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# Real-Time Guidance and Anatomical Information by Image Projection onto Patients

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**Abstract**

*The Image Projection onto Patients (IPoP) system is work in progress intended to assist medical practitioners perform procedures such as biopsies, or provide a novel anatomical education tool, by projecting anatomy and other relevant information from the operating room directly onto a patient's skin. This approach is not currently used widely in hospitals but has the benefit of providing effective procedure guidance without the practitioner having to look away from the patient. Developmental work towards the alpha-phase of IPoP is presented including tracking methods for tools such as biopsy needles, patient tracking, image registration and problems encountered with the multi-mirror effect.*

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computing Methodologies]: Computer Graphics—Picture/Image Generation; J.3 [Computer Applications]: Life and Medical Sciences—Medical Information Systems

## 1. Introduction

Augmented reality is a method of enriching the perception of people by superimposing computer graphics onto the scene [ABB*01, ZFWL16]. The use of this type of technology in medical procedures intends to assist and facilitates clinicians' work by allowing additional information to be presented in the field of view of the user. One of the early applications in the clinical field was the use of augmented reality to assist with dental work by superimposing the drill and implants over the patients' dental anatomy [PWEE95]. Since then, in the light of modern technological developments, virtual image guided interventions, supporting navigation and anatomical information, have received increased attention from researchers and clinicians alike and many models and tools were developed for various procedures [CP10, MIH11].

The Image Projection onto Patients (IPoP) system is introduced in this paper. IPoP is an augmented reality system that will provide intuitive access to patient data such as anatomy or other assistive information (e.g. needle trajectory) during an intervention.

The clinician will not wear cumbersome head equipment or need to move away from the patient to look at monitors. This feasibility project is focused on spinal navigation and the overall design is based on a user requirements gathering exercise with subject matter experts. The proposed tool will use the medical scan data set used in the procedure (X-Ray, CT, MRI or Ultrasound) or 3D models to provide an online map of the underlying anatomy for any individual patient, potentially avoiding harmful radiation doses. Real-time guidance and anatomical information will be provided by IPoP and updated as the procedure progresses. When a medical scan has not been performed in advance, IPoP will use an intra-operative screening X-ray to overlay an anatomical map.

## 2. Background

The superimposition of computer generated data is commonly achieved using head-mounted displays or camera-equipped mobile phones, often employing some form of computer vision. Most of these applications are domain specific and several computing techniques such as image processing and registration are addressed at a low level. Though such systems can be useful for medical applications, they can be restrictive due to the covering of the eyes, limited field-of-view and bulky headsets. On the other hand, in medical settings, the use of a computer monitor often draws the clinician's attention away from the patient. An alternative is to project the computer generated images directly onto the patient's skin, which allows the user to be more focused on the patient rather than their own surroundings during the procedure [KK14, KHK*08, SYK*10]. It is envisaged that direct projection of the anatomy of interest will also assist with the perception and understanding of how the underlying organs could interact with the procedure [KPR*12].

The current developmental applications of IPoP are to deliver a general anatomy education tool; and to explore a specific clinical application as a guidance aid for lumbar biopsies. Navigation from outside the body to defined areas within the central nervous system is an essential part of both neurosurgery and neurological intervention and investigation. The nervous system is a delicate struc-





