

# CTSNet & Chelsea Westminster Hospital Robotics

User Interface Design by Ed Collins, Team 19



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# Project Outline

As surgical technology advances, more and more emphasis is placed on Minimally Invasive Surgery.

MIS lacks any form of depth sensing or haptic feedback due to its use of 2D endoscopes. This project aims to begin to solve this problem.

Using an Xbox Kinect 2.0, a prototype for an endoscope that can observe depth and present this information to the surgeon will be created.

The project will potentially then progress to using this information to provide haptic feedback for robotic surgery.



# User Interface

During minimally invasive, or laparoscopic surgery, the surgeon will use an endoscope inserted into the patients body, along with two to three other instruments, to perform the operation.

The endoscope's image is displayed on the monitor, as shown in the picture to the right. This project aims to redesign the way in which the endoscope gives feedback to the surgeon, to allow it to display how far away observed objects are.

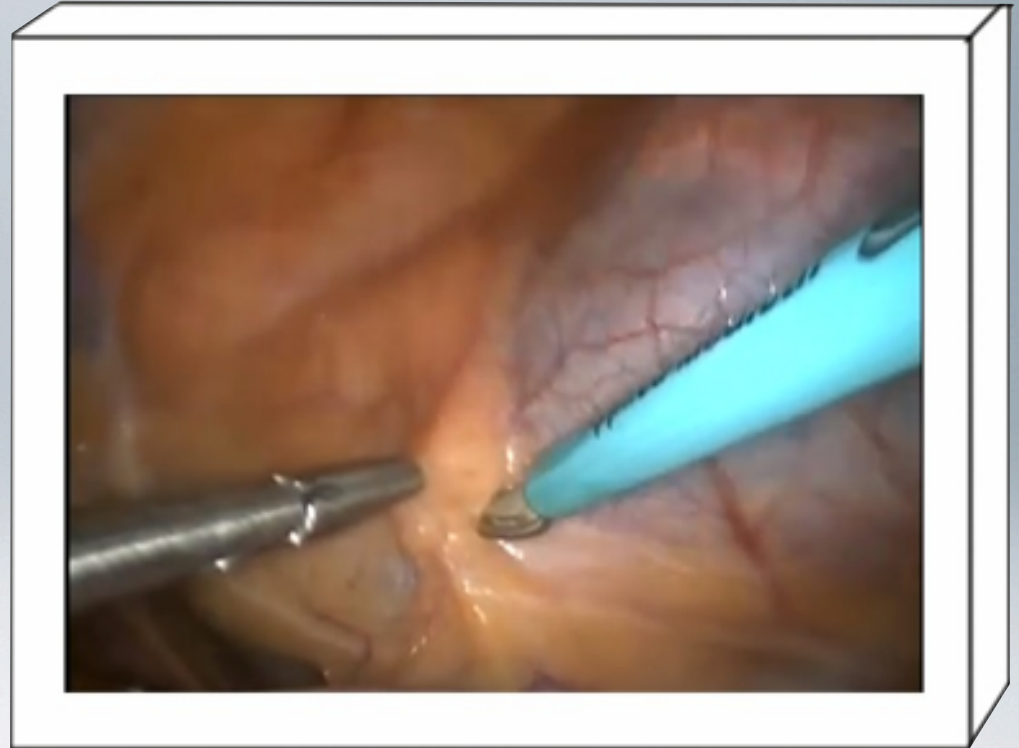
There are several options for how this feedback could be given.



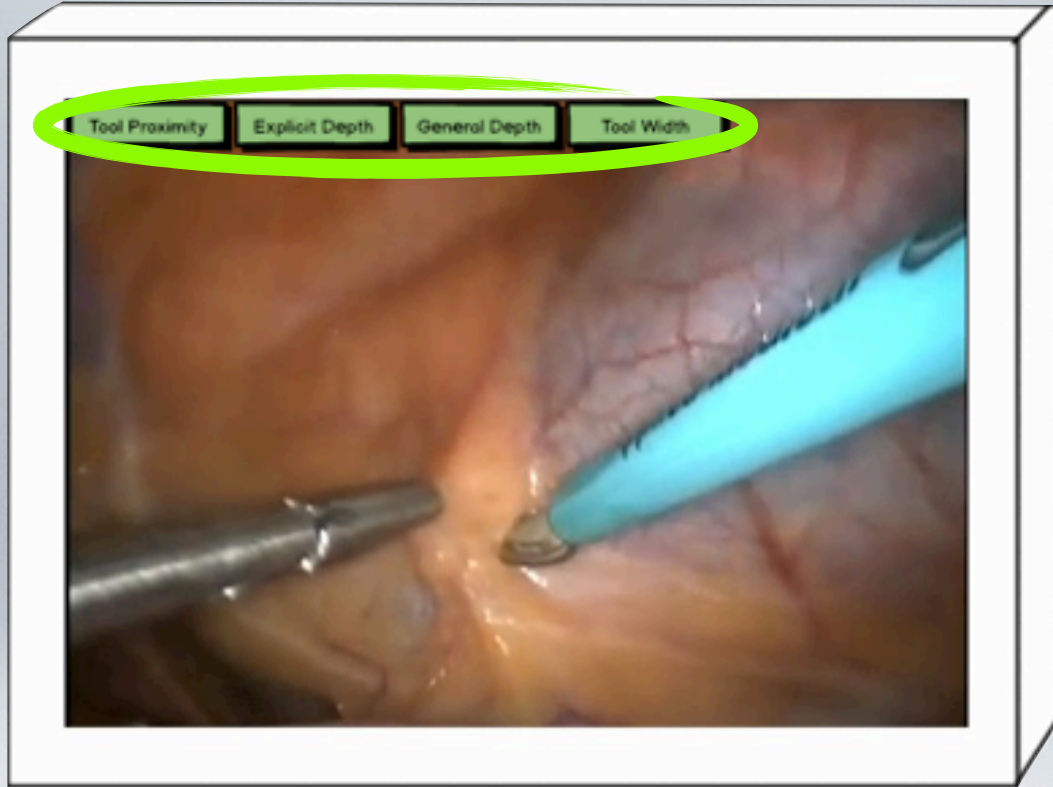
# Visual Augmentation

The first way in which endoscopic feedback could be improved is through visual augmentation of the camera feed.

This would mean overlaying a colour scheme to indicate depth or measuring the precise distance of tools from the camera and then displaying this information.



The options for augmenting the feed are presented in four buttons in the top left corner of the screen; which do not obscure the surgeon's view from the endoscope.

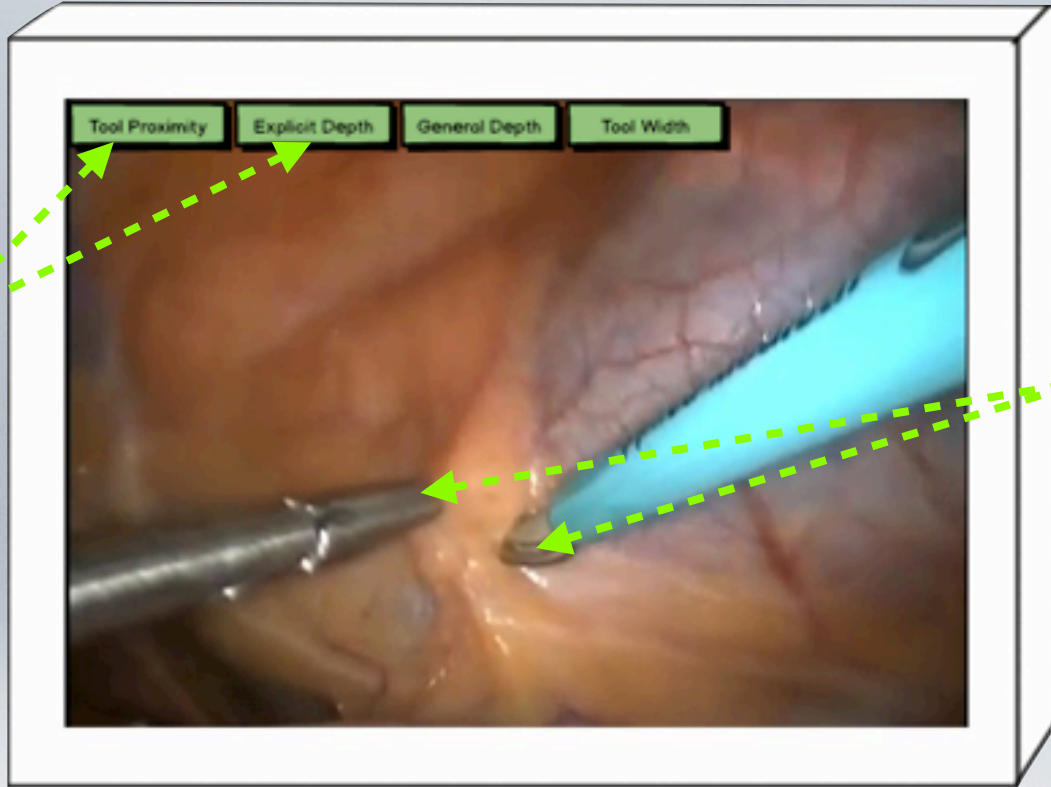


With this design, the surgeon has four different options for how the endoscope feed will be presented.

# Endoscope Interface: Redesigned

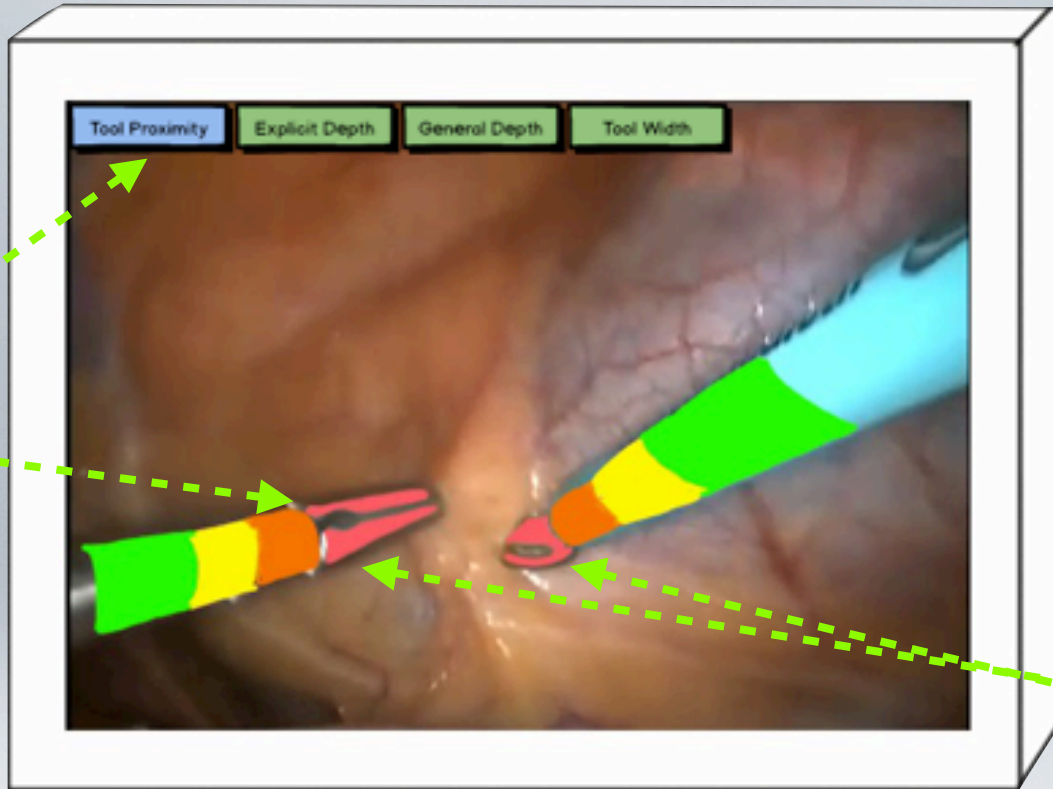
These are toggle buttons. Each button augments the feed in a certain way. More than one can be toggled at once, to provide a multitude of ways to alter the image.

Design principles:  
Mapping: buttons show their functions, Visibility: buttons are always visible, Affordance: these are clearly buttons.



Surgeon's tools. The surgeon gets no haptic feedback from these, nor is there any accurate sense of depth. This can lead to too much force being applied to the tools, which could be extremely dangerous.

# Normal Feed



Design Principles:  
Consistency: buttons  
always visible. Feedback:  
buttons highlight when  
selected.

The tool's depth is  
colour coded to show  
how far away the tools  
are from the flesh of the  
body. This would show  
the surgeon when the  
tools are close to or  
touching the flesh, so  
they know not to apply  
too much force.

- Red Touching flesh
- Orange Within 2 mm of flesh
- Yellow Within 10 mm of flesh
- Green > 10 mm away from flesh

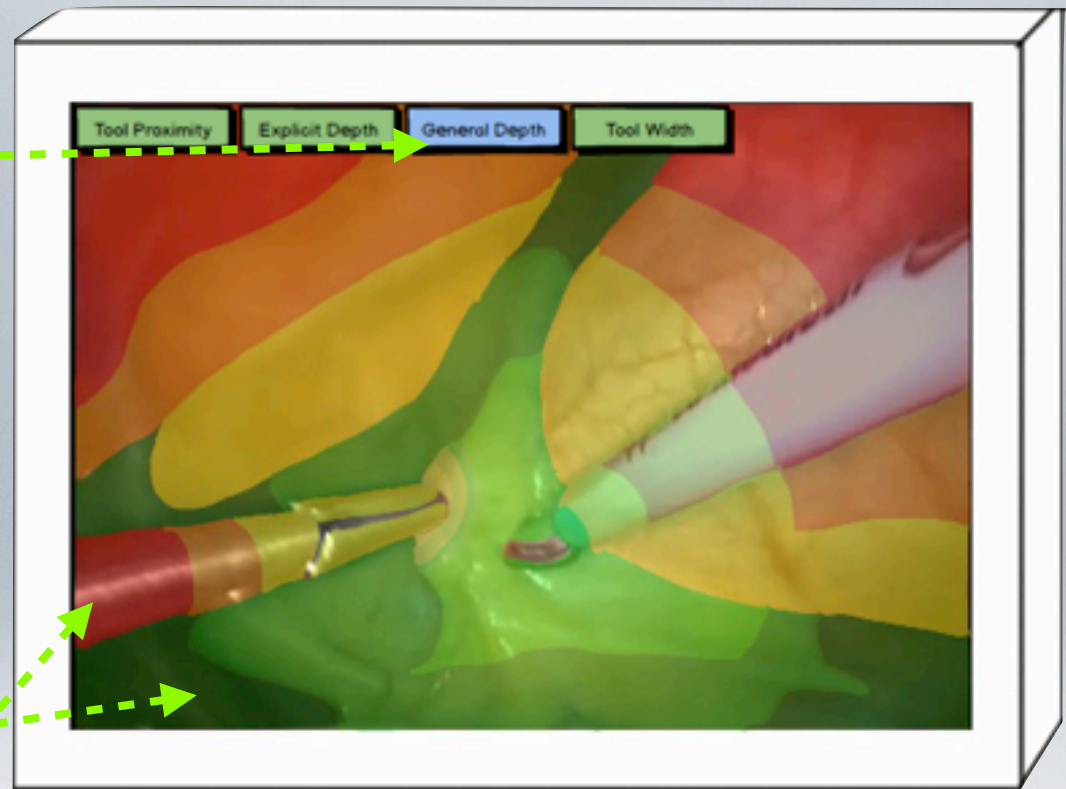
Design Principles:  
Consistency: have used  
convention of red to  
indicate closeness, green  
to indicate further away.

