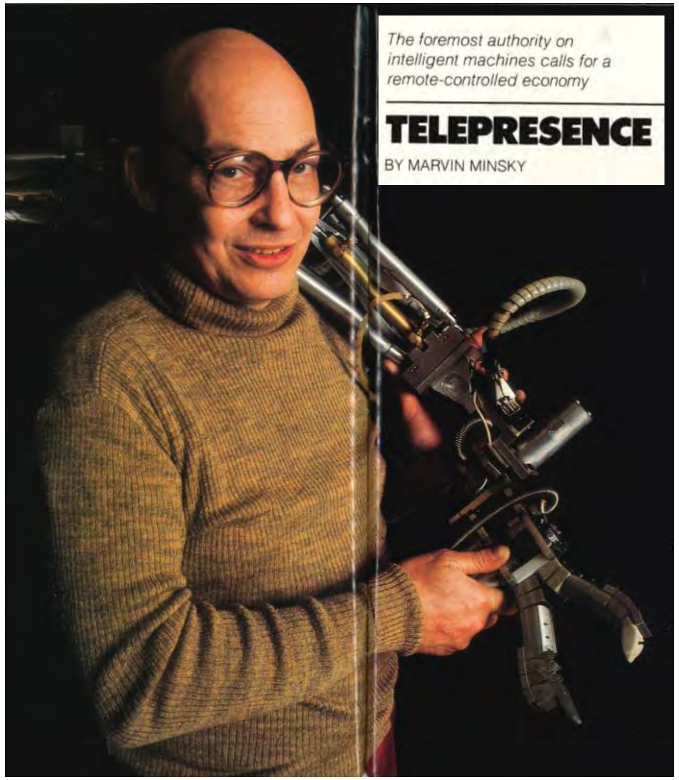
Robotics, telepresence and minimal access surgery
- A short and selective history

Luke Hares, Technology Director, Cambridge Medical Robotics

- Disclaimer!
- Highlights of robotics and telepresence
- A brief history of Minimal Access Surgery
- A natural fit
- Next steps

Early days

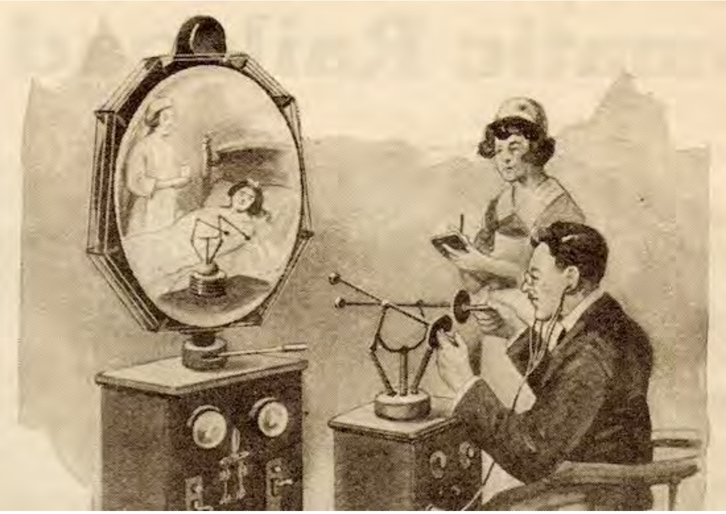
Telepresence defined

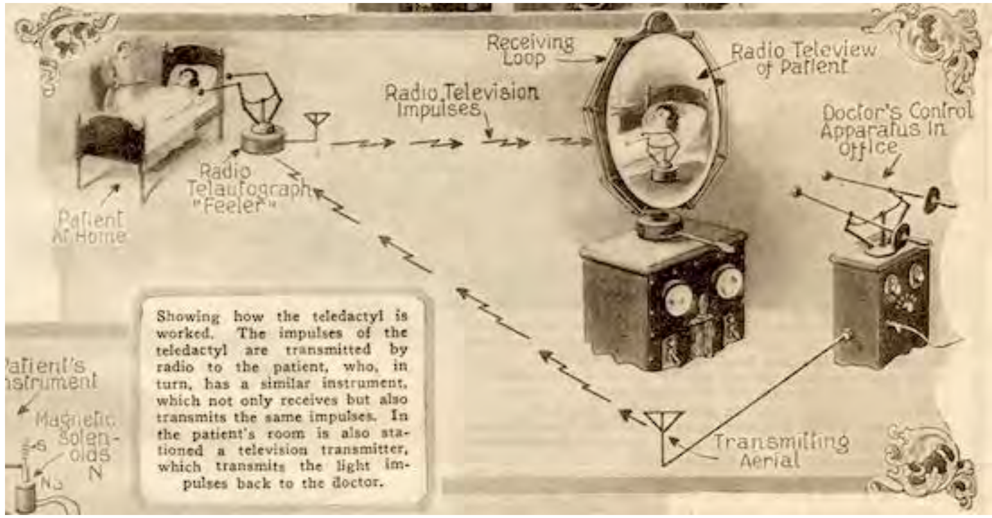


The Radio Teledactyl

By HUGO GERNSBACK
Member American Physical Society

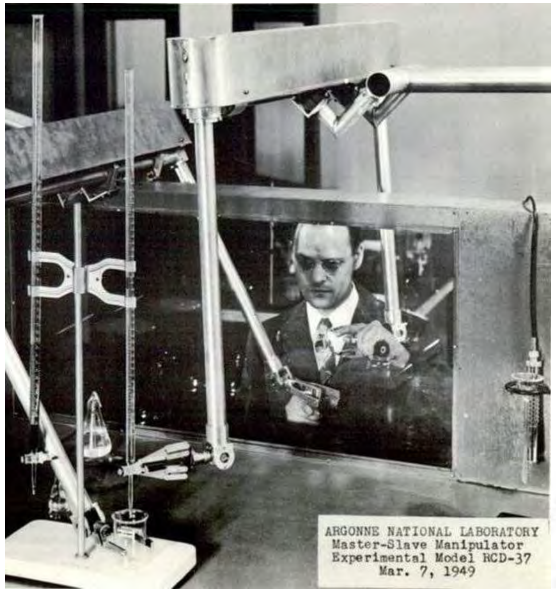
Science and Invention for February, 1925





Minsky invented the term Telepresence in 1980 but the idea had been around for much longer

Mechanical coupling – only scaling allowed!