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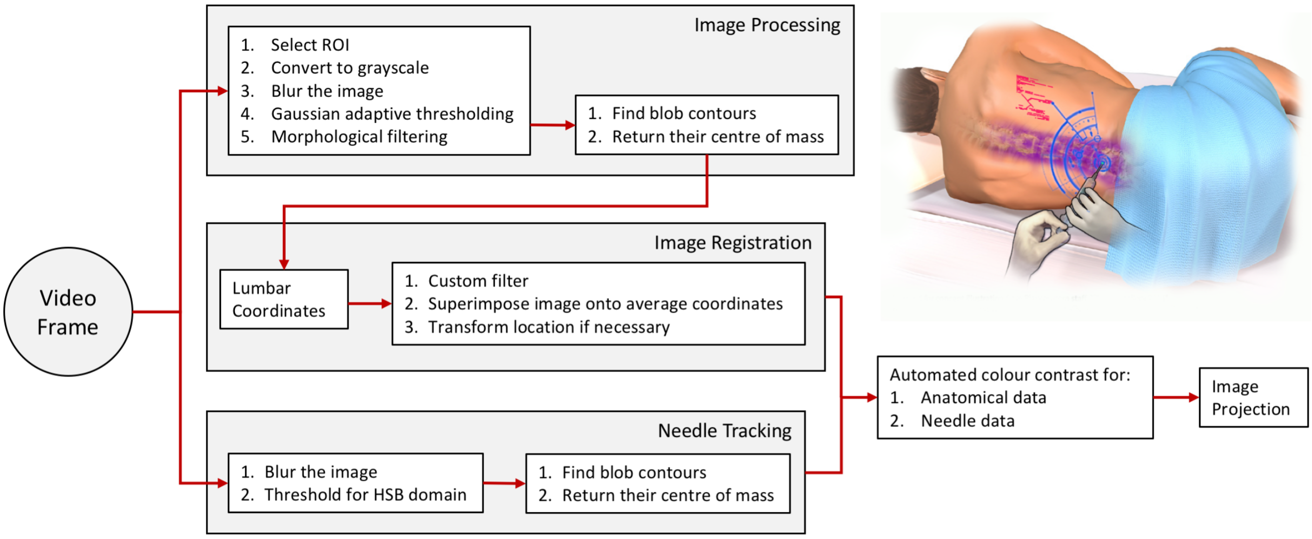


**Figure 1:** *System Architecture for the alpha-phase of the IPoP software. Side illustration adapted from Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010ISSN20018762*

ture surrounded and protected by bone and other vitally important bodily structures and organs. The growth of minimally invasive spinal surgery has established patient and health economic benefit over the years. Such techniques require ever more robust, safe and user-friendly guided navigation within the spine, to avoid significant complications and catastrophic events such as wrong site surgery [MIH11].

The value for such inter-operative tools is readily apparent. In the United Kingdom alone, more than a third of the lumbar punctures carried out every year are performed on patients having their therapeutic spinal nerve root blocked using local anaesthetic and a large majority of them undergo radio frequency denervation of the lumbar facet joint [NHSb]. These are investigative and interventional pain management procedures, which together with other complex surgical procedures, such as cervical discectomy or lumbar micro discectomy, require some form of imaging guidance. Until better techniques or tools become available, using conventional X-rays covers the imaging aspect of the procedure.

## 3. IPOP System Design

Following consultation with several medical practitioners at local hospitals, we found that doctors prefer not to have a fully automated tool for procedures such as lumbar biopsies, but favour a more flexible tool that can be adjusted during use. For example, palpating the spine to ensure the superimposed image is properly registered and the ability to adjust its position, or type of displayed information, if necessary. The development process took this feedback into account and the final product will be tailored to their needs. IPoP has the potential to hold a database of anatomical structures and display them onto any part of the body. Moreover, the potential appearance of laser projectors on the market is also welcomed as images can be projected onto undulating or curved surfaces without losing focus. The system architecture used for the alpha phase of IPoP is summarised in Figure 1. It has been implemented in the Python programming language using the Python OpenCV wrapper. A mannequin has been used to test the initial implementation. Ethical approval for tests with real patients will be obtained for the next phase of the project.

Two male torso mannequins (Only Mannequins, 1.8 Kg, 55.9 x 40.6 x 25.4 cm) of dark and light colors were used for the patient tracking and color contrast experiments. Three reflective motion capture markers (OptiTrack, 7/16 inch) were placed onto the back of the mannequin; one at the neck region and the other two at the hips. The placement of the projector (Benq, MX620ST digital projector) is at the base of the mannequin and at a distance of two meters. The infrared camera of the Microsoft Kinect (10 Nov. 2010 model, Depth Camera: 640x480 pixel resolution @30FPS ) was used to track the IR reflective markers placed on the mannequin.

