Mobile surgery Robot

Project final report – medical robotics course

Presented by Alexander Erick Trofimoff

EE PhD Student, Drexel University,

Philadelphia, PA, Fall 2011

ROBOT FOR SURGICAL APPLICATIONS

Inventors: **Dmitry Oleynikov**, Omaha, NE (US); **Shane Farritor**, Omaha, NE (US); **Adnan Hadzialic**, Lincoln, NE (US); **Stephen R. Platt**, Lincoln, NE (US)

Assignee: **Board of Regents of the University of Nebraska**, Lincoln, NE (US)

The designers

The tiny robots from Nebraska were co-designed by Dmitry Oleynikov, M.D., director of minimally invasive surgery at UNMC, and Shane Farritor, Ph.D., associate professor of mechanical engineering at the University of Nebraska-Lincoln. During live videoconferences, Dr. Oleynikov will guide the undersea astronauts, or aquanauts, in how to manipulate and position the mini-robots to help perform surgery

Dmitry Oleynikov, M.D., left, and Shane Farritor, Ph.D., discuss the surgical robots.

Dmitry Oleynikov, MD, FACS

Associate Professor, Department of Surgery
University of Nebraska Medical Center
Department of Surgery
983280 Nebraska Medical Center
Omaha, NE 68198-3280, USA
Phone: 402-559-4581
Fax: 402-559-6749

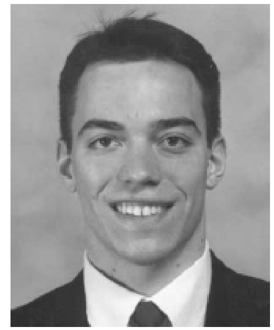
Curriculum Vitae

Graduate:	Albert Einstein College of Medicine, Bronx, NY
Residency:	University of Utah Medical Center, Salt Lake City, Utah
Fellowship:	University of Washington School of Medicine, Center for Videoendoscopic Surgery, Seattle, WA
Board Certification:	American Board of Surgery
Academic Appointment:	Associate Professor of Surgery
Other Appointments:	Co-Director of Education and Training Center for Minimally Invasive and Computer Assisted Surgery Initiative Medical Director for the Nebraska Medical Center's Minimally Invasive Surgery Program (MIS)

Shane M. Farritor received the B.S. degree from the University of Nebraska, Lincoln, in 1992, and the M.S. and Ph.D. degrees in mechanical engineering from the Massachusetts Institute of Technology, Cambridge, in 1998.

He is currently an Associate Professor of Mechanical Engineering at the University of Nebraska, and holds courtesy appointments in both the Department of Surgery and the Department of Orthopedic Surgery at the University of Nebraska Medical Center, Omaha. His current research interests include space robotics, surgical robotics, biomedical sensors, and robotics for highway safety.

Dr. Farritor serves as the Chairman of the American Institute of Aeronautics and Astronautics (AIAA) Space Robotics and Automation Technical Committee.



Mark E. Rentschler received the B.S. degree in mechanical engineering from the University of Nebraska, Lincoln, in 2001, the M.S. degree in mechanical engineering from the Massachusetts Institute of Technology, Cambridge, in 2003, and the Ph.D. degree in biomedical engineering from the University of Nebraska in 2006.

In 2003, he was a National Defense Science and Engineering Graduate Fellow at the Massachusetts Institute of Technology. He is currently a Postdoctoral Research Associate at the University of Nebraska Medical Center, Omaha. His current research interests include the areas of surgical robotics, mechanical design, tissue mechanics, and medical mechatronics.

Stephen R. Platt received the B.A. degree in physics and astronomy from Williams College, Williamstown, MA, in 1983, the M.S. and Ph.D. degrees in astronomy and astrophysics from the University of Chicago, Chicago, IL, in 1991, and the M.S. degree in mechanical engineering from the University of Nebraska, Lincoln, in 2003.

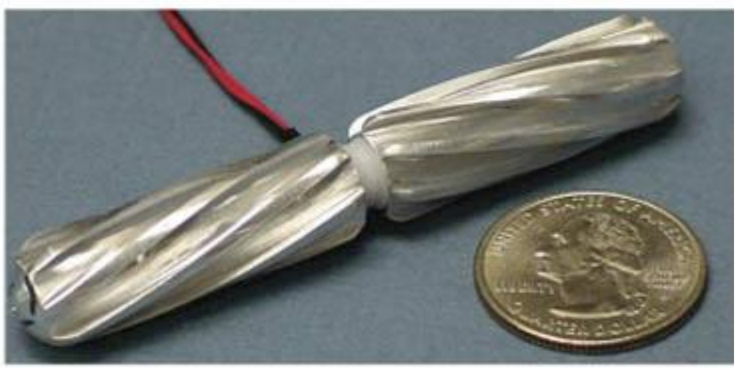
He is currently a Research Assistant Professor in the Department of Mechanical Engineering, University of Nebraska. His current research interests include biomedical sensors, surgical robotics, and millimeter-wave detector systems for observational astrophysics applications.

Publishing of this Research Project

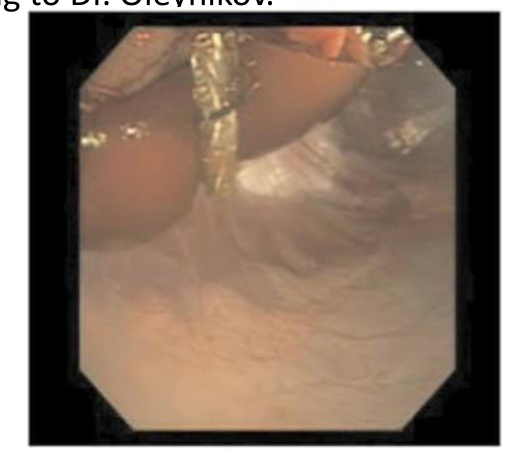
In one study at the 2006 annual meeting of the Society of American Gastrointestinal and Endoscopic Surgeons, Dmitry Oleynikov, MD, assistant professor of surgery, University of Nebraska Medical Center, Omaha, presented data on the use of a miniature wireless robot to explore and perform a biopsy in the abdominal cavities of two pigs.

The robots, measuring 12 × 55 mm and cylindrical in shape, were inserted through the mouth of the anesthetized pigs and entered the abdominal cavity through a gastrostomy that was created under esophagogastroduodenoscopic control. The robot provided an enhanced view of the abdominal cavity along with a number of different visualizations, was able to perform a biopsy and was then retrieved.

The most important finding of the study was "that natural orifice surgery was significantly improved when the endoscope was combined with the miniature robot to perform natural orifice procedures because the robot was free of the endoscope and its limitations," according to Dr. Oleynikov.



A wireless endolumenal mobile robot like this could one day be used to assist in natural orifice procedures.



The robot (in a pig's stomach) is able to pass through an endoscopically-created gastrostomy, provide visualization of the abdominal cavity and take a biopsy.

Challenging task of design

Dr. Oleynikov said that the main challenges of using an endolumenal mobile robot are its current large size and limitations of battery power.

"We are able to drive around and get angles you usually can't get with a single scope, because you can look from the back and side, and from up and down," explained Dmitry Oleynikov, MD, Assistant Professor of Surgery, and Co-director of Education and Training, at The Minimally Invasive and Computer-Assisted Surgery Initiative, at the University of Nebraska Medical Center in Omaha.

Dr. Oleynikov is studying the use of miniature mobile robots, one of which is shown here being maneuvered within the abdominal cavity of a pig.

Minimally Invasive Surgery : Haptics (The competition)

- Minimally invasive surgery (MIS) reduces patient trauma and shortens recovery time, but also limits the dexterity of the surgeon because degrees of freedom are lost due to the fulcrum effect of the entry incisions.
- Visual feedback is also limited by the laparoscope, which typically provides two-dimensional feedback and is constrained by the entry incision. Developments within surgical robotics aim to mitigate these constraints.
- However, these developments have primarily included large external machines that augment vision and improve dexterity, but are still fundamentally constrained by the use of long tools through small incisions.

Important features on this new surgical Technology

- A new area of surgical robotics focuses on placing robots entirely inside the patient. These i*n vivo* robots currently lack some of the precise control provided
- This alternative concept is the use of miniature in vivo surgical robots that can be placed entirely into the peritoneal cavity through either an abdominal incision, or, after insertion into the stomach through the esophagus, can enter through a gastrostomy.
- The main advantage is the ability to externally control a robot that is located completely inside a cavity to accomplish interventional therapeutic goals.

Minimally Invasive Surgery Laparoscopic MIS (The competition)

- Robotic arms are long and bulky to allow the necessary range of motion for maneuverability of the tools. Moreover, large excursion arcs of the arms result in frequent collisions outside of the patient, and if ports are incorrectly positioned collisions can occur inside the patient as well.
- The widespread use of these robotics for laparoscopic MIS remains limited due to high cost, large size, and the diminished impact of the dexterous improvements in the performance of less complex laparoscopic procedures.
- *In vivo* robots are small, inexpensive, and easily transported, making it more likely that this technology can be more widely adopted.

Important features of surgery in vivo robots

- The objective is to develop wireless imaging and task-assisting robots that can be placed inside the abdominal cavity during surgery. Such Robots will provide surgical task assistance and enable an on-site or remote surgeon to view the surgical environment from multiple angles.

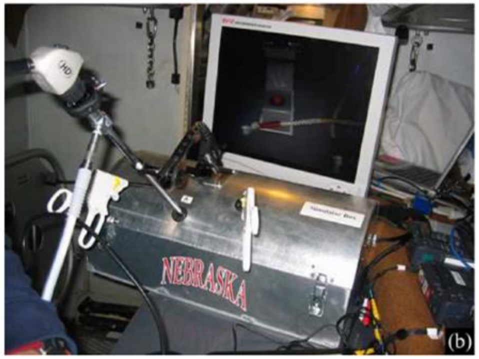


Fig. 1. (a) Abdominal cavity simulator equipment setup and (b) prepared for task completion in the Aquarius habitat.

Improvements to come in the future

- As these robots get smaller, however, he envisions their increased potential use as a replacement for conventional laparoscopy.

- “Our research shows that the miniature robots one day may be swallowed in the surgeon’s office and can be remotely controlled in order to perform internal surgical procedures and have the patient return home and safely pass the robots without abdominal wall scars or incisions,”

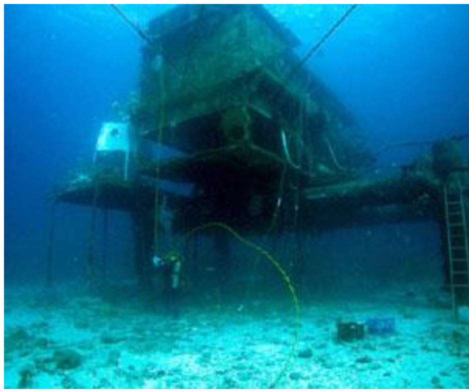
- Steven Schwaitzberg, MD, chief of surgery, Cambridge Health Alliance, Cambridge, Mass., emphasized both the investigative nature of the work as well as its exciting potential. “This is not a near-future project, but it is not science fiction either,” he said. “It is obvious that there will be a collision of this technology with nanotechnology, maybe to look for metastases or clean up infections or adhesions. In less than 10 years, we will see a viable clinical application.”

