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# Virtual Femoral Palpation Simulation for Interventional Radiology Training

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**Abstract**

*A femoral palpation simulation for training purposes has been developed to simulate the initial steps of the Seldinger technique which is currently neglected in both commercial and academic medical training simulations. The simulation co-locates visual and haptic feedback through the use of an augmented reality video see-through visualisation whilst requiring no headwear to be worn. The visual simulation implements shadowing of the users real hand in the virtual world to increase depth perception, textured deformable tissue and visually realistic cloth, whilst haptic feedback combines both tactile and force feedback based on in-vivo measured force and tactile data. The simulation is a work in progress and is to undergo validation.*

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Computer Graphics]: Multimedia Information Systems—Artificial, augmented, and virtual realities

## 1. Introduction

The growing pressure to reform medical training practices from the traditional apprenticeship model, and the use of virtual environments has been widely discussed [CMJ10]. Interventional radiology (IR) is one medical specialty at the forefront of such initiatives. IR is a minimally invasive technique to perform tasks such as; unblocking obstructed arteries, blocking bleeding arteries and arteries supplying tumours, biopsying masses, draining abscesses and obstructed organs such as the liver and kidney, and infusing drugs into organs via the vascular system. A number of these tasks have been partially simulated in virtual environments.

The steps of a vascular interventional radiology procedure can briefly be described by cues and actions to enable: tool introduction through the Seldinger technique [SEL53] and wire guidance to a target. After visually inspecting the patient, the operator locates the proposed site of access. A fenestrated surgical sheet is placed over the patient with its opening at the proposed access site. Palpation is used to locate an artery at a specific anatomical location in relation to palpable landmarks The artery is felt as a pulsating, tubular structure at a variable depth beneath the skin. Wearing surgical gloves, the practitioner's fingers depress the skin to accurately locate the femoral artery anatomy, the depth of the depression and resulting forces depend upon the habitus (quantity of muscle and fat) of the patient. The skin depression required to adequately feel the pulse is greater in an obese patient compared to a lean patient with less local fat. This tissue thickness influences the apparent force of the

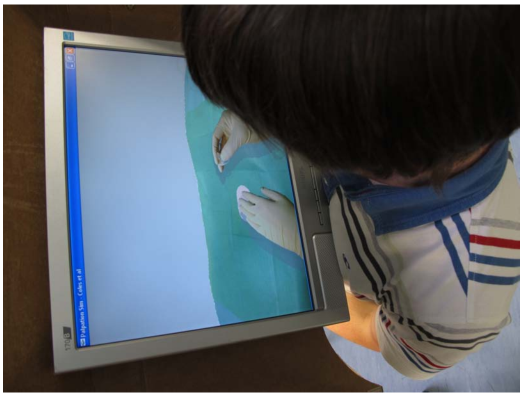

**Figure 1:** *AR femoral artery palpation simulation*

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pulse as perceived by the operator, while various medical conditions (e.g. low blood pressure, vascular obstruction upstream) determine the actual pressure within the vessel at the puncture site. Once located, a needle is inserted into the location of the artery as felt by the clinician; a guidewire is then manipulated through the needle and into the vessel. When sufficient wire is located within the vessel, the needle is removed and a catheter or sheath fed over the wire. The wire can then be removed and the sheath or catheter used as a conduit for device (coils, balloons, stents, etc) introduction, or for injection of contrast medium or drugs.

Commercially available virtual simulations of interventional radiology procedures [CMJ10] train wire and catheter manipulation and guidance, but omit the challenge of femoral artery location and needle insertion, greatly reducing the simulation complexity but also the face validity. There are no commercial IR medical training simulations that offer a complete procedural simulation from start to finish as all simulations providing force feedback do so only through tool interaction. Conveying haptic feedback though haptic end effectors which imitate surgical tools reduces the complexity of reproducing both haptic and visual cues.