# Tool Proximity

These toggle buttons are highlighted when selected.

This feed shows how far away anything in the camera's field of view is from the camera itself; to give the surgeon a sense of how close the camera is to the flesh.

Design Principles:  
Consistency: convention that red indicates proximity, green: distance is followed.



Red

Less than 2 mm away

Orange

More than 2 mm, less than 4 mm away

Yellow

More than 4mm away, less than 6 mm away

Green

More than 6mm away, less than 8mm away

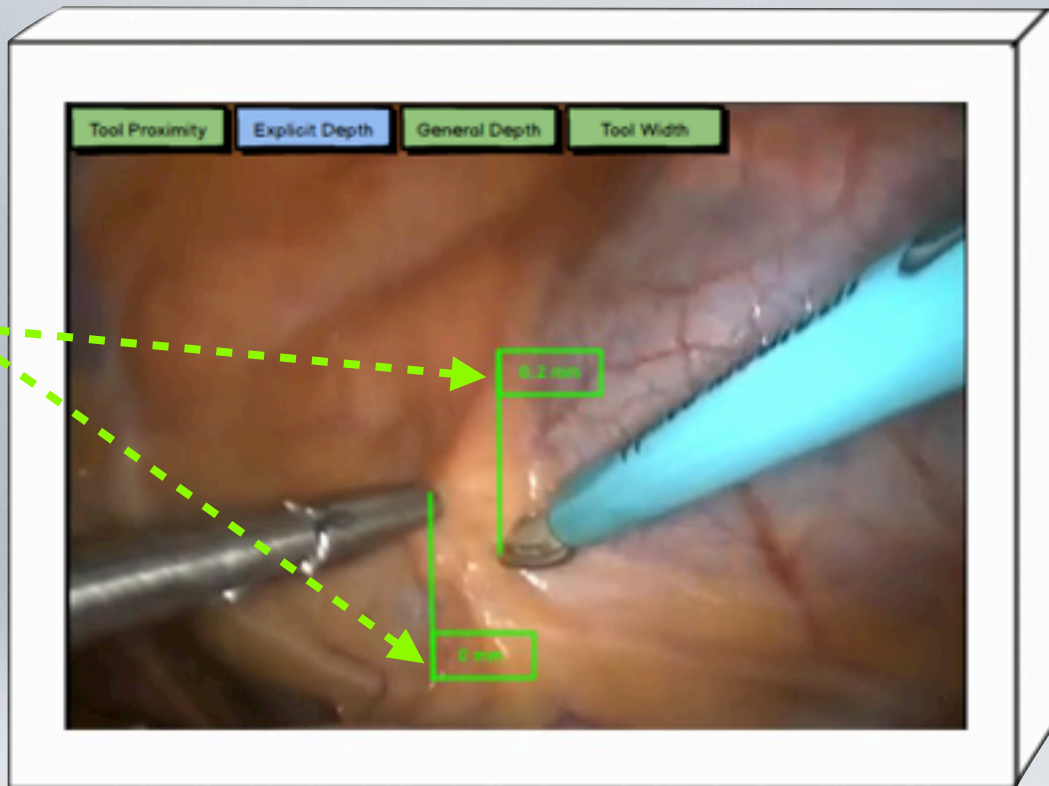
Dark Green

More than 8mm away

# General Depth



The “Explicit Depth” option measures the distance of the tip of the tool to the nearest area of flesh.

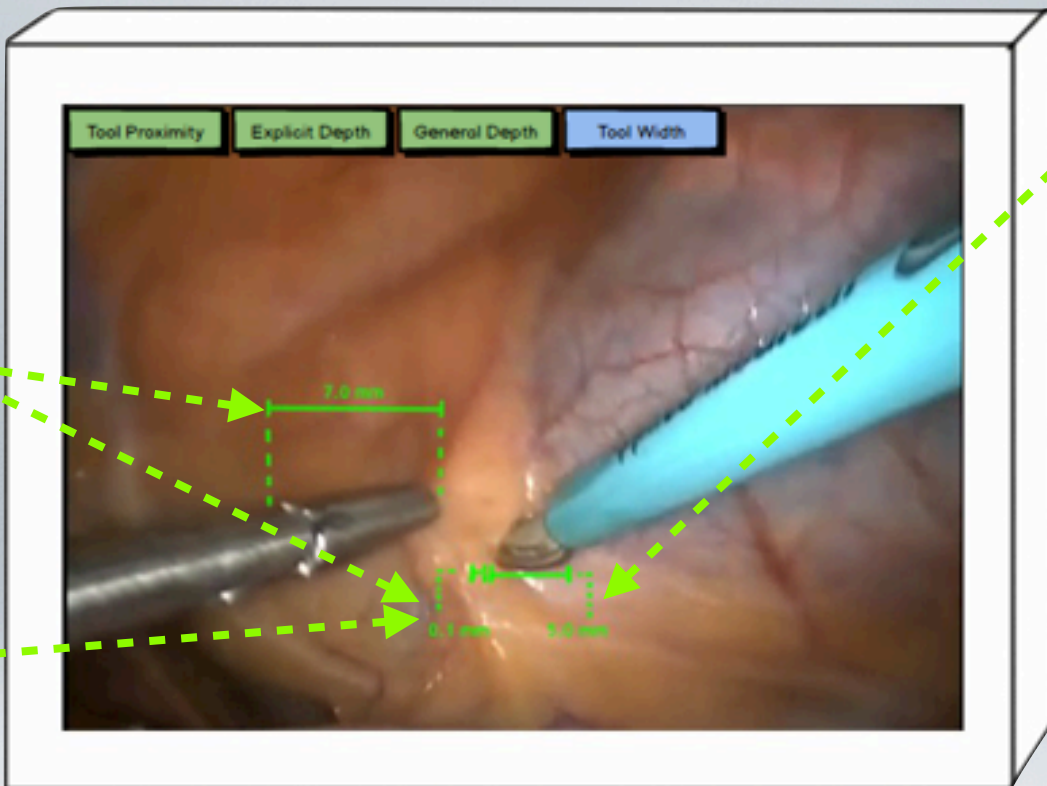


The use of this would be to get an exact measurement of how far away the tools are from the body. This gives the surgeon a sense of how close the tools are to the body. This is useful if the surgeon is not sure if a tool has room to maneuver. They can simply check the Explicit Depth and it will tell them.

# Explicit Depth

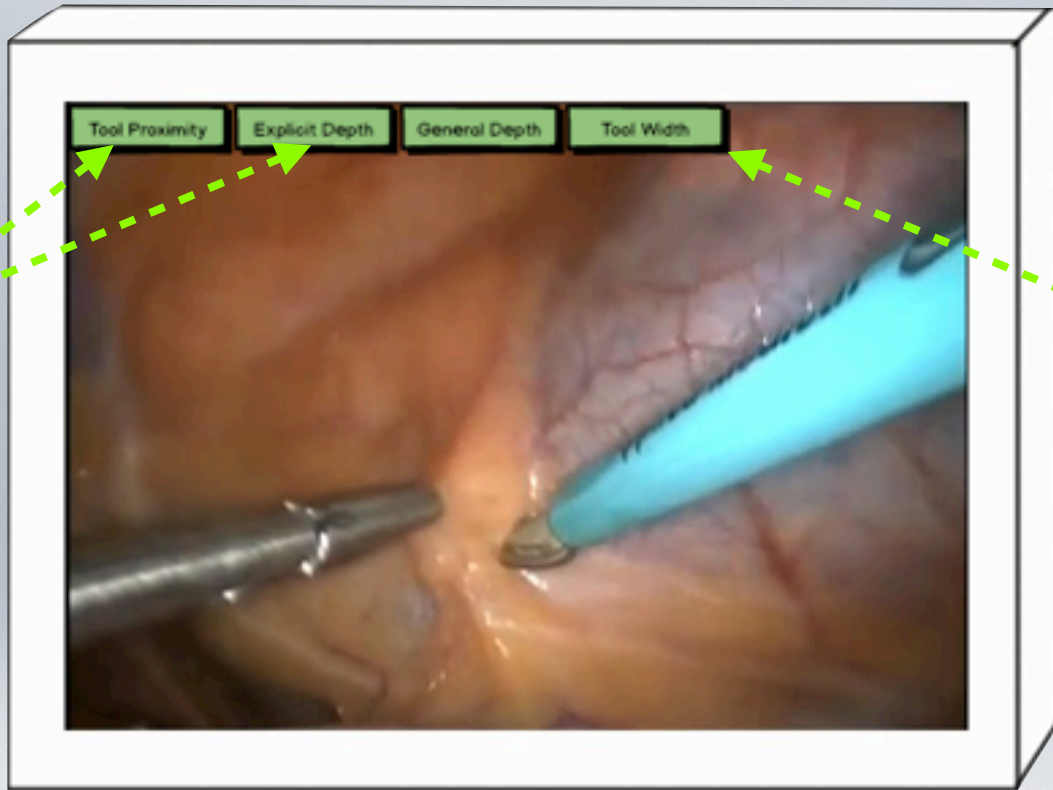
The “Tool Width” option takes a measurement of the functional part of the tool and presents it to the surgeon.

In this example, this tool has been inserted 0.1 mm into the flesh.



This section is split into two measurements. This is the true usefulness of this function: First, the functional part of the tool is measured. If this tool is then inserted into the flesh so that it cannot be seen, and its full width has previously been measured, then it is easy to calculate how far the tool has been inserted into the body. This is very useful as it could prevent the surgeon from pushing the tool too far into the body and thus damaging the patient.

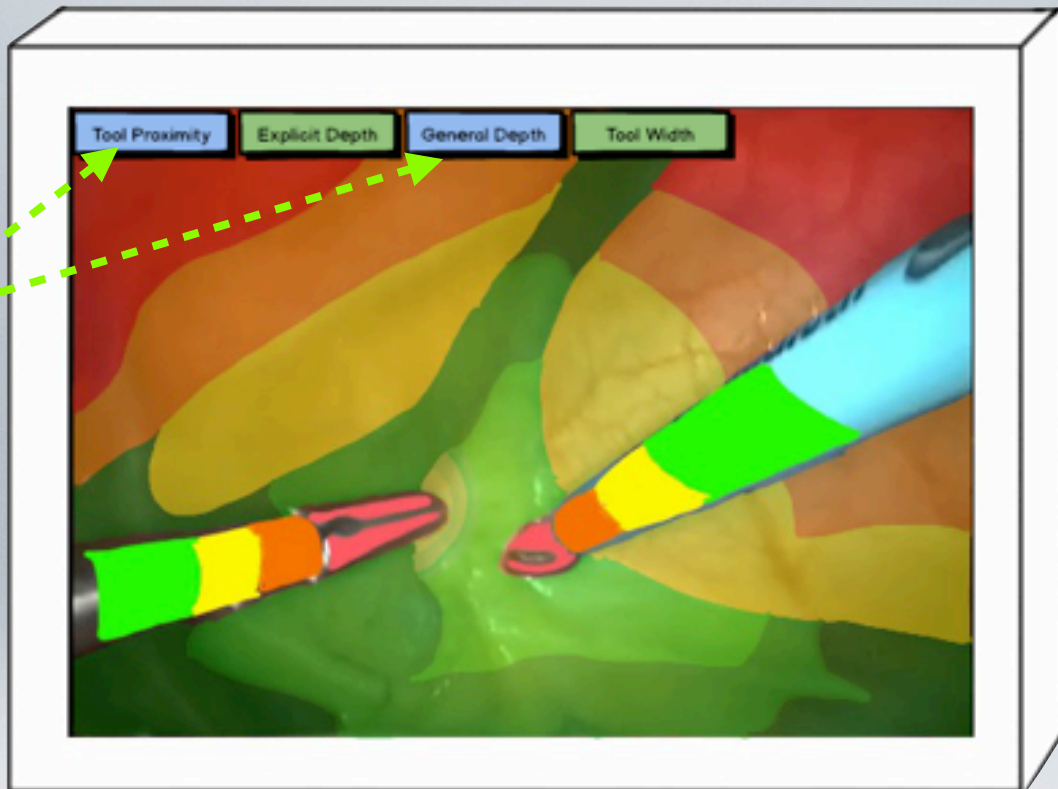
# Tool Width



The advantage of making these options toggle buttons is that more than one augmentation can be overlaid on the feed at once.

