Design issues of robots used in Healthcare/Surgery

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***Abstract*—**This Report presents various Robots used in Health care Industries. We will look into origin of these robots and how they contributing in present health care problems. This report also deals with various robots such as Vivo Surgical Robots, Nate Robots, Tyler Robots, Soft Robots, Da Vinci Robots etc. We also discussed about applications, advantages and Design issues of these robots.

Keywords—In Vivo, Da Vinci, Nate, Tyler.

INTRODUCTION

Surgical robots are robots, that are used to improve the outcome of surgery. A Robotic surgery, or robot-assisted surgery, allows doctors to perform many types of complex procedures with more precision, flexibility and control than is possible with conventional techniques. Surgical Robots, is a very new and developing area in the field of robotics as well as medical.

Before we move on to the evolution of these robots, the areas of usage of these can broadly be categorized into:

1. Cardio Thoracic
2. Orthopedic Surgery
3. Neurosurgery
4. General Surgery
5. Urology
6. Ophthalmology

And the robots are mainly used for

1. MIS
2. Reproducibility
3. Mechanical Stiffness
4. Guideways

In our report first we have tried to cover the evolution of surgical robots along with their pros and cons. Then we have focused on in vivo type of robots, along with detail analysis of design of 2 types of bots.

I. EVOLUTION OF SURGICAL ROBOTS

PAST, THE FIRST COHORT:

Surgical robotic systems based on an industrial active robot or with an autonomous approach make up a first cohort of surgical robots. An autonomous approach means that the system will carry out tasks automatically at some stage, without direct intervention of the surgeon. Following are some of the examples of early developments, though very few of them actually went into the market.

1. Industrial robot, a Unimation PUMA 200, was used to probe a brain biopsy using CT guidance.
2. Probot, a special purpose robot developed at Imperial College London, was used to autonomously remove a significant amount of tissue.
3. Robodoc system for total knee arthroplasty
4. Computer Assisted Surgical Planning And Robotics (CASPAR), an industrial PUMA robot adapted for total hip and knee arthroplasty and for anterior cruciate ligament repair.
5. CyberKnife System, a radiosurgery robot which uses radiation to treat tumors while minimizing radiation to the adjacent tissues.
6. Bone Resection Instrument Guidance by Intelligent Manipulator (BRIGIT), was intended to be used for total knee arthroplasty(TKA) and allowed the accurate positioning of a guide according to a patient specific preoperative plan.
7. BrainLab's Vectorbot was an advanced 7 DoF robotic arm and a compact design with all electronics integrated into the articulated arm. Vectorbot was described as an intelligent instrument guide to enable surgeons to reliably align endoscopes, biopsy needles, deep brain stimulation electrodes, catheters and pedicle screw drills with millimeter precision.

PRESENT, THE SECOND COHORT:

A second cohort of robots relates to assistive or collaborative devices, i.e. robotic devices that are able to move autonomously but are not programmed to do so. Instead, they are programmed to reproduce the surgeon's motions in a master/slave configuration (such as Intuitive's daVinci and Hansen's Sensei),or in a ‘‘hands-on’’ mode(such as Acrobot's Sculptor and Mako's RIO). The devices in this second cohort all intend to enable MIS.

1) The daVinci surgical robot is a master/slave system consisting of single or dual surgeon's console, a patient-side cart with three or four robotic arms, a visualization system and proprietary instruments. The daVinci system translates the surgeon's hand, wrist and finger movements at the console instrument controls into corresponding scaled down movements of instruments positioned inside the patient in real time, filtering tremors. The surgeon operates while seated at a console viewing a 3D image of the surgical field. The instruments have seven degrees of motion that mimic the dexterity of the human hand and wrist, offering an even greater range of motion. The Da Vinci provides surgeons with haptic feedback as they perform a surgery, but utilizes sensory substitution to display the information through visual cues. Ideally, tactile feedback from the device would

render the exact applied forces and tissue deflections resulting from the surgical procedure.

2) The Sensei robotic catheter system (Hansen Medical Inc.,Mountain View,CA,USA) is a master/slave system for interventional cardiology.

3) Acrobot Sculptor is also a synergistic device but now with a ‘‘hands-on’’ control, the device is a small, low-powered, special purpose robot built for use in a crowded sterile operating theatre environment.