Exclusive market of space exploration : Telemedicine in orbit or even in other worlds

- This approach is applicable to long-duration space flight, battlefield situations, and for traditional medical centers and other remote surgical locations.
- National Aeronautics and Space Administration (NASA) using the Aquarius underwater habitat to test telerobotic surgery in remote and extreme environments.
- The NASA Extreme Environment Mission Operations (NEEMO) uses Aquarius several times each year to provide analogous extravehicular activity (EVA) and extended duration training for Astronauts.
- During NEEMO 9, *in vivo* robots from the University of Nebraska were also tested and evaluated by the crew. All four members of the crew performed simulated surgical tasks that included bowel inspection, stretch and dissect, and appendectomy procedures.
- The NEEMO 9 mission is a joint project of McMaster University's CMAS at St. Joseph's Healthcare, the U.S. Army Telemedicine and Advanced Technology Research Center, the National Space Biomedical Research Institute, NASA, and the Canadian Space Agency.

"These robots, with suggestions from doctors on earth, would allow astronauts to perform a number of different emergency surgeries in space," Dr. Oleynikov said.

As NASA sends more astronauts to explore Mars and the moon, surgical needs could arise during expeditions. This is NASA's ninth underwater NEEMO mission. NEEMO stands for NASA Extreme Environment Mission Operations.



The underwater habitat, called Aquarius, is 63 feet below sea level and models the isolated environment in which astronauts work. The procedures simulated in Aquarius may one day be used to respond to emergencies on the International Space Station, the moon or Mars.

One of the tasks assigned to NEEMO's aquanauts is to use the mini-robots to help perform a laparoscopic appendectomy on a human simulator. The benefit of performing surgery laparoscopically is it requires very small incisions and generally leads to a much quicker surgical recovery.

During the simulated appendectomy, Dr. Oleynikov will tele-mentor the aquanauts to insert the lipstick tube-sized robots into the "pretend patient" through laparoscopic tubes. One of the robots has a camera that tilts and pans. The other robot is also fitted with a camera, but is mobile and can be directed to move within the abdominal cavity. Both give the surgeon much better views of the abdomen than traditional laparoscopic cameras, which have very little mobility.

Competition : **Externally Manipulated haptic and Endoscopy robots.**

- Commercially available MIS robotics, such as da Vinci (Intuitive Surgical), generally have multiple arms that are tele-operated by the surgeon. These robots attempt to augment surgical dexterity and visual feedback through features including articulating end effectors, tremor filtering, motion reversal correction, stereoscopic vision, and motion scaling.
- Another approach for exploring the gastrointestinal (GI) tract is swallowing an untethered camera pill. One such commercially available device, called M2 A from Given imaging Ltd , returns multiple(thousands) of images as It naturally moves through the GI tract. However, because the device is entirely passive, it Cannot be directed to image a particular location and the exact locations of the images are not known.
- The simplest such mechanisms have been endoscopes that include actuators that can turn the endoscope tip after it enters the body , leaving the power and control equipment outside the body.
- Other scopes developed to explore hollow cavities such as the colon or esophagus have included locomotion systems based on “inch-worm” motion that use a series of grippers and extensors , rolling tracks , or rolling stents .
- Combined with the very large volume of images, the use of this device for diagnosis is difficult.
- Other work has focused on a mobile robot to traverse the surface of a beating heart .This robot uses suction cups and has demonstrated successful prehension, turning, locomotion, and dye injection in a porcine (pig) model.

Evolution of In vivo MIS Robots

Fixed-base robots

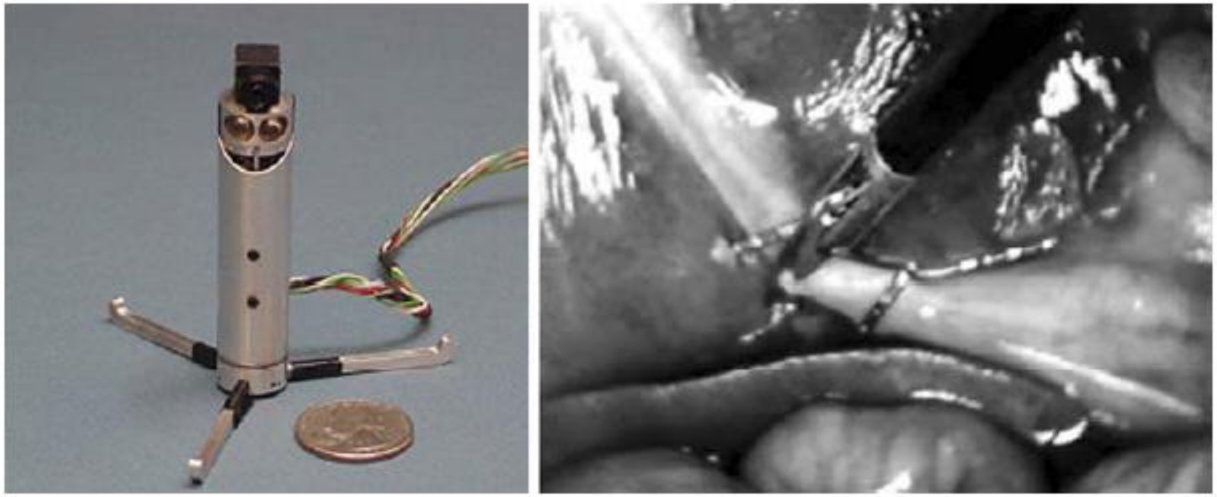
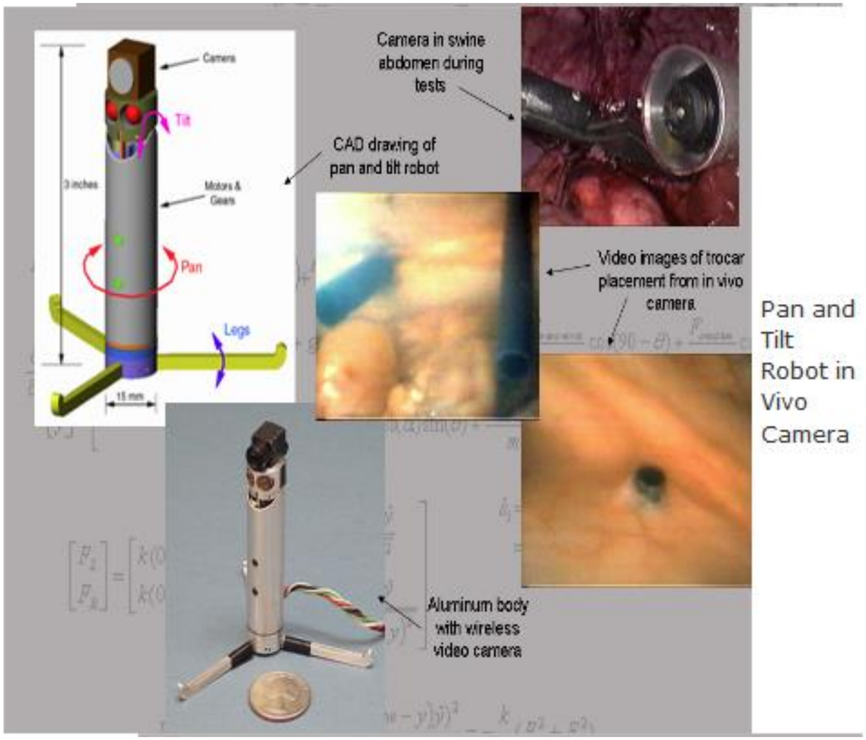


Fig. 1 Pan and tilt camera robot (*left*) provides visual feedback during cholecystectomy (*right*)

The primary objective of laparoscopic robots with a fixed-base platform is to provide auxiliary viewpoints of the surgical field, thereby augmenting vision and improving depth perception.

These robots are placed by the surgeon using traditional laparoscopic tools and can be relocated throughout a procedure without the need for a new incision.

Initial work within this area has led to the development of a miniature pan and tilt camera robot.



Pan and Tilt Robot in Vivo Camera

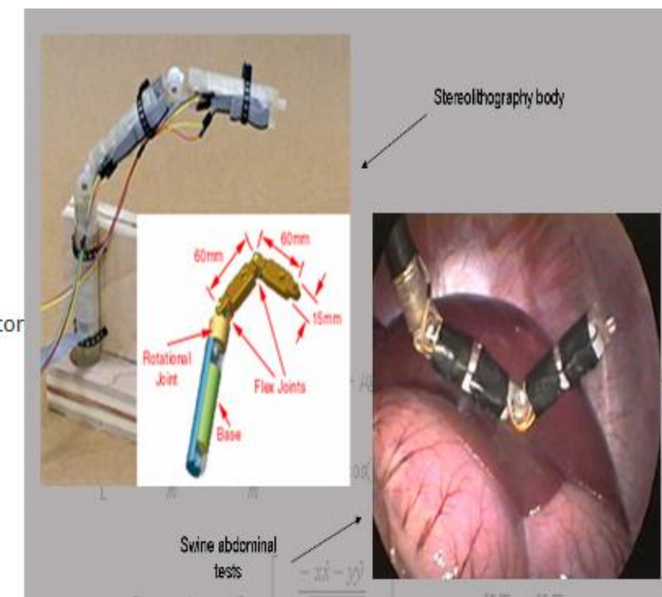
Fixed-base robots

The robot, rotates the camera about two independent axes, allowing for panning of 360° and tilting of +-45°.
Illumination of the surgical field is accomplished using two light-emitting diodes (LEDs).

The platform of this robot consists of legs that are abducted by torsion springs.

The platform design and the 15 mm diameter housing allows for the insertion of the robot using a standard laparoscopic port.