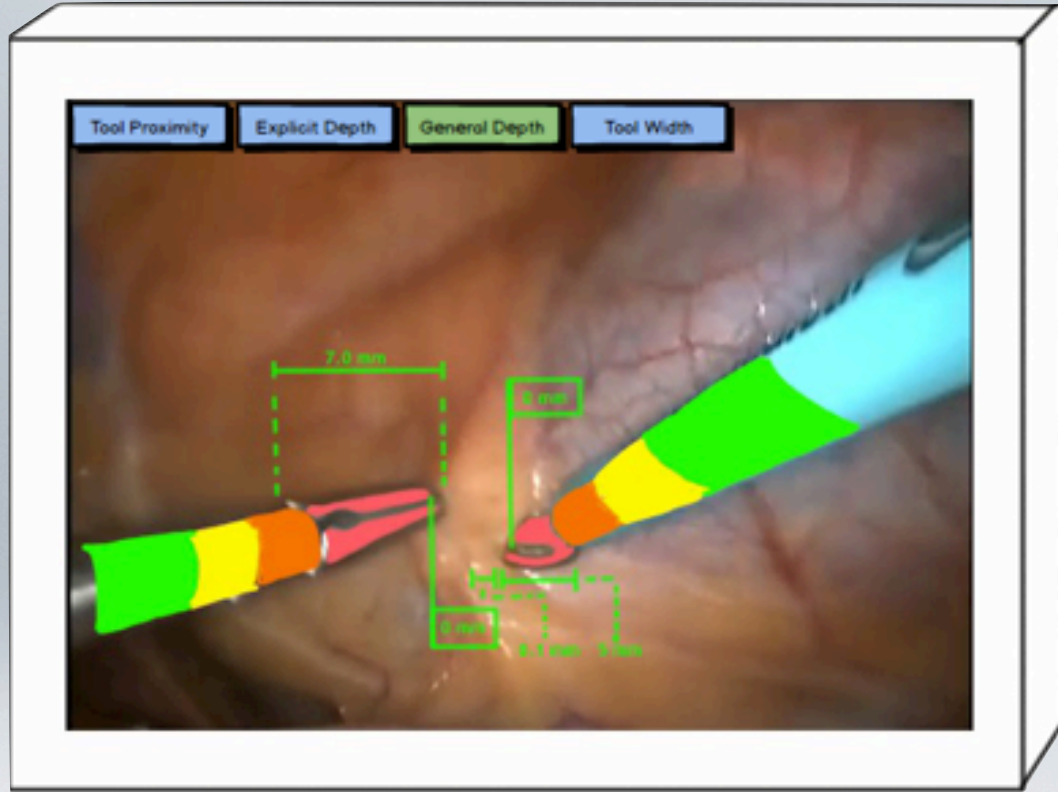
Design principles:  
Constraints: there is no constraint on how many augmentations the surgeon implements at once, meaning they can get a full sense of the distance of objects from the camera.

# The Advantage of Toggle Buttons



More than one augmentation can be selected at once.

# Tool Proximity & General Depth



Tool Proximity, Explicit Depth and Tool Width

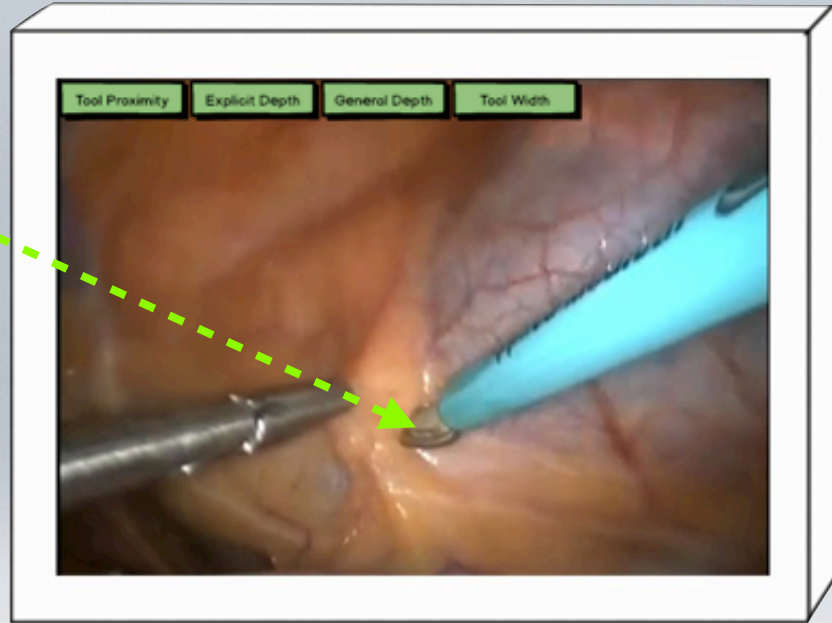
# Audio Feedback

This is a simple but powerful method of providing feedback. It is based on the principle of a car parking sensor.

The camera would monitor the depth of the tools, and as they approach the body a series of beeps would get more and more frequent to give the surgeon an indication of how close the tools are to the body.



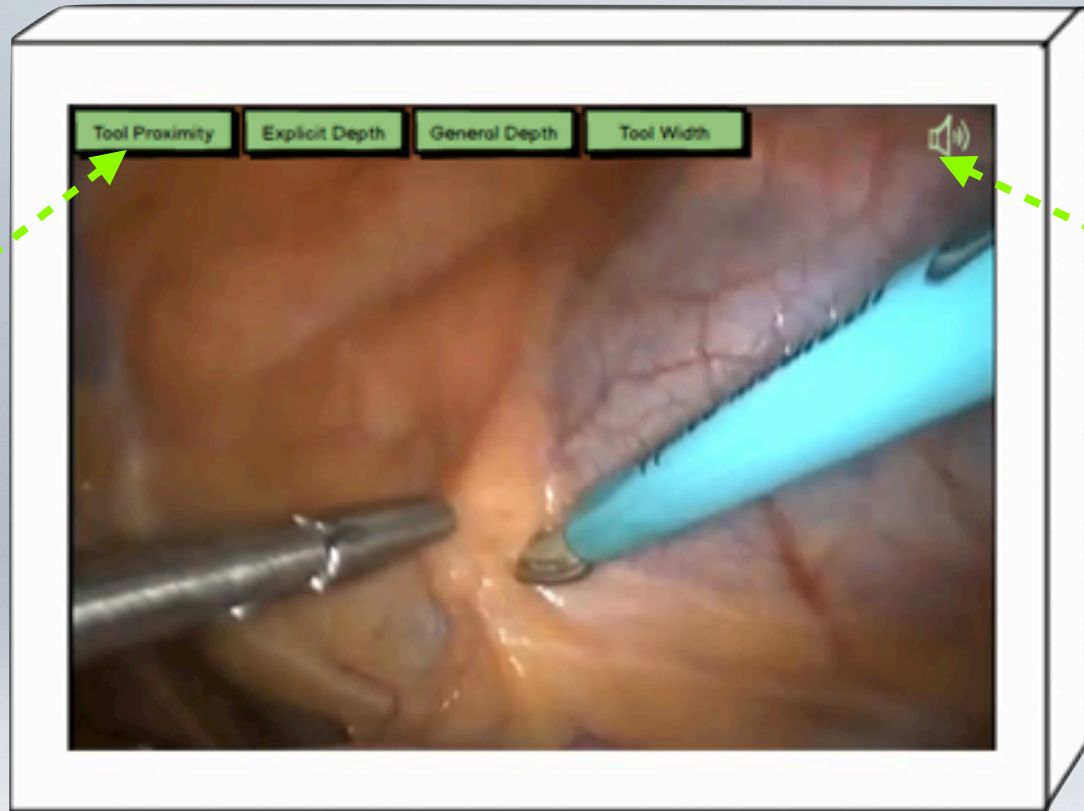
# Audio Feedback



The proximity of the tools to the flesh is measured by the camera. As the tools get closer, the beeps emitted from the speakers get more frequent, like with a car parking sensor.

To produce the beeps, a separate speaker could be attached to the endoscope system of the beeps could be produced directly from the computer that controls the endoscopic unit.



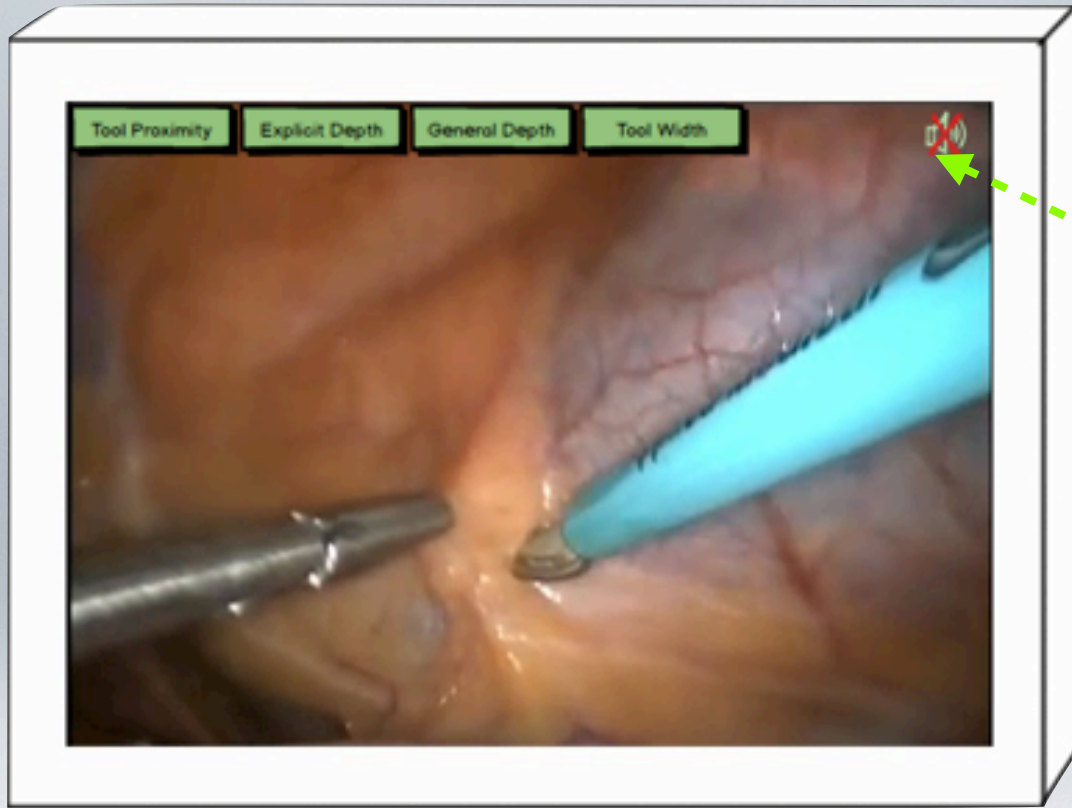


Having the visual augmentation buttons present as well as the audio feedback button means audio feedback can be combined with the visual feedback.

A toggle button which uses the universal symbol for sound would be used to turn audio feedback on and off.

# Turn Audio Feedback On





When the audio feedback is turned off a red cross would appear over the sound icon to indicate this.

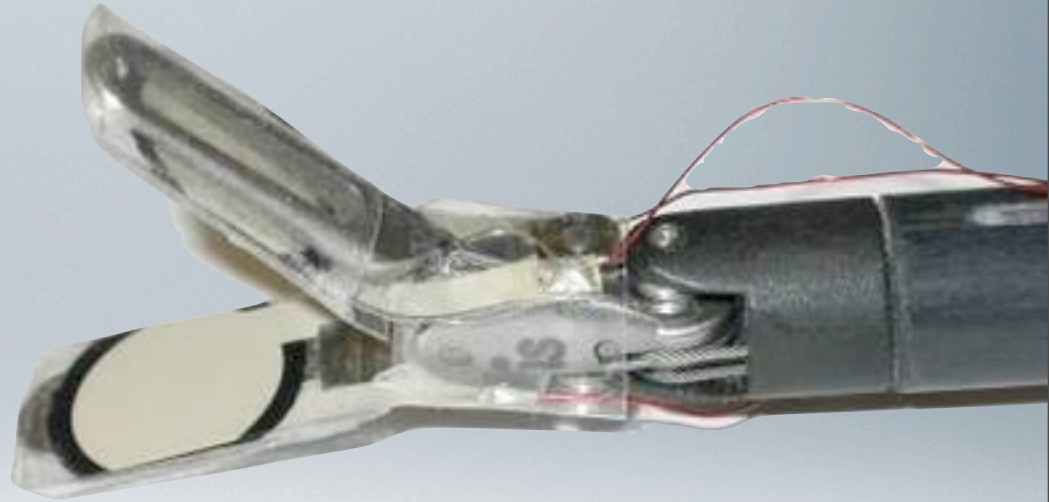
# Turn Audio Feedback Off

# Haptic Feedback

This method is slightly more advanced than the others, and would be a later goal of the project.

When the surgeon is using tools in MIS, they lack haptic feedback. This can lead to too much force being applied to a tool and damage being done to the patient.

By using a camera that can tell how close tools are to the patient, a method of providing haptic feedback could be derived for when the tools touch the patient.



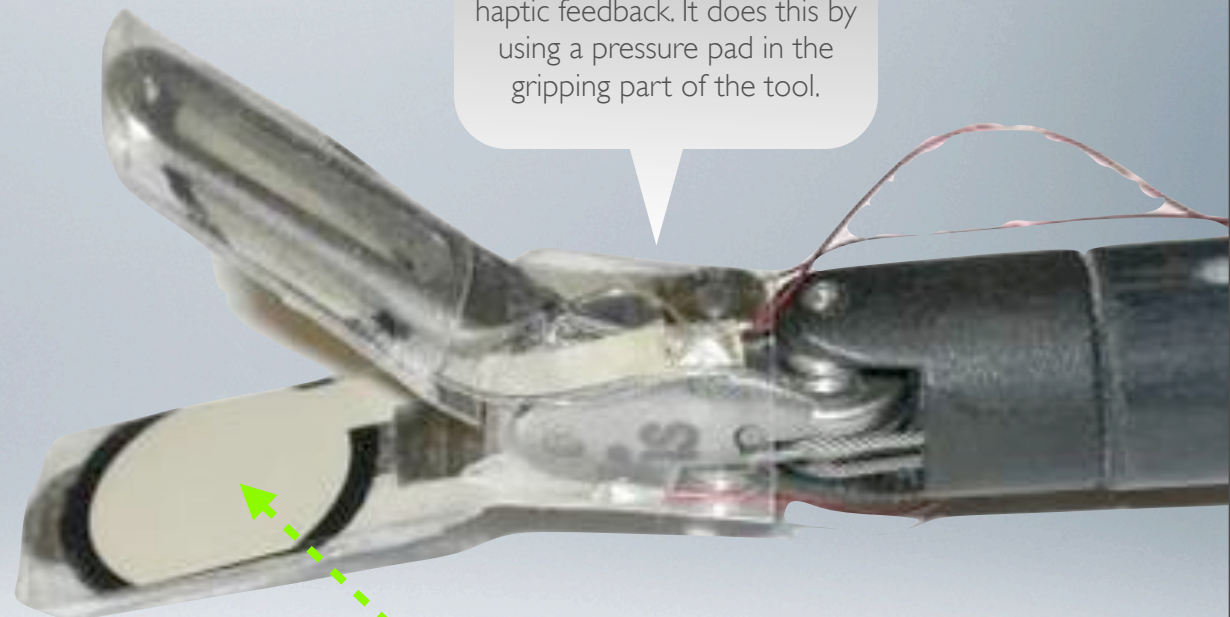
# Case Study: Experimental Surgical Tool

This depth sensing camera would not be able to tell how much force is being applied in the functional part of the tool. A pressure pad is needed to do this.