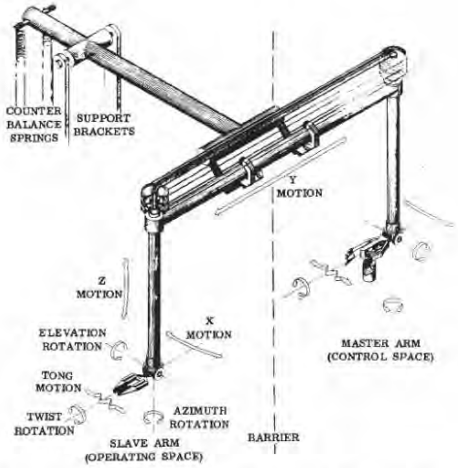


FIGURE 4.—The ANL Model–1 experimental mechanical master-slave manipulator. Motions of the master arm are mechanically communicated to the slave arm. Because the reverse is also true, this is termed a "bilateral" manipulator. (Courtesy of Argonne National Laboratory.)

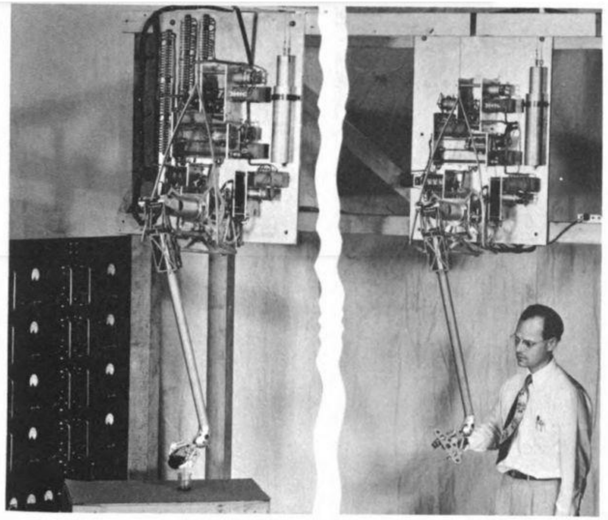


FIGURE 6.—The ANL Model E1 electric master slave. Used only for experimental purposes, this bilateral manipulator was developed in 1954. (Courtesy of Argonne National Laboratory.)

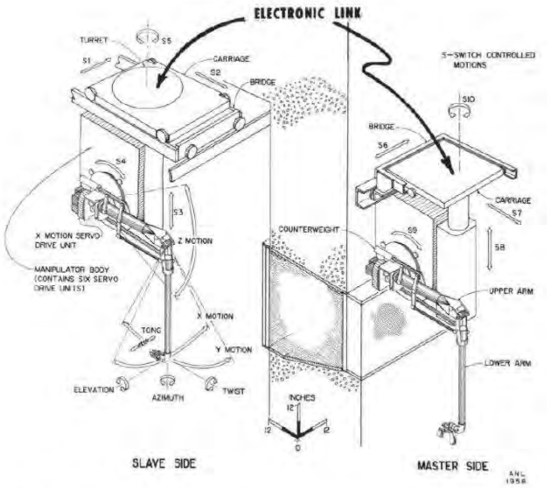


FIGURE 112.—Installation diagram of the ANL E3 electric master-slave. The normal degrees of freedom of the master-slave are combined with additional degrees of freedom provided by the overhead rectilinear bridge-crane-type carriage. (Courtesy of Argonne National Laboratory.)

1949

1954

The first teleoperators were mechanical master slave devices such as those developed by Ray Goertz at Argonne National Laboratory in the US; quickly the advantages of electrically operated devices were realised

Nuclear, submarines and space

Goertz teleoperators in the film Dr No, 1962

1958/59 Handyman – GE – Ralph Mosher – the first force reflecting manipulator was developed for the atomic aircraft programme

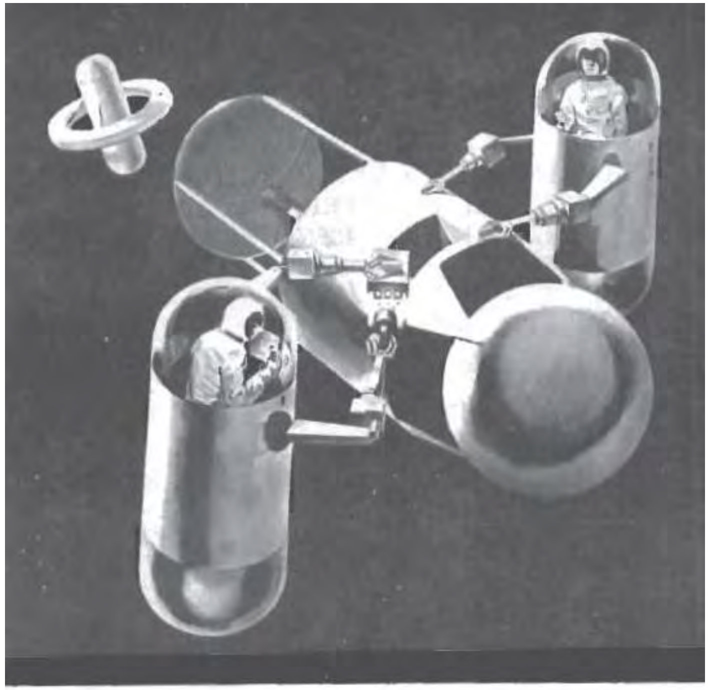
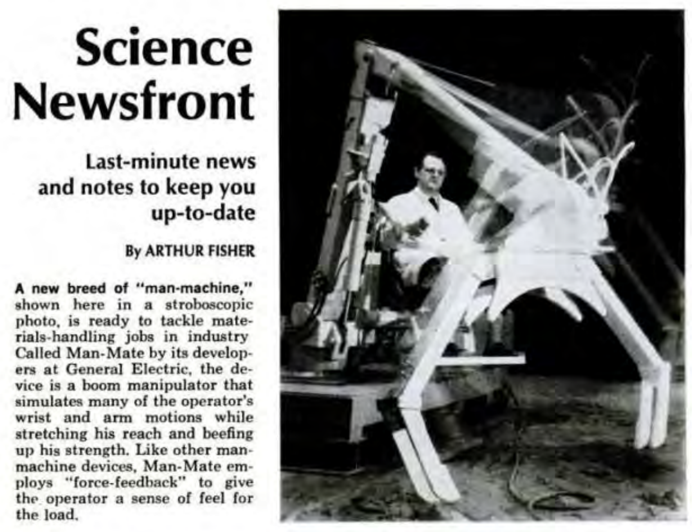