Robot Manipulator

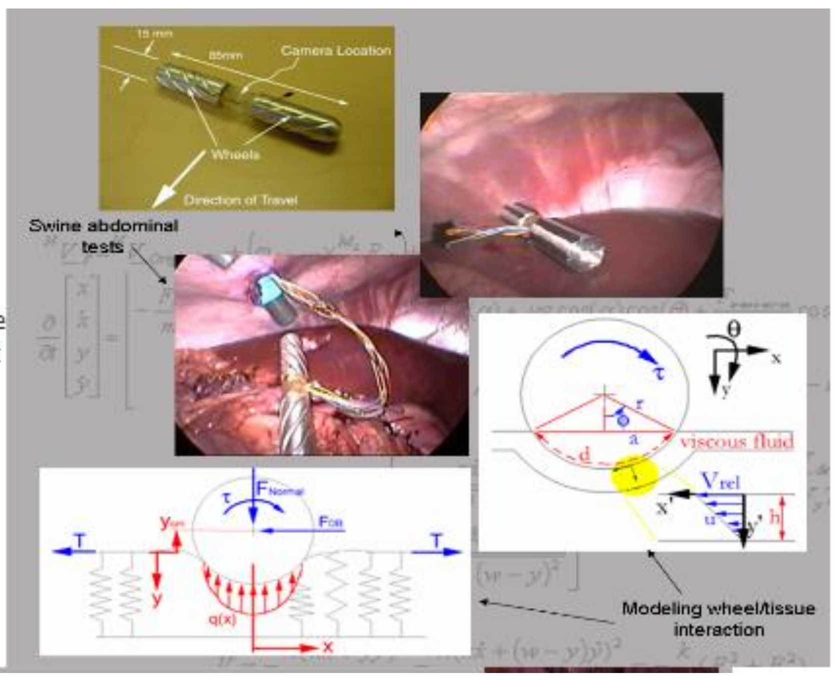


Mobile robots

Mobile robots provide a remotely controlled movable platform for vision and surgical task assistance. The basic design of a mobile robot consists of two independently driven wheels that provide for forward, reverse, and turning motion.

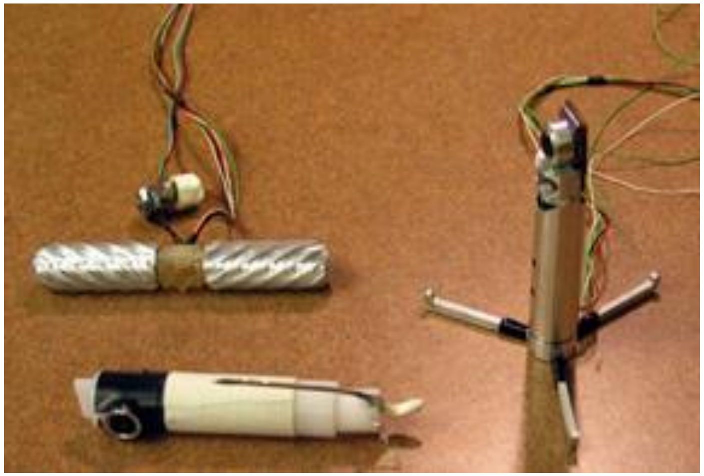
A tail prevents counter-rotation while allowing the robot to reverse directions. Viscoelastic modeling together with bench top and in vivo testing led to the development of a helical wheel design for the mobile robot .

Mobile Robot



A helical wheel design robot with a 15 mm diameter, has proven maneuverable on all of the pelvic organs (liver, spleen, small and large bowel) and capable of climbing highly deformable structures two to three times its height without causing any visual tissue damage in a porcine model.

The three generations of MIS mobile In vivo Robots



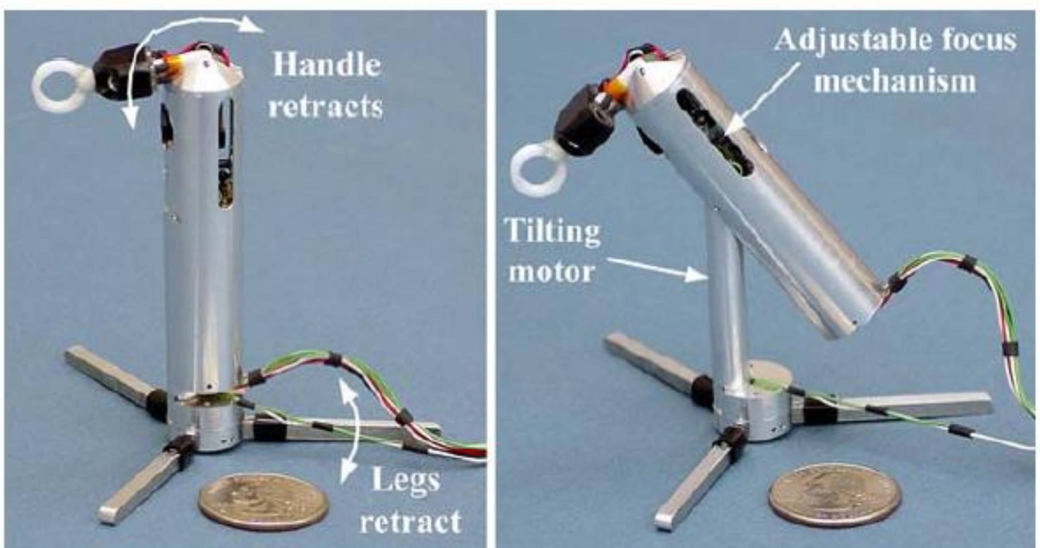


Fig. 4. The tilting camera robot design included a spring-loaded handle that the surgeon can grasp during retraction. The tripod legs are also spring-loaded so that they can be abducted during retraction.

Mobile MIS robots : Imaging Technology

- A similar mobile robot with the addition of an adjustable-focus camera for vision assistance has also been developed. The adjustable-focus capabilities of the camera allows for a greater understanding of depth within the peritoneal cavity and the views provided are comparable to those from currently available laparoscopes.

- Similar to the fixed-base robots, the mobile adjustable-focus robotic camera aided the surgical team with the planning and vision for additional trocar insertions, and with tool placement during a laparoscopic gall bladder removal in a porcine model .

- Throughout this procedure, the mobile camera robot provided the sole visual feedback thereby demonstrating the potential for reducing patient trauma through the removal of the third camera port incision.

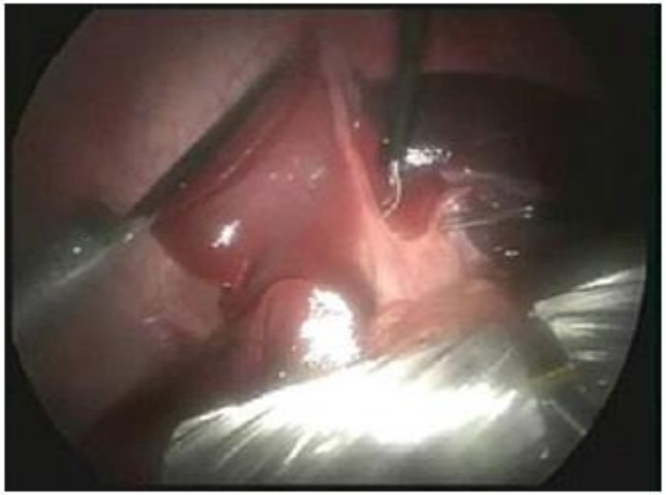


Fig. 3 Mobile camera robot provides visual feedback for cholecystectomy as viewed by laparoscope

Testing of the wheels for best locomotive system on alive tissues

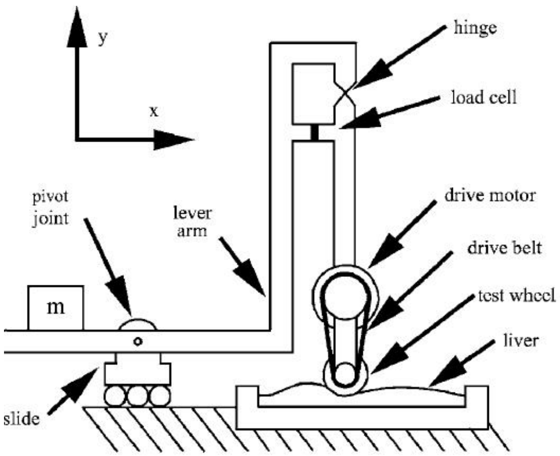


Fig. 3 Laboratory bench-top wheel test platform schematic

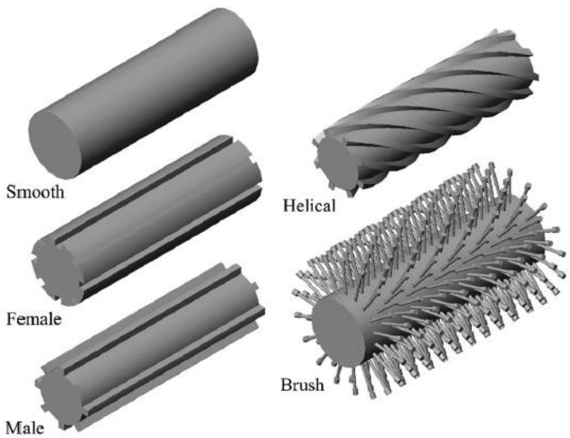


Fig. 5 Five different wheels tested in the laboratory using the wheel test platform

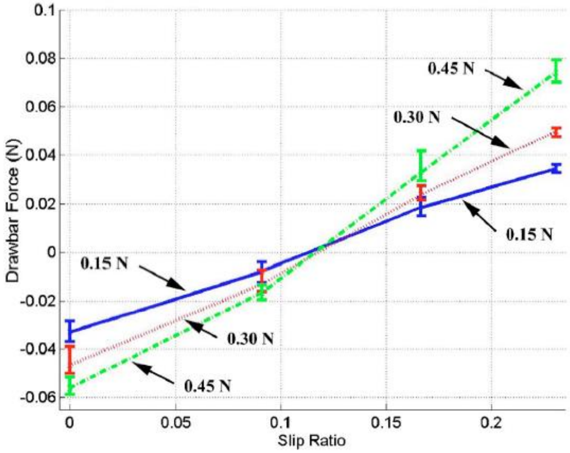


Fig. 6 Helical wheel test platform laboratory drawbar force results for three different robot weights (0.15 N, 0.30 N, and 0.45 N) and four different slip ratios (SR=0.00, 0.09, 0.17, and 0.23)

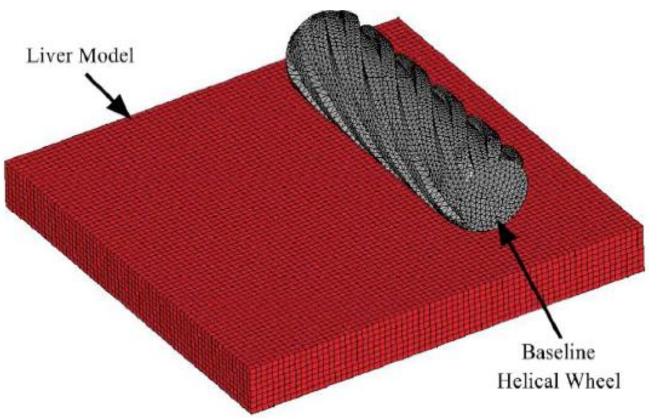


Fig. 7 Finite element simulation model using the baseline helical wheel

MIS mobile In vivo robots : Locomotion, Grasping and Extraction of tissues

The robot was then driven using remote control to
the chosen
site.