However what a depth sensing camera could do is register when a tool is touching the patient. It may not be able to tell how much force is being applied, but it could provide feedback to the surgeon in a tactile form to let them know the tool is touching the flesh.

This surgical tool can provide haptic feedback. It does this by using a pressure pad in the gripping part of the tool.

Pressure pad



# The Advantage of Haptic Feedback

Haptic feedback has several advantages over visual or audio feedback. If the surgeon feels the tool they are using vibrate or stiffen, then their natural response is likely to be to move slowly and apply less pressure to the tool.

This contrasts with a visual or audio feed, where the surgeon may know they are touching the patient but as the tool physically does not feel any different, they may not change the force being applied.

In short, haptic feedback is:

- Safer for the patient because the surgeon will actively decrease pressure applied to a tool when they feel it vibrate or stiffen.
- Less distracting, as the surgeon can focus on the camera feed and if they touch any part of the body with the tool by mistake, the vibration will let them know.
- More interactive. Haptic feedback would make MIS feel more like real surgery as there is some feedback of force through the tools as there would be if the surgeon were using their hands.



Gaming controls give haptic feedback to gamers. They do this through vibration. A motor spins an axle with an off-centered weight attached, causing the vibrations.



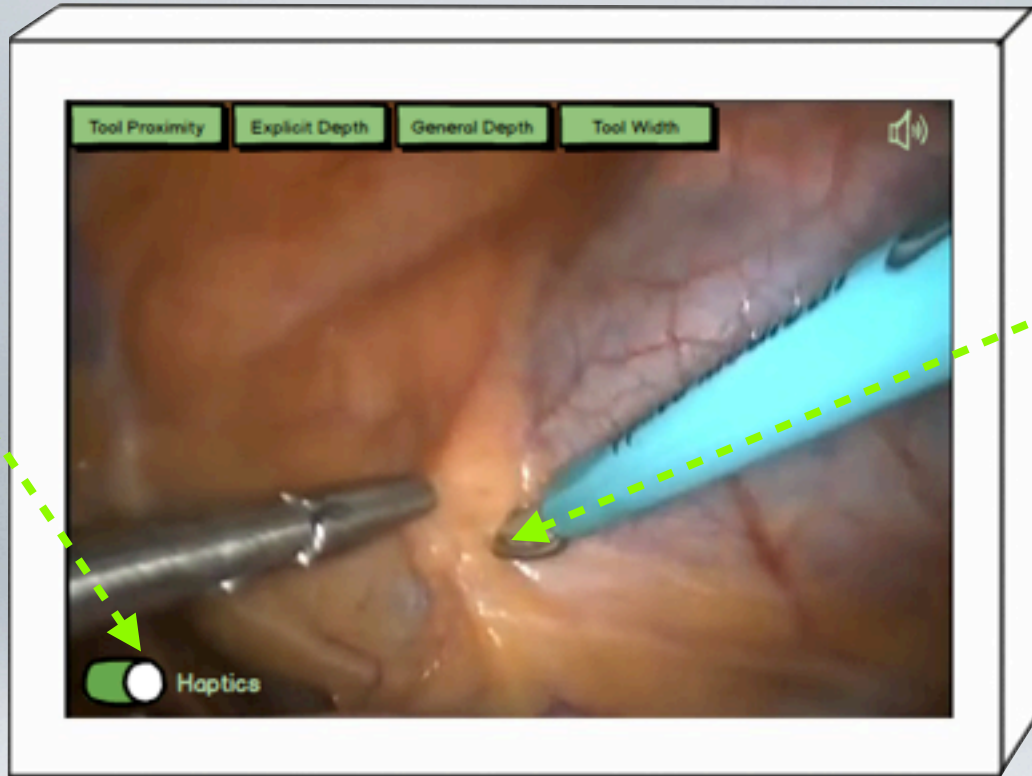
The haptic feedback mechanism is incredibly simple, yet can be used to simulate a huge variety of events from explosions in the game, accelerating a car or shooting a gun.

It is amazing that such a simple mechanism can improve user experience so much. This could be adapted to be a very useful tool for a surgeon.

# Case Study: Gaming Controls

There are two parts to this design: how haptics would be turned on and how the feedback itself would be delivered to the surgeon.

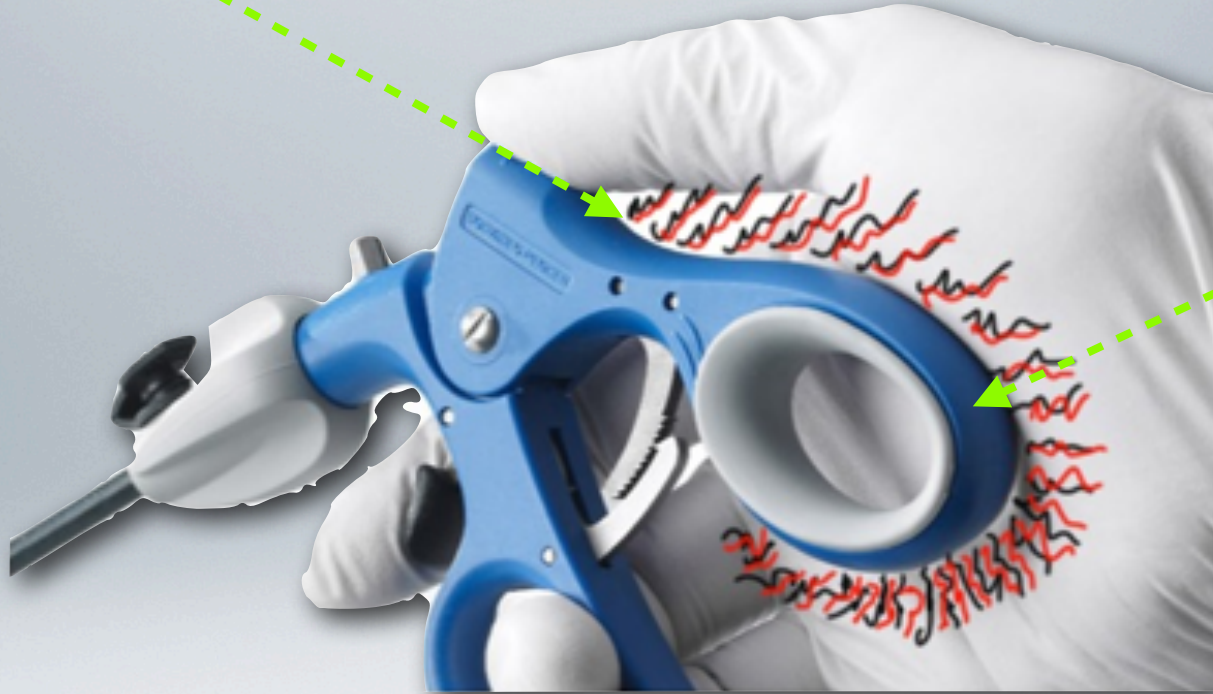
This On / Off button would allow the surgeon to tell the system whether haptics should be enabled. This means that should the feedback become annoying, it is easy to turn off.



Feedback would be given when the camera notices that a tool is coming very close to or touching the patient's flesh.

# Haptic Feedback Design

The haptic feedback would be a vibration rather than a stiffening of the tool in this case. This is because a stiffening of the tool is more suited to use of pressure pads in the tool's functional part. This project is more concerned with the non-functional parts of the tool touching the body when they shouldn't be; hence a vibration seems the best course of action.



When the camera notices that the tool has touched something inside the body, this part of the tool control would vibrate to notify the surgeon.

# Haptic Feedback Design

# Disadvantage of Vibration as Feedback

If the tool is to vibrate when the surgeon touches a part of the body that they shouldn't with the tool, then this could potentially be extremely dangerous to the patient as the tool itself would vibrate and possibly damage the patient. This whole project is concerned with promoting a patient's safety, so this issue must be solved.

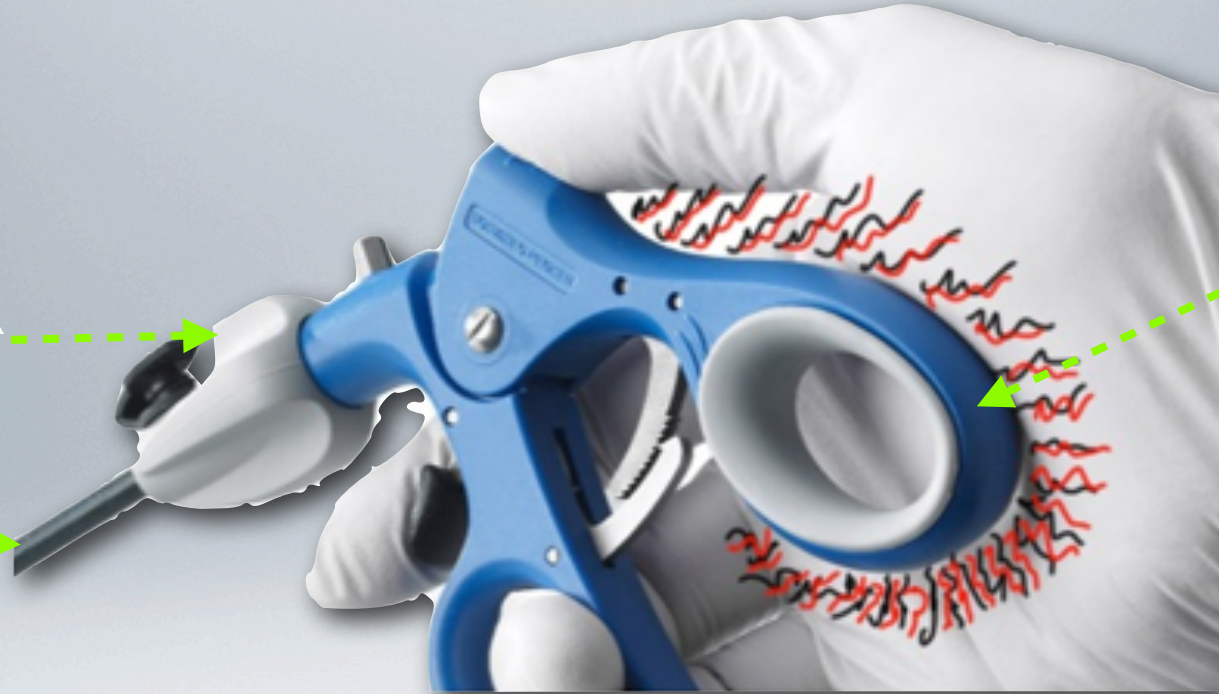
There are three apparent solutions to this problem:

- Have the vibration of the tool so faint that it would not upset the movement of the tool in anyway. For example, when the keyboard is pressed on an Android phone the phone vibrates very slightly to show this. The tool could vibrate in a similar way. However as surgery is extremely precise even the smallest vibration could upset it.
- Include a damper in the tool that would absorb the vibrations so that the part of the tool actually in the patient would not vibrate - just the handle of it.
- Re-design the haptic feedback system.



A damper could be included here in the tool which would absorb any vibrations before they can interfere with the part of the tool actually inserted in the body.

Part of tool that enters body.

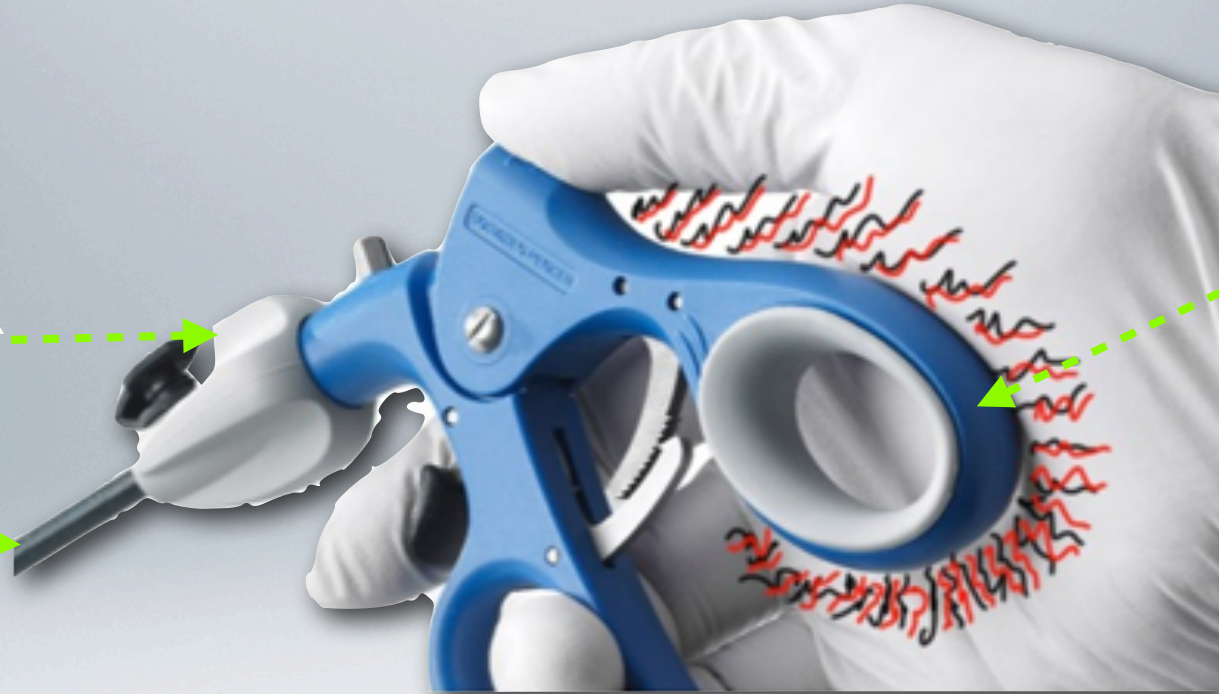


These vibrations would be as faint as possible so that they are easily absorbed by the damper.

# Haptic Feedback Vibration Solution One

A damper could be included here in the tool which would absorb any vibrations before they can interfere with the part of the tool actually inserted in the body.

Part of tool that enters body.



These vibrations would be as faint as possible so that they are easily absorbed by the damper.

# Haptic Feedback Vibration Solution One

How would a surgeon interact with this system?

# Option One: Button on Endoscope

The image on the right shows the controls for a surgical endoscope. An additional button could be added to allow the surgeon to select and then toggle augmentations, audio and haptic feedback.

