Computer Graphics in Medicine

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For my presentation, I will discuss several different papers that are related to graphics and imaging in the medical field. The main areas that the papers cover are: compression of medical images, Hough transforms and how they are used for medical visualization, computer graphics in medical training, and the future of graphics in medicine.

Compression of Medical Images

The medical field is one of the only areas of computer imaging where lossless compression is used almost exclusively. Even a small amount of data loss in an x-ray image may theoretically cause a doctor to misdiagnose a patient. Another reason that lossless compression is needed for medical image is because often images must be analyzed by non-human observers, meaning computers, who may be confused by lossy images. Because lossy compression can produce near perfect image representation and compress at a much higher rate then lossless compression, most research on image compression focuses on lossy compression.

The paper I will be discussing compares different lossless methods, from non-image compression methods, such as ZIP, to advanced image processes, such as JPEG 2000. The first step of the paper is to classify the different lossless compression schemes:

- Predictive with statistical modeling (Original JPEG schemes)
- Transform based (JPEG 2000)
- Dictionary (GIF, TIF, PNG, etc.)
- Ad hoc (Run line encoding)

The hypotheses of the paper is as follows:

1. state of the art lossless compression techniques perform substantially better than older lossless compression techniques;
2. new international stands for compression schemes perform as well as the best state of the art lossless compression techniques;
3. state of the art lossless compression techniques perform substantially better than non-image based compression techniques;
4. predictive schemes with statistical modeling and transform based coding perform substantially better then dictionary based coders.

The images were compared based on compression ratio, which is just the Raw Image Data / Compressed Image. The speed of the compression was not considered in the final data, but the researchers note that SZIP, JPEG, and JPEG-LS were the fastest compression schemes, and CALIC was the slowest. The analysis also excludes “region of interest” compression (this is where the critical part of the image in compressed with lossless compression, but the rest of the image is compressed with a lossy method.)

Two pieces of information that are important: the researchers did not use the optimized version of the PNG method, and for the JPEG 2000 method, the researchers used the best performing wavelet for the final test data (in this case, it was the integer 5,3 wavelet.)

Table 2 – Byte Compression Ratio compared with Compression Scheme and Modality – Full Image Set.