Fig 1. Manned Space Capsules Outfitted with Remote Manipulators Performing a Typical Space Task

1961 – Orbital Space Tug (concept)

Through the 60s and 70s remote manipulators improved in performance and imagination enabling human operators to be remote from various hazardous environments


Science Newsfront

Last-minute news and notes to keep you up-to-date

By ARTHUR FISHER

A new breed of "man-machine," shown here in a stroboscopic photo, is ready to tackle materials-handling jobs in industry. Called Man-Mate by its developers at General Electric, the device is a boom manipulator that simulates many of the operator's wrist and arm motions while stretching his reach and beefing up his strength. Like other man-machine devices, Man-Mate employs "force-feedback" to give the operator a sense of feel for the load.

GE Man Mate – 1969


Man-Mate Industrial Manipulator designed for work in a forge shop. The operator sits in an insulated air-conditioned cab manipulating the boom arm which can reach up to 24 ft (7.3 m.), and can work in temperatures up to 135°F. The system is based on a servomechanism with force feedback, which means that the operator can sense the power which is being exerted through the control mechanism.


Courtesy of Reynolds Sub/Marine Services Corporation

Figure 2 — The Aluminaut beginning a descent.

Aluminaut - 1964

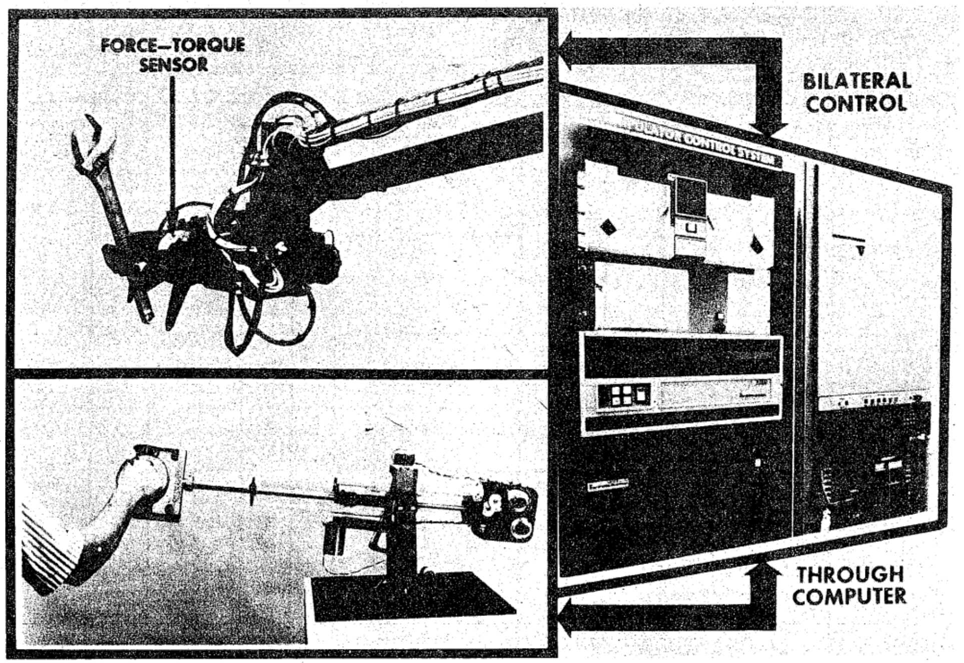
Through the 60s and 70s remote manipulators improved in performance and imagination enabling human operators to be remote from various hazardous environments

The next step 1980s -> now

- Mechanically different – specialised for task
- Frame of reference transform now possible – the camera / slave relationship can be different from the operator /manipulator relationship

2.3 Universal Hand Controller

Jet Propulsion Laboratory has developed a six degree of freedom force reflecting universal hand controller (FRHC), described in Corker and Bejczy (1985) and Bejczy and Salisbury (1983). This master arm is an isotonic joystick that serves to (1) transform the human operator's translational and rotational motions into an equivalent six dimensional motion of the teleoperated manipulator and (2) reflect the forces acting at the slave hand to the operator's hand. It can operate any slave arm system by means of real time transformation of the kinematic dissimilarities between the slave and the master. The authors have given special consideration to the space applicability of this device and have designed and fabricated a part-simulation system to provide compensation for the force of gravity on the human arm throughout the working range of an operator using the FRHC. The universal controller technique has a distinctive advantage for use on the space station. It could allow a single operating station to control different teleoperators at different locations, or different transformation software could teach desired motions to different robots around the space station.



- Antal Bejczy et al early 1980s JPL, Universal bilateral 6 DoF hand controller

At the start of the 80s, a key breakthrough was the realisation that the master and slave could be mechanically different, with mappings between them performed by computer

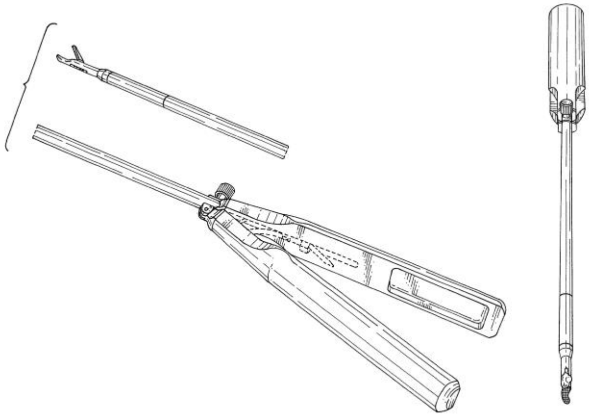
- Fast
- Hygiene and anaesthetics
- Minimal Access Surgery (MAS)