Advantages:

- Easy to control
- Surgeon has direct control over feed.

Disadvantages:

- Requires complete re-design of endoscope system to add a new button or buttons.
- Surgeon must take hands away from tools currently inside the patient to control the endoscope feed.



# Option Two: Control on Endoscope Software

The image on the right shows an endoscope unit. As can be seen, there is a normal PC toward the right of the photograph which runs the endoscope software. To control the augmentation, the surgeon could tell an assistant who is controlling the endoscope software on this PC what settings to apply to the endoscope feed.

Advantages:

- Easy to do, cheap to implement. Just needs a modification to the endoscope software.

Disadvantages:

- Surgeon does not have direct control over the augmentations.



# Option Three: Voice Command



The Kinect 2.0 has a high-quality microphone capable of recognising voice commands. A similar microphone could be used in the operating theater, and the surgeon could simply say which feedback types are desired and the feed would change accordingly.

## Advantages:

- Surgeon has direct control of system.
- Does not require redesigning of endoscope system, could just add microphone and necessary software.
- Completely hands-free control - surgeon does not have to stop operating procedure to press a button and change the feed.

## Disadvantages:

- If voice commands fail, there needs to be a secondary method of control.

# Proposal for Control

In light of the advantages and disadvantages associated with each option for control of the system, the proposed method of control is a combination voice command and direct control by computer.

This means that should the microphone fail for any reason, the surgeon can instead ask an assistant to alter the feed, providing the necessary backup option to make voice control viable.



Audio feedback also provided here.



Headset vibrates to provide haptic feedback.

Contains microphone to receive voice commands for the system.

This would contain the microphone for voice control, provide audio feedback and could also vibrate to provide haptic feedback.

All of the ideas for the control, haptic and audio feedback of the system could be combined into one simple tool with a headset

# Haptic Feedback Vibration Solution Two



# Evaluation

As this system is designed for use by experts (surgeons) and not by the public, heuristic evaluation was performed on these prototypes in place of a lab study with participants.

These lo-fi prototype designs aimed to test the most important part of the design, which is the actual feed that the surgeon watches as surgery is performed. It is important that the various depth tools implemented do not obstruct the surgeon's field of view, but rather enhance it.

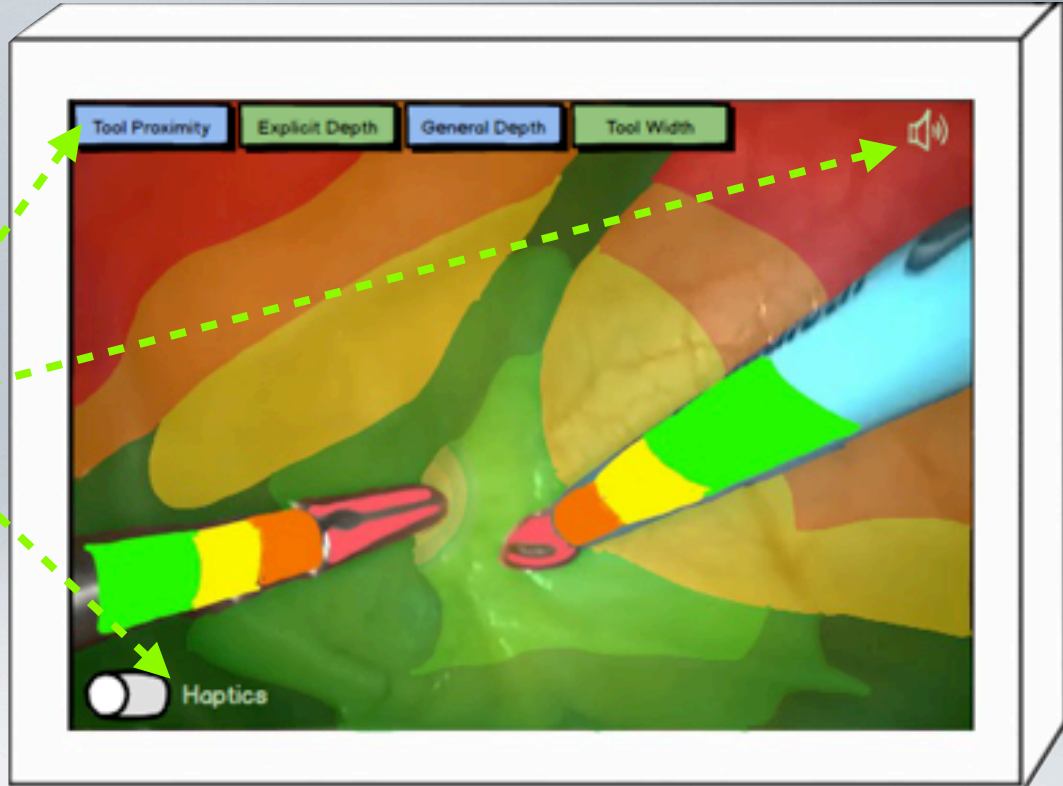
This prototype is in the form of a series of augmented reality images of a laparoscopic operation, showing what the final UI may look like.

# Evaluation

## Visibility of System Status

The four toggle buttons at the top left of the user interface clearly show which augmentations are currently selected. In addition, the buttons for turning audio feedback and haptics on are clear, and their state is clear. The haptic button follows a conventional switch style to indicate whether it is activated. In addition, the audio button has a red cross over it when it is not active.

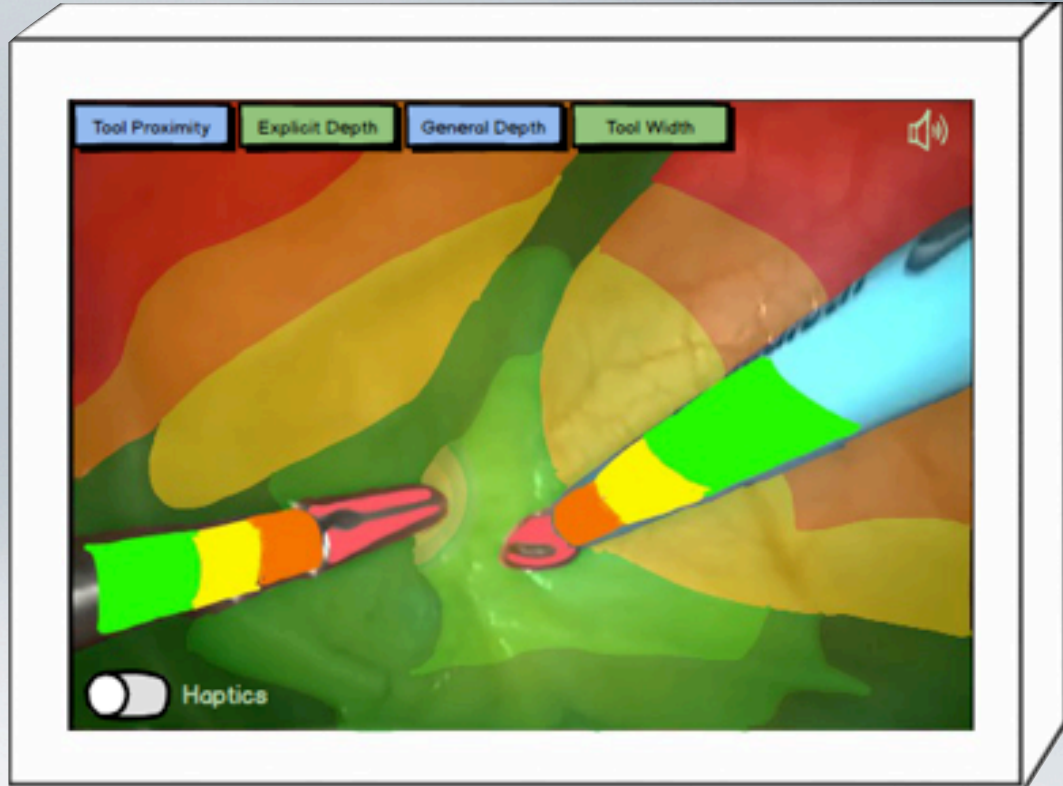
One thing not included is some indication of whether the system is listening for voice commands. A small icon to show this could be useful.



# Evaluation

## Match Between System and Real World

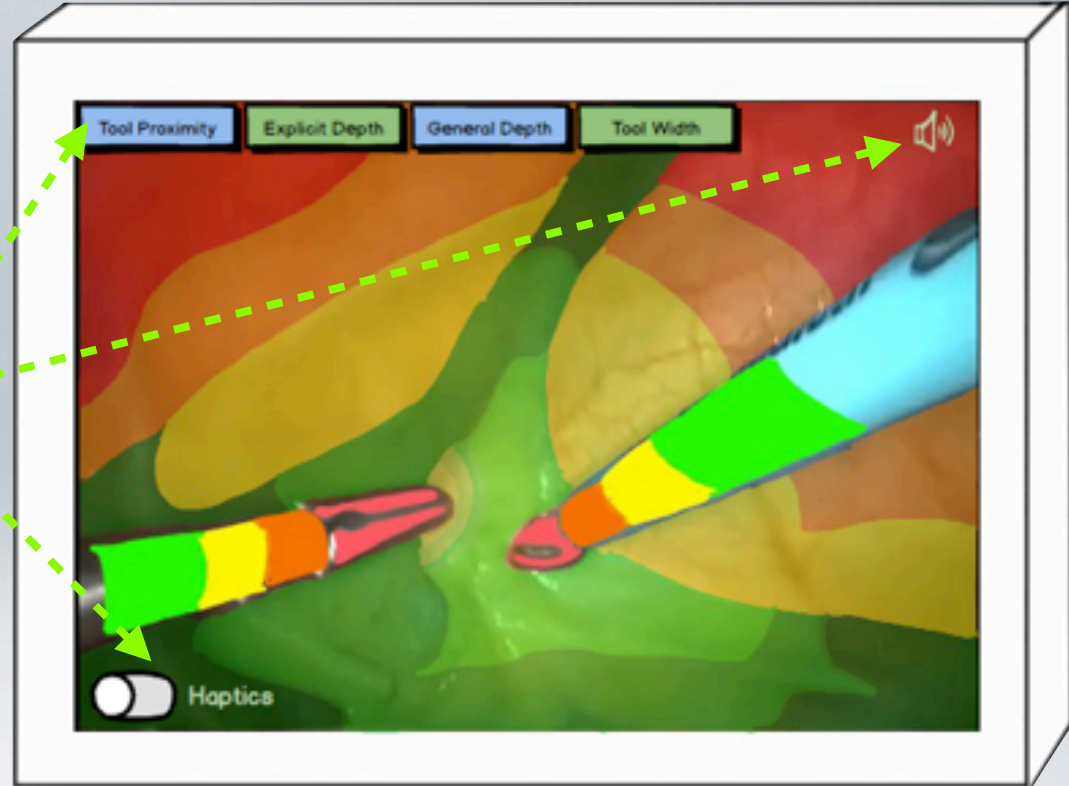
In real life, the images on the screen would be constantly moving, so the augmentation would need to be continually adapting to the changing picture. This could be a disadvantage as it may be computationally expensive to do this, which runs a risk of slowing down the entire feed. The audio and haptic feedback on the other hand should not slow computation significantly enough to be noticed.



# Evaluation

## User Control and Freedom

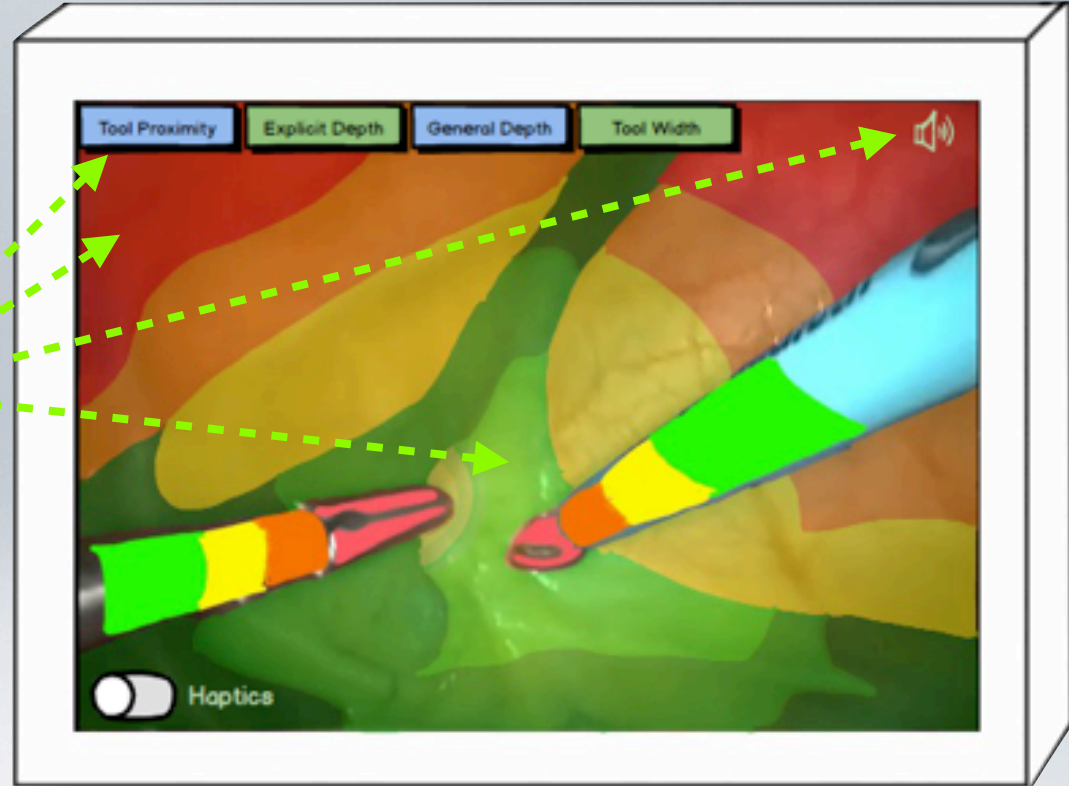
Restrains are not imposed on the number of toggle buttons that can be toggled at once, giving the user maximum freedom. Voice control means the system can be used while the hands are occupied which is essential for surgeons.