The grasper was used to cut almost all of the tissue with the remainder being pulled free by driving the robot slowly away from the biopsy site.

The tissue sample was then extracted and retrieved. The successful completion of this porcine test demonstrated the capability to perform a one-port laparoscopic biopsy.

A 12 mm diameter in vivo mobile robot, was able to traverse within the gastric cavity under esaphagogastroduodenoscopic (EGD) control upon insertion using a sterile over tube.

The ability to traverse the entire peritoneal cavity was demonstrated. For this procedure, the robot was observed using an endoscope.

After successfully demonstrating the mobility within the peritoneal cavity, the endoluminal robot was retracted into the gastric cavity and retrieved using an endoscopic snare.

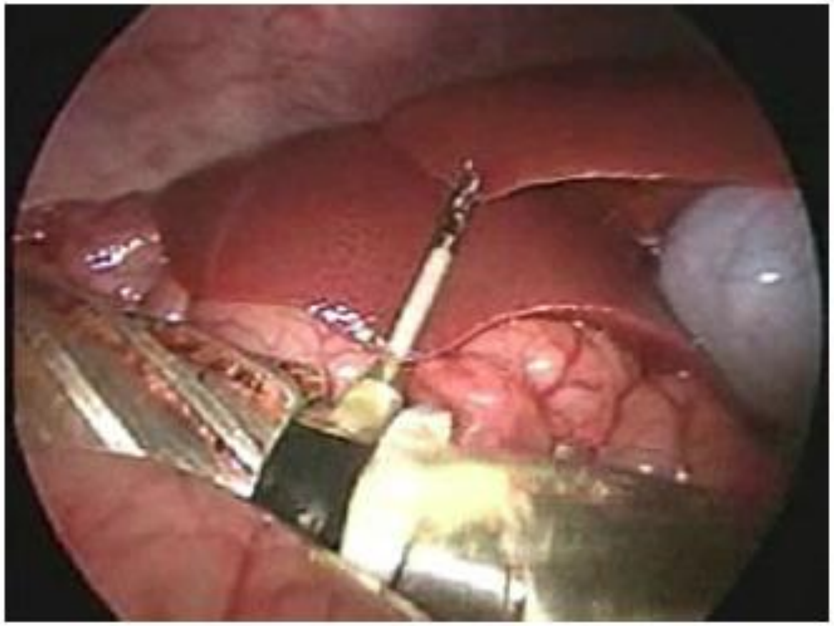


Fig. 4 Mobile biopsy camera robot performs biopsy of hepatic tissue as viewed by laparoscope

Locomotion, Grasping, Extraction MIS mobile Robots : Future improvements of these miniature robots

- The further development of wireless capabilities and the design of a biopsy grasper capable of clamping a severed artery are important for the application of in vivo robotics as a remote first responder in forward environments such as battle-fields.
- With the integration of a camera and a manipulator, the endoluminal mobile robot could provide assistance during procedures within the peritoneal cavity.
- Eventually, minimally invasive procedures will incorporate a team of miniature in vivo robots equipped with sensors and manipulators to cooperatively assist the surgical team from within the gastric or peritoneal cavity.

Demonstrations have shown the effectiveness of these devices for biopsy, investigation, and as an assist device for complex surgical procedures.

It is conceivable that smaller robots with more-complex control functions will be used in a variety of applications from intravascular to intracranial.

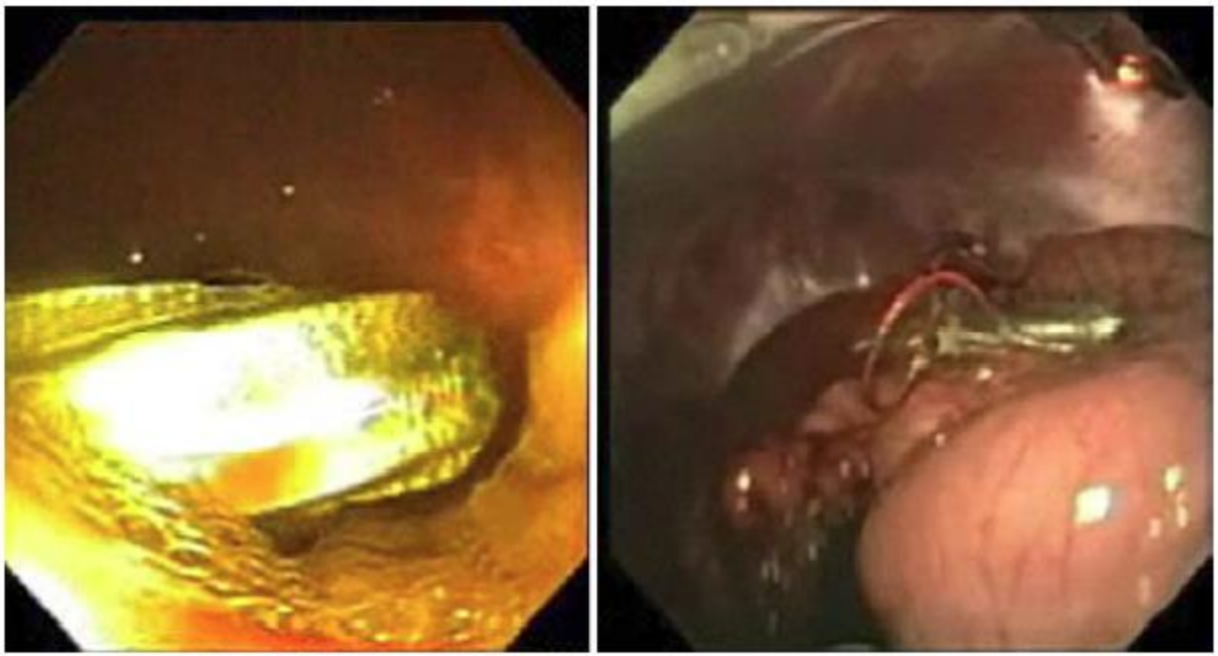


Fig. 5 The 12 mm mobile robot successfully traverses within the gastric (*left*) and peritoneal (*right*) cavities

Perhaps future robots will even be small enough to be used on a cellular basis. Such machines would be delivered through needles or would be swallowed instead of being inserted through large incisions.

The next generation of Surgical Robots

A prototype next generation surgical robot will be evaluated with surgeons in Hamilton, Canada, attempting remote surgical procedures using the robot and a patient simulator in the Aquarius Undersea Habitat.

Medical responders of the future may be three inches tall or less. But, these tiny-wheeled robots - slipped into the abdomen and controlled by surgeons hundreds of kilometers away - may be giants in saving the lives of roadside accident victims and soldiers injured on the battlefield.

Each camera-carrying robot -- the width of a lipstick case -- would illuminate the patient's abdomen, beam back video images and carry different tools to help surgeons stop internal bleeding by clamping, clotting or cauterizing wounds.

The 3-inch long, aluminum-cased robots contain gears, motors, lenses, camera chips and electrical boards. "Three inches seems to be our limit at the moment because of the electrical components we use," said designer Mark Rentschler, a Ph.D. candidate in biomedical engineering at UNL. "If we were to make 1,000 robots we would be able to afford customized electrical components that would reduce the size of the robot by half."

University of Nebraska Design Team

The design team said initially the mini-robots will be single-use devices, although they eventually may be able to be sterilized for multiple use.

The group intends to create a local, spin-off company and then seek FDA approval of the devices, which would be applicable for any laparoscopic or minimally invasive surgery - from gall bladder to hernia repair.

"We're the first in the world to come up with this technology," Dr. Oleynikov said. "Everybody knows this is a Nebraska effort.“

The tiny robots were designed by a team of graduate students and researchers led by Oleynikov and Shane Farritor, an associate professor of mechanical engineering at the University of Nebraska-Lincoln.

The mobile robot has an edge over traditional laparoscopic surgery — which uses a camera at the end of a tube— because it can move around and give a surgeon much better views from different angles.

The use of a robot also requires fewer incisions and is less invasive.
“With traditional laparoscopic surgery you’re pretty much confined to one area unless you make another hole,”

A Potential new market for Robotic Surgery: Battle field Medical attention



The cutting-edge technology has its roots in the Mars Rover program. Before coming to UNL in 1998, Farritor was involved in Mars Rover research at the Massachusetts Institute of Technology.

He helped develop a sensor that allows rovers to locate the sun. Farritor is still conducting Mars Rover research at UNL but has since branched out into the field of medical robotics.

Farritor said the U.S. Army is interested in the robotic research because it needs to do surgery in remote areas.

"Almost all battlefield deaths occur in the first 30 minutes because of severe abdominal bleeding," he added. "The idea is to give surgical assistance when soldiers fall."

Currently, each robot is built one at a time at a cost of about $1,500, not counting student labor, Farritor said.

Technical aspects of the Design

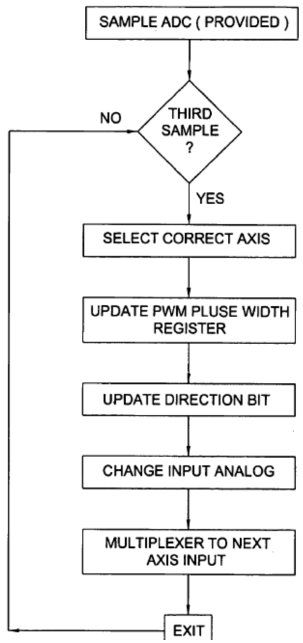


FIG. 20

FIG. 20 is a flowchart for an interrupt service routine used in one embodiment of the manipulator arm of the present invention.

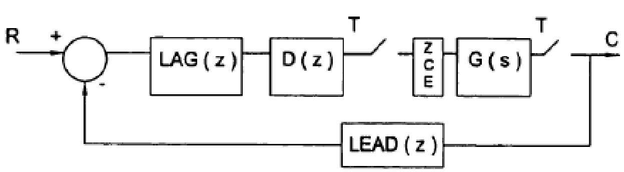


FIG. 30

FIG. 30 is a system block diagram for a final design of a controller of a three-link manipulator arm according to one embodiment of the present invention.

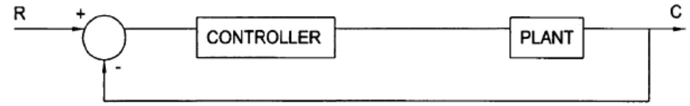


FIG. 21

FIG. 21 is a block diagram of a controller and plant for a modern control system for control design of a three-link manipulator arm according to one embodiment of the present invention.