	Compression Ratio (Raw Image Bytes vs. Compressed Image Bytes) (top five (or more if ties) for each modality are in bold italics)																			
Compression Scheme (1)	All	<= 8	> 8	CT	CT (film)	MR	MR (film)	NM	US	All RG	DX	CR	All MG	MG (film)	MG DX1	MG DX2	RF	XA	PX	IO
Number of Images	3679	731	2948	1180	44	1331	12	71	268	143	49	76	81	51	10	20	127	35	18	212
PACKBITS (2)	1.66	1.66	0	0	0	0	0	2.58	1.79	1.21	1.21	0	0	0	0	0	1.33	0	1.32	1.19
Unix pack	1.73	1.63	1.75	1.6	1.32	1.88	1.41	3.13	1.86	1.36	1.29	1.43	1.32	1.3	1.63	1.21	1.35	2	1.1	1.3
Unix compress BE	2.24	2.47	2.18	2.08	1.65	2.14	1.65	4.77	2.47	1.92	1.68	2.09	1.42	1.33	2.13	1.28	1.94	***3.73***	2.17	1.93
Unix compress LE	2.24	2.47	2.18	2.08	1.65	2.14	1.65	4.77	2.47	1.92	1.68	2.09	1.42	1.33	2.13	1.28	1.94	***3.73***	2.17	1.93
GNU gzip BE	2.38	2.54	2.35	2.24	1.72	2.3	1.72	5.36	2.53	1.99	1.77	2.18	1.67	1.52	2.65	1.54	1.96	3.48	2.34	1.96
GNU gzip LE	2.39	2.54	2.35	2.25	1.72	2.3	1.72	5.36	2.53	1.99	1.77	2.18	1.67	1.52	2.65	1.54	1.96	3.49	2.34	1.96
JPEG SV 3	2.58	2.14	2.69	2.67	2.07	2.62	2.14	4.44	1.98	2.53	2.13	2.87	2.18	2.13	3.02	1.91	2.16	2.86	2.2	1.93
JPEG SV 2	2.76	2.34	2.87	2.86	2.2	2.8	2.27	4.68	2.13	2.65	2.17	3.02	2.26	2.15	3.21	2.07	2.35	3.03	2.56	2.11
PNG	2.76	3.31	2.62	2.64	1.7	2.54	1.77	5.07	3.04	2.18	1.84	2.28	1.89	1.69	3.14	1.76	2.65	2.6	3.78	2.44
JPEG SV 1	2.79	2.37	2.89	2.91	2.19	2.8	2.29	4.76	2.3	2.64	2.2	2.99	2.31	2.26	3.2	1.96	2.24	3.11	2.56	2.1
JPEG SV 7	2.85	2.4	2.96	2.99	2.24	2.89	2.35	4.42	2.22	2.73	2.24	3.1	2.32	2.26	3.14	2.05	2.39	2.96	2.7	2.14
S+P Huffman	2.87	1.95	3.11	3.19	1.73	3.15	1.86	4.47	1.52	2.16	1.79	2.31	1.85	1.85	0	0	2.47	2.96	1.71	1.51
JPEG SV 6	2.89	2.42	3	3.09	2.3	2.91	2.41	4.2	2.26	2.64	2.14	3.02	2.28	2.19	3.16	2.1	2.31	2.91	2.92	2.12
JPEG SV 5	2.92	2.45	3.03	3.13	2.26	2.92	2.38	4.5	2.33	2.64	2.16	3.01	2.3	2.24	3.16	2.02	2.27	2.94	2.89	2.13
JPEG SV 4	2.98	2.53	3.09	3.27	2.3	2.91	2.44	4.44	2.36	2.56	2.07	2.94	2.25	2.15	3.18	2.05	2.19	2.99	3.32	2.16
JPEG best	3.04	2.62	3.14	3.29	2.31	2.97	2.45	4.86	2.38	2.76	2.26	3.14	2.38	2.32	3.21	2.11	2.4	3.14	3.41	2.3
NASA szip	3.09	2.81	3.17	3.17	2.24	3.12	2.41	5.36	2.72	2.79	2.24	3.21	2.42	2.26	3.68	2.19	2.5	3.15	2.81	2.15
JPEG-LS no run	3.31	2.98	3.39	3.61	***2.56***	3.22	***2.77***	4.56	2.86	2.99	2.39	3.41	2.52	2.39	3.43	2.37	2.8	3.26	3.7	2.52
S+P Arithmetic	3.4	2.46	3.64	3.72	1.79	***3.71***	1.97	5.78	1.68	2.28	1.85	2.43	1.93	1.93	0	0	2.86	3.49	1.88	1.62
CREW	3.56	3.38	3.6	3.67	***2.54***	3.56	2.76	5.32	2.91	***3.15***	***2.45***	***3.62***	***2.61***	***2.41***	***3.82***	2.4	2.9	3.42	3.99	***2.53***
JPEG2000 2x10	3.66	3.43	***3.72***	***3.83***	2.5	***3.67***	2.73	5.38	2.93	3.12	2.41	3.61	2.54	2.38	3.78	2.4	2.91	3.39	***4.02***	2.51
CALIC Huffman	***3.67***	***3.52***	3.71	3.79	***2.54***	***3.59***	2.74	***6.05***	***3.2***	3.12	2.41	3.61	***2.6***	***2.4***	***3.94***	***2.42***	***3***	***3.51***	3.52	***2.57***
JPEG-LS HP	***3.81***	***3.86***	***3.8***	***4***	***2.58***	***3.59***	***2.77***	***6***	***3.39***	***3.15***	***2.43***	***3.64***	***2.62***	**2.43**	***4.02***	***2.43***	***3.08***	***3.55***	***4.2***	***2.66***
JPEG-LS MINE	***3.81***	***3.86***	***3.8***	***4***	***2.58***	***3.59***	***2.77***	***5.98***	***3.4***	***3.15***	***2.43***	***3.64***	***2.62***	**2.43**	***4.02***	***2.43***	***3.08***	***3.55***	***4.2***	***2.66***
JPEG2000 5x3	***3.81***	***4.11***	***3.74***	***3.88***	2.49	***3.63***	***2.72***	***5.69***	***2.97***	***3.14***	***2.43***	***3.63***	2.4	2.38	3.53	***2.41***	***2.94***	3.42	***3.95***	2.51
CALIC Arithmetic	***3.91***	***3.93***	***3.9***	***4.01***	***2.59***	***3.72***	***2.8***	7.04	***3.5***	***3.23***	***2.46***	***3.74***	***2.64***	***2.45***	***4.01***	***2.45***	***3.14***	***3.62***	***4.22***	***2.7***