4) Cooperative Robots – While minimally invasive techniques offer significant patient advantages, the procedures are surgically challenging. Miniature invivo robots are being developed that are completely inserted into the peritoneal cavity for laparoscopic and natural orifice procedures. These robots can provide vision and task assistance without the constraints of the entry incision and can reduce the number of incisions required for laparoscopic procedures.

POSSIBLE FUTURE, THE THIRD COHORT:

The characteristics of a third cohort of surgical robots are still to be defined but it is anticipated these intelligent new tools will be smaller, special purpose, lower cost, possibly disposable robots, providing alternatives to the current large, versatile and expensive systems. One existing type of small, special purpose robots includes guide positioning devices. The devices are attached to the patient, eliminating the need for patient immobilization or motion tracking, which greatly simplifies the robot's registration to the target anatomy. The following are examples that can become reality in near future.

1. HeartLander, intended to be disposable is a miniature mobile robot that delivers minimally invasive therapy to the surface of the beating heart. Heartlander is placed on the surface by the surgeon and then controlled by a joystick and a graphical interface.

2. Using Weak AI – In future the robots will be able to learn from the surgeon's actions using weak AI techniques like machine learning. But they will not be able to take decisions. Few researches that are going on in the third cohort are

A) Force free input: In minimally invasive robotic surgery the surgeon usually operates in front of a console with input devices. The single steps of the intervention are realized by transferring the movement of the input devices to the robots.The advantages of optical motion tracking are a relatively large workspace and its high accuracy. However, latencies caused by image acquisition and processing, and partial occlusions of the tracked objects, as they often occur during bimanual manipulation, have to be considered. By fusing optical data with accelerations and angular rates obtained from an inertial measurement unit and using controllable, active markers, the requirements can be met. The system should be usable as an alternative input modality for the surgeon or enable the assistant to undertake subtasks.

B) Using Magnetic control to help the robot navigate inside the body. It uses the basic principle of magnetic field to generate magnetic force, which acts as the driving force. One of the challenges of this technology is to control multiple bots inside body using magnetic field. This project tends to solve this by creating a global magnetic field having a hole inside the device known as free field point. After going through various sources, the advantages and disadvantages of surgical robots can be summarized as follows.

ADVANTAGES

1. Incisions made are smaller, so less recovery time, less blood loss.
2. Gives better view of the surgical site, easier access to hard to reach places and tighter control over smaller and more precise surgical instruments attached to robot arms.
3. The robot's computer software filters out naturally occurring human tremors that increase the risk factor in very intricate surgeries.
4. Surgeons perform robotic assisted surgery while sitting down, so they can work longer hours tirelessly, which lowers the risk factor caused by fatigue and hence more surgeries can be carried out in the same time as compared to conventional surgeries.

PRESENT LIMITATIONS

1. Higher cost of robot as well as the disposable supplies. Very important barrier. Another important reason is high annual maintenance cost. da Vinci Surgical Systems - costs on average slightly under US$2 million, in addition to several hundred thousand dollars of annual maintenance fees.

2. The learning curve for surgeons who adopt use of the system is too long. Still studies are going which is a better way in the long run. More than learning curve it is the number of operations a surgeon will have to do before he can perform it on a human. Example Da Vinci Laparoscopy for Urology requires a surgeon to have performed the procedure at least 200 times before he/she can perform it on a human.

3. Also, the Setup time very high for some of the robots.

4. Other issues - The da Vinci system uses proprietary software which cannot be modified by physicians, thereby limiting the freedom to modify the operation system.

5. There have also been claims of patient injuries caused by stray electrical currents released from inappropriate parts of the surgical tips used by the system. Intuitive counters that the same type of stray currents can occur in non-robotic laparoscopic procedures.

6. A study published in the Journal of the American Medical Association found that side effects and blood loss in robotically-performed hysterectomies are no better than those performed by traditional surgery, despite the significantly greater cost of the system.

7. If there's some complication because human body in completely unpredictable, the intervention by a human surgeon is very important and the time of reaction is also a very crucial factor there so this also is a barrier for the adoption of robots in surgery.