Clearly, the lack of palpation simulation must be addressed to offer a full procedure, IR training simulation. Combining the visual and haptic cues as a trainee touches a virtual patient's skin is the focus of this paper. The simulation described below aims to provide high fidelity visual and haptic feedback, in addition to patient variability in both habitus (related to a patients quantity of muscle and fat) and pulse strength (related to a patient's anatomy and medical condition). In-vivo force measurements will be used to validate the simulation's haptic feedback.

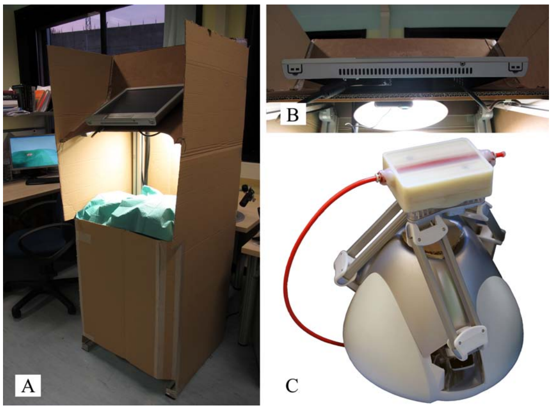

**Figure 2:** *A) A co located Haptic / Augmented Reality workstation. LCD display and camera mounted above haptics device. B) Side view of LCD display with camera mounted beneath. Bright lighting to achieve fast shutter speed is mounted behind. C) Modified Falcon Force feedback device with tactile component.*

## 2. Simulation Requirements for Femoral Palpation

To effectively simulate a femoral palpation the visuo-tactile nature of this task requires collocated visual and haptic perception. A semi transparent mirrored display is commonly used in such a visualisation [PS96], combined with eye tracking technology. This display offers a visualisation of the virtual environment with 50% opacity which allows the viewer to see through the mirror to their hand and the haptic device below. In the context of palpation simulation, as the practitioner reaches underneath the projection plane to where they perceive the patient to be, a 50% occluded image of the simulated patient appears over the users hand which is also only 50% visible. In addition, the user must also choose to focus on the hand below the mirror or on the image itself producing suboptimal viewing conditions. To overcome this occlusion limitation, an augmented reality visual viewing system based upon well established chroma-key technology has been developed to provide a visualisation that enables co-located visual and haptic feedback whilst masking the haptic device providing the force and tactile feedback.

## 3. Augmented Visual Feedback

During an IR procedure, a patient will lay on their back upon a table. This situation can be visualised by mounting an LCD monitor horizontally and projecting an image such that a virtual patient appears below the screen. To produce the augmented feedback, a wide angled camera is mounted behind the LCD display to film the activity below the monitor. The hardware arrangement and visual output can be seen in Fig2.

The image stream from the camera is processed in real time using chroma-key technology to extract objects with a predefined chromatic representation from the background. The live image stream of extracted objects (the users hands and needle) is transformed and super imposed into the visualisation so that the LCD screen appears to offer a transparent view though the screen to the patient and the practitioner's hands below it. This is analogous to performing a real IR procedure whilst viewing the scene through a horizontally mounted frame creating a high degree of realism. The hand extraction can be broken down into two stages: A pre-processed acquisition stage which need only be performed once, in which the chromatic range of the hand image is captured and secondly, during simulation, a continuous video extraction loop in which the hand image is extracted.

### Acquisition Phase

Initially the users must place their gloved hand into the workspace area below the LCD screen. From the image captured by the camera, the user must select areas of pixels which depict the hand. The hue and saturation of each selected pixel is recorded and smoothed with a Gaussian filter to create a map of the average colour range for the hand as seen by the camera. This information is stored in a lookup table and saved as a grey scale image for future reference. The HSV colour representation is used to increase the extractions robustness to fluctuating light when compared to an extraction using the more common RGB colour descriptor. This only needs to be repeated if the glove colour is changed.