# Evaluation

## Consistency and Standards

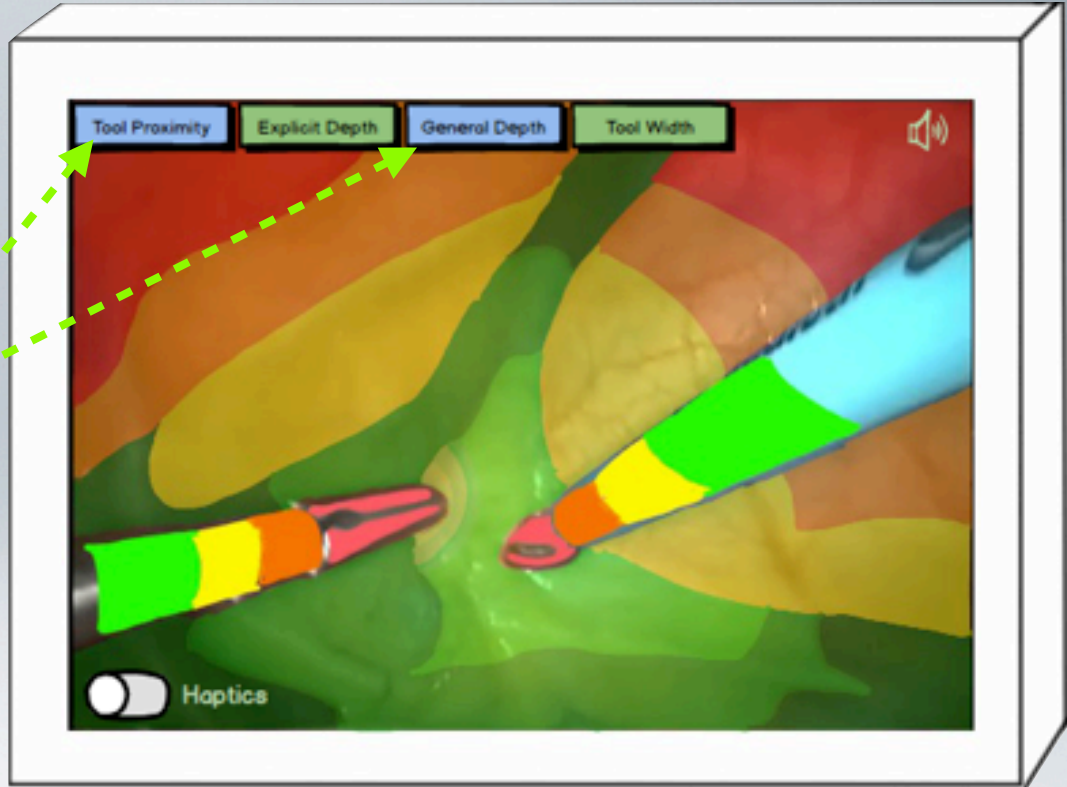
All buttons remain in the same position at all times. In addition, a conventional colour scheme is used for representation of depth - that is red to indicate that things are close and hence potentially at risk - green to indicate that things are further away. In addition, audio feedback is given as a series of beeps that increase in frequency as tools get closer to the body. This is consistent with a car park sensor which does the same.



# Evaluation

## Error Prevention

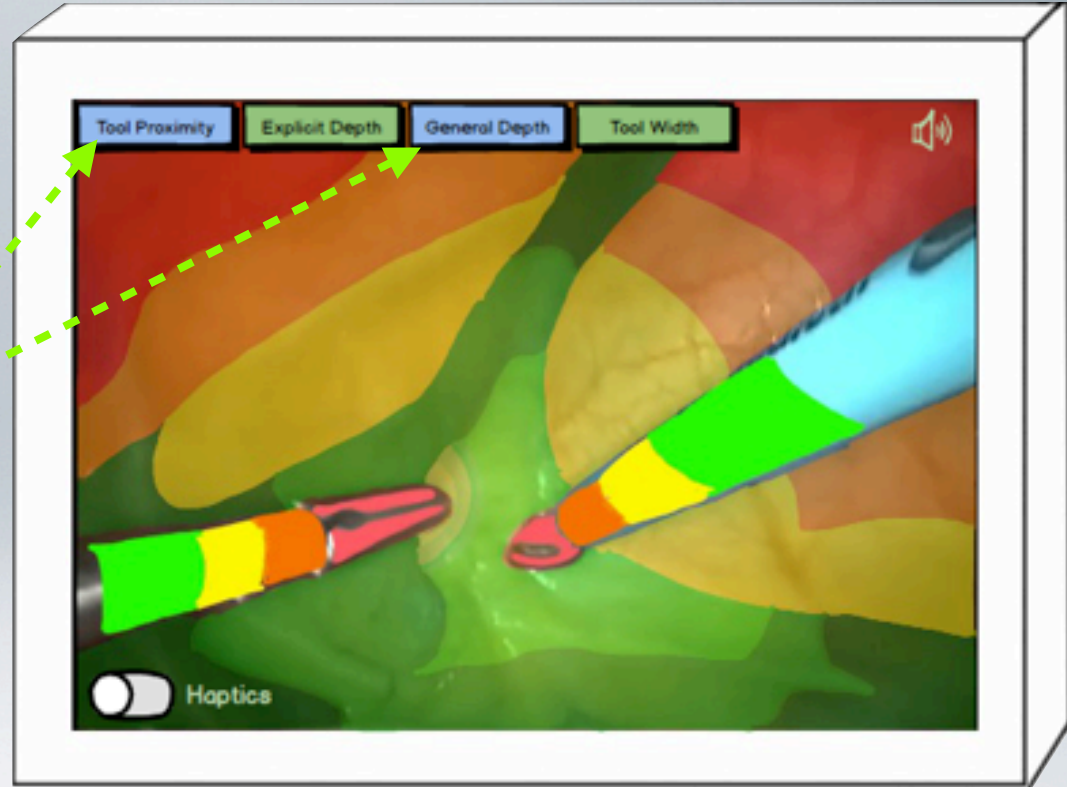
It may be necessary to include some sort of tutorial, so that the user can be informed of what “Tool Proximity” and “General Depth” mean and how the haptic and audio system works. The meaning of some of these buttons is potentially unclear, and misinterpreting the feedback’s meanings could present a risk for the patient.



# Evaluation

## Recognition Rather Than Recall

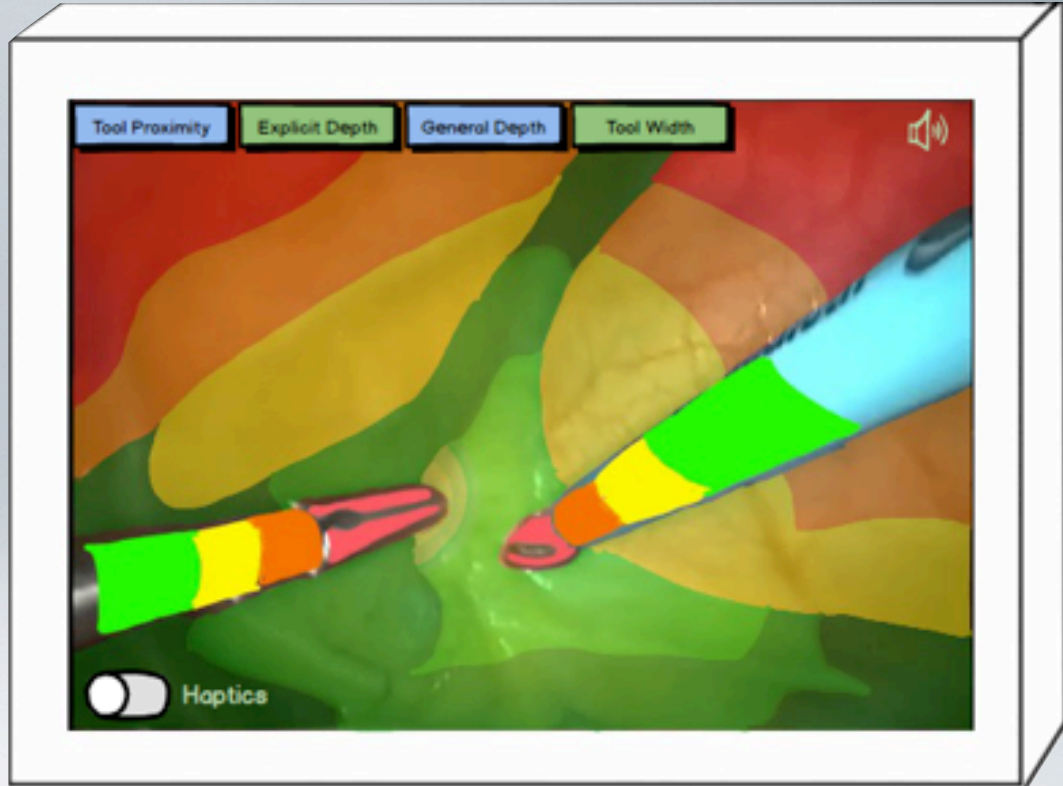
The conventional colour scheme is easy to recognise and its meaning clear. The user is not required to recall the meanings of the colours as they follow a convention - red meaning 'Risk' and green 'Safe'. In addition, they will recognise the more frequent beeping of the audio system as similar to that of parking sensors, with more frequent beeps meaning the object is closer. Finally, the user will recognise that vibration of the tool with haptic feedback means they need to be careful.



# Evaluation

## Flexibility and Efficiency of Use

The depth feedback is flexible as it can be used with any sort of endoscopy. The prototypes shown here are efficient to use due to the small number of available controls, which are clearly marked.

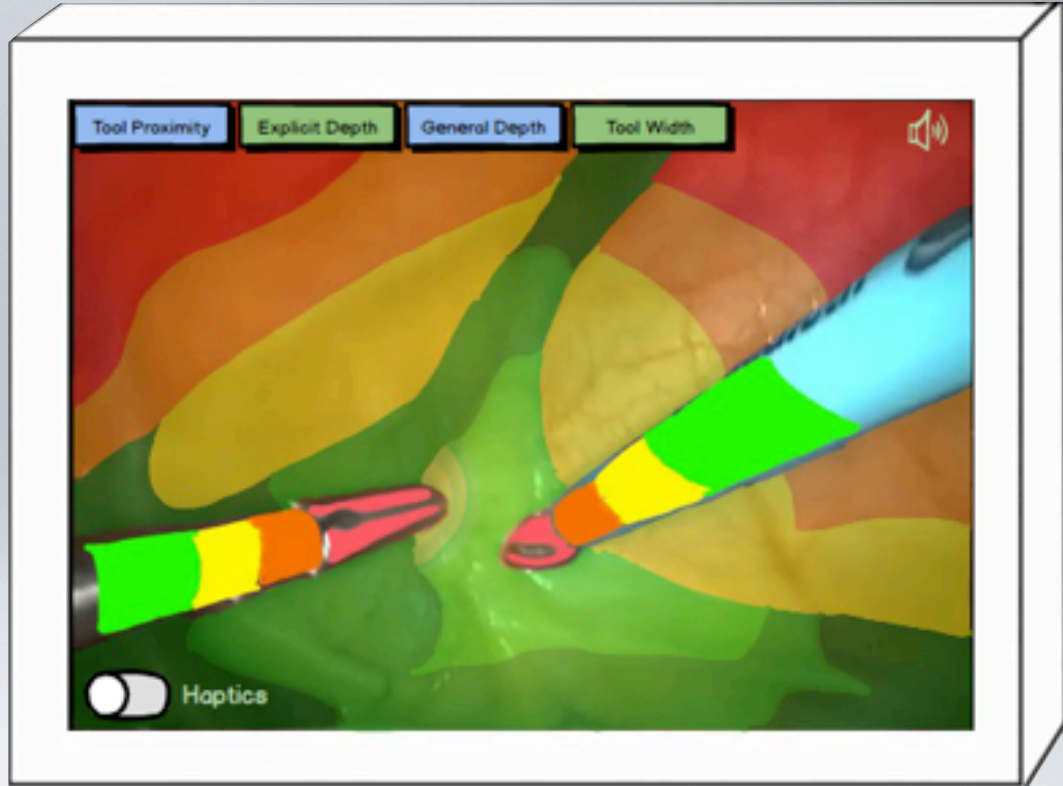




# Evaluation

## Aesthetic and Minimalist Design

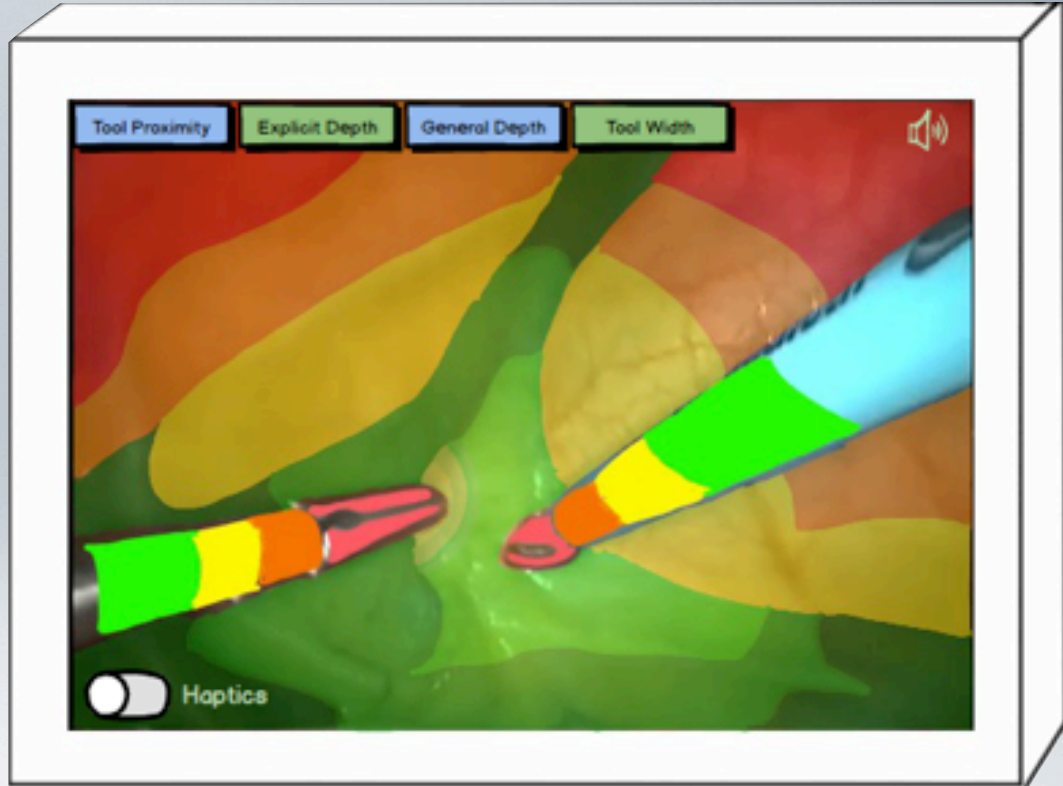
There are only a small number of buttons on the main UI at any time, so there is no clutter to obscure the surgeon's view. The buttons are also small to prevent visual overload. There is no way of hiding these buttons or moving them to a different part of the screen. Even though they are small, they may still obscure a surgeon's view, so a way to hide them should be included.