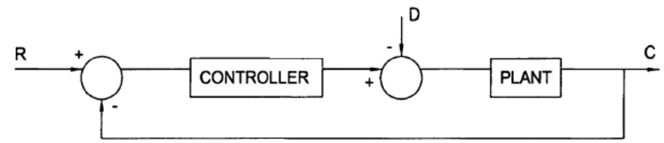


FIG. 22

FIG. 22 is a block diagram of a controller and plant for a modern control system for a three-link manipulator arm according to one embodiment of the present invention. In this block, a disturbance is included.

FIG. 25

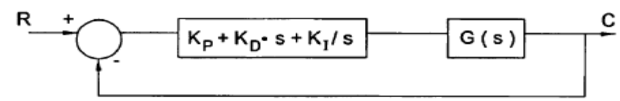


FIG. 25 is a system block diagram for a controller based on Ziegler-Nichols tuning.

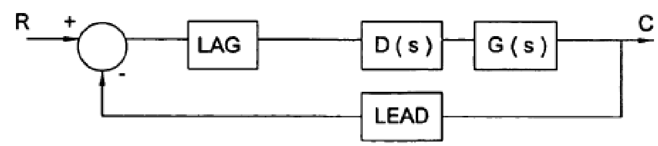


FIG. 28

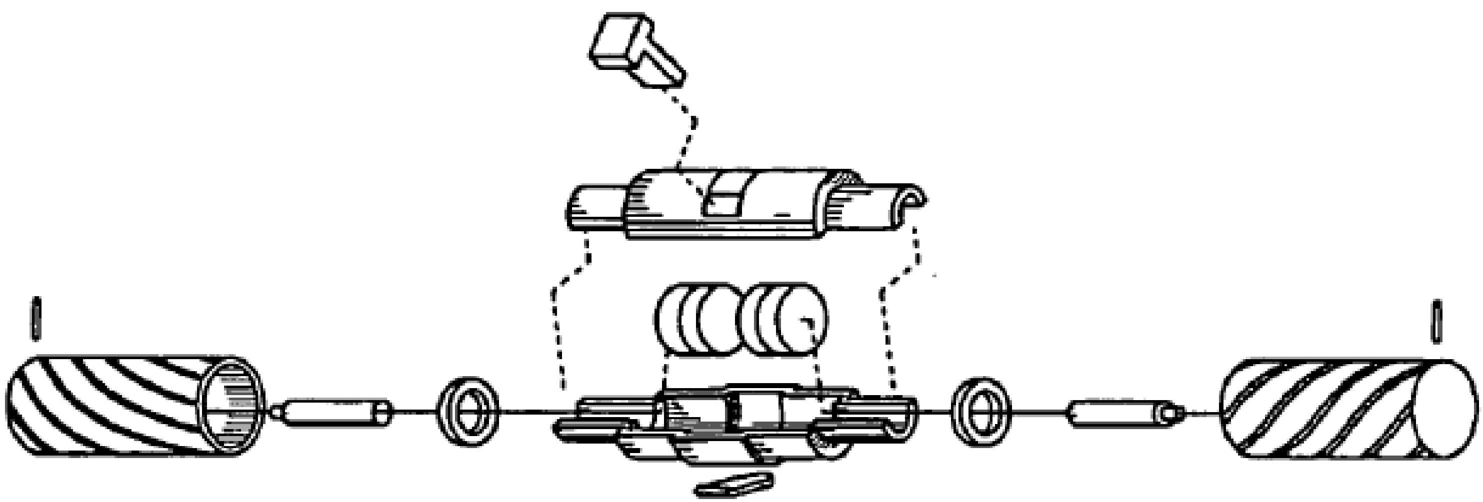
FIG. 28 is a system block diagram for a controller with lead and lag compensators integrated into the design.

Why it was needed this surgery mobile robot?

This device facilitates surgery in a way
Laparoscopic one cannot, since this one
Lacks of the important sensory feedback,
Limited imaging and very reduced mobility
With a major invasive technique.

This mobile robotics approach is able to enhance
All these aspects improving perception and access
To the organs that are treated.

The present invention provides robotic wired and wireless manipulator, imaging and sensor devices for use in vivo. The robots may take on any configuration and be equipped with any number of sensors, manipulators or imaging devices. There are hundreds of different components known in the art of robotics that can be used in the construction of the robots of the present invention; for example, there are hundreds controllers, motors, power supplies, wheels, bodies, receivers, transmitters, cameras, manipulators, and sensing devices that can be used in various combinations to construct robots according to the present invention.



Assembling of the MSI in vivo Mobile Robot

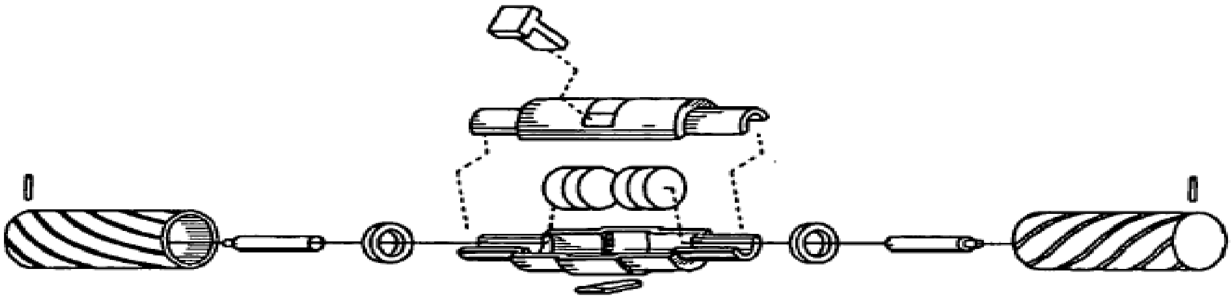


FIG. 5

Based on the criteria described, an initial concept was created using a UniGraphics® solid modeling and component assembly. The main body of the initial device was made up of two nearly identical halves. The camera and LED were mounted to the top half, while the tail extended from the bottom half.

To assemble the robot, the LED and camera were attached to the top half of the body. Next, the batteries, motors, tail and other electronic components were installed into the bottom half of the body. The two body halves were brought together and a nylon bushing was pressed over each end. The motors and batteries were held tightly within the body. Finally, the wheels were pressed onto the motor shafts.

The central space within the body housed two batteries and the electronic components required to control the motors and transmit the video signal. The motors were held in the slots at each end of the body. The wheels were designed to be as long as possible to minimize surface contact with the center section. Nylon bushings were used to support the inside diameter of the wheels and prevent wobble. The bushings were a light press fit with the body halves and had a smooth running fit with the wheels. The wheels had a line-to-line fit with the motor shafts.

Due to the very small size and relative complexity of the main body, machining appeared to be an unlikely method of fabrication. The only remaining inexpensive, rapid prototyping method was stereolithography. The wheels were to be turned from a solid aluminum bar. Any number of flexible materials could be used for the tail. An exploded perspective of the initial prototype is shown in FIG. 1.

New capabilities provided in this surgery robot:

This approach provides semiautonomous and
Autonomous remotely controlled robots that are
Able to move inside cavities, becoming a less
Invasive technique of surgery.

More sensors, more cameras or manipulators
Provides an stereoscopic image of the abdominal
Cavity, all this in only one incision on the body.

The prototypes has a form that facilitates at the same
Rapid insertion in the body and mobility with wheels
That can run over any surface of organs or tissues.

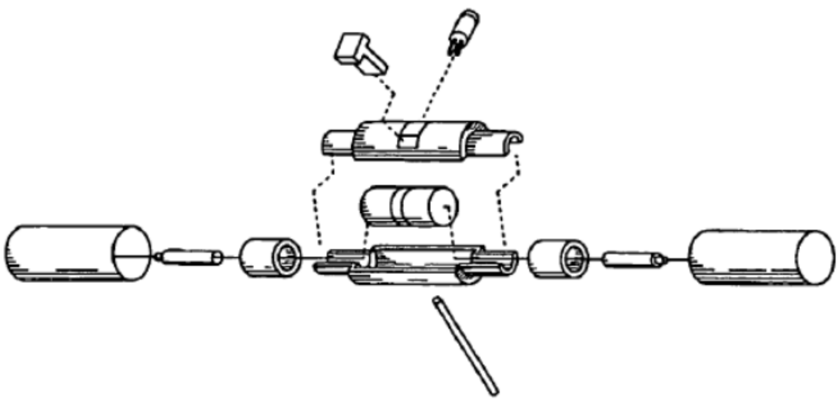


FIG. 1

An exploded perspective of the second version of the mobile robot is shown in FIG. **2**. The primary changes are the addition of wheel set screws and a flattened tail. In addition, the LED was removed as the purpose of the initial prototypes was to maximize mobility and maneuverability.

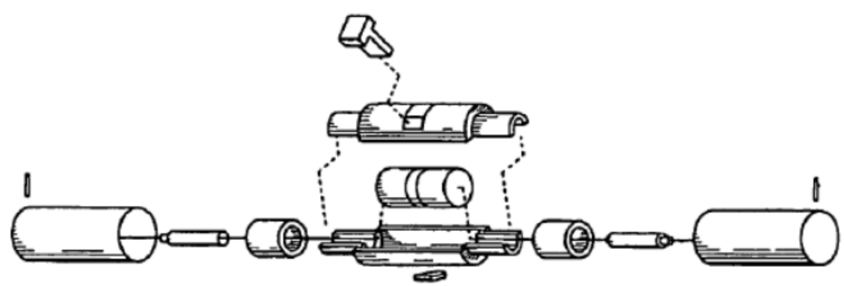


FIG. **1** is an exploded view of the initial prototype of the mobile robot.

FIG. **2** is an exploded view of the second prototype of the mobile robot.

FIG. 2

Adaptive Locomotion system:

Avoiding the rigid laparoscopic tools this robot
Has many possibilities of locomotion, not only
Wheels but can be adapted to legs, inchworm or
Snake configurations that can move by contortions
Through any possible cavity of the body.

An exploded perspective of the third version of the mobile robot is shown in FIG. 3. The primary changes were that the two batteries were replaced with four smaller batteries and reduced diameters on the wheel and main body.

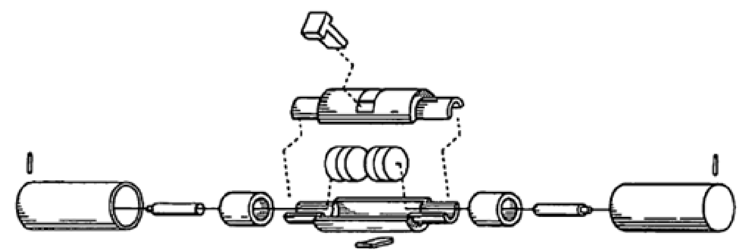


FIG. 3

Version four of the mobile robot is shown in FIG. 4. The primary changes were the enlarging of the center section from ø10.4 mm to ø13 mm and the addition of 3 mm wire channels. Since the walls of main body were very thin and stereolithography can make very complex shapes, a 0.5 mm radius was also added to all interior angles.