IN VIVO SURGICAL ROBOTS

INTRODUCTION:

An alternative approach to externally actuated systems is the use of miniature robots that can be completely inserted inside the body. These devices do not have the constraints associated with working through an access port. This class of surgical robots are called in vivo robots. Minimally Invasive Surgery (MIS) is replacing open procedures, thereby providing patients with significant benefits including reduced trauma and costs along with faster recovery times, improved cosmetics, and decreased mortality rates. Laparoscopy, a form of MIS in which long, rigid instruments are inserted through small incisions, has become the standard care for many routinely performed surgical procedures. While replacing a large open incision with multiple small incisions offers significant advantages, limitations such as reduced dexterity, lack of tactile feedback, the fulcrum effect and two-dimensional imaging lead to more technically difficult surgeries. Natural Orifice Translumenal Endoscopic Surgery (NOTES) is the ultimate MIS goal. NOTES completely eliminates all external incisions by accessing the peritoneal cavity through a natural orifice, leaving no external scars and further reducing the risk of infection to the patient. NOTES offers additional advantages to MIS, but is limited by the size of the natural orifice and the requirement that instruments be flexible enough to traverse the natural lumen. Laparoendoscopic Single-Site Surgery (LESS) has been viewed as an important step, and possibly a bridge to NOTES. LESS surgery is performed by utilizing multiple articulating, bent, or flexible laparoscopic tools inserted through a single specialized port in the abdominal wall.Current LESS techniques involve crossing the bent tools, resulting in collateral hand movements in which the surgeon's right hand controls the left end effector and vice versa.

DESIGN CONCEPTS:

With single incision surgery, there are many constraints with instrument placement, visualization, and tissue manipulation. Dexterous in vivo robots aim to replace standard laparoscopic tools in general MIS. The basic robot design consists of two arms that can be separated and inserted individually through a single small incision. After the robot is completely inserted within the abdominal cavity, both arms are positioned and mated together using a central assembly rod. This assembly rod protrudes out through the incision and allows the robot to be supported and grossly positioned, if needed. In order to be inserted through a small incision for LESS, the robot arms' diameter must never be greater than 30mm. Both arms are designed to have capabilities similar to if not greater than traditional laparoscopic tools. Because the robot is completely contained within the abdominal cavity, there are no kinematic issues with working through a single, small incision. The robot is designed to have four degrees of freedom in each arm along with open/close actuation of the end effectors**.**

NATE ROBOT

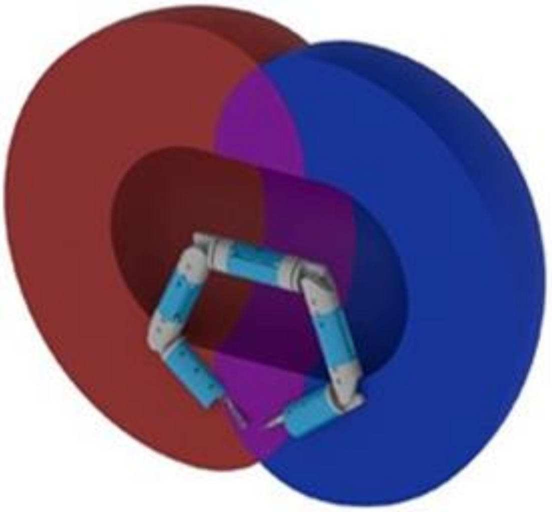
During the development of the surgical robots, as the focus shifted from NOTES to LESS, larger robots with advanced capabilities were designed. A case study of such a bot developed at the University of Nebraska-Lincoln Advanced Surgical Technologies Lab would be discussed. This series of surgical robots were more focused on LESS. The first of these robots to incorporate a rotating elbow joint instead of a translating arm. The rotating elbow significantly improved upon the robot's workspace and dexterity.

Design

Both arms could be straightened so they were aligned with the body segment. This allowed the robot to be inserted through an overtube in the esophagus, where it could successfully navigate the upper gastrointestinal tract to enter the abdominal cavity. For better LESS capabilities a support rod attachment was added to the main body. Fig. 6.1 Attached to the main body segment were two symmetric 4-DOF arms. Each arm includes a 2-DOF shoulder joint that provided yaw and pitch, as well as an elbow joint that provided yaw. This robot also had interchangeable end effectors. End effectors could now be quickly bolted on and off to create new combinations for different surgical tasks. Typical end effectors for this prototype included graspers and DC eye cautery. Each end effector has a rotational degree of freedom, along with open/close actuation if necessary. The Denavit-Hartenberg parameters defining the kinematics of this robot are shown in Table 6.1. These parameters can be used to describe the robotic arms. Parameters L1 and L2 are constants defining the link lengths. L1(upper arm)= 88.4 mm. L2 (the forearm)= 123 mm. Shoulder pitch ($\theta 1$), shoulder yaw ($\theta 2$), elbow yaw ($\theta 3$), and end effector rotation ($\theta 4$) define rotations of the robot with respect to intermediate frames of reference.