Beginnings

- The first experimental laparoscopy was performed on a dog in Berlin in 1901 using a previously invented viewer system called a Cystoscope
- The first human laparoscopic procedure was carried out by Hans Christian Jacobaeus in Stockholm in 1910; he invented the term "laparothorakoskopie" in 1911
- Various advances in optics helped it start to become common in gynaecology in the 1970s
- Early 80s – CCDs, first endoscopic video cameras
- 90s onwards – significant uptake, explosion of tools and methods

Hans Christian Jacobaeus

Specialised tools



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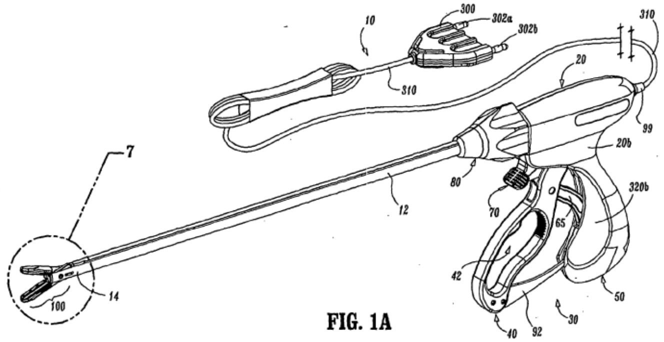


FIG. 1A

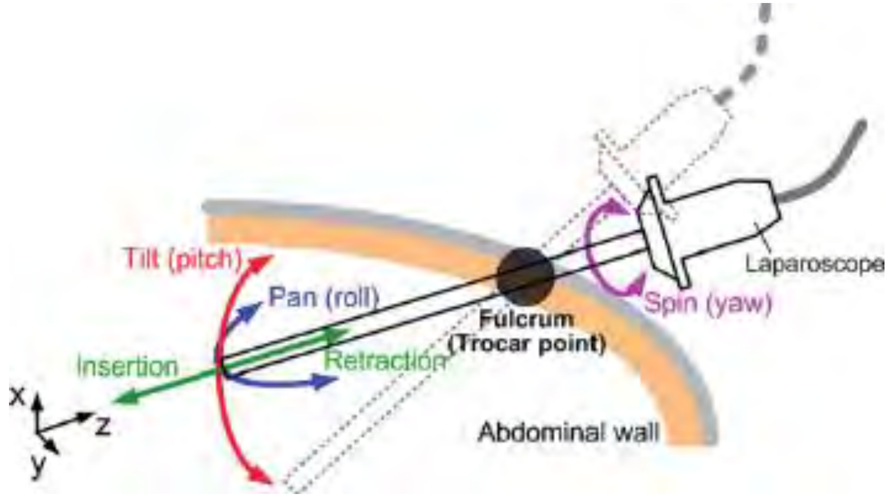
EP1535581B1

A huge growth in staplers, needle holders, needle drivers, vessel sealers, tackers, graspers……

Minimal Access Surgery needs

*MAS is **hard***

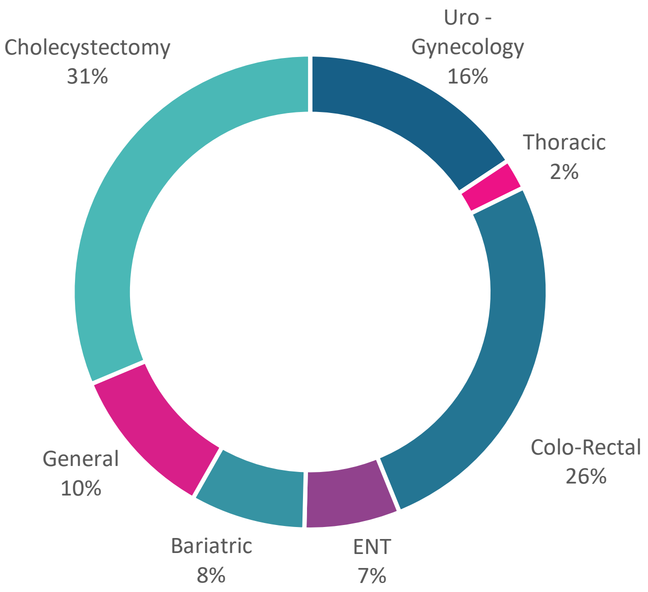
- Precision
- Specialised manipulators – Remote Centre of Motion (RCM) a natural fit
- Frame of reference transformation
- Ergonomics
- Good visualisation - stereo 3D vision



Robotics for Minimally Invasive Surgery: A Historical Review from the Perspective of Kinematics Kuo and Dai, 2009

Consequences

Total MAS Procedures in 2015: 6M



Source: Company estimates, McWilliams, Andrew. (2009, March). The Market for Minimally Invasive Medical Devices. BCC Research, p.14

- **Cooper et al *BMJ.* 2014; 349**
  - *Mean hospital MAS utilisation:*
  - *Appendix (40 – 93%)* *71%*
  - *Colectomy (6 – 49%)* *28%*
  - *Hysterectomy* *13% (0 – 33%)*
  - *Lung lobectomy* *32% (3.6 – 65%)*
  - *Complication rate:*

	MAS	Open
Appendix	3.9%	7.9%*
Colectomy	13%	35%*
Hysterectomy	4.6%	6.6%*
Lung lobectomy	17%	25%*

- Cost of Complications - $25 billion annually
- Estimated 6 million procedures p.a. which should be performed using MAS techniques today

Minimal Access Surgery is hard, and this has consequences

A natural fit

First steps - Precision

- In 1985, Kwoh used a robot based upon a Unimate PUMA 200 to perform stereotactic brain surgery