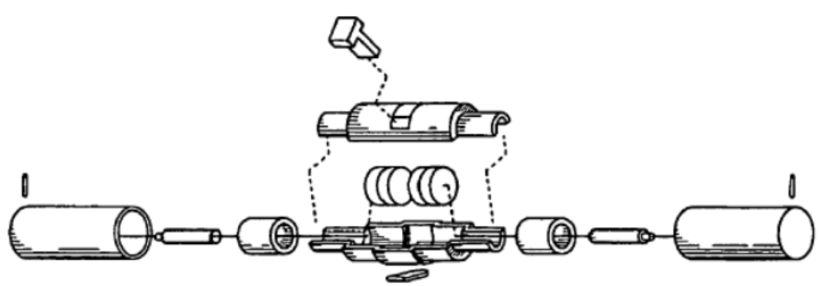


FIG. 4

FIG. **3** is an exploded view of the third prototype of the mobile robot.

FIG. **4** is an exploded view of the fourth prototype of the mobile robot.

Locomotion:

FIG. 5 is an exploded view of the fifth prototype of the mobile robot.

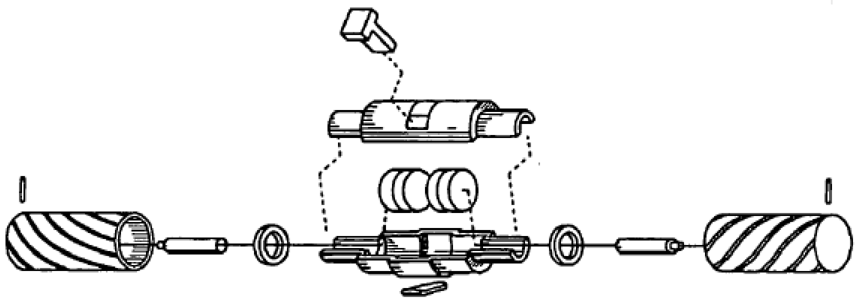


FIG. 5

Special form and better range of motions:

With a cylindrical form, and a diameter of less than 15 mm this robot can be inserted to a standard medical Port.

With textured wheels, in spiral, like the ones of modern land rovers, the current prototypes have a traction that permit not only the motion but the actual climbing of any possible wet surface in side the body.

Additionally provided with a set of differential Motions that is several times finer than
any thing done Before in Laparoscopy , also allowing the surgeon to Work on very specific areas without causing damage to the Surrounding tissues.

Improved traction :

The lack of enough traction that the first Prototypes showed working inside animal Bodies, caused due to the softness of the Surface of the organs, with very small friction Coefficient unable to provide enough resistance To the torques of the wheels, was overcome By doing a force analysis based on elastic Foundation, assuming that the robot will roll On elastic surfaces.

Great care with the fragility of inner body surfaces:

Each wheel is able to produce enough shear torque against the Internal organs to move as required While not damaging the tissues.

Great directionality :

Allowing it to move forward, backward and to turn in the smallest possible circle, with a two wheel traction. This is possible using skid Steering, like the war tanks, with motors rotating at different speeds or directions. Therefore each Wheel is controlled individually and also provided With a separate motor.
The robot was designed such it would not become High centered on its tail or on the non rotating center section, in this way it m minimizes the area that contact the organ surfaces.

Dynamics of the MIS mobile robot

The next step in choosing a motor was to determine how much torque would be needed to move the robot. To calculate the needed torque, a free-body diagram of the robot sitting motionless on a slope was used to calculate the torque required to keep the robot stationary on the slope. This calculation would be the stall torque that the motor would need (provided that the friction of the surface was enough to prevent the wheels from slipping). The free-body diagram is shown below in FIG. **6**.

From this free-body diagram the following equations were written:

$$(W \sin\theta)r = (ma) + I\alpha + \tau$$

$$W \sin\theta - f = ma$$

$$W \cos\theta = N$$

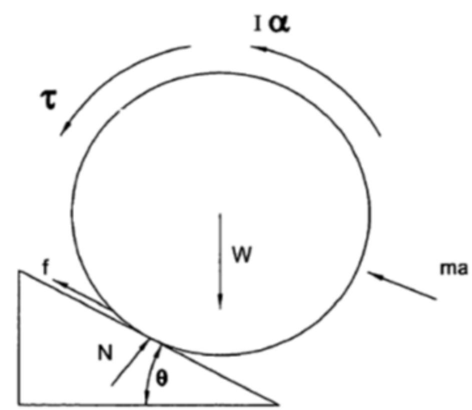


FIG. 6

FIG. **6** is a free body diagram of the mobile robot sitting motionless on a slope.

This results in the following:

$$\tau = (W \sin\theta)r$$

where

W is the weight of the cylinder,

θ is the angle of the slope,

r is the radius of the cylinder,

m is the mass of the cylinder,

a is the acceleration of the cylinder,

I is the moment of inertia of the cylinder,

α is the angular acceleration of the cylinder,

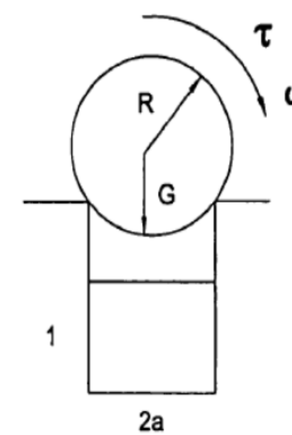
τ is the torque of the motor,

f is the friction between the cylinder and slope,

N is the normal force.

FIG. **7** is an elastic body model used in friction analysis of the mobile robot.

FIG. 7



Actuators of In vivo MIS Robots :

Likewise, actuators useful in the present invention may be of many types. The mobile robot described herein used a Nakamishi brushless direct current motor that has been used commonly in robotic and other applications. These motors require external communication, generally performed by a circuit supplied by the manufacturer. The manipulator described in the Example herein used a permanent magnet DC motor made by MicroMo™. Again, permanent magnet DC motors are commonly used devices. However, other devices would be useful in alternative embodiments of the present invention, including shape memory alloys, piezo-electric-based actuators, pneumatic motors, or hydraulic motors, or the like. Pneumatic and hydraulic motors are efficient, but the pump generally must be external to the robot. Thus, such motors may be useful in a tethered or wired embodiment of the present invention, but not in the wireless embodiment of the present invention.

FIG. 8

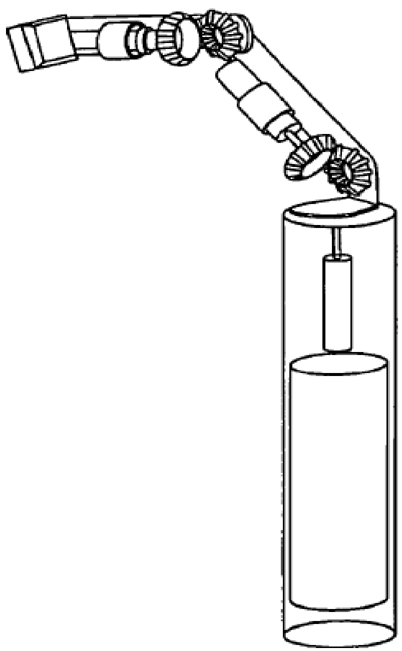


FIG. 8 is a CAD drawing of one embodiment of a manipulator arm according to the present invention.
FIG. 9 is a CAD drawing of another embodiment of a manipulator arm according to the present invention.

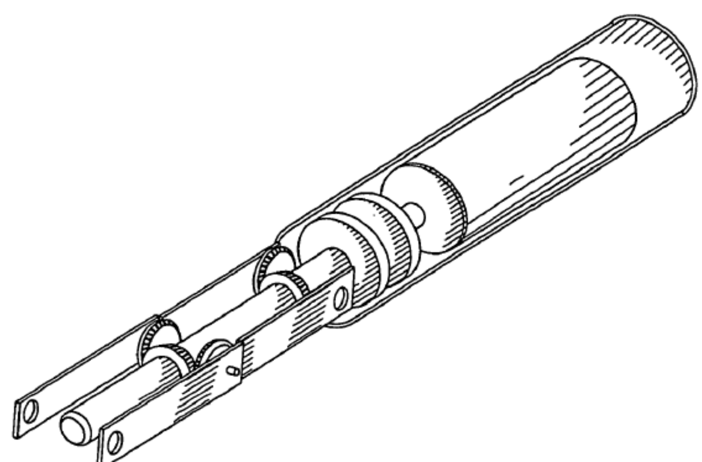


FIG. 9

Unique Wireless surgery robot:

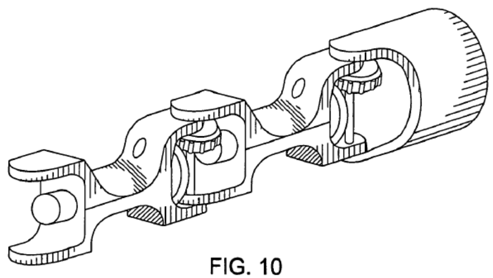


FIG. 10

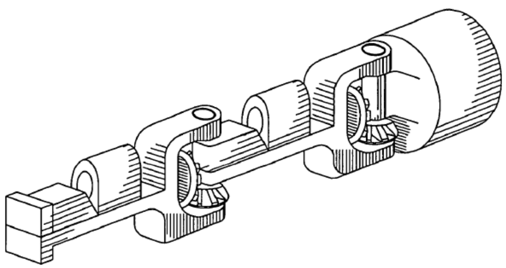


FIG. **10** is a CAD drawing of yet another embodiment of a manipulator arm according to the present invention FIG. **11** is a CAD drawing of yet another embodiment of a manipulator arm according to the present invention.

FIG. **12** is a CAD drawing of yet another embodiment of the manipulator arm according to the present invention.

FIG. **13** is an expanded CAD drawing of the embodiment of a manipulator arm shown in FIG. **12**.

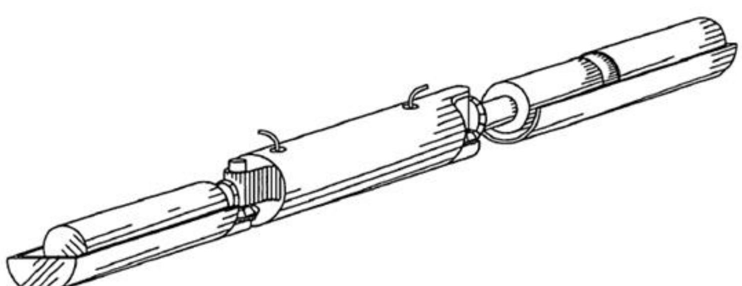


FIG. 12

With cameras and lighting led mounted on to the Main body of the robot it is possible to provide the Needed steadiness to give orientation to the operator Surfing inside the cavities.