# Evaluation

## Help Users Recognise, Diagnose and Recover From Errors

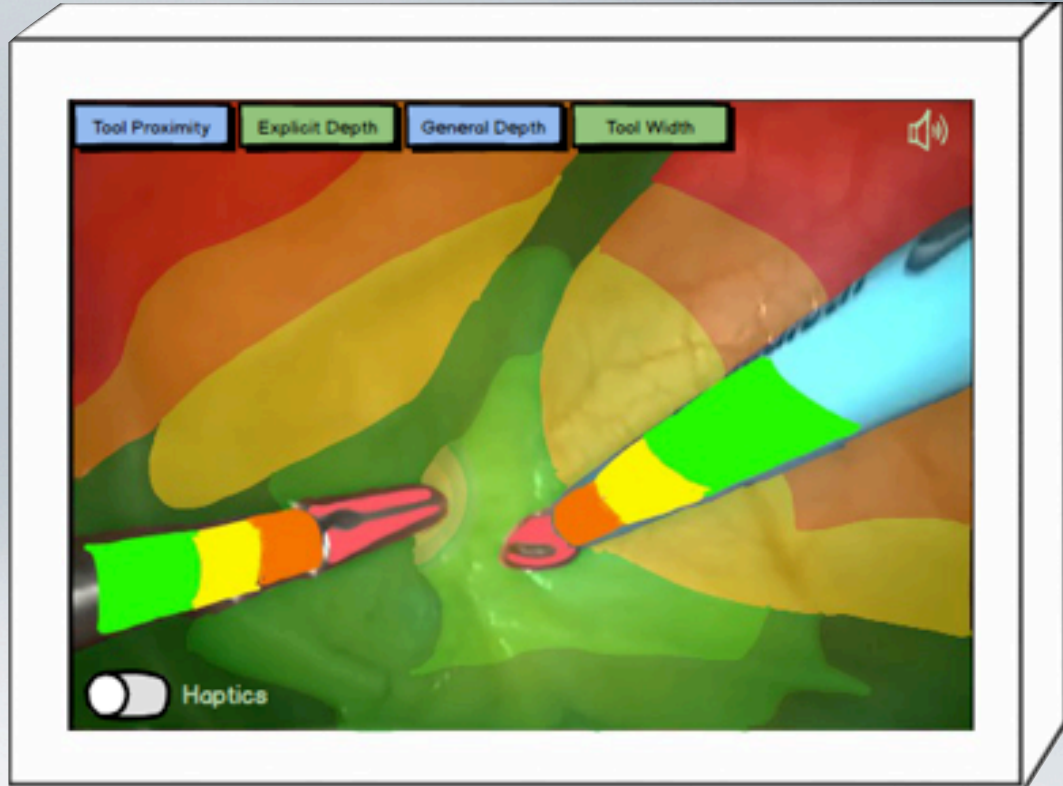
Errors would most likely occur with the control system, such as with the microphone if the system does not understand a voice command. If this happens, there would be a backup control system on the endoscope console so the surgeon can ask an assistant to control the feed. However the voice recognition software should be of sufficient quality that most voice commands in any accent can be understood.



# Evaluation

## Help and Documentation

No buttons exist on the main UI to help or instruct users. A suggestion is to have a short tutorial when the program is run for the first time, or perhaps include a help button on the main screen that could explain how the camera feed augmentation and audio and haptic feedback works.



# Evaluation - Positive Findings

The positive features gleaned from the evaluation are:

- The colour scheme. This colour scheme that follows conventional colours (red for risk, green for safe) makes it extremely easy for the user to understand what is going on.
- The use of a simple four button system to change augmentation of feed. This provides minimum cluttering of the screen while still providing decent functionality.
- Use of voice to control the system. This allows the surgeon total control over the system, even while their hands are busy as no physical button need be pushed.
- Audio feedback system. This follows the convention of more frequent beeps meaning that a tool is closer to the body. This also makes it easy for a user to understand what is going on.
- All different feedback options can be easily turned on and off and the way in which this is done is obvious.

# Evaluation - Issue One

It is important to inform the user what all of the different augmentations do, so that they do not get confused by the colour scheme and accidentally damage the patient.

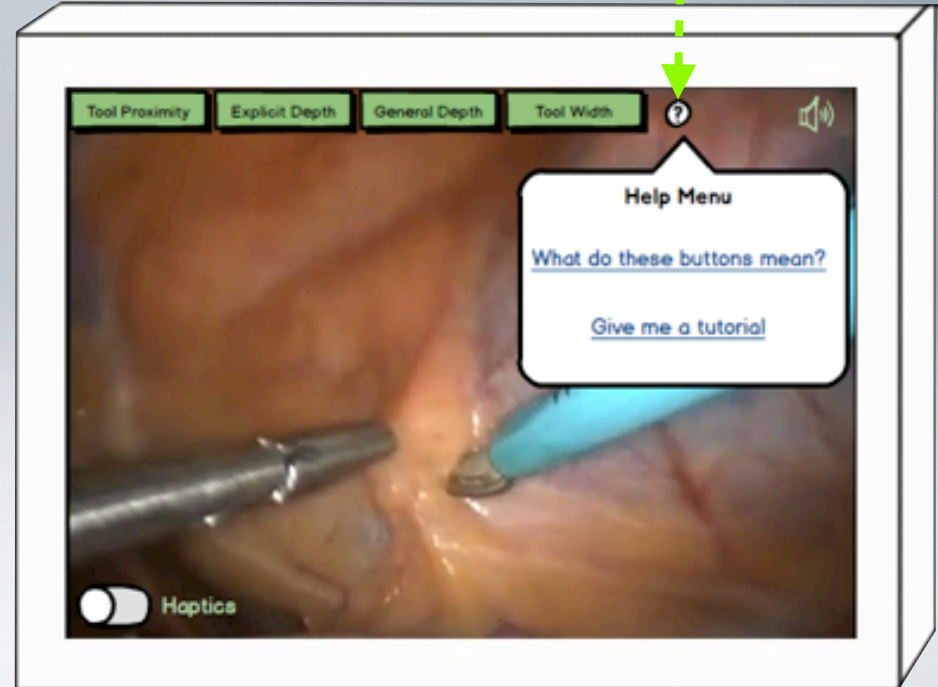
Although the colour scheme follows a convention, the user must be left in no doubt as to what each colour means.

In addition, there is no readily available help section.

## Suggested Solution

Have a small help button present on the screen so that the user can quickly find information on the system if they are unsure.

Help button could be a solution. On command a popover appears with links to help the user.



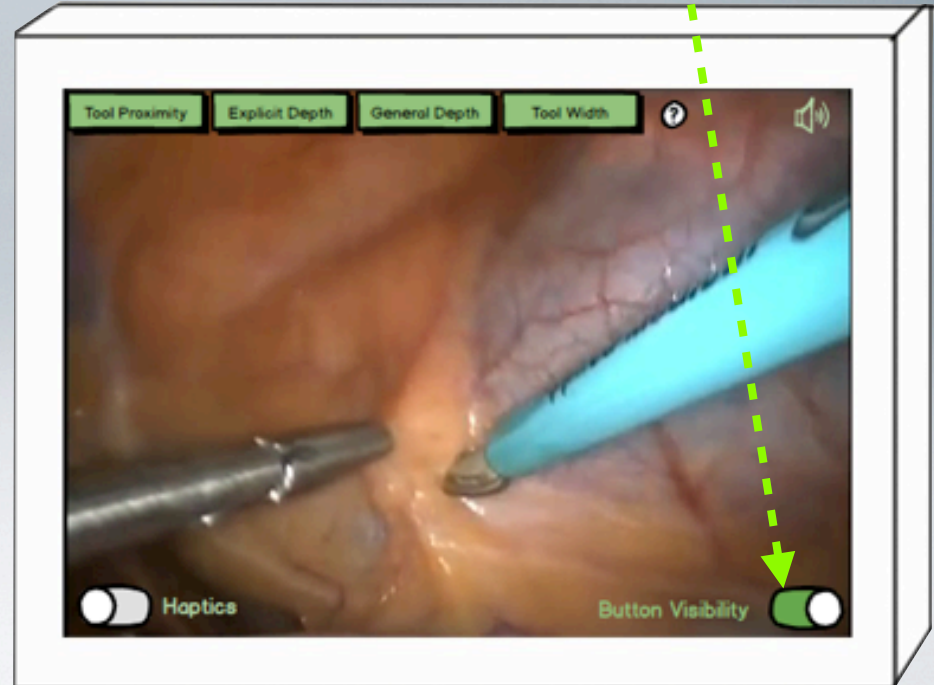
# Evaluation - Issue Two

The four toggle buttons at the top of the screen, despite being small, may annoy the surgeon by obscuring view. It is necessary to have a way of hiding these buttons

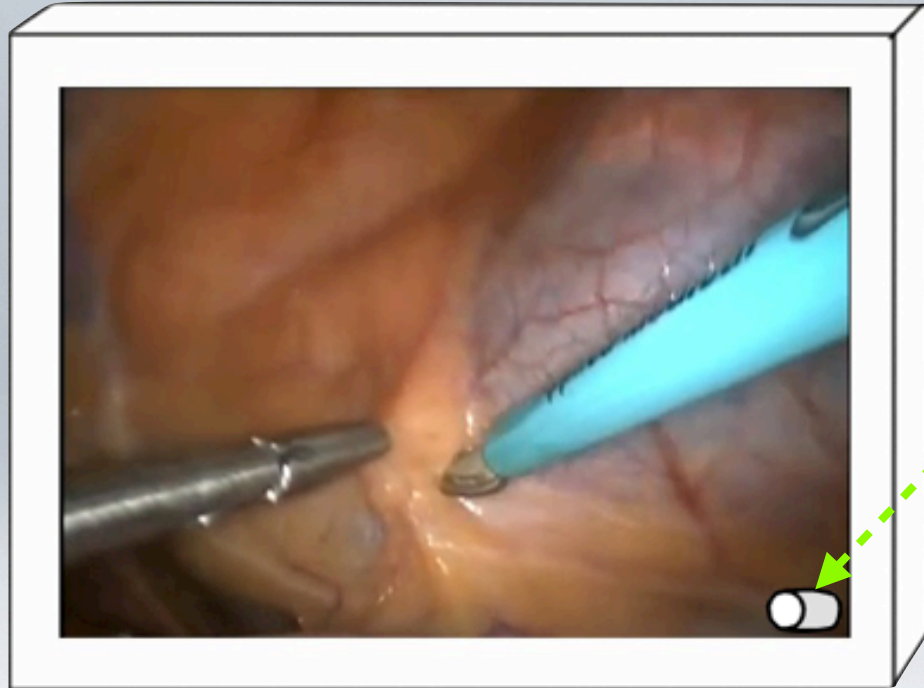
## Suggested Solution

Have an on / off button for button visibility. The surgeon, to hide buttons, would simply speak the command "Hide Buttons" and the screen would clear. All of the functionality behind the buttons would still be available when they are not shown. If the surgeon were to change augmentation while buttons are hidden, then the four buttons would appear briefly to show which feeds are selected before fading out again.

This On / Off button is used to control whether buttons are visible. The surgeon speaks the command "Hide Buttons" to change this switch.

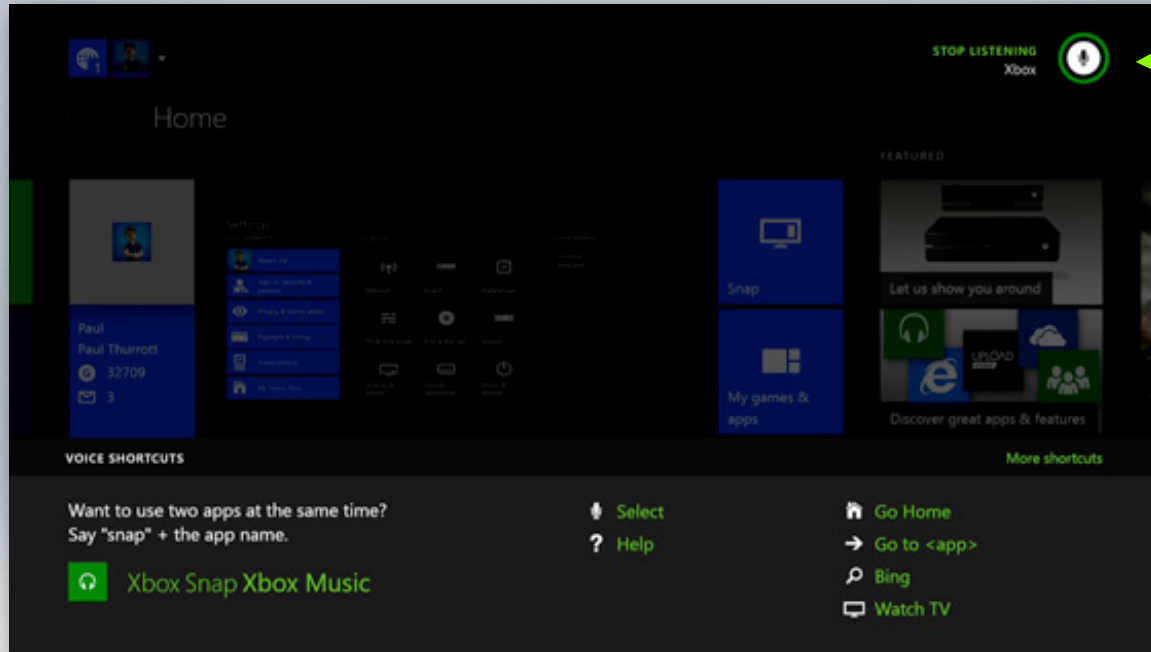


# Evaluation - Issue Two Continued



Once button visibility is turned off, this button changes to the "Off" state. It will remain on screen for 5 seconds before fading out to leave just the camera image.

# Evaluation - Issue Three



Shows that the Xbox is listening for voice commands.

There is no icon that indicates whether the system is listening for voice commands. For example, with Xbox One there is an icon indicating whether the Xbox is listening for voice commands, as shown on above.