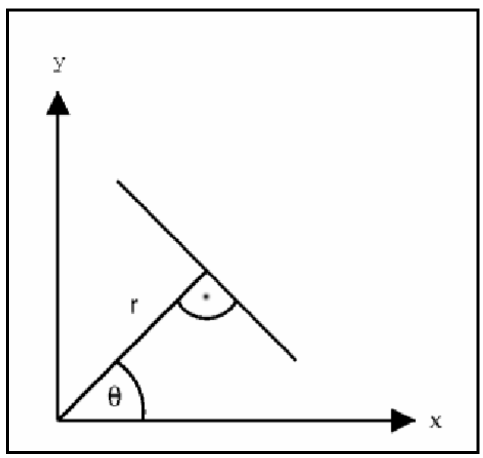
Notes: 1. Sorted in order of increasing compression ratio for all images combined.
2. The PACKBITS implementation only supports 8 bit pixels so not all modalities could be tested and data present reflects only the subset of images for each modality that were <= 8 bits in depth

Hough Transforms

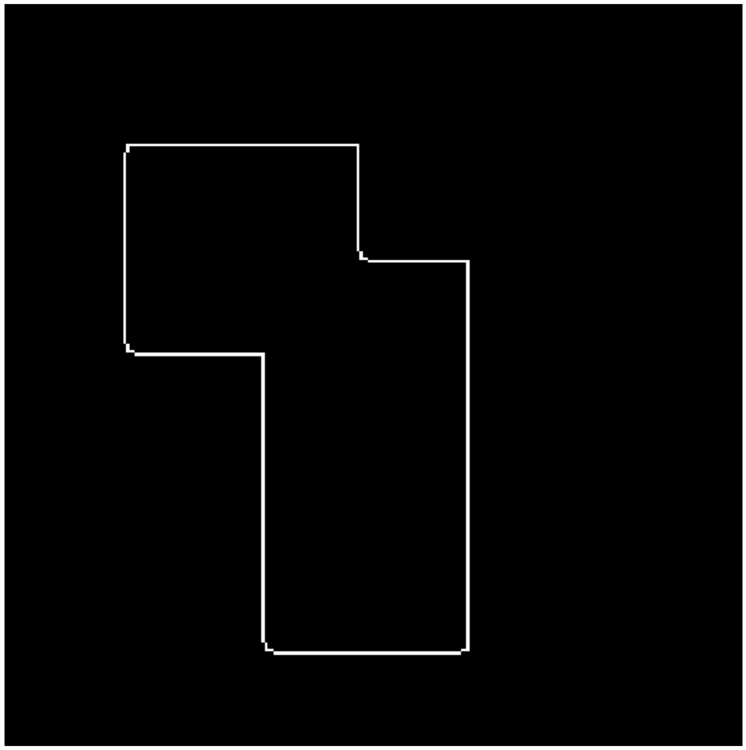
The purpose of performing a Hough Transform is for feature extraction. This is where objects in the image (lines, circles, etc.) are extracted from the image. A Hough Transform uses a one-to-many scheme, which means that for each analyzed point in the original image, one curve is drawn in Hough space.

Line Hough Transforms:

$$x\cos(\theta) + y\sin(\theta) = r$$



In this line equation, r in the length from the origin to the line, and θ is the angel from r to the *x*-axis. The edge pixels of the image are converted from (*x, y*) form to (θ, r) form using the equation above. An accumulator is created for each (θ, r) to count the number of edge points that have the same θ and r values. If the value in an accumulator is large, that means that there are many points that lay on a particular line.