### Continuous hand extraction

During simulation a video feed of the interactions below the monitor is manipulated and placed into the virtual environment. Each image in the stream is scanned for pixels whose hue and saturation are within the range described by the pre-recorded lookup table. If a pixel does not fall within this range it will be given a transparent opacity value. However, if the pixel falls within the range, it is assigned an opacity value between 0 and 1 dependent upon the certainty that it is a pixel that represents the users hand. This range, which produces a visually pleasing transition between the users hand and the virtual world, was produced by performing a Gaussian filter on the data in the acquisition stage. In addition to the complexities involved in co-locating visual and haptic feedback whilst using a semitransparent mirrored display, the separate view of the hands from the camera viewpoint below the screen requires additional processing. The image from this viewpoint must be transformed such that when combined with the image of the virtual world, it appears to have been taken from the same viewpoint. As the difference in viewing angle from camera and eye is small, an affine transformation of this image is sufficient to approximate the expected view. The transformation illusion breaks down as the user moves their hand upward (towards the camera/eye) since the hand is too close to the camera lens for a complete hand image to be captured. To preserve the video see-through illusion, the opacity of the hand image is smoothly faded to zero if the users hands come too close to the camera. If the users hands move toward the edges of the camera's field of view, fading also occurs and a visual indicator guides the user to move their hand(s) back into the field of view.

To alleviate depth perception problems inherent in a 2D visualisation of a fixed viewpoint 3D simulation, shadowing of the hands and tool has been implemented. The shadowing relies on a second low resolution side mounted camera (Fig3A) used to visually measure the distance of the users fingertips from the virtual skin's surface (and haptic device). Two shadow images (grey scale representations of the hand image) are subsequently scaled and displaced from the original reference image of the hand depending upon a factor of the hand's height. These images are also rendered at varying opacities to provide the illusion that the shadows are created by two different intensity light sources and an ambient light. As the user's fingertips approach the virtual skin's surface, the displacement of the shadow images from the hand image decreases to zero as the users fingertips come into contact with the haptic device.

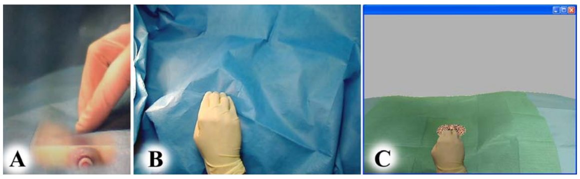

**Figure 3:** *Hand extraction. A) Side camera view B) Top camera view C) Extracted hand image transformed and superimposed into simulation.*

The visually pleasing deformable skin is represented by a skin textured dense vertex mass spring model which stretches in a visually realistic manner, described below.

## 4. Force and Tactile feedback

The simulated palpation forces should match those felt in a real femoral palpation and include all palpable cues necessary to successfully locate the femoral artery. These forces are conveyed via a modified Falcon force feedback device (Novint, Albuquerque, USA). As a successful palpation requires a practitioner to interpret force and tactile cues, a custom end effector incorporating a tactile feedback component has been added to the Falcon. The Falcon has been modified by rotating the device through 90 degrees to face upward and is rigidly mounted to the frame to which the LCD and cameras are attached. The components measured positions and orientations guarantee visual and haptic alignment.

Throughout the simulation development the method of force calculation has evolved. Initially force calculations estimated an output force using a single deformable mass spring model for both visual and haptic feedback. This method of deformable modelling, which is commonly used in computer graphics to simulate graphically pleasing deformable objects, allowed force approximations to be calculated at a fixed rate of 400 Hz (Hertz). The output forces were filtered to eliminate high frequency vibrations and interpolated to increase the perceived haptic feedback rate to 800Hz. A mass spring model was used to achieve a high frequency force calculation, trading off accuracy for speed. Dependent upon the interaction which is to be simulated (hard or soft contacts), it is accepted that an ideal haptic feedback loop should operate in the range of 600 to 1000 Hz. The described implementation offered a smooth force feedback that feels realistic to the novice touch and can be finely tuned to a trainer's perceived ideal output. However, concerns over negative training where incorrect procedural training can lead to enforcing dangerous practices upon patients, has led to a new data driven approach for force and tactile feedback.

