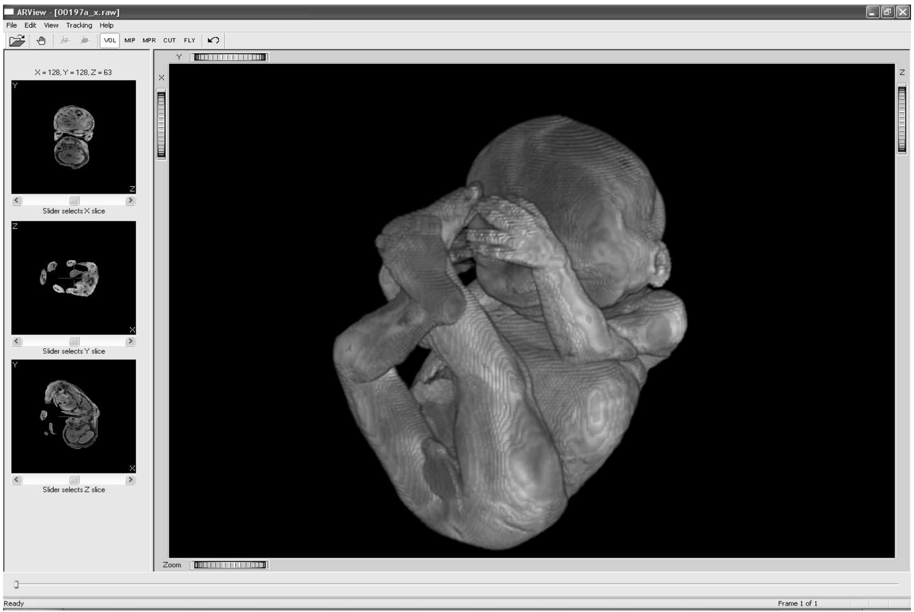



**Fig. 2.** 3DView volume rendering interface and segmented fetus model from MR images after using active watershed segmentation.