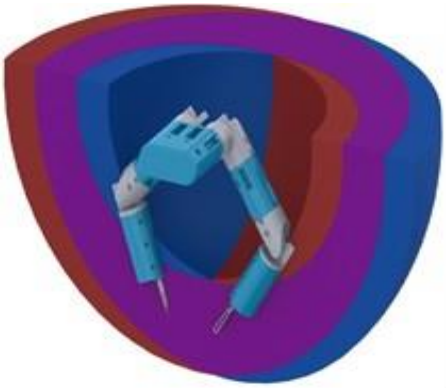
Issues:

While the first nate bot offered significant advancements over previous versions of the multi-functional in vivo robot family, it also brought forth new issues. The workspace volume of the nate bot's arms is shown in Figure 6.2. The red, blue, and purple volumes represent the left arm, right arm, and intersecting workspaces, respectively. During benchtop tests and in vivo surgical tests, surgeons commented on the lack of the robot's ability to cooperatively use the arms. The purple volume, or intersecting workspace, shown in Figure 6.2 is a very small portion of the overall workspace. Because of this, the robot had to be continually repositioned to perform simple surgical tasks. The reason for this lack of intersecting workspace is due to the robot's poor joint limits with respect to its kinematics. The robot's shoulder joints were too far apart to create an efficient intersecting workspace. This led to further development on the kinematics of this robotic prototype.



NATE BOT 2

After additional analysis, simple kinematic changes were utilized to make large changes to the intersecting workspace. The kinematic change was completed by ‘breaking’ the robot’s body segment in half, rotating the new body segments ninety degrees so they were parallel and no longer coaxial, and re-attaching the body segments. This change resulted in the robot’s shoulders being closer together and a more efficient intersecting workspace was created. This new workspace is shown in Figure 6.3. Again, the red, blue, and purple volumes represent the left arm, right arm, and intersecting workspaces, respectively. It is easy to see how the new intersecting workspace spans the majority of the workspace volume and is no longer a small subset.



DESIGN:

The new version of the Nate-Bot family of robots was designated as NB2 and is shown in Figure 6.4. This robot was very similar to NB 1 in almost all design aspects except for the kinematic change. The modified Denavit-Hartenberg parameters defining NB 2 are shown in Table 6.2. Again, parameters L1 and L2 are constants defining the link lengths and θ1, θ2, θ3, and θ4 define rotations of the robot joints. The distance between the shoulders was reduced from 108.4 mm in NB1 to 36.7 mm in NB2.

One beneficial side effect of splitting the two arms was the ability to now individually insert each arm for LESS surgery. Due to the limited space within the abdominal cavity, the task of inserting a complete robot proved to be quite difficult. Separating the arm modules simplified the insertion procedure. Once the arms were individually inserted, they could be brought back together and mated to the support rod.

END EFFECTOR ATTACHMENTS MONOPOLAR CAUTERY:

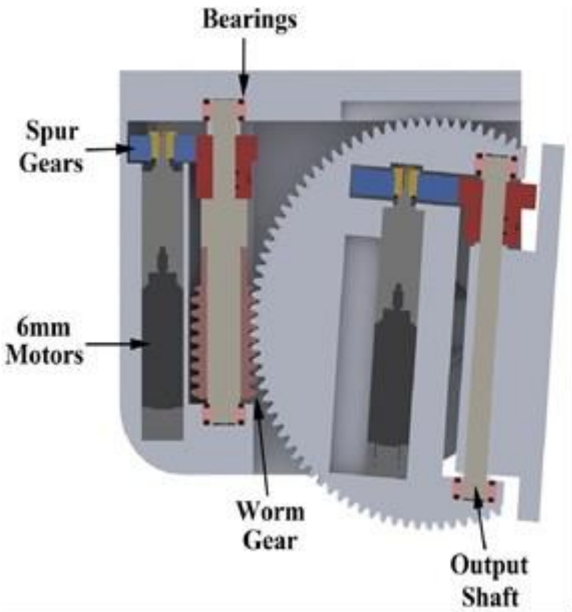
During the development of the NB2 robotic prototype, several new peripheral components were designed. A monopolar hook cautery was designed to replace the DC eye cautery that had been used. The DC eye cautery is a wire resistor that heats up when current is applied. This heated wire is then use to cut through tissue. While simple to implement, this method is very inefficient and can break downuite easily. During monopolar cauterizing, a grounding pad is attached to the patient and AC current is applied to the cautery tip. When the cautery tip touches the patient a circuit is completed and the electricity flow heats up the tissue at the point of contact and thus can be used to cut and coagulate. Implementing the monopolar cautery on NB2 was simple. A hook connected to an electrosurgical generator was added as an end effector to the robot. Initially, problems occurred because the generator created a very electrically noisy environment around the robot. This caused problems with the accuracy of the motor encoder readings. To compensate, double-shielded wire and filter boards were used to keep the signal clean.