Circle Hough Transforms:

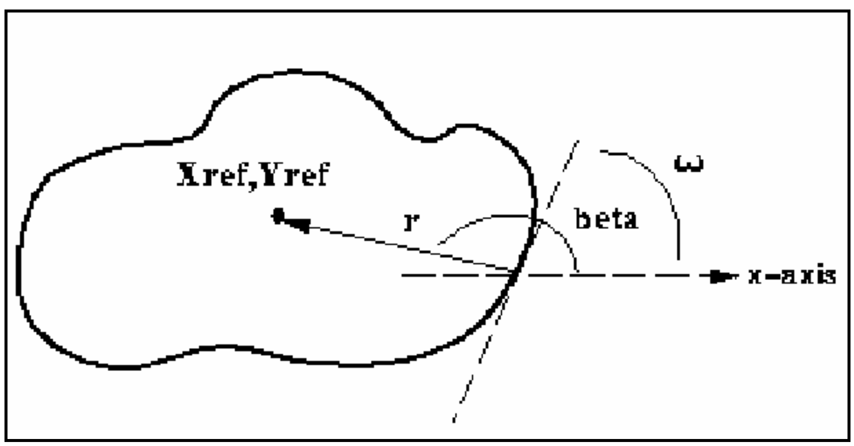
$$(x - \mathrm{a}x)^2 + (y - \mathrm{a}y)^2 = \mathrm{R}^2$$

In the case of the Hough circle transform, each (x, y) is converted to a $(\mathrm{a}x, \mathrm{a}y, \mathrm{R})$ value. The major different between the circle transform and the line transform, is that in the circle transform, a (x, y) value be a part of many different possible circles.

Generalized Hough Transforms:

The real potential of the Hough transform is to detect shapes that are not in parametric form.

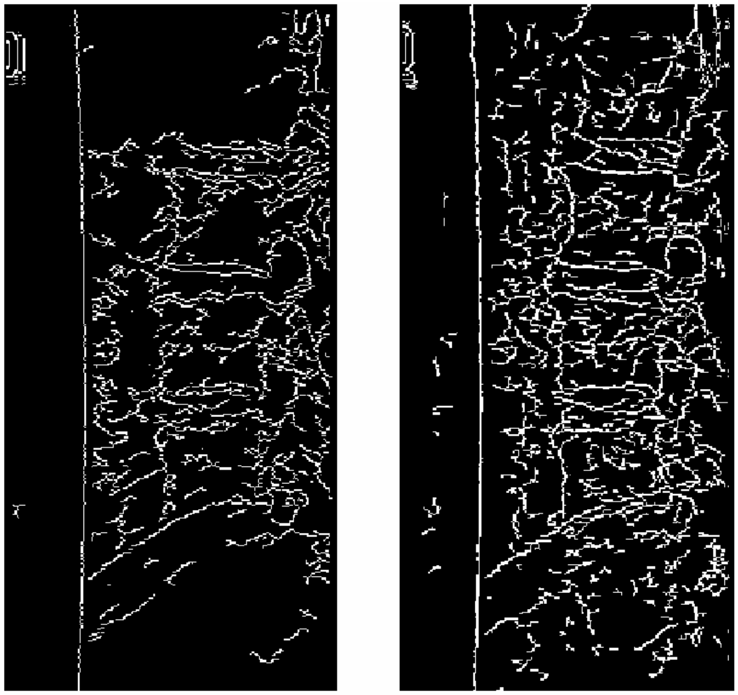
$$x\mathrm{ref} = x - \mathrm{r}\cos(\beta)$$
$$y\mathrm{ref} = y - \mathrm{r}\sin(\beta)$$