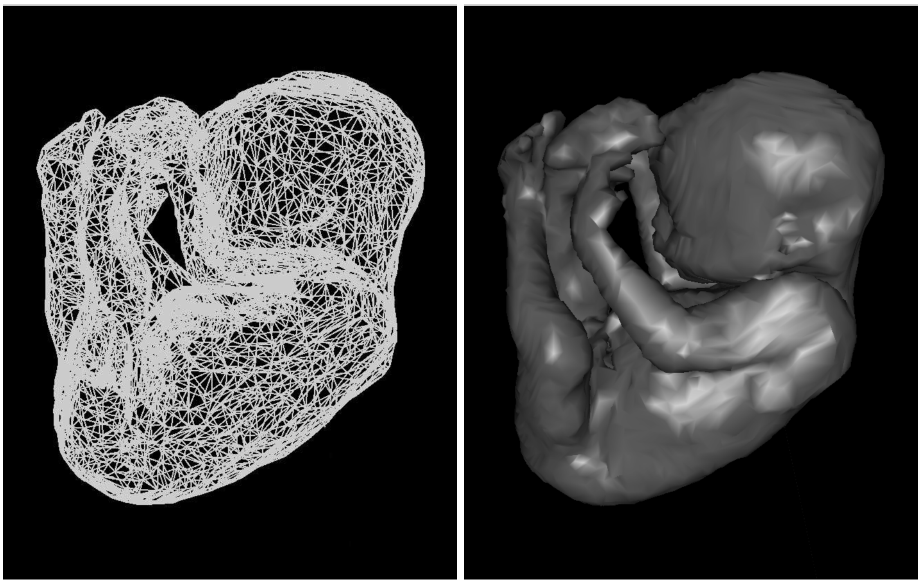


**Fig. 3.** Wireframe and shaded polygon model of a segmented fetus from MR images after mesh simplification.

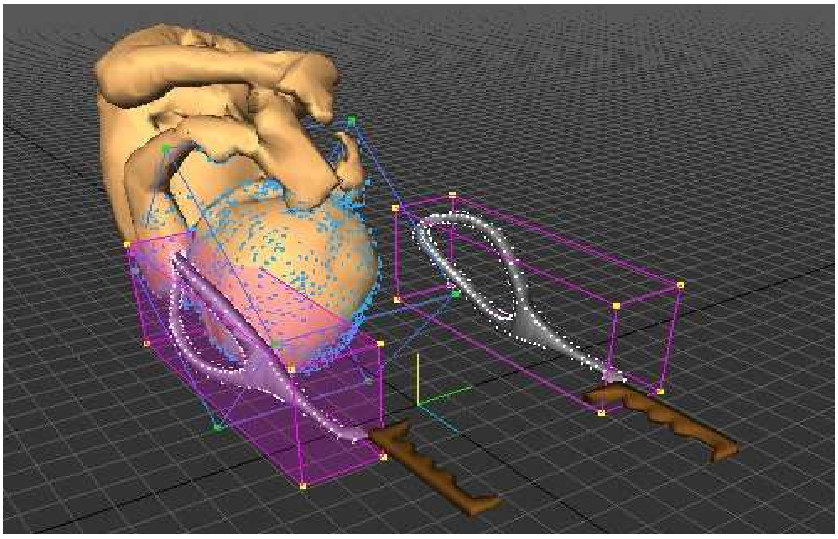


**Fig. 4.** Hierarchical collision detection between left forceps and fetal head using bounding box, surface normal direction and triangle to triangle intersection of the final reduced candidate polygon subsets. The right forceps will be clipped on next, using the same procedure. Interface and algorithm designed by J. Villagrana [13].

head. This step delivers a selected subset of candidate polygons for contact interaction between forceps blade and fetal head model. Further refinement of the subsets is obtained by comparing the direction of surface normals. Finally, in the last step the remaining polygons for each model are pairwise checked for overclosure. Note that for collision response, the selected polygons of the forceps mesh model will be used as the master surface whilst those from the head model will function as the slave surface. In contact mechanics models (see next section) it is a convention that the master surface can overclose (penetrate) the slave surface. Considering the fact that the forceps is in steel as compared to the bony skull/head, this choice makes sense.

### 2.4 Collision response: contact mechanics model

Of all surgical interventions, obstetric forceps delivery may well be one of the more complex problems to model from a mechanical point of view. Indeed, we are dealing with a double sliding contact problem. Double, in the sense that the forceps (or rather both forceps blades) are in contact with the head, whilst the opposite side of the blades is likely to be in contact with either the bony pelvis or the inner lining of the birth canal and the pelvic floor under which the pelvic floor muscles and ligaments are located. Both contact areas will effect the pressure on the fetal skull bones and their subsequent deformation.

# 3 Results

## 3.1 Tracked forceps intervention in an augmented environment

Figure 5 shows snapshots of a Neville-Barnes forceps simulation of a normal vertex presentation. The pelvis model, shown here is real, though a virtual counterpart exists for registration purposes. The fetus, extracted by the user is virtual. The augmented environment is displayed on a DTI 1015XLS stereoscopic display[3]. The movements of the user are recorded for further use in post-diagnostic assessment.

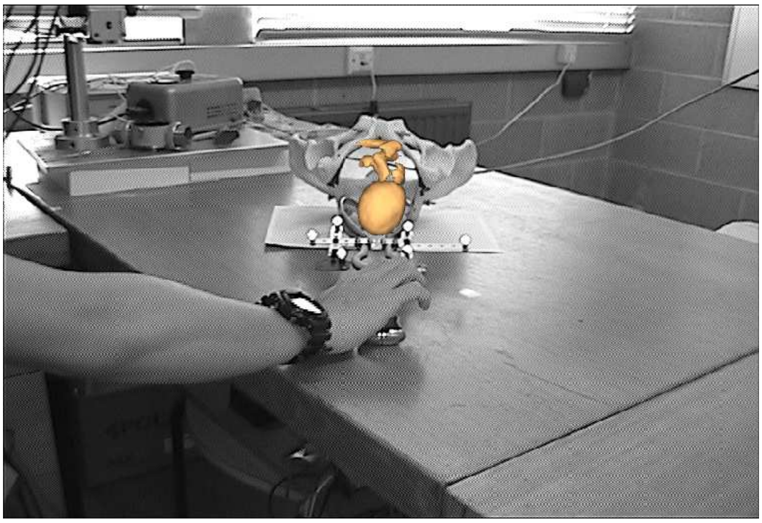
## 3.2 Effect of forceps traction on the parietal bone