NEEDLE GRASPER:

Another peripheral design was needle drivers to be used with the interchangeable end effectors. Suturing of tissue is a common surgical task. Tissue manipulation graspers are typically serrated with teeth to grasp tissue more effectively. These teeth are not ideally suited to grasp a needle used for suturing. Small modifications were made so that the graspers resembled traditional needle drivers. These changes included shortening the graspers and replacing the teeth with a knurled face. A rendering of the needle graspers design on the surgical robot is shown in Figure 6.6.

ON-BOARD CAMERA:

Another accessory that was added was an actuated on-board camera. An onboard camera prevents the need for an external laparoscope to be introduced for visualization. This camera was designed as a third module that could be mated between the two arm modules. The camera has two degrees of freedom. The actuated panning and tilting of the camera allows the entire robotic workspace to be visualized. A monoscopic or stereoscopic imager set-up allows for 2-D or 3-D viewing. A cross section of the camera design is shown in Figure 6.7. The tilting of the camera is achieved by a 6mm motor attached to a worm gear that rotates the housing of the pan mechanism and the imager. Panning is accomplished by a 6mm motor attached to a spur gear output that rotates the imager. While this design was bulky, it provided excellent visualization capabilities.



Soft Robotic Device for the Failing Heart:

Soft robotic devices have significant potential for medical device applications that warrant safe synergistic interaction with humans. The optimization of an implantable soft robotic system for heart failure whereby soft actuators wrapped around the ventricles are programmed to contract and relax in synchrony with the beating heart. Elastic elements integrated into the soft actuators provide recoiling function so as to aid refilling during the diastolic phase of the cardiac cycle. Improved synchronization with the biological system is achieved by incorporating the native ventricular pressure into the control system to trigger assistance and synchronize the device with the heart. A three-state electro-pneumatic valve configuration allows the actuators to contract at different rates to vary contraction patterns. An in vivo study was performed to test three hypotheses relating to mechanical coupling and temporal synchronization of the actuators and heart. First, that adhesion of the actuators to the ventricles improves cardiac output. Second, that there is a contraction– relaxation ratio of the actuators which generates optimal cardiac output. Third, that the rate of actuator contraction is a factor in cardiac output.

Why to use this robotic device?

In Heart Failure, the heart cannot pump a sufficient blood flow to meet the metabolic demands of the body. Heart Failure prevalence in the United States is around 5.7 million people and around half of those diagnosed will die within 5 years of diagnosis.[16] The total financial cost of HF in the United States is estimated at $30.7 billion per year.[16] For patients with advanced HF, transplantation is widely accepted as an effective treatment, but limited donor availability means that many patients will die waiting for a donor heart.

Ventricular assist devices (VADs) provide a means of unloading the heart by supplementing pumping function for patients with advanced Heart Failure. The VADs in current clinical practice work by extracting blood from the ventricles or great vessels before pumping the blood back in to the aorta or pulmonary artery so as to assist left or right ventricle function, respectively. VADs can be utilized either as a bridge to transplantation or for permanent implantation in some cases.

Implantable Soft Actuators and Control System:

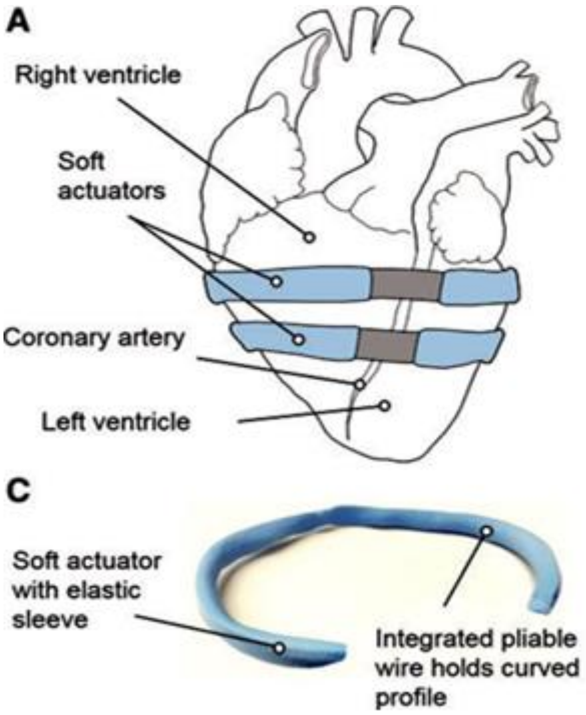
McKibben-based actuators to assist the native heart muscle are most adopted. McKibben actuators are composed of an inflatable bladder placed within a mesh: when the bladder is pressurized, the mesh contracts linearly and expands radially (Fig. 1).