Currently a quantitative approach to force simulation and validation is not commonly used and validation practices rely heavily on an "it feels right" approach employing experts in the field to recall and compare the forces felt during a real procedure. A scientific approach to in-vivo recording of force data and validation of the output through numeric comparison is currently being undertaken. In contrast to the previous force estimation through evaluation of a mass spring model for visual and haptic feedback, both feedback loops are now calculated separately sharing only hand position data. Hence, by decoupling the force feedback from the mass spring model allowing in-vivo force data to be used in force replication, the risk of negative training should be reduced.

At the time of writing, whilst waiting for detailed in-vivo force data from medical partners, output is calculated by fitting a curve to data comparing skin displacement against resistance. As the planned in-vivo data is acquired, it will be possible to build 3D force estimations from which force will be simulated. This data will then be used to validate the output of the simulation by recording force output from the force and tactile devices with the same force sensor used to record the data in-vivo.

A second modified force feedback device for needle insertion simulation is currently under development although not yet ready for testing. The force feedback device is gravity compensated such that if a trainee releases their grip on the needle it will remain where it is inserted in the virtual tissue. A real needle end effector is used to increase the fidelity of tactile feedback.

### 4.1. Tactile feedback

The tactile response of the pulsing femoral artery is also to be recorded in-vivo as a high frequency, low force response. Previous work [CJGC09] has reviewed three tactile technologies for use in a virtual femoral palpation simulation: piezoelectric materials, micro speakers, and pin arrays. To overcome problems with these approached, a fourth hydraulics-based technology has been investigated. Researchers at the Royal Liverpool University Hospital developed a hydraulics based device (called SimPulse) as a mannequin based tactile feedback device. The SimPulse solution is the inspiration for our latest implementation, where a thermoplastic tray structure is firmly mounted to the Falcon force feedback device and holds a water actuated tube mounted in silicon. An external piston and servo motor assembly creates the pulse waves. Various prototypes of the tactile end effector have been manufactured in preparation for a preliminary simulation review by subject experts prior to a numerical evaluation through force measurement. Gravity compensation of the Falcon device allows the end effector to be positioned at the virtual skin's surface whist the practitioner is not performing a palpation.

## 5. Simulation Validation

Simulation validation will be conducted in two phases. The first phase will compare force data recorded in vivo against simulated force output recorded at the tactile end effector using the same measurement device used for data acquisition. This ensures correct force calibration of the force feedback and tactile simulation devices.

The in-vivo recorded data will describe position on the patient's skin, skin deformation depth and a resistive force for each deformation. The force data may contain a temporal fluctuation if the recorded position is close to the femoral artery. To extract this data which is necessary for tactile validation, each recorded force shall be measured for a fixed time period to produce a profile of the force fluctuations.

The second phase of validation will follow a more commonly used virtual simulation validation approach whereby the verbally communicated perception of the simulation according to both experienced and trainee users, is collated and evaluated in combination with a questionnaire.

## 6. Conclusions and Future Work

The simulation currently offers a compelling alternative for virtual femoral artery palpation simulation. Validation has been planned and will be undertaken in the near future. The virtual simulation's ability to replicate a variety of patients' habitus and varying medical conditions by altering visual, force and tactile cues, when combined with the simulation's reusability could, after validation, replace existing mannequin based or cadaver based training systems which do not offer such flexibility.

Decoupling the haptic and visual feedback has allowed an increase in fidelity of both cues through utilisation of multi-threading. This new, more modular design allows the visual deformation model to be changed without the need to modify or redesign the haptic model or vice versa. The simulation uses a multi-core PC designed for video games and does not require a high cost professional processor or graphics card.

Future work will integrate in-vivo force recordings and validate the output against the recorded data. Future modifications to the tactile and force hardware are planned to offer higher fidelity feedback. A marker free head tracking system is planned which will increase the perception of three dimensional visualisation.

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