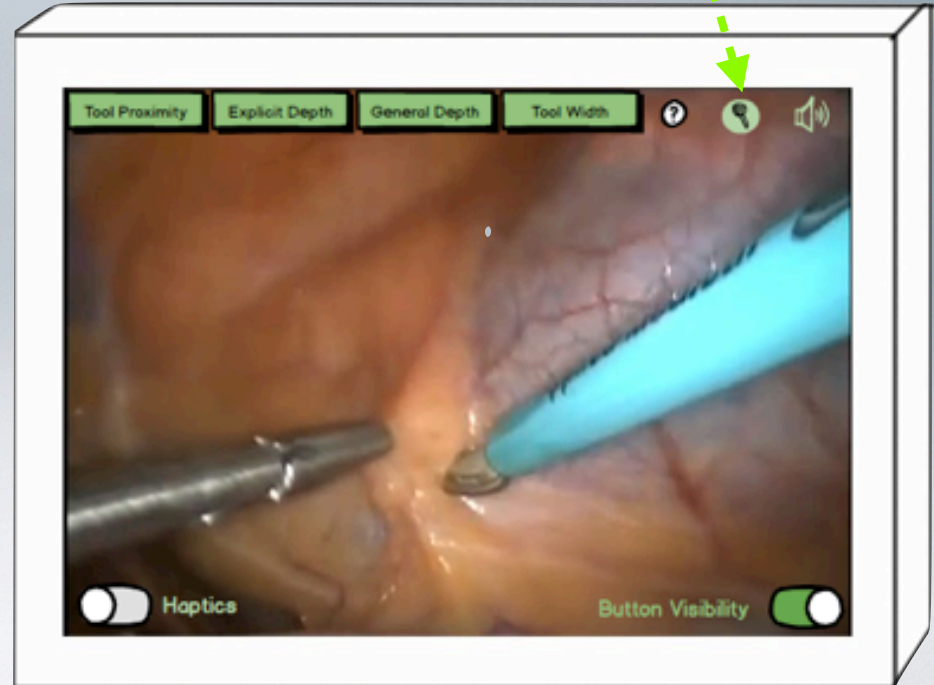
# Evaluation - Issue Three Continued

## Suggested Solution

Have a small icon in the top right corner of the screen that only appears when the system is listening for voice commands, as with the Xbox. Once the user tells the system to stop listening, this icon disappears.

The system would start listening as soon a command is said along with the system name. For example the Xbox will not listen for commands unless one says "Xbox ..." first. This system would act accordingly. Once the microphone has appeared the user would not need to call the system by name to use voice commands, they could simply say the command.

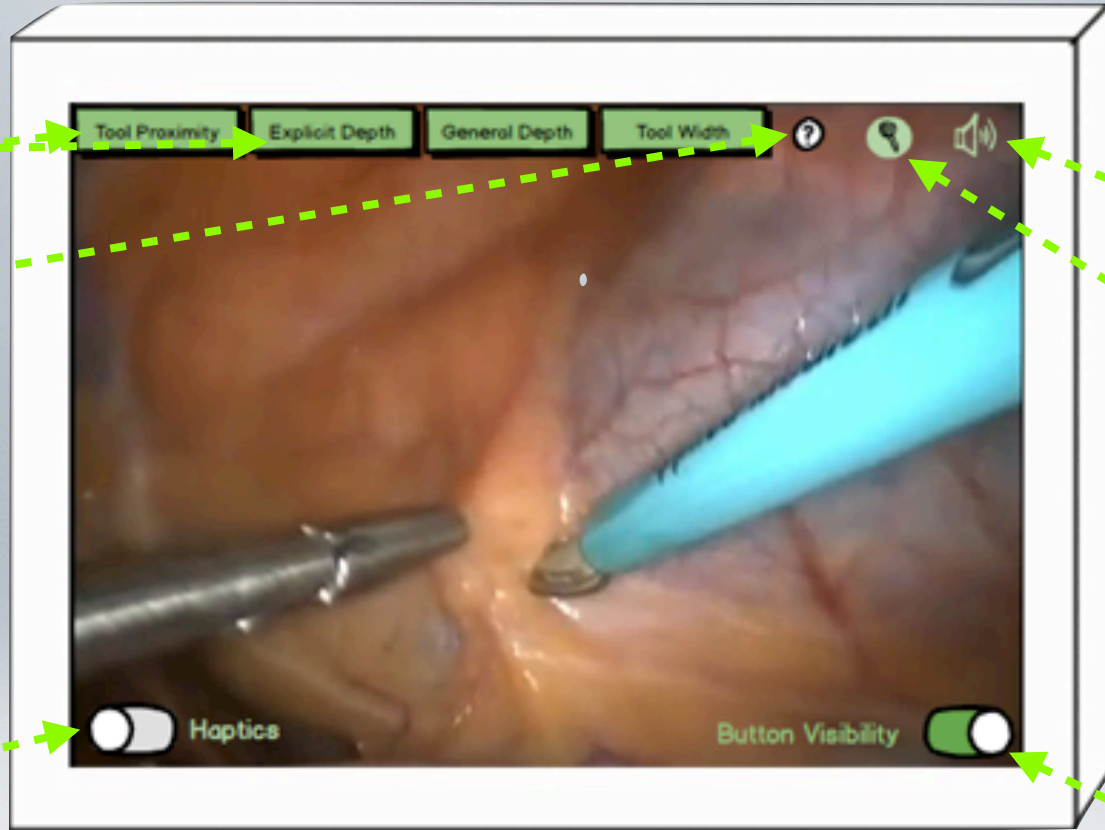
This icon would only appear when the system is listening for voice commands.



Options for augmenting visual feed.

Help button to explain button meanings.

Virtual switch to turn haptic feedback on.



Button to turn audio feedback on and off.

Microphone icon indicates system is listening for voice commands.

Virtual to switch to turn button visibility on and off. Microphone icon would still be visible if system is listening for commands.

# Final User Interface Design

System would be controlled by voice command. There would be a back up secondary control on the endoscope terminal.

This headset would be the control unit for the system. It is wireless and could be worn by a surgeon while performing surgery

The headset would provide audio feedback to the surgeon



The headset would also provide haptic feedback by vibration when this feature is enabled

Voice commands would be received by a microphone in the headset.

# Final User Interface Design



Should it be too complex to design a haptic feedback headset, the Kinect 2.0 sensor will be used to receive voice commands

# Final User Interface Design

# Future Development

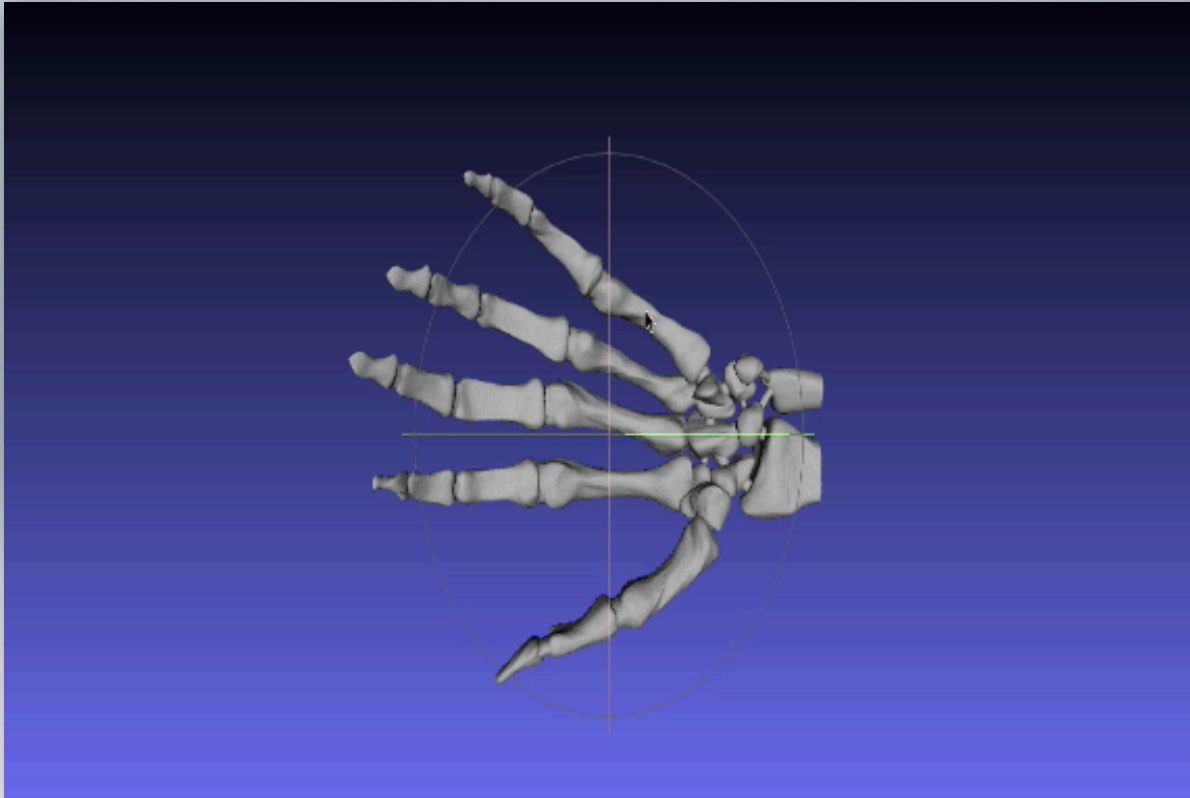
Should this project reach the stage where this UI is fully designed and implemented and a small endoscopic prototype has been designed, then the team may develop the technology further in several ways. One of these ways is to look at providing haptic feedback for robotic surgery. Another, slightly less complex way is implementing a 3D feed.

The Kinect 2.0 is able to produce full 3D images that can be rotated and viewed from different angles, with the Kinect remaining in the same place. The team may look at incorporating this into endoscopic technology.

# 3D Camera Feed

The Kinect is capable of producing similar images to this. While in the context of surgery it would not be showing bone structure like this, this picture is a good example.

The advantage of this is that the surgeon could rotate the endoscope feed to see the tool in the body from any angle, to see exactly how close it is to the flesh at any point or where exactly it is touching.

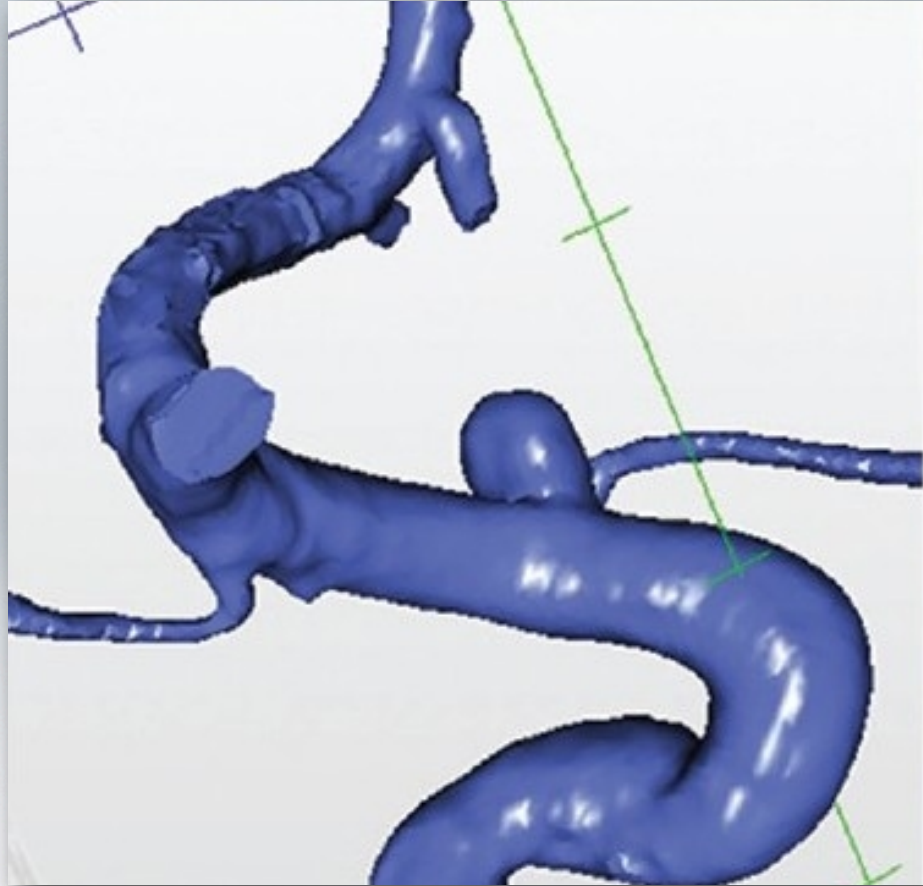


Example 3D feed created using MeshLab

The surgeon would be able to rotate the camera image to see it from many different angles.

# 3D Camera Feed

Another example of a 3D image that could be created.



This image is an example of what a blood vessel may look like when using this 3D view, allowing the surgeon to see it from many angles.

# Conclusion

This user interface is designed for surgeons performing laparoscopic surgery using endoscopes. Having this interface would allow the surgeon to gain a depth perspective while using the endoscope, something which endoscopes are not currently able to provide. This design would provide several different visual augmentations of the standard camera feed, as well as audio feedback of tool proximity to the body and potential haptic feedback in the form of a light vibration in the tool - light enough so as not to disrupt the surgery taking place and damaging the patient.

The system would have two options for control: the primary being use of voice command. This allows the surgeon to control the feedback mechanism even when both hands are busy with surgery. Voice command technology is rapidly advancing and new technologies as used in the Kinect 2.0 are extremely good at listening to and recognising commands.

The second control option is a backup encase voice commands fail for any reason. This option is direct control of the system from the endoscope terminal, which would have to be done by a surgical assistant who the surgeon gives requests to.



# Conclusion Continued

On the UI would be the buttons to augment the feed, turn audio and haptic feedback on as well as a help button for guiding the user through the meanings of the buttons if they are unsure of them. In addition is a button that can be used to make all buttons invisible so that they do not clutter the surgeon's field of view.

This design has been evaluated by heuristic evaluation and accordingly altered to rectify any negative features that were found here.

Finally, should there be sufficient time, the User Interface may extend to providing 3D imaging and / or providing a way for surgical robots to give their controllers haptic feedback.

# References

- Program used to create augmentation protoypes: Sketchbook Express.
- Program used to finalise UI designs: Balsamiq Mockups.
- Presentation created by Ed Collins (UCL) using Apple Keynote.
- Gaming controls photo: <http://pegasouno.keyvideo.info/files/000269/00026976.png>