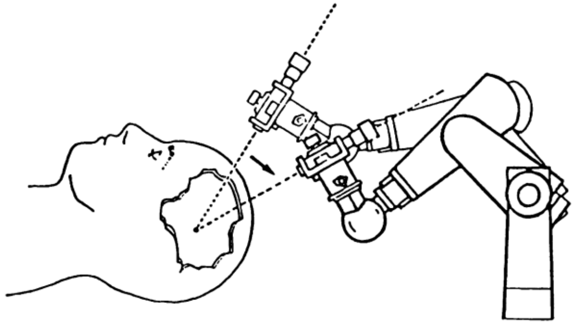
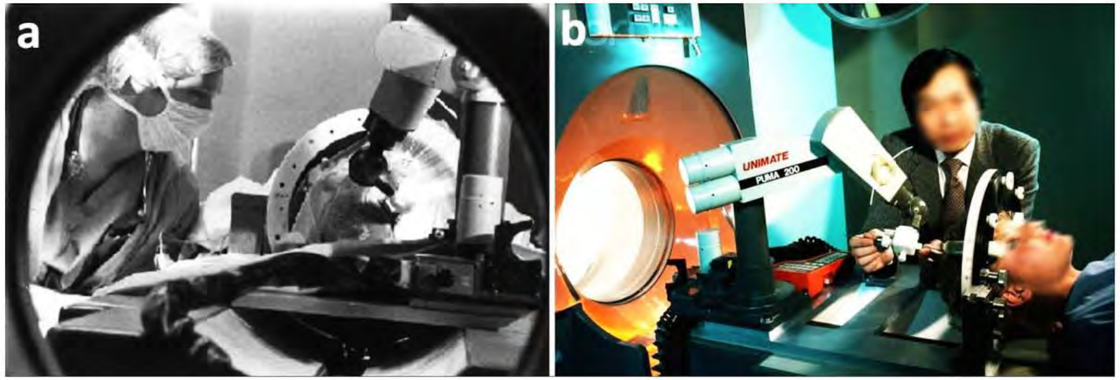


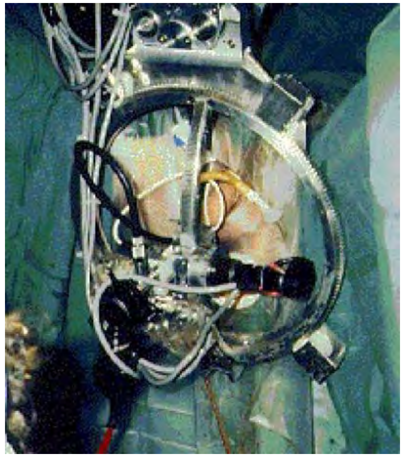
Fig. 5. Complete Software Maintains the Probe Holder Trajectory Pointing at the Target Constantly

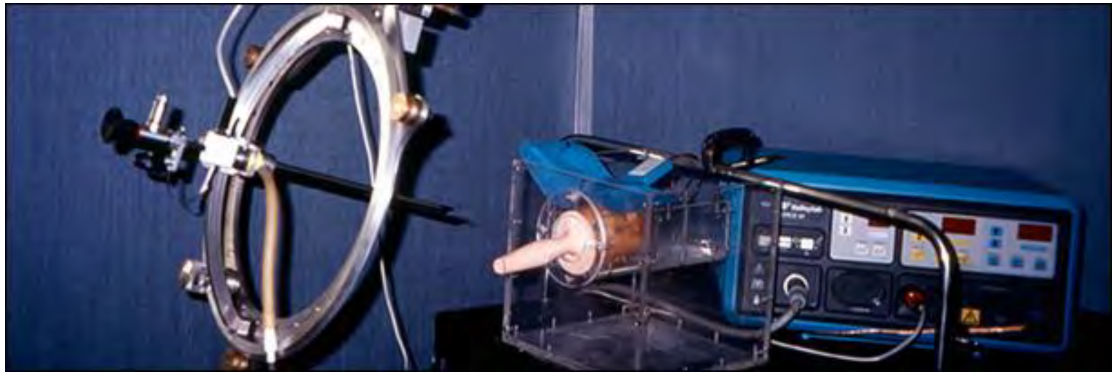
Figure 2. The first robot that performed (assisted with) human surgery in 1985 (Kwoh, 1988); Dr. Kwoh with the Unimate robot prepared for stereotactic neurosurgery
(Image credit: Corbis)



An initial objective for surgical robots was precision

- In the late 1980s Brian Davies developed a robot to perform precise proctectomies

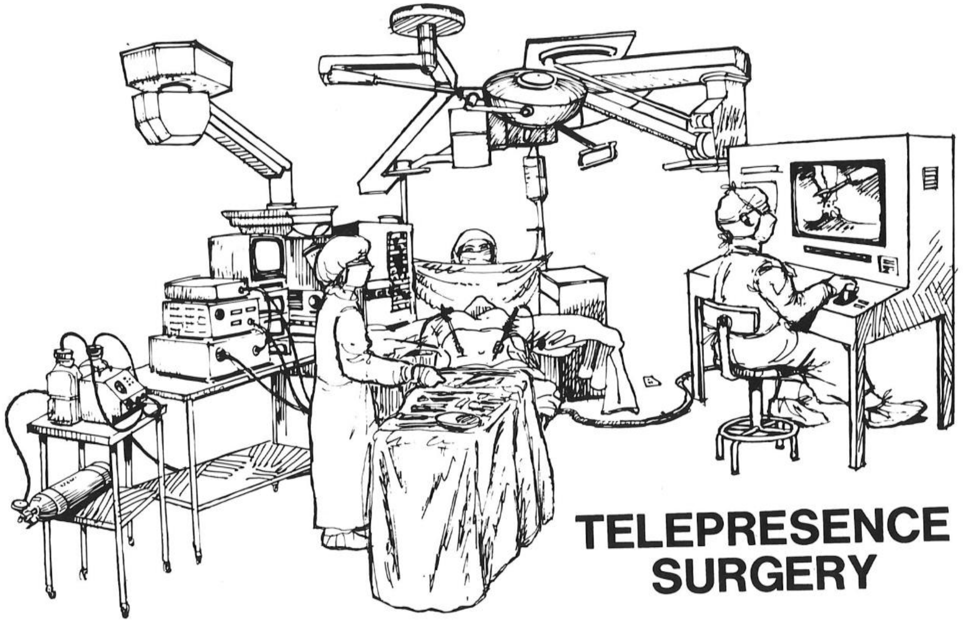




A natural fit

First steps

- By 1993, Colonel Richard Satava speculated that robotic systems could be used for telepresence general surgery
- Robots were also being developed for orthopaedic procedures to give precise bone removal and joint positioning