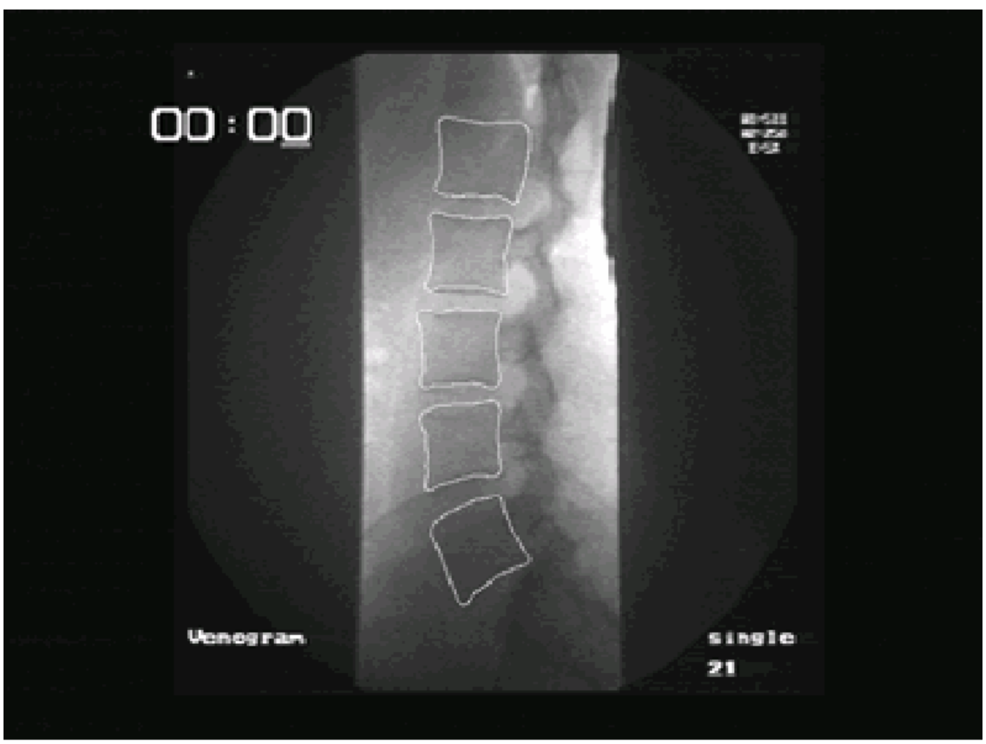


The generalized Hough transform uses a look-up table to store r and β values, which can be looked-up based on a w value, which can be calculated using the gradient around the (x, y) value of a point.

Some interesting things about Hough transforms:

- Hough transforms can detect objects in an image given only 5 – 15% of the pixels from the image
- The Hough circle transform, and similar transforms, can detect a circle, sphere, or eclipse, even when only 20% of the object is visible.

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Computer Graphics in Medical Training

Surgical training simulators are a very important piece of equipment for surgical resident who need practice performing complicated procedures. One procedure that is very commonly preformed, but is very involved and can lead to serious problems if perform incorrectly, is a laparoscopy. A laparoscopy is where a small camera is placed inside the abdomen of a patients is that the surgeon can view the patients internal organs on a video screen. This allows the surgeon to perform delicate operations with small surgical instruments while guiding the instruments by viewing the video screen.

One common procedure that is preformed by laparoscopy is a cholecystectomy (gallbladder removal). The gallbladder is attached to the liver and stores bile that helps with digestion. When gallstones form between the gallbladder and the bile duct (where the bile travels to the intestines), it can cause major programs that require surgery. One of the must difficult parts of a cholangiography is when the cystic duct is inspected before the surgery by placing a small catheter directly into the duct.

According to the paper "Virtual Environments for Medical Training: Graphical and Haptic Simulation of Laparoscopy", the four major difficulties that surgeons face when performing laparoscopy are: The limited field of view of the camera; the fact that the monitor reflects a mirror image of the actual movements of the surgical instruments; the haptic effects (force feedback) of the surgical immurements is greatly reduced due to the distance from the end of the tools to the surgeon's hands; and the fact that the surgical tools most rotate around a fixed point, making movement difficult.

Surgical residents are often trained to perform the procedure using what is called a laparoscopic training box. This is basically just a box that encloses an endoscopic camera and laparoscopic tools. According to the above mentioned paper, the biggest problems with training surgeons using a training box are that: the simulations are usually poor imitations of the actual surgery, the box is not easily customizable, and the performance of the user cannot be measured.

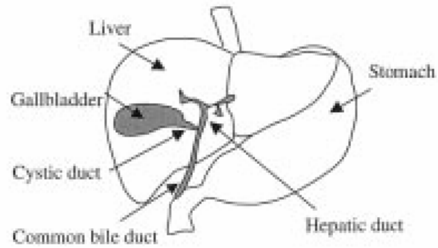


Fig. 1. Anatomy of the gallbladder.

