

An introduction to

Virtual Reality - and its application to medicine

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MSc Virtual Reality: Slide 1

Contents

Introduction
Types of Virtual Reality
History of Virtual Reality
Application to Medicine

MSc Virtual Reality: Slide 2

What is Virtual Reality?

“Virtual reality is a way for humans to visualize, manipulate and interact with computers and extremely complex data.”

The technology attempts to immerse the user into a computer generated world.

The user interacts with the world and can directly manipulate objects in the world.

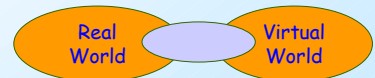
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Creating Presence

Virtual reality systems attempt to create “presence”.

Presence is the un-remarked sense of being in and reacting to the events in a place.

It is un-remarked because for most of our conscious lives we know exactly where we are (at least we think so)



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What is Immersion?

Immersion in an environment (real or virtual) is related to the quantity and quality of sensory data from that environment

Immersion in a virtual environment can be gauged by the extent to which the computer shuts out sensations from the real world and accommodates different sensory modalities (vision, audio, haptic)

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Applications of VR

Entertainment
Education
Medical Training and Support
Aviation (training)
Architectural Planning
Scientific Visualisation

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Introduction
Types of Virtual Reality
History of Virtual Reality
Application to Medicine

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Types of VR Systems

Window on World Systems
Video Mapping (1st Person shooters)
Head Tracking Systems
Immersive Systems
Telepresence
Mixed or Augmented Reality

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Window On World

"One must look at a display screen, as a window through which one beholds a virtual world".

Ivan Sutherland 1965

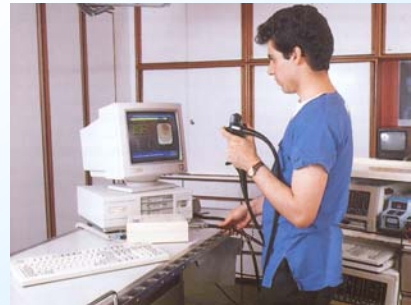
Conventional computer monitor
(possibly stereo with shutter glasses)
Realistic Sound
Special input devices



(In reality just simple computer graphics, but still appropriate for many medical applications)

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Window on the World - Colonoscopy Simulation



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Video Mapping

Refers to systems where the user controls a virtual actor in a virtual world.

Some systems show the user (or a silhouette) inside the world, but more commonly the view is of the virtual world through the actor's eyes.

Possible for medical visualisation and surgical simulation



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Systems with head tracking

Using simple stereo devices there is one correct position from which to view a scene. By tracking the user's head, and computing the stereo image pair accordingly a more accurate 3D image can be created.

When applied to limited space around a simple screen this is sometimes termed "Fish tank virtual reality"



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Hands in the fish Tank

Stereo displays can be constructed that allow the user to put his own hands into the fish tank, and possibly interact with the image through a haptic device.



They have been applied to simulating laparoscopic procedures.

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Haptic Devices

One of the main difficulties in applying these techniques in medicine is designing haptic devices that are realistic enough.

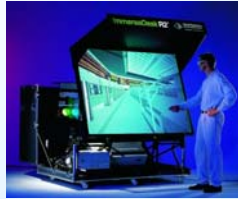
They are expensive and application specific.



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Immersa Desks

These devices use all the techniques discussed so far, but are scaled up.



Some have drafting capabilities, and are more suited to applications in architecture than in medicine.



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Immersive Systems - Head Mounted Displays:

Provide an immersive experience by blocking out the real world

Do not restrict user from moving around in the real world

Are relatively inexpensive and can achieve good stereo quality



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Immersive Systems - Head Mounted Displays

However, they have been rarely used for any serious purpose because of many drawbacks:

- Restricted field of view with no peripheral vision
- Unnaturally close image
- Isolation and fear of real world events
- Uncomfortable to wear

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Immersive Systems - Cave Installations

A room with projection on the walls floor and ceiling

Provides complete visual immersion

Driven by a single or group of powerful graphics engines



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Immersive Systems - Cave Installations

Provides high resolution and large field of view with light weight shutter glasses for stereo viewing.

Real and virtual objects can be mixed

A group of people can inhabit the space simultaneously



Medical applications could include simulating operating theatre dynamics, but this has not been tried.

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Immersive Systems - Cave Installations

Cave installations are unlikely to be used extensively in medical applications because of various drawbacks which are:

they are very expensive (approximately 1 million pounds)

they require a large amount of permanent physical space

the projector calibration must be maintained

real physical objects cannot be easily incorporated with the graphical objects

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Telepresence

Sensors and manipulators are remotely controlled by a human operator

Some spectacular success, such as the exploration of the Titanic.

Applications including fire fighter robots and unmanned military vehicles.

Proposed for endoscopic or robotic surgery, but not really required in practice



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Augmented Reality

Adding computer generated information to the real world.



Overlaying a real image with segmented scan data for surgery

Computer generated maps and data overlaid on transparent head mounted displays.