### 3.1. Segmentation and tracking of markers

Infrared markers are placed onto the base of the neck and the lower back. Further, the markers are detected and segmented by: (i) illuminating the back with infrared light; (ii) cropping the region of interest (ROI) in each video frame; (iii) Gaussian blurring of each ROI frame; (iv) Adaptive Gaussian thresholding; (v) Morphological filtering using opening and closing methods; and (vi) detect contours using the Suzuki algorithm — this segments all three infrared markers [SHS03]. Once the markers are segmented their pixel coordinates are found using the connected component algorithm to detect blobs (based on the sequential grass-fire algorithm [LL92]).

During a lumbar puncture, the patient lies on an operating table and has to stay still to reduce discomfort as the needle is

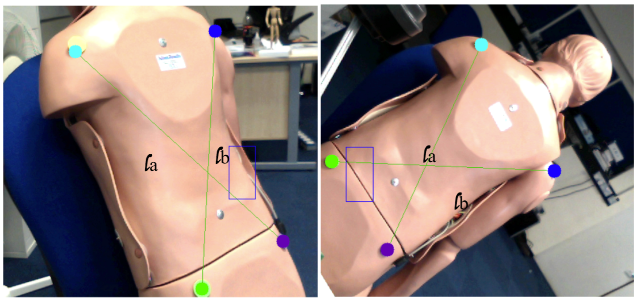

**Figure 2:** *Previous method using colour markers using HSB colour tracking. Rotating the camera to simulate patient movement did not affect the crossover point*

inserted [NHSa]. However, it is important to incorporate patient tracking into the software to compensate for small movements. Once the marker blobs are identified and their coordinates obtained, mannequin/patient distance and motion can be tracked. Colour tracking of the needle (see Figure 4) was chosen to prototype the needle/tool functionality for IPoP. It is not totally robust as it can be prone to interference form objects that have similar hue values. However, additional selection methods help to reduce interference such as the deletion of small blobs in the binary image and the detection of the needle only when a bounding box condition is satisfied. This method helps to track the coloured markers even with changes in background light intensity and colour (Figure 4). Infrared markers are not used for the needle so that they can be distinguished from the body markers. Work is also being carried out to track light-emitting diode markers on the needle tracker so that their HSB values are not changed, should the projected image shine onto them.

Rotational tracking of the markers is divided into two methods; (a) in-plane measurements; (b) out-of-plane measurement i.e. when the needle is rotated towards and away form the camera. This method suffers from gimbal lock at needle angles $\pm 50$ degrees but is currently acceptable for the alpha phase of development since patient rotation will be at a minimum. In-plane rotational angles are calculated in this way: (i) convert the ROI into a complex plane; (ii) locate the topmost needle marker in the (x,y) plane; (iii) calculate the vector from the centre of mass to the neck marker and find its phase value (angle). The out-of-plane angle is calculated from area ratios of the neck and lower back markers using a calibration plot of distance vs. area of markers.

Segmentation of the patient's outline uses the same process as for the body markers except that no ROI is selected so that the needle can be tracked within the whole video frame. The specific HSB colour is extracted from each frame through thresholding. Tracking is then achieved by measuring the centre of mass of the detected marker contours. The needle distance is calculated by measuring the blob area of the markers and comparing the value to a calibration equation obtained by moving the markers at 10cm intervals within the range [10cm, 200cm] from the camera. The current method for measuring the needle rotational angle is based on the in-plane and out-of-plane methods discussed above.