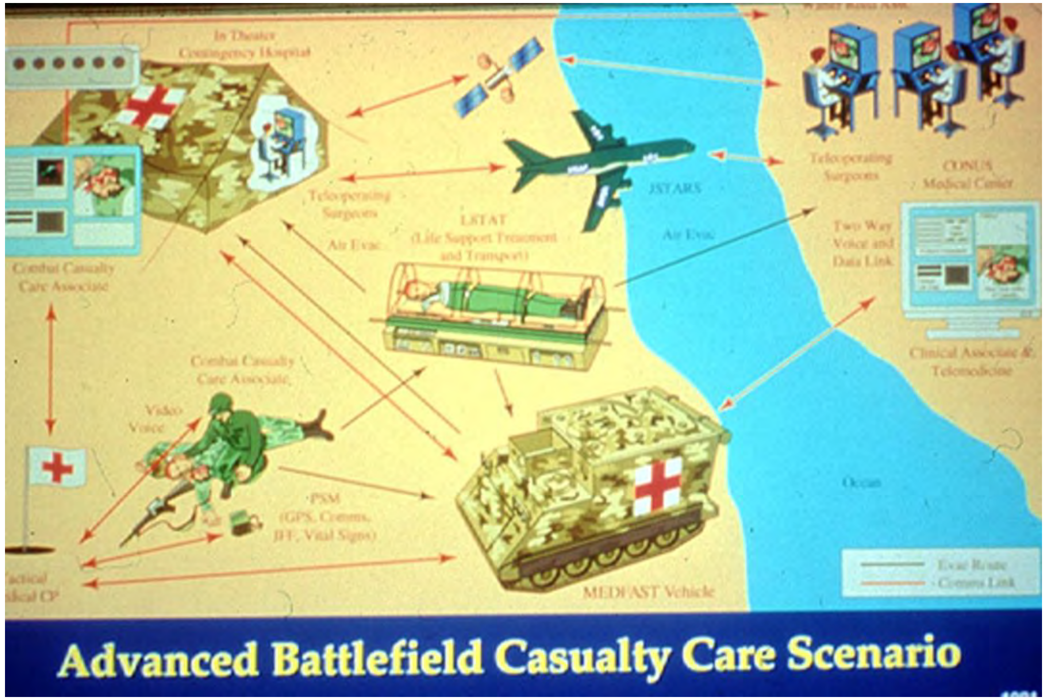


The robotic assistant, Acrobat, significantly improves surgeons accuracy during knee surgery

A natural fit

In the US

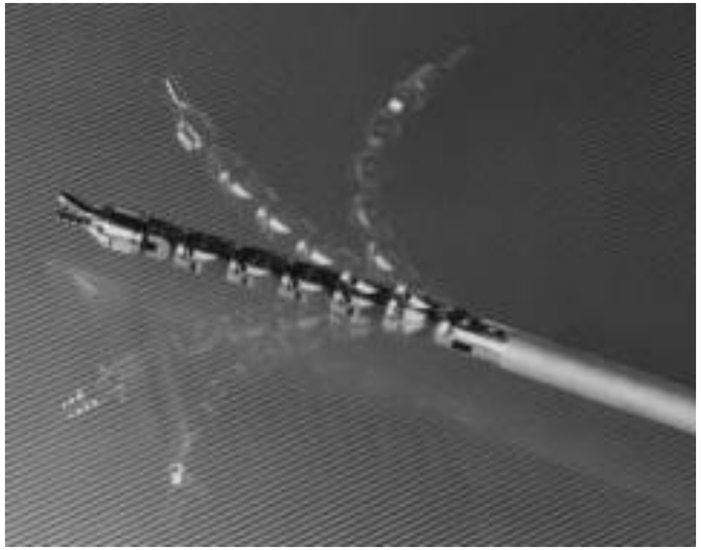
- During the 90s, in the US, DARPA projects explored the concept of telesurgery for the military
- Yulun Wang and his company, Computer Motion, developed AESOP – a robotic endoscope holder to perform the role of the surgical assistant
- Akhil Madhani developed a remote centre of motion manipulator for surgery