Currently, the simulation tool records movements which are subsequently used for diagnostic purposes using FEA. To do this, a fetal skull model, created for previous analysis on fetal head moulding during the first stage of labour [4][6][8], was used. This model was registered with the MR fetus shown in Figure 2 by matching landmarks and thin-plate spline based warping [5]. Currently forces cannot be recorded from the simulation as no haptic feedback is yet involved. Thus, traction forces were obtained from clinical experiments by Moolgaoker et al. [12]. They report average traction forces of 30.66N for Neville-Barnes forceps. They also report an average pressure exerted by the blades on the fetal skull of 26.9kPa (200mmHg). Figure 6 shows the contact areas (bright green) of the forceps blade with the fetal skull. Traction force is employed at the handles in the negative z-direction (direction away from the fetal skull's maxilla). Material properties of fetal skull bones and fontanelles with hyperelastic properties have been reported in [6]. Both models employ shell elements. This is justified considering the small thickness of fetal cranial vault bones (0.75mm on the average) compared to in-plane dimensions. Also, the thickness of the active part of the forceps blades is small compared to in-plane dimensions. The ABAQUS finite element software was used to perform standard non-linear geometry FEA. Results of the analysis after traction are shown in Figure 7. Note that the deformations shown in Figure 7(b) are magnified with a factor 3. The influence of the front of the forceps blades, where both pressure and traction load are concentrated, can be clearly seen in the deformed model, with a marked indentation of the sphenoidal fontanelle. The lifting of the parietal bones, also observed in normal vaginal deliveries [4][6][8], is present.

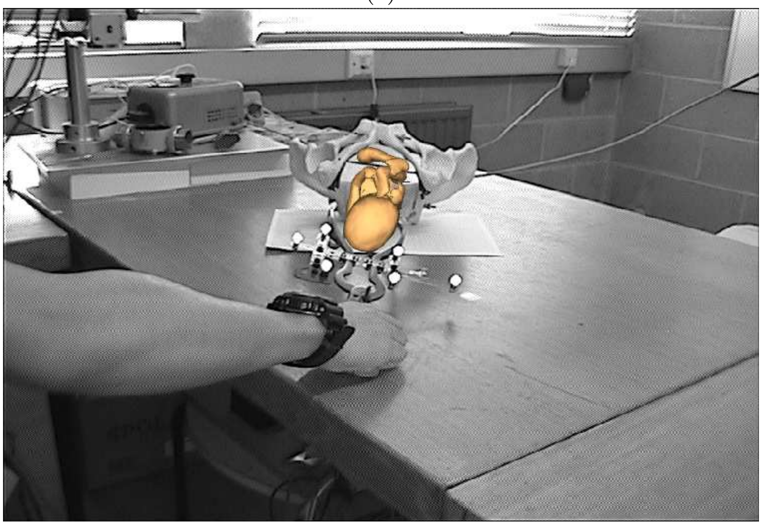
# 4 Discussion and further development

Currently, the simulation tool allows the user to extract a virtual fetus from a real pelvis model. Collision detection is present between the virtual forceps and the virtual fetus. Due to the absence of haptic feedback at this stage, collisions cannot be fed back to the real forceps, hence interpenetration or loss of contact may occur due to tracking error. The mounting of a real forceps on commercial

[3] Note that a head-mounted display can be used as well.



(a)



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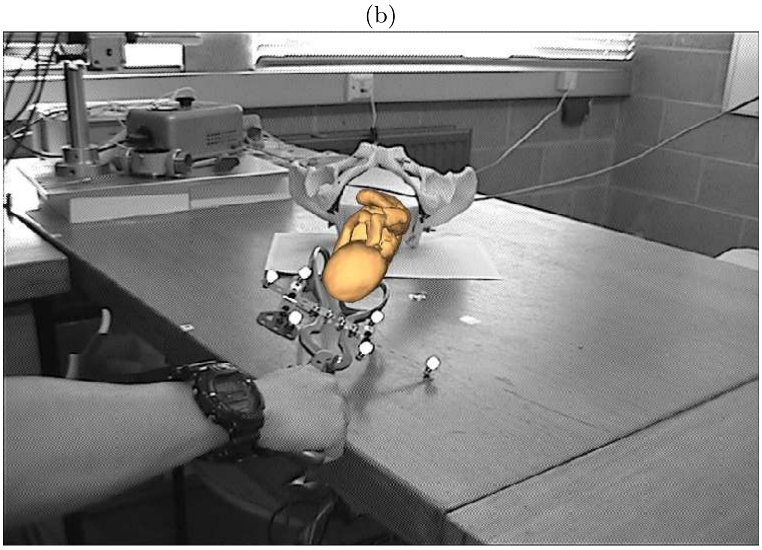
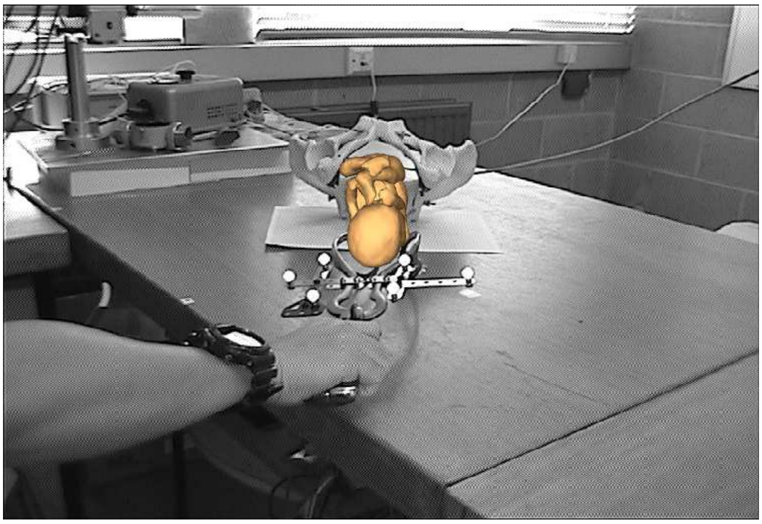