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Introduction

Types of Virtual Reality

History of Virtual Reality

Application to Medicine

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History of VR

Flight Simulators:



1910 Mechanical Simulators

1929 Concept for electronic simulators

1945 Point light source projection
(simulating runway lights)

1955 Video Based systems

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The Sensorama - Circa 1960



A Cinematographic Experience

3D Imagery
Contextual Smells
Stereo Sound
Vibration
Wind in the hair

Motorcycle ride through
Brooklyn

History of VR 1970's

First film special effects using computer graphics

First video arcade games - pong

Data Glove

Sandin and Sayre bend-sensing glove 1977

G.J. Grimes, patented a data entry glove 1983
(assigned to Bell Telephone Labs)

Polhemus Tracker (Raab et al 1979)



History of VR 1980's

See through Head Mounted Display
(Callahan (MIT) 1983)

Commercial head-mounted displays
(VPL Research and Autodesk 1989)

Term "Virtual Reality" coined
(Jaron Lanier VPL 1989)

SGI Reality Engine (1989)



History of VR 1990's

First Applications of Virtual Reality in
medical teaching:

Colonoscopy Simulation

Upper GI tract endoscopy simulation

Improved general purpose haptic
devices (Sensible)

First attempts at simulation of
laparoscopy



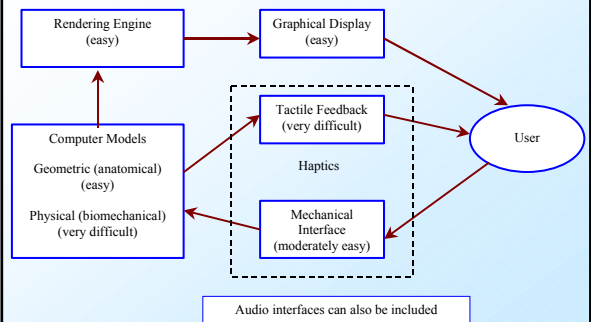
Introduction

Types of Virtual Reality

History of Virtual Reality

Application to Medicine

Architecture of a VR system



Virtual Reality in Medicine

Training

(Popular and feasible)

Assessment and Certification

(Gaining acceptance, feasible)

Telepresence (Interaction with remote environments)

(Popular but not very useful)

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Geometric Modelling

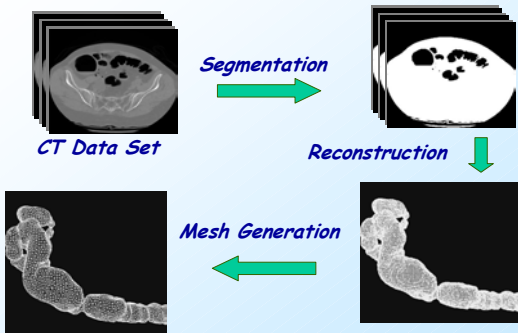
Geometric modelling can be used to reproduce anatomy:

Walk through the peritoneum, lungs colon etc

Geometric models can be derived from scan data

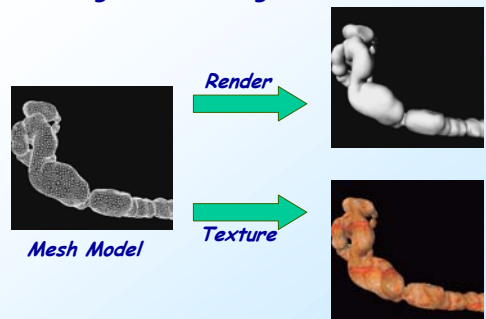
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Extracting Geometric Models



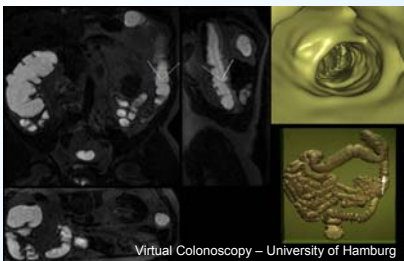
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Creating Walk throughs



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Walking Through



Virtual Colonoscopy – University of Hamburg

Problem - colour and texture are fake

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Limitation of Geometric Model

Triangulated models are easy to obtain, but are difficult to deform. (large number of triangles)

They are suitable for rigid structures (larynx, lung, trachea etc)

They are less suitable for deformable organs (colon, GIT, gall bladder etc.)



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Higher order models

Quadratic surfaces (spheres etc)

Cubic surfaces based on splines.

Geometric deformations are easy to achieve, but are anatomically less accurate

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Sphere model of the Colon

Easy to create effects such as spasm, inflation of the colon

Anatomy can be constrained to be representative of a real colon.



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Free Form Surfaces

Free form surfaces have shapes that are controlled by a small number of control points (or knots)

They can be easily adapted to a wide variety of shapes

However, they are harder to match to real anatomical data.