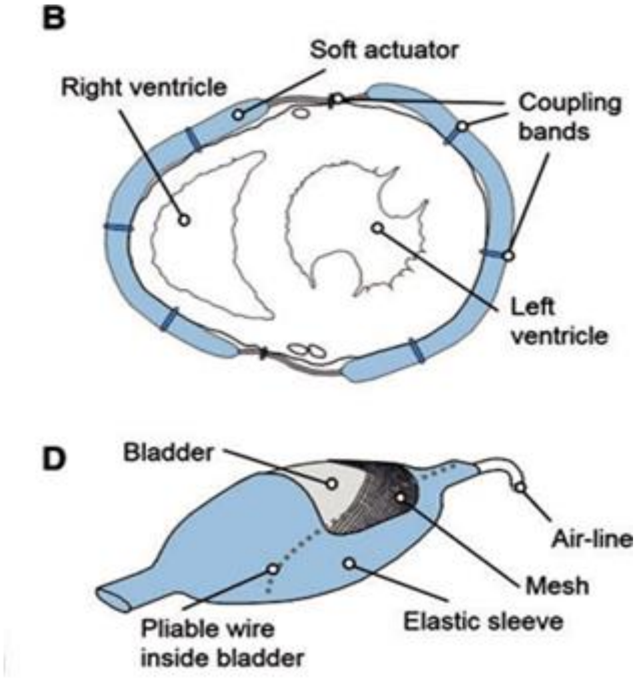
McKibben actuators are wrapped around the heart ventricles (Fig. 1). This approach allows the surgeon to systematically position and orients the actuator on the ventricle which allows control over the device placement in vivo. The surgeon can choose how many actuators are placed and the size of each can be specified to account for variability between hearts. This also enables an actuator to be placed away from important structures such as the coronary vessels or in regions that might impair function of the valves. The overall size and weight of the implant is also minimized which may allow improved refilling during the diastolic phase.

The McKibben-based actuator design incorporates a pliable wire within the bladder. The ductility of the wire allows the surgeon to individually bend each actuator to fit the shape of the ventricle surface (Fig. 1). Matching the actuator profile to that of the ventricle surface forgoes the need for over tightening which could constrict the ventricle and impede refilling.

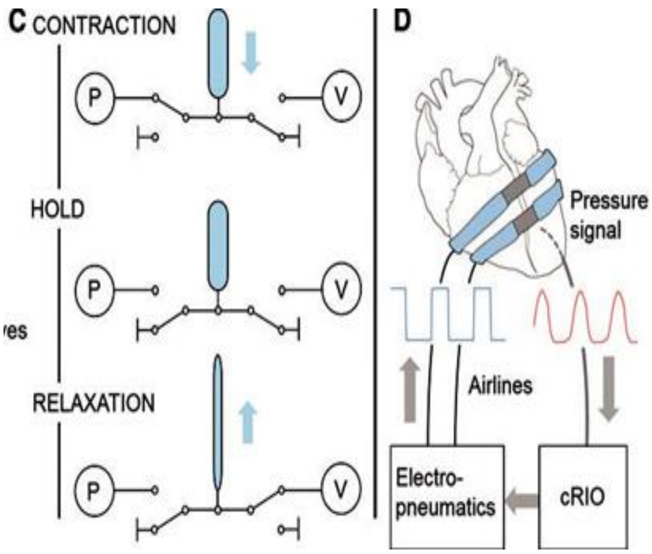
Conventional McKibben actuators can generate significant loads in contraction as a result of the bladder pressure. However in relaxation, the force generated is much less and largely determined by elastic energy stored in the actuator mesh structure. In the diastolic relaxation phase of the cardiac cycle, the heart muscles recoil so as to cause rapid refilling To mimic and enhance this effect in an actuator, we incorporate an elastic sleeve that is placed over the mesh so as to circumferentially stretch during contraction. When depressurized, the elastic energy stored in the stretched sleeve is transferred back to the actuator allowing it to recoil to a fully elongated state (Fig. 2A).