A natural fit

Late 90s, Europe

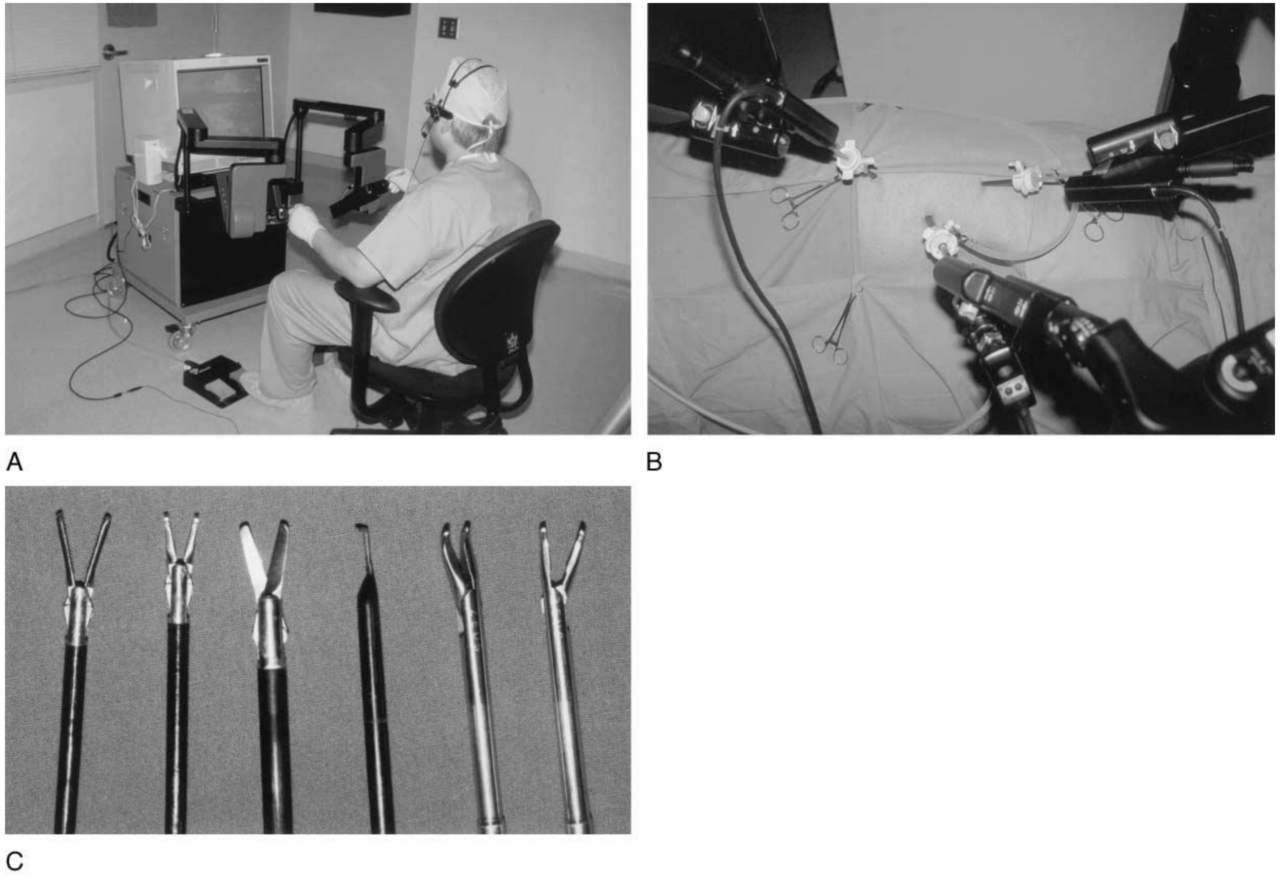
- ARTEMIS
- Karlsruhe Research Centre, Central Engineering Dept.
- Wristed instruments, RCM mechanism, 3D endoscope

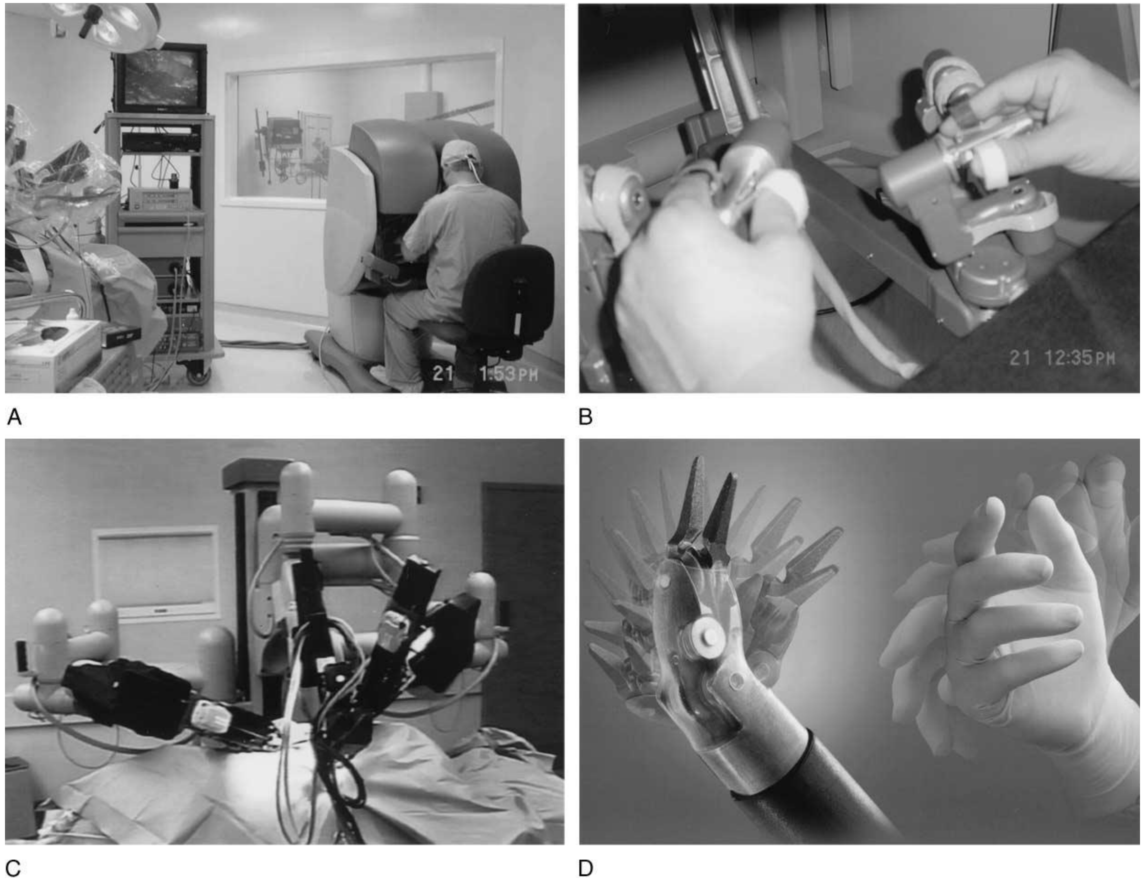


Eventual fate unknown…

Computer Motion & Intuitive

Early 2000s





2001 Sung and Gill - ROBOTIC LAPAROSCOPIC SURGERY: A COMPARISON OF THE da VINCI AND ZEUS SYSTEMS

Unmet needs

Present day

- Not general purpose – limited in application due to the need to adapt surgery to the limitations of the system
- Difficult to set up and move about
- Poor utilisation ~once every other day
- Far too expensive
- ~750k of 12M-15M
- The problem of universal access to MAS has not been solved