Trade off:

Ease of Computation vs Anatomical Accuracy

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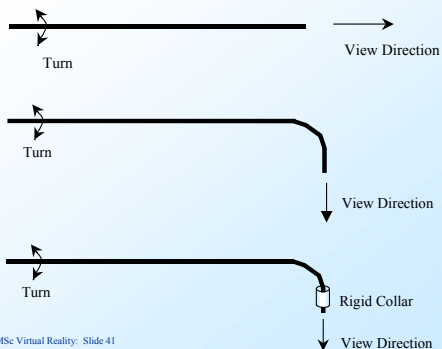
Problems in using the Geometry

Even given an accurate anatomical model there are still problems in building accurate simulations.

These are a result of the mechanical properties of the human body and the instruments being simulated.

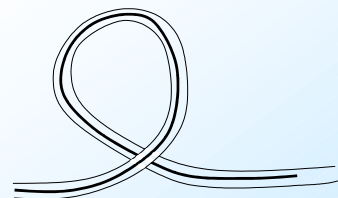
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Modelling Problem - Colonoscopy



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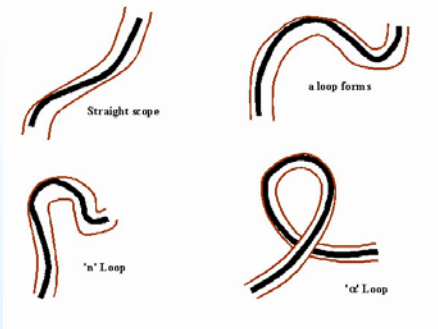
In a real colonoscopy we might find



If we twist does the loop tighten or the image rotate?

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There are many possibilities



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Biomechanical Modelling

One solution to the previous problem is biomechanical modelling - however this is fraught with problems. For example, in colonoscopy:

What happens when you push the colon wall?

What dynamic properties does the endoscope have?

What frictional forces are acting?

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Behavioural Models

For many endoscopic procedures we cannot see the deformation that is caused.

Thus simulators can get by modelling only the behaviour of the instrument.

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Can we simulate real deformations?

Answer - No

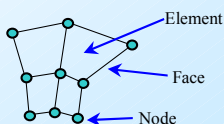
Certainly not in real time with any degree of accuracy

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Modelling deformations

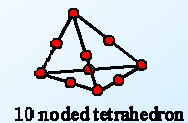
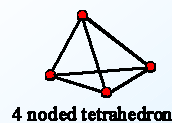
The most accurate modelling tool uses the finite element method.

In the finite element method a surface or volume is divided into small parts called elements.



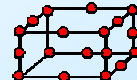
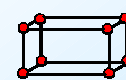
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Typical 3D Elements



4 noded tetrahedron

10 noded tetrahedron



8 noded brick

20 noded brick

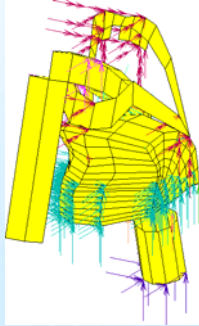
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Finite Element Study of Laryngoscopy

Geometry must be extracted from scan data.

Boundary conditions (attachment points and rigid parts defined)

Material properties must be determined

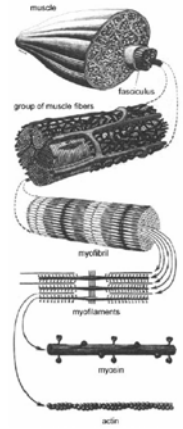


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Problems

Real time finite element solutions are possible for small numbers of isotropic linear elastic elements.

Muscle tissue is not isotropic or linear elastic, and large numbers of elements are required.



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Possible solution

Pre-computation and encoding of a large number of accurate solutions using statistical shape modelling.

Restricts the number of degrees of freedom but may be appropriate for certain techniques.

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Simulating laparoscopic surgery procedures

A topic of great interest due to the potential commercial value.

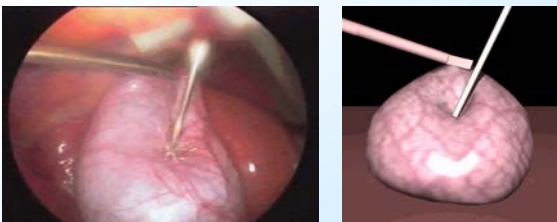
Perceived as more important than colonoscopy or laryngoscopy due to the associated dangers.

Hardest to achieve accuracy on since it involves interaction of several systems:

Gall Bladder ---- Bile ---- Surrounding organs

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Visually appealing results are possible



But how far do they reflect the real procedure?

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Summary

No deformation - easy

↑ Bronchoscopy

Colonoscopy

Upper GI endoscopy

ERCP

Laryngoscopy

↓ Laparoscopic Cholecystectomy

Large and Complex Deformations - very difficult

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Validation Issues

Creation of convincing simulations is now possible, but there is no real way of assessing how accurately they reproduce the real procedures.

On the one hand we know that the underlying modelling must be approximate, and it is possible that using computer simulation might induce “bad habits”

On the other hand as training methods for manual skills they could be just as effective - if not better - than older methods