FIG. 1: (A) Front view of heart and placement of the actuators. (B) Section view of the heart showing the locations of coupling bands that adhere to the ventricle surfaces (three per actuator and two near the septal region). (C) Photograph showing a soft actuator configured in to a profile and its shape retained by the integrated ductile wire. (D) Shows a section view of the contracted actuator with elastic sleeve and pliable wire within the bladder.





The actuator inner bladders are fabricated from a thermoplastic elastomer. This is a 38 um thick material that can be thermally bonded in to a bladder using a heat press. The inner pliable wire is adhered to the airline and is made to be less than 60% of the length of the bladder so as not to cause rupture of the inner bladder when contracted. The elastic sleeve is manufactured from dipped rubber of *250 lm in thickness. In addition to the elastic sleeve, we adhere each actuator to the heart surface using elasticated rubber bands of 1.3mm diameter that are tightly sutured to a point on the ventricle. Like the elastic sleeve, the elastic coupling bands can also stretch in systole and transmit stored elastic energy back to the heart in diastole.



P = Pressure & V = Vacuum

FIG. 2: (A) McKibben actuators with elastic sleeve in both relaxed and contracted states. (B) Underside view of the control box plate with mounted hardware. (C) Schematic of the three-state valve system that allows pressure to be held inside the actuators. (D) Pressure triggering control scheme for soft robotic implant.

Advantages:

(1) Recoiling ability to refill the heart.
(2) A method of device adhesion to the ventricles to enable diastolic assistance.
(3) A control system based on real-time hemodynamics for synchronization with the native heart.
(4) Configurable actuators that can be formed in situ to fit the ventricle.
(5) A control system that allows different rates of actuator contraction to optimize system performance.

TYLER ROBOT FAMILY

Since the NB were too large for LESS surgery a new type of robots were required. This led to the birth of the Tyler Bot family.

TYLER-BOT 1 (TB1):

Design

A new robot design, designated TB1, was created that focused on Drive train and link design. Gear train and shape of the robot was changed. Kinematics remained same as NB2.1 but the motor placement was changed in order to allow easier movement. The shoulder joint links were shaped with a minimalist approach so that they would allow full mobility of the shoulder. The elbow joint was placed in the middle of the upper arm. This shrank the overall length of the arm. The TB was the first robot to implement insertion protocol.

Design Issues:

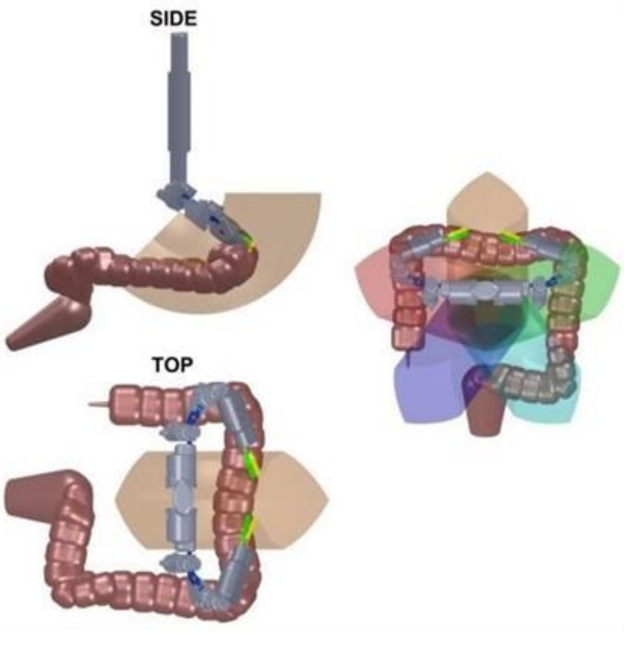
1. This robotic prototype had a very short lifespan and had reliability problems.
2. The size was still too large even after the motor placement.
3. Motors were prone to overheating because of poor heat sink design.
4. The motors were long with small diameter and not very space efficient.