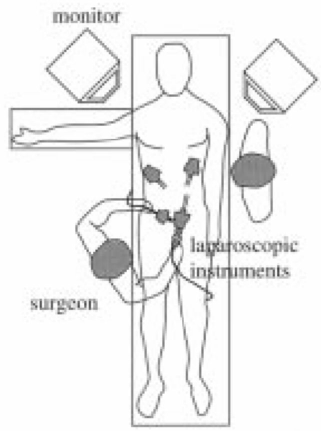
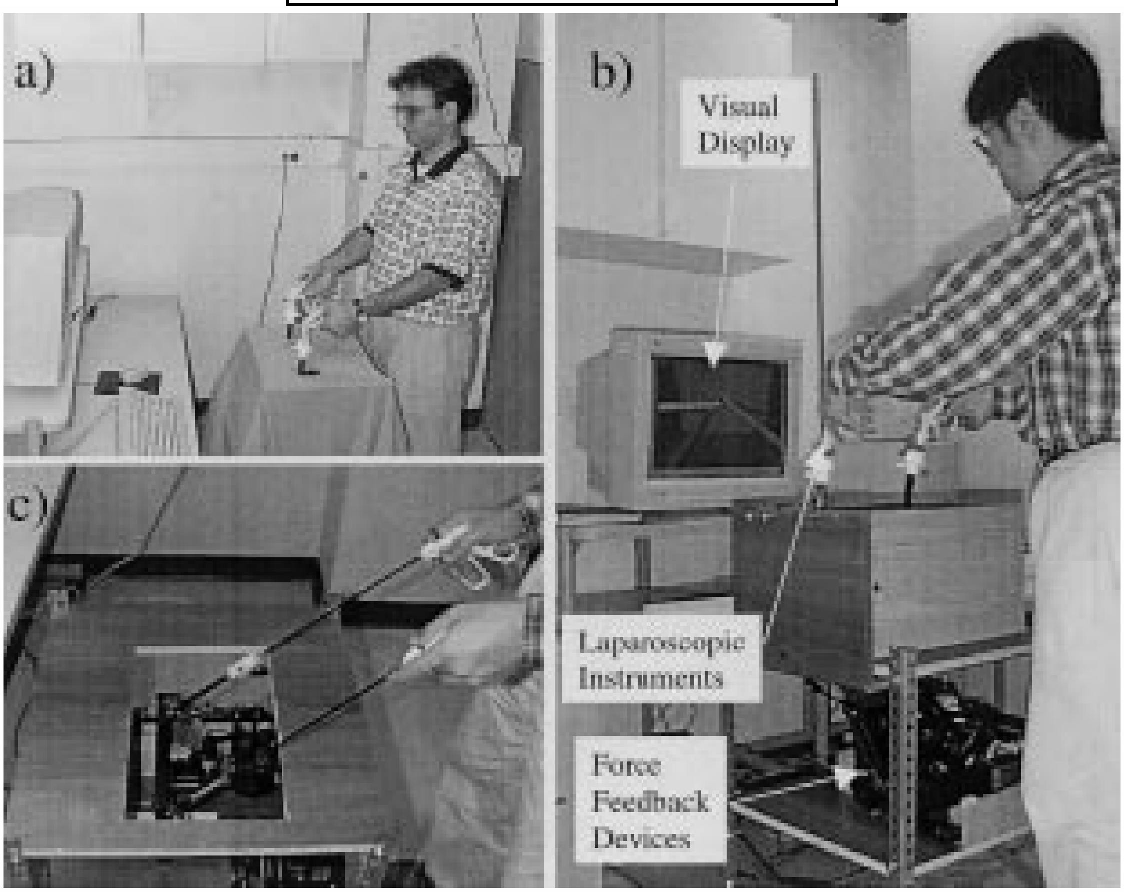
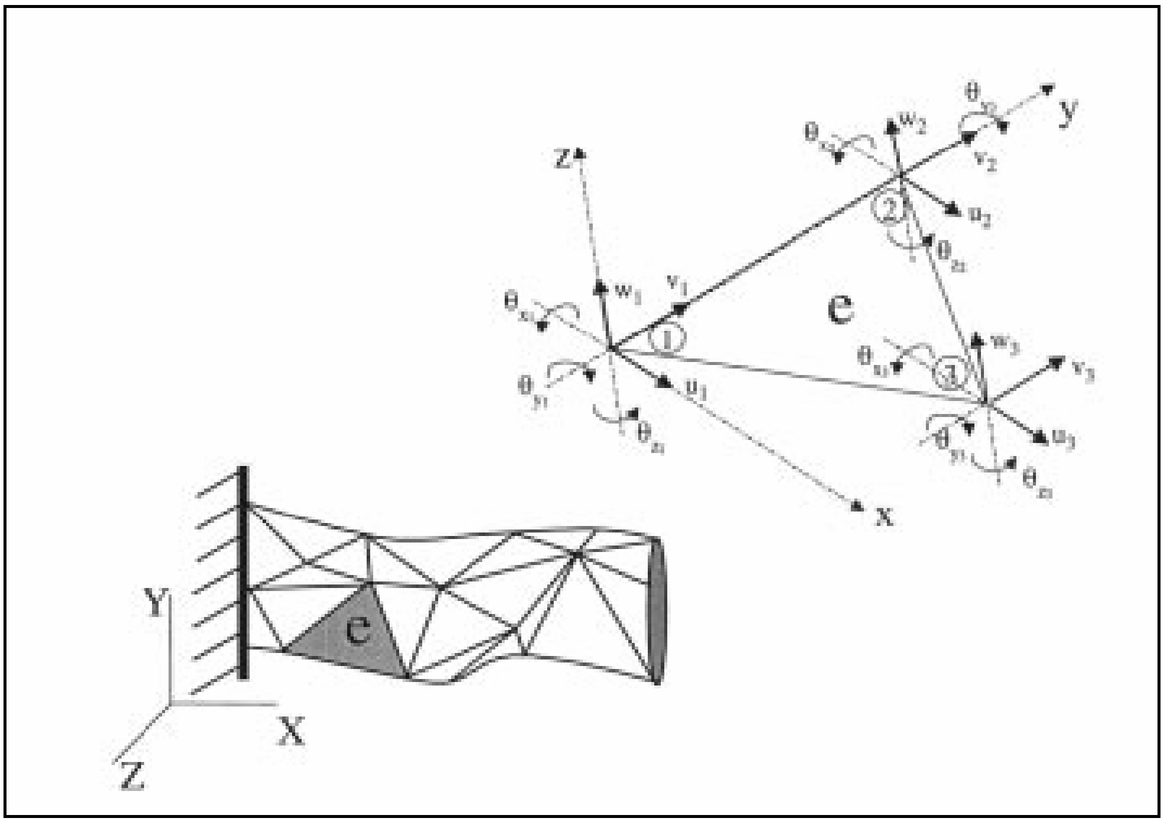