The wireless embodiment of the robot carry its own power source to operate the motors and the cameras.

This also suppose the existence of motors with wireless receivers to proceed the Commands that are transmitted by the operator.

Other embodiment of the robot carries a lot of sensors that are able to measure a lot of Parameters like temperature, pressure, presence Of gases or humidity.

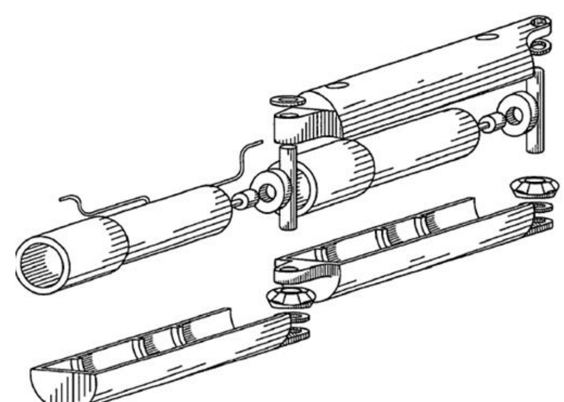


FIG. 13

Power supply for the MIS in Vivo robots:

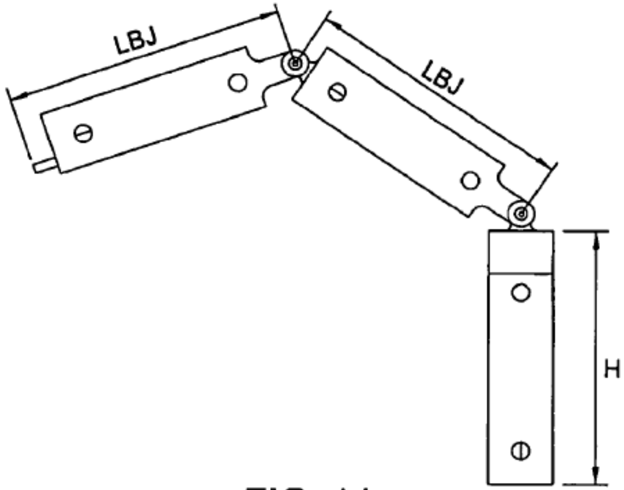


FIG. 14

FIG. **14** is a model of the manipulator arm used to determine the Jacobian.

FIG. **15** is a top view of one embodiment of a manipulator arm according to the present invention.

FIG. **16** is a model of one embodiment of a manipulator arm according to the present invention labeled with the parameters used to determine properties of the links.

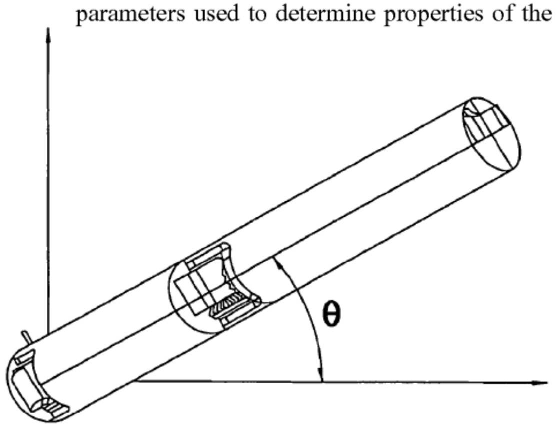


FIG. 15

When selecting a power supply, both the mobile robot and the manipulator of the present invention used external power supplied in a tethered configuration, but in an alternative embodiment, could have been powered by batteries. Versions of the robot and/or manipulator of the present invention may use alkaline, lithium, nickel-cadmium, or any other type of battery known in the art. Alternatively, magnetic induction is another possible source of power, as is piezoelectrics. In addition, one of skill in the art could adapt other power sources such as nuclear, fluid dynamic, solar or the like to power the robots of the present invention.

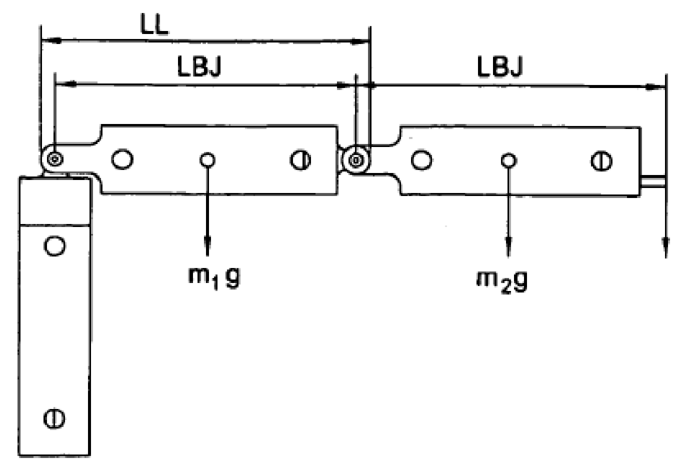


FIG. 16

Velocity Control and Degrees of Freedom

The robot is able to move about the abdominal
Cavity of the human being and transmit real-time
Video without distracting the surgeon.

The rotational speed of the motor is controlled with
a potentiometer that acted as a voltage divider.

The controllers has two buttons that are pushed through
Thumb sticks with three degrees of freedom. They control
De direction of each motor.

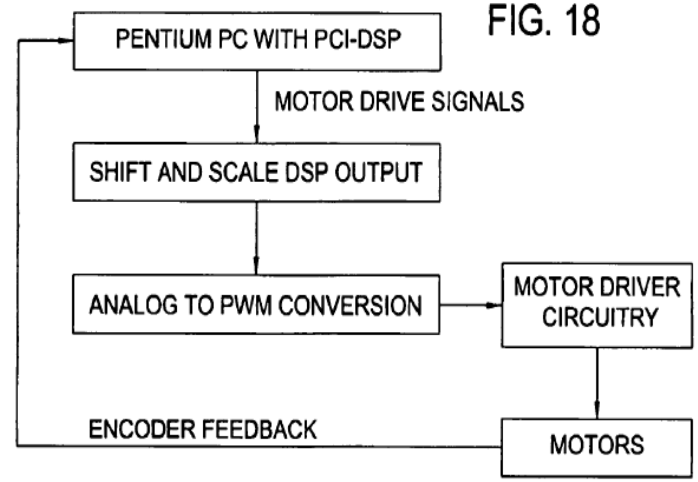


FIG. 18

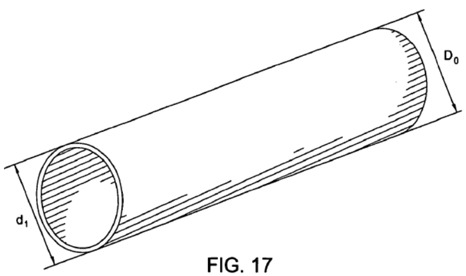


FIG. 17

FIG. **17** is a representation of the link shape assumed to calculate moment.

FIG. **18** is a block diagram of the electronics and control system used in one embodiment of the manipulator arm of the present invention.

FIG. **19** shows two circuits used in one embodiment of a manipulator arm of the present invention. FIG. **19**A is an inverting amplifier circuit, and FIG. **19**B is a summer amplifier circuit.

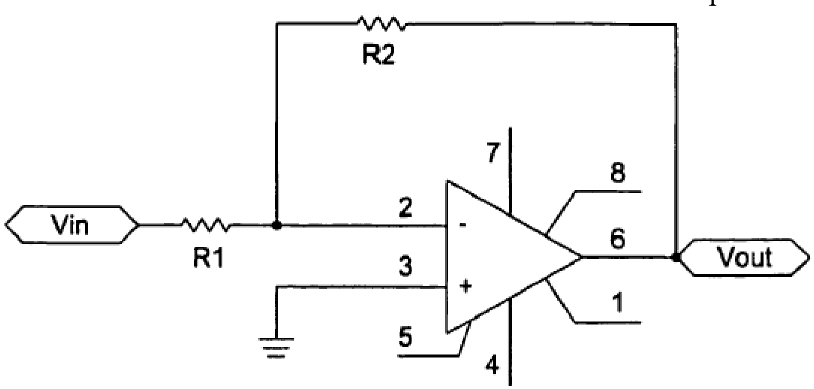


FIG. 19A

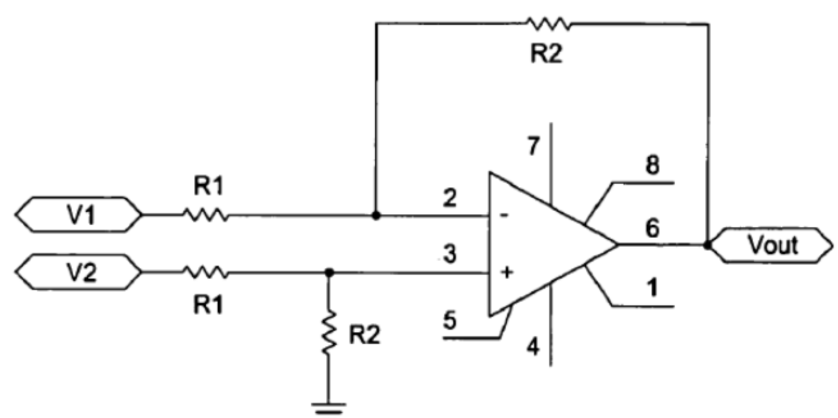


FIG. 19B

Sensing and transmitting feedback data

Receivers and transmitters useful in the present invention are many, such as those used on remote locks, such as for cars and other vehicles, other remote controls, and receiver and transmitter elements used in cell phones. Essentially, the input to the robot would be user command signals to the device, for example, to move various components such as the device itself, or for positioning the camera, sensor components or manipulator. The output from the robot would be primarily data from the video or sensors.

Torques, Motors and Controls

The size and function of this robot dictated also the use of very small electric motors. The first motors tested were motors that are used to vibrate pagers and mobile phones; however, these motors were found to be inadequate to supply the torque needed to move the robot. A suitable motor was selected. The electronics selected initially consisted of a modified control chip for the brushless motors that were selected. After control for the motors was established, the motors were wired to a game controller consisting of two joysticks. Each wheel on the robot was controlled by a separate joystick.

Patent and claims

- http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1033&context=mechengfacpub

What is claimed is:

1. A mobile robot comprising:

(a) a body sized to operate within a cavity of an animal;

(b) a translational mobility component coupled with the body;

(c) a motor coupled with the translational mobility component;

(d) a power supply coupled with the motor;

(e) a controller component coupled with the body; wherein the robot is configured to apply translational pressure on any a surface for purpose of mobility or immobility.