(c)



(d)

**Fig. 5.** Snapshots from a simulation extracting a virtual fetus from a real pelvic model in an augmented environment. Movements are recorded for later post-diagnostic FEA. (a) Initial stage - traction; (b)-(c) Clockwise rotation; (d) Final extraction.

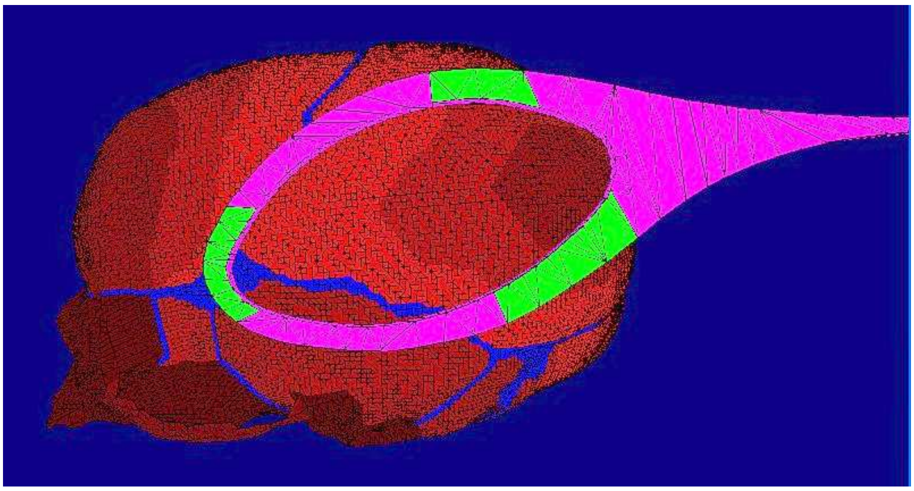
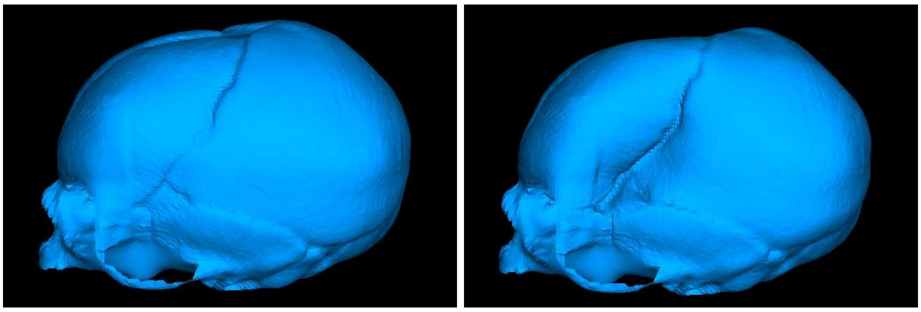


**Fig. 6.** Contact areas of forceps (bright green) with fetal skull. The different colours on the fetal skull indicate different material properties and/or shell element thicknesses. The blue coloured elements represent soft tissue sutures and fontanelles of which the contribution to fetal head moulding is significant (see [6]).



(a) (b)

**Fig. 7.** (a) Undeformed fetal skull and (b) deformed skull (deformation magnification 3) after FEA contact analysis of a traction manipulation.

haptic feedback devices such as the popular and relatively low-cost Phantom Desktop is undesirable as the latter does not provide torque - which is crucial to the rotational operations with a forceps - and due to its low peak force as compared to typical forceps traction forces (up to 50N). The authors have recently implemented an open surgical simulation on a novel haptic feedback device, the TELLURIS system, developed at the University of Grenoble [3]. This device allows peak forces of 200N and consists of sensor/actuator mechanisms which allows mounting of arbitrary tools with full 6 degrees of freedom per node. In the next stage of the project, the forceps will be integrated in this system to resolve the previously mentioned problem.