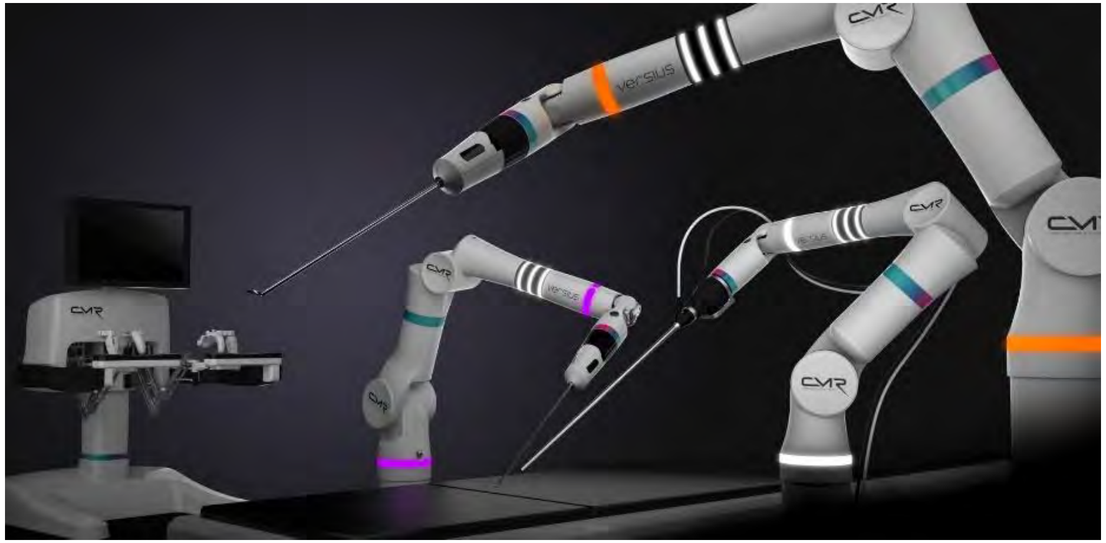
But robotics is here to stay, one big incumbent but several companies working in the area

Collaborative robotics and (eventually) big data

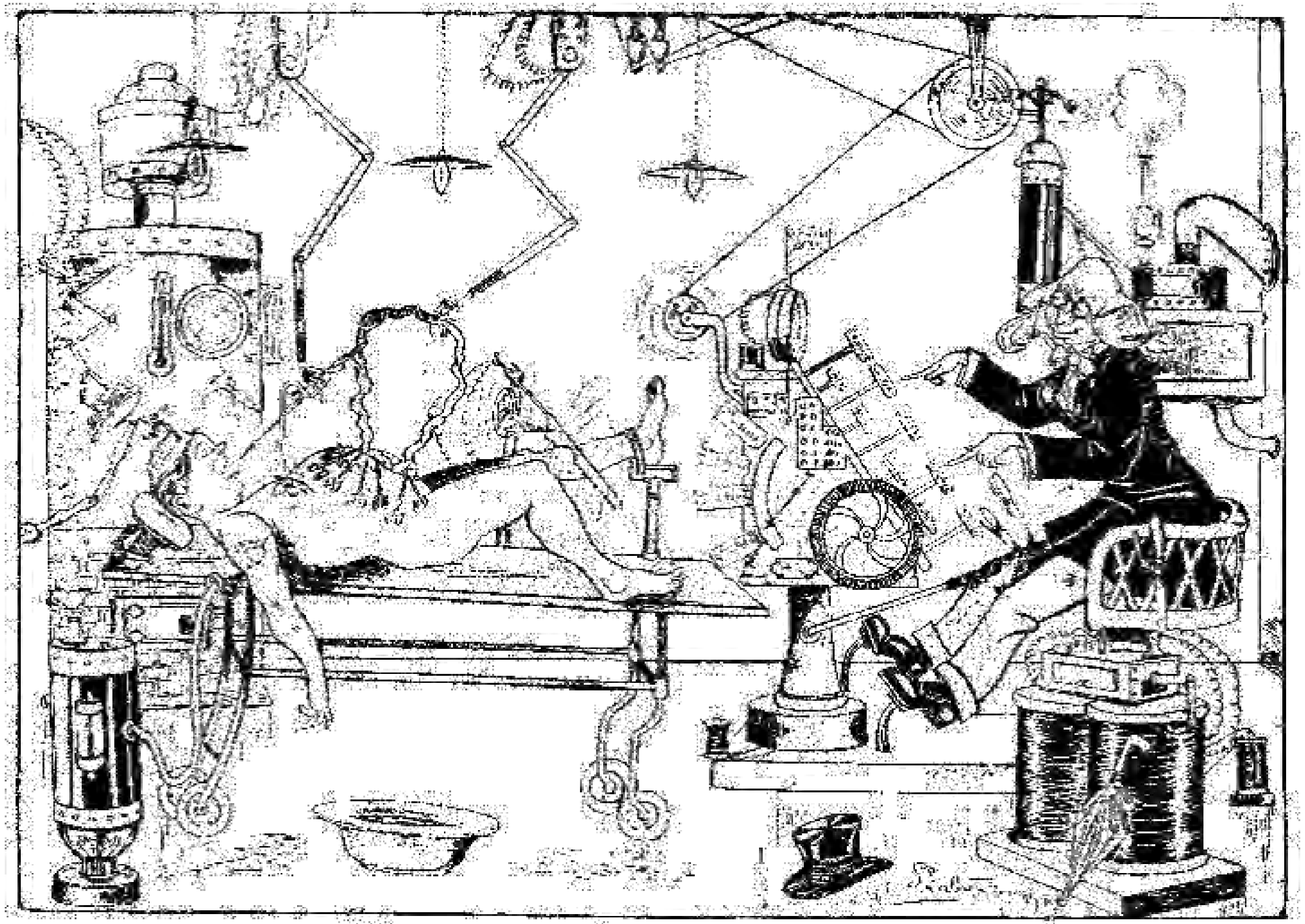
The future

- A surgical robotic system must work closely with OR staff, in a conventional OR environment
- Integrate tele-presence, MAS and collaborative robotics
  - General purpose
  - Easy to use
  - Drive up utilisation
  - Transform the economics – and so make it available

- Big data comes next



The Future



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