2. The robot of claim **1**, wherein the mobility component comprises at least one wheel.

3. The robot of claim **1**, wherein the mobility component comprises a first wheel and a second wheel, wherein the first and second wheels are configured to rotate independently of each other.

4. The robot of claim **1**, wherein the body has a substantially cylindrical shape.

5. The robot of claim **1**, wherein the body is shaped substantially like a cylinder, sphere, snake, or small vehicle.

6. The robot of claim **1**, wherein the robot is configured to travel forward and backward along a path that is perpendicular to the length of the body.

7. The robot of claim **1**, wherein the controller is wirelessly coupled with the motor.

8. The robot of claim **1**, wherein the controller comprises a wireless transmitter and wherein the robot further comprises a wireless receiver.

9. The robot of claim **1**, wherein the controller is physically coupled with the motor.

10. The robot of claim **1**, wherein the cavity is an abdominal cavity.

11. The robot of claim **1**, wherein the cavity is a peritoneal cavity.

12. The robot of claim **10**, wherein the peritoneal cavity has been insufflated with a gas.

13. The robot of claim **1**, wherein the at least one surgical component comprises a manipulator device.

14. The robot of claim **1**, wherein the at least one surgical component comprises a sensor device.

15. The robot of claim **1**, wherein the at least one surgical component comprises a manipulator device and a sensor device.

16. A mobile robot comprising:

(a) a body sized to operate within a cavity of an animal, the body comprising a single axle;

(b) first and second mobility components coupled to the single axle, the first and second mobility components configures for translational movement;

(c) at least one motor coupled with the first and second mobility components;

(d) a power supply coupled with the at least one motor;

(e) a controller component coupled with the at least one motor; and

(f) at least one surgical component coupled with the body.

17. The robot of claim **16**, wherein the at least one motor is configured to independently propel each of the first and second mobility components, whereby the body can be steered.

18. The robot of claim **16**, wherein the robot is capable of changing direction with a zero radius turn.

19. The robot of claim **16**, wherein the robot is configured to apply translational pressure on a surface for purpose of mobility or immobility.

20. The robot of claim **16**, wherein the cavity is an abdominal cavity.

21. The robot of claim **16**, wherein the cavity is a peritoneal cavity.

FOREIGN PATENT DOCUMENTS

WO	WO 02/082979	10/2002

OTHER PUBLICATIONS

Abbou, Clement-Claude et al. "Laparoscopic Radical Prostatectomy with a Remote Controlled Robot." *The Journal of Urology*. Jun. 2001, 165: 1964-1966.

Fraulob, S. et al. "Miniature assistance module for robot-assisted heart surgery." *Biomed. Tech*. 2002, 47 Suppl. 1, Pt. 1: 12-5.

Guber, A. E. et al. "Miniaturized Instrument Systems for Minimally Invasive Diagnosis and Therapy." *Biomedizinische Technik*. 2002, Band 47, Erganzungsband 1: 198-201.

Thomann, G. et al. "The Design of a new type of Micro Robot for the Intestinal Inspection." *Proceedings of the 2002 IEEE/RSJ Intl. Conference on Intelligent Robots and Systems EPFL*. Oct. 2002: 1385-1390.

Guo, Shuxiang et al. "Fish-like Underwater Microrobot with 3 DOF." *Proceedings of the 2002 IEEE International Conference on Robotics & Automation*. May 2002: 738-743.

Fukuda, Toshio et al. "Mechanism and Swimming Experiment of Micro Mobile Robot in Water." *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*. 1994: 814-819.

Guo, Shuxiang et al. "Micro Active Guide Wire Catheter System-Characteristic Evaluation, Electrical Model and Operability Evaluation of Micro Active Catheter," *Proceedings of the 1996 IEEE International Conference on Robotics and Automation*. Apr. 1996: 2226-2231.

Yu, Sun et al. "Microrobotic Cell Injection." *Proceedings of the 2001 IEEE International Conference on Robotics & Automation*. May 2001: 620-625.

Ruurda, JP et al. "Robot-assisted surgical systems: a new era in laparoscopic surgery." *Ann. R. Coll. Surg. Engl*. 2002, 84: 223-226.

Menciassi, A. et al. "Robotic Solutions and Mechanisms for a Semi-Autonomous Endoscope." *Proceedings of the 2002 IEEE/RSJ Intl. Conference on Intelligent Robots and Systems EPFL*. Oct. 2002: 1379-1384.

Ishiyama, K. et al. "Spiral-type Micro-machine for Medical Applications." *2000 International Symposium on Micromechatronics and Human Science*. 2000: 65-69.

Fearing, R. S. et al. "Wing Transmission for a Micromechanical Flying Insect." *Proceedings of the 2000 IEEE International Conference on Robotics & Automation*. Apr. 2000: 1509-1516.

Mei, Tao et al. "Wireless Drive and Control of a Swimming Microrobot." *Proceedings of the 2002 IEEE International Conference on Robotics & Automation*. May 2002: 1131-1136.

Marcia Yu, BSN, RN, "M2ATM Capsule Endoscopy A Breakthrough Diagnostic Tool for Small Intestine Imaging," vol. 25, No. 1, *Gastroenterology Nursing*, pp. 24-27 2001.

Andrew Miller, D. et al., "In-Vivo Steroscopic Imaging System with 5 Degrees-of-Freedom for Minimal Access Surgery," Dept. of Computer Science and Dept. of Surgery, Columbia University, New York, NY, p. 7. No Date.

Strong, et al. "Efficacy of Novel Robotic Camera vs a Standard Laparoscopic Camera," *Surgical Innovation*, vol. 12, No. 4, Dec. 2005, Westminster Publications, Inc., pp. 315-318.

Worn et al., "Espirit Project No. 33915: Miniaturized Robot for Micro Manipulation (Miniman) ", Nov. 1998, http://www.ipr.ira.uka.de/-microrobot/miniman/.

Meron, G., "The development of the swallowable video capsule (M2a)," Gastrointestinal Endoscopy 2000, 52, 6;817-819.

Phee et al., " Development of Microrobotic Devices For Locomotion in the Human Gastrointesinal Tract ", *International conference on Computational Intelligence*. No Date.

Breda et al., " Future developments and perspectives In Lacroscopy ", *Eur. Urology*, 2001, 40, 1: 84-91.

* cited by examiner

Typical cost of this type of research, Source: http://seedgrant.colorado.edu/content/new-dynamic-tissue-modeling-mobile-vivo-surgical-robots

Request amount:
$50,000.00

Review venue:
•Eng
Budget justification:
A. Salaries and Wages:
We request one year support for a post-doctoral research associate. The postdoc will develop a finite element model to study the dynamic response of various tissues under loading of mobile in vivo robotic devices. To implement accurate tissue models, the postdoc will study compressive loading features of a number of tissues in collaboration with surgeons at the University of Colorado at Denver School of Medicine as described in the proposal. The postdoc will also study mobile platform performance to help optimize a mobile in vivo robotic system for various tissue locations and specific surgical procedures.
Total: $40,000
B. Travel:
We request funds to attend one professional conference (ASME Design Engineering and Technical Conference).
Total: $2,500
C. Other Direct Costs (Materials and Supplies):
Tissues: $2000
Mechanical testing fixtures: $2500
Computing facilities: $1500
Finite Element software license: $1500
Total: $7,500
Project budget:
This Innovative Seed Grant proposal requests one year support for a post-doctoral research associate to setup finite element modeling and experimental studies of solid organ tissues and to investigate wheel performance and tissue damage to optimize robot designs. $40,000
Travel: $2,500
Materials and supplies: $7,500
Project plan:
CU-ISG-ResearchPlan-Rentschler.pdf
Selected Honors and Awards:
BMW Group International Passion for Innovation Scientific Award Finalist (5 finalists out of 241 applicants from 25 countries), 2007
University of Nebraska Outstanding Graduate Research Assistant Award for University-wide Best Research, 2006
National Defense Science and Engineering Graduate (NDSEG) Fellowship, 2001-2004
Tau Beta Pi Centennial Graduate Fellowship, 2001-2002
Goddard Award for Excellence for outstanding research efforts and overall NASA Academy commitment, 2001
Other Research Support:
NIH (pending), $357k, A Trocar Camera System for Laparoscopic Surgery, 7/2009-6/2011
NSF (pending), $560k, A Design-Centered Approach to In vivo Robotic Devices, 6/2009-5/2012

Ethical aspects on the Training for the manipulation of these robots

The training and assessment problem for laparoscopic surgery is both acute and well-recognized .
Previous studies have shown that low-level, psychomotor skills can be taught using simple, inanimate training systems (box trainers), such as those from the common Fundamentals of Laparoscopic Surgery program .
To train higher-level skills, simplistic models may be insufficient .

Two main approaches for the instruction of higher-level skills are virtual reality (VR) simulators and *in vivo* animal models.

While VR simulators show great promise, and may someday provide sufficient realism to make the use of living tissue in training redundant, accurate and real-time simulation of the complex deformations, piercing, tearing and cutting of organic tissue remains an unsolved problem.

The porcine model was recognized early-on as effective for the training of a variety of laparoscopic procedures [8–10].
Although the porcine model is a powerful pedagogical tool, there remain barriers to its widespread use in surgical training.

While ethical questions about the use of animals for training are not to be ignored, generally the most limiting impediment to the use of animal models is the expense and difficulty of maintaining a veterinary facility . Such expense is compounded by the need to maintain close proximity to a medical school.

Bibliography

The current state of miniature in vivo laparoscopic robotics Amy C. Lehman · Mark E. Rentschler · Shane M. Farritor · Dmitry Oleynikov J Robotic Surg (2007) 1:45–49 Springer
DOI 10.1007/s11701-007-0019-9
http://www.engineering.unl.edu/research/robots/medical.shtml
Gastroenterology and Endoscopy News ISSUE: AUGUST 2005 | VOLUME: 56:08
For Transgastric Surgery, One Thing Is Certain: Much Remains Unknown
by Monica J. Smith
Gastroenterology and Endoscopy News ISSUE: APRIL 2007 | VOLUME: 58:04 Wireless Robot Enhances Effectiveness of Natural Orifice Surgery by Mary Beth Nierengarten
Tiny in vivo robots to aid surgeons by Karen Burbach, UNMC public affairs October 14, 2005
NU robots designed to train doctors to operate in outer space ALGIS J. LAUKAITIS / Lincoln Journal Star JournalStar.com | Posted: Sunday, April 16, 2006
NU's surgical robots in 18-day aquanaut expedition
by Margaret Bumann, UNMC public affairs, and Kelly Bartling, University of Nebraska-Lincoln
April 13, 2006
Wireless Robot Enhances Effectivenes of Natural Orifice Surgery
by Mary B. Nierengarten , ISSUE: JULY 2006 | VOLUME: 33:07 General Surgery news
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04358884