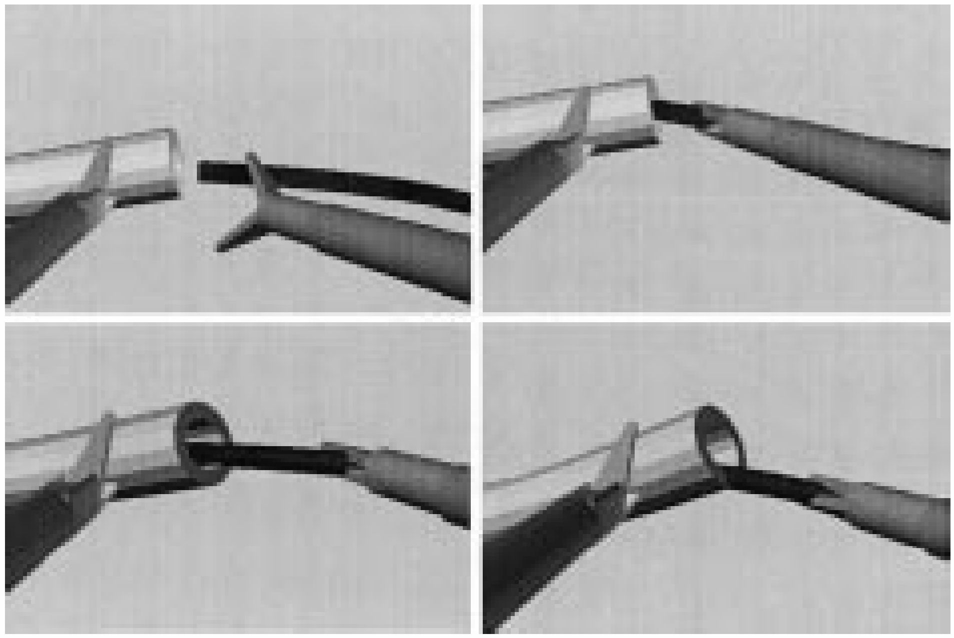
Fig. 2. Operating room setting for laparoscopic surgery (top view).