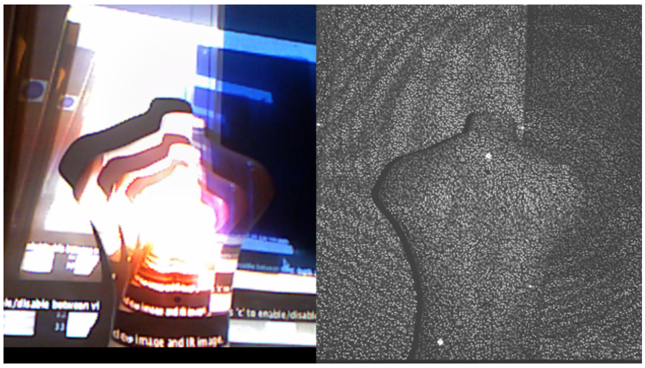

**Figure 3:** *Multi-mirror effect on the left. The image on the right is taken using an infrared camera which does not detect the projected images.*

### 3.2. Registration of projected images onto the mannequin

The symmetry of the human body is utilised in locating the lumbar region by finding the mean position of the three body markers [SV80] in the upper part of the lumbar region. The position of the projected image can then be superimposed in relation to those 2D coordinates. The image can then be scaled manually until the desired size is achieved using palpation to help superimpose the CT scan onto the spinal ridges. Further work is needed to transform the image dimensions should the patient or projected image be significantly non-perpendicular. A simple bespoke filter has been developed to nullify the jittering of the marker blobs in the images. The filter works by locking the mean centre of mass of the body markers, unless the mannequin moves beyond a pixel distance threshold. Further improvements are being made to ensure that the image is correctly registered after moving the mannequin.

Currently both medical scan images and 3D anatomical models are being used to test IPoP on mannequins. The projected image or textual information is also adjusted to compensate for the colour of the patient's skin colour. Averaging the pixels' hue values at the lumbar region and subtracting 180 degrees from the average hue, to create a contrasting HSB colour, achieves a good colour contrast.

## 4. Discussion and result

Our initial approach was to use coloured markers placed at the shoulders and hips (Figure 2). Drawing diagonal lines between the markers helped locate the lumbar region where they crossover. This point could, as well as with marker orientation, be used to register images onto the back of the mannequin. However, projecting an image back onto the mannequin created a multi-mirror effect, which is not reported in the literature. The same effect is seen when holding two mirrors up to each other and the light (scene) is reflected ad infinitum. This phenomenon slowed the segmentation process and made it almost ineffective as multiples images were being segmented simultaneously (Figure 3). The solution was to make the video image for segmentation different to the projected image. This was achieved using a near infrared camera whose images are unaffected by the projected light. Projecting the scene back onto the mannequin was not detected by the near infrared camera thereby cancelling the unwanted effect.

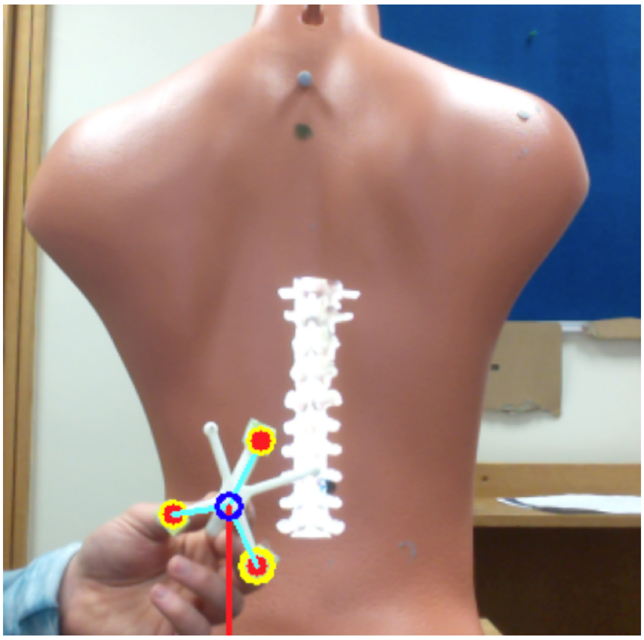

**Figure 4:** *Simultaneous tracking, registration and projection using a mannequin.*

The colour correction technique used here attempts to compensate for the colour transformation that occurs once light interacts with skin, as well as a method for achieving the best colour contrast of the projected data with the surface. The colour of incident light onto a surface is influenced by contributions from other sources such as; (i) fluorescent lights; (ii) external lights; (iii) other sources (e.g. computer monitors) and secondary reflections form nearby objects. This means that the intended projected colours might not be the actual colours detected by the camera. Additional factors with real skin include transformations due to subsurface scattering and absorption. For example, Angelopoulou [A99] showed that skin reflects orange and red well, whereas higher energy light such as ultraviolet (<400nm) and blue (460nm -> 500nm) is reflected less. In other words, skin is less absorbent to red colours than it is to blue.