Post-diagnostic analysis based on simulated trajectories is useful on itself, though ultimately, these calculations should happen in real-time. The current calculations were performed using standard FEA. Explicit FEA has been used in surgical simulation for tissue cutting [11] though the mesh models are typically of low resolution and only point-based tool-to-tissue contact exists. Also tool to tissue sliding contact models in conjunction with haptic feedback have been designed, e.g. [10], however the complexity of these implementations do not match the non-linear contact mechanics models which are crucial to obstetric forceps simulations. Explicit FEA would yield faster results than standard analysis, though with the current double contact complexity it is doubtful that real-time performance would be obtained without resorting to parallel processor solutions.

## 5 Conclusion

A simulation of obstetric forceps delivery for training and diagnostic purposes is novel. Also, the double mechanical contact problem, typical for such a simulation, is an interesting challenge in the field of tool-to-tissue interaction for surgical simulation. If a satisfactory solution (i.e. real-time plus sufficient accuracy) to this problem can be found, it may serve other applications in the field.

In this paper we presented the first stage implementation of such an augmented reality based simulation, allowing obstetricians to simulate forceps manipulations and assess the effect of those manipulations from off-line FE calculations. Further development will include haptic feedback in conjunction with collision detection and response through optimised real-time contact mechanics modelling, to arrive at a realistic real-time simulation of obstetric forceps delivery for training and diagnosis.

## 6 Acknowledgements

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## References

1. G.V.P. Chamberlain. *Obstetrics by Ten Teachers.* Arnold, 1995.
2. M. Garland and P.S. Heckbert. Surface simplification using quadric error metrics. In *Proceedings of SIGGRAPH 97*, pages 209–216, 1997.
3. R.J. Lapeer, P. Gasson, J-L Florens, S. Laycock, and V. Karri. Introducing a novel haptic interface for the planning and simulation of open surgery. In *in Medicine Meets Virtual Reality - MMVR12*, pages 197–199, 2003.
4. R.J. Lapeer and R.W. Prager. Finite element model of a fetal skull subjected to labour forces. In *Medical Image Computing and Computer-Assisted Intervention - MICCAI'99*, volume 1679 of *Lecture Notes in Computer Science*, pages 1143–1155. Springer, September 1999.
5. R.J. Lapeer and R.W. Prager. 3D shape recovery of a newborn skull using thin-plate splines. *Computerised Medical Imaging and Graphics*, 24(3):193–204, 2000.
6. R.J. Lapeer and R.W. Prager. Fetal head moulding: finite element analysis of a fetal skull subjected to uterine pressures during the first stage of labour. *Journal of Biomechanics*, 34(9):1125–1133, 2001.
7. R.J. Lapeer, R.S. Rowland, and M.S. Chen. PC-based volume rendering for medical visualisation and augmented reality based surgical navigation. In *MediViz 2004 Conference proceedings.* IEEE Computer Society Press, July 2004.
8. R.J.A. Lapeer. *A Biomechanical Model of Foetal Head Moulding.* PhD thesis, University of Cambridge - Department of Engineering, August 1999.
9. W.E. Lorensen and H.E. Cline. Marching cubes: A high resolution 3D surface construction algorithm. *Computer Graphics*, 21(4):163–169", 1987.
10. M. Mahvash and V. Hayward. Haptic simulation of a tool in contact with a nonlinear deformable body. In *Surgery Simulation and Soft Tissue Modelling*, volume 2673 of *Lecture Notes in Computer Science*, pages 311–320. Springer, June 2003.
11. C. Mendoza and C. Laugier. Tissue cutting using finite elements and force feedback. In *Surgery Simulation and Soft Tissue Modelling*, volume 2673 of *Lecture Notes in Computer Science*, pages 175–182. Springer, June 2003.
12. A.S. Moolgaoker. A Comparison of Different Methods of Instrumental Delivery Based on Electronic Measurements of Compression and Traction. *Obstetrics & Gynecology*, 54(3):299–309, 1979.
13. J.G. Villagrana. Designing a 3D interface to simulate obstetric forceps. Master's thesis, School of Computing Sciences, University of East Anglia, 2003.
14. M. Waterstone, S. Bewley, and C. Wolfe. Incidence and predictors of severe obstetric morbidity: case-control study. *British Medical Journal (BMJ)*, 322:1089–94, May 2001.