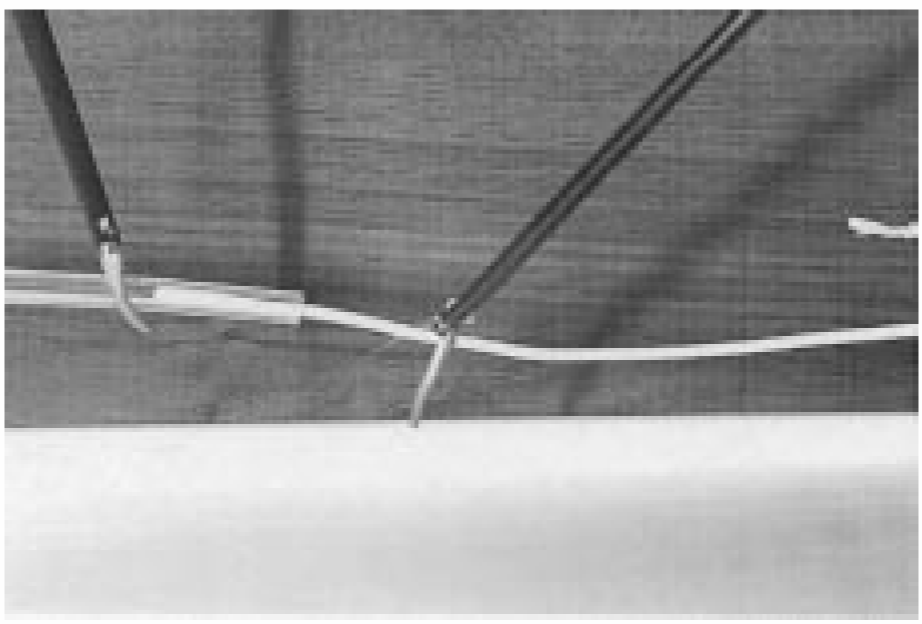
The authors of this paper designed a 3D laparoscopic training machine that they felt worked better than the laparoscopic training box. The major components of the 3D simulation are: the 3D representation of the surgical tool and the tissue being operated on, collision detection, and force feedback.

The catheter and surgical tools were modeled using a simple partial-based method that was easy to simulate, and computationally fast. The real difficultly was simulating the soft tissue response. Although soft tissue simulation equations exist, this system needed to be real-time, and running the full set of equations was too slow. The researchers ended up using a method called the Finite Element Method (FEM).





(a)



(b)

The Future of Graphics and Imaging in Medicine

The paper "Graphics and Imaging in Medicine" by Parvati Dev from Stanford University discusses how computer graphics will change the medical field in the future. The paper is split up into three sections: 5 years in the future, 50 years in the future, and 500 years in the future. Because the paper was written in the year 2000, we are currently at the 5 year mark that the paper describes, so it's easy to view how accurate the predictions are.

2005:

According to the paper, hospitals will have a file containing 3D models of patents which can be used during surgery to show doctors if they are getting too close to dangerous areas and can draw their attention to areas where the data looks suspicious or abnormal. This information can be overlaid on the operating table via a head mounted display. Although systems like this due exist, they are not wide spread, and definitely not widely used.

2050:

Because there will be so much information that can be obtained and stored, the biggest problem is how the computers represent the data. Small objects, such as tumor tissue, that is too small for the human eye to see, can now be detected through a computer diagnostic program. In fact, although x-rays and other images will be stored in medical databases, computers will be able to simply print out a diagnostic for doctors to read, instead of the doctors having to scan the images for themselves.

Patients can be quickly scanned for height, weight, and many other measurements, such as fat-water ratio, before they even see a doctor. This way, obvious problems can be detected before a patent has to describe symptoms. The doctor can also show the patient a 3D representation of their body, so that they can see clearly what is causing them discomfort.

Because the imaging ability will be so much more advanced, doctors can do surgery by simply controlling micro-robots inside of a person, instead of making incisions.

2500:

At this point, the computers can not only diagnose a problem, but they can take corrective actions. The job of medical professionals will be to build and maintain these machines. Humans will no longer need to physically operate on other people, although “classical” medicine will still be preformed as a more natural option, and will be treated by most as an a form of art.

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