The difference between incident and reflected light onto skin was measured by; (i) projecting red (HSB: 0.00, 1.00, 1.00), green (HSB: 0.317, 1.00, 1.00) and blue (0.500, 1.00, 1.00) colours onto the skin of a human hand and head followed by (ii) sampling a region of the hand and head; (iii) measuring the average HSB for those samples and (iv) comparing the detected HSB values with the original values set.

The detected colours are generally darker than the original colours. Interestingly, blue light seems to have the highest reflectance (this could be associated with skin oil or moisture on the hand). This method of visualisation also helps to reveal the relative shifts of colours; red and blue colours shifted towards higher hues than green. An issue here is that it is difficult to compensate for the colour transformations between incident and reflective light. Integrating all of the above components allows us to track the mannequin, register the image and project it onto the mannequin (Figure 4).

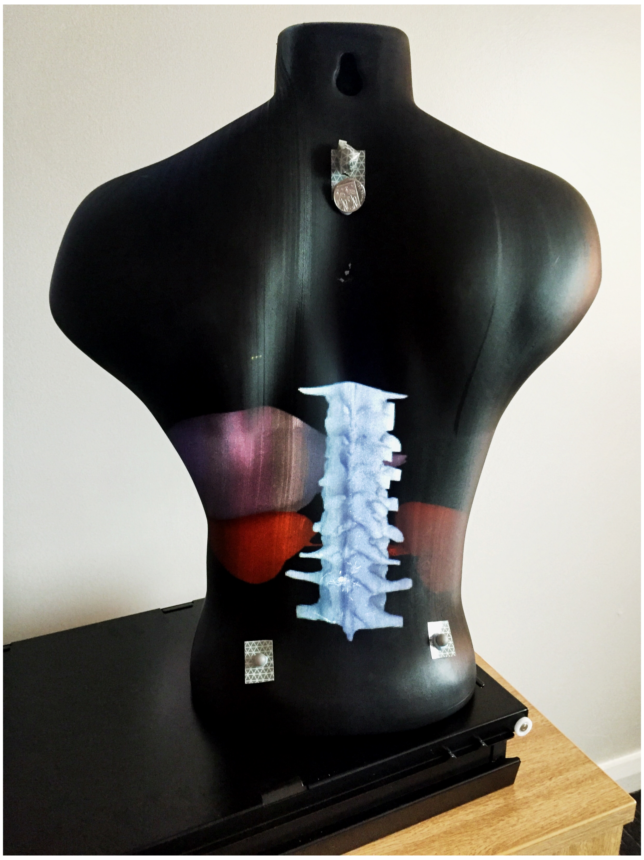

**Figure 5:** *IPoP's current implementation used in the purpose of anatomy education.*

### 4.1. Conclusion

We are working on increasing the performance of the alpha version of IPoP, which currently has a registration rate of approximately 10 frames per second (iMac 3.2GHz Intel Core i5, 16GB 1867 MHz DDR3 RAM). Introducing concurrent tasks will increase performance. The system architecture is such that symmetry in the system can also be exploited to make IPoP run faster by splitting image processing, image registration and needle taking into separate tasks. Figure 5 shows our current implementation being used for the anatomy education tool with the lower spine, kidneys, and liver being projected at a one to one scale onto the back of the mannequin.

Methods that will allow the user to manually adjust or fine-tune the image registration with a glove or bespoke thimble fitted with coloured Light Emitting Diodes (LED) for HSB colour tracking are also being investigated. Changing the colour of the LED activates a different function: red for scaling and blue for re-positioning. A switch sewn into the glove or a micro-switch embedded into the thimble allows the different coloured LEDs to be activated.

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