TYLER-BOT 2(TB2):

Tyler- Bot 2 (TB2) was designed based on the knowledge gained from the previous surgical robotic prototypes. The robot was simple, durable, compact and insertable. The next iteration in the TB family has been by far the most successful. TylerBot 2 (TB2) was designed based on the knowledge gained from the previous surgical robotic prototypes. Several fundamental criteria were used as benchmarks in the robot's design. The robot must be simple, durable, compact, and insertable. Along with these, the robot joints must have a large range of motion to maximize the workspace, and the endpoints must generate the force and speed required for surgical tasks

Workspace:

The workspace of this robot was similar to the large intestine. And this allows the robot to do surgery on the large intestine.



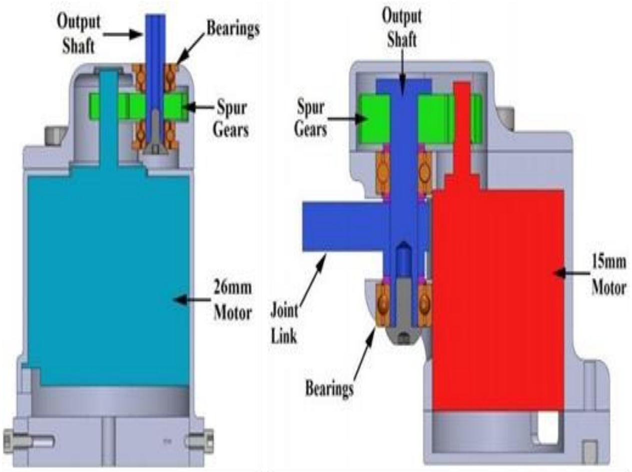
Design:

All joints are actuated using Faulhaber coreless brushed permanent magnet direct current motors with magnetic encoders. The joints are precision machined 6061 aluminum. The body housings are rapid prototyped.

Torso, Upper Arm, Fore Arm:

Torso includes a single 26 mm motor that provides actuation for the shoulder pitch. Upper arm has 2 15mm motors. Forearm has a 8mm motor for twist and a 15mm for open close actuation.

The motor revolves and this makes the drive shaft screw in and out and therefore makes the end effector close and open.



Electronics and Controls:

Remote Surgical User Interface:

The surgeon interface is located remotely within the operating room. It consists of a video display, triple-action foot pedals, and two PHANTOM Omni (Sensable) Controllers.

1-DOF On-Board Camera:-DOF camera was also designed for this robot. This camera was built directly into the assembly support rod and fits right between the two arms.

IN VIVO RESULTS AND CONCLUSIONS FOR TYLER ROBOT:

TB-2 was used in 2 porcine model colectomy. The incision size was 5 cm and could be reduced to 3.5 cm. This shows its ability to be of use in LESS surgeries. TB2 had a better design that NB2 and TB1 and was able to perform the required surgery. In future more tests are required to improve but in general TB2 has shown that robots are capable of performing surgeries in vivo.

HEALTHCARE ROBOTS

The worldwide population of elderly people is growing rapidly and in the coming decades the proportion of older people in the developed countries will change significantly. This demographic shift will create a huge increase in demand for domestic and health-care services and this in turn has the potential to create a major new market for domestic service robots that can assist with the care and support of the elderly and infirm. However, unlike industrial robots, assistive service robots are still under-developed and are not widely deployed. Assistive robots for health and welfare applications are required to display perceptual, cognitive and bodily-kinesthetic capabilities that are natural and intuitive for older people and persons with disabilities to interact with, communicate with, work with as partners, and learn to adapt to their needs.

Case Study:

Title: Ingestible, Controllable, and Degradable Origami Robot for Patching Stomach Wounds

Introduction: Miniature origami robots can provide versatile capabilities for gastrointestinal interventions, especially when used in conjunction with imaging technologies, as they can move and manipulate with a high degree of control and be minimally invasive for the patient.
In the stomach, the robot self-deploys and is controllable using an external magnetic field to reach a location of interest where it can use its body to patch a wound such as an inflammation made by an accidentally swallowed battery. Origami robot designs are well suited for tasks that require multiple modalities of locomotion, such as traveling through the esophagus and the stomach, because they can do the first task in a compact shape (e.g. a pill shape) and then morph to enable a solution for the second task. Additionally, building on this work anyone can manipulate the trajectory of the robot using an external magnetic field.
One example of clinical interventions where a multifunction miniature robot is desired is the ingestion of button batteries. It is reported that more than 3500 people of all ages ingest button batteries in the United States every year, and the incidence is growing (National Capital Poison Center. 46 deaths and 183 cases with severe esophageal or airway burns and subsequent complications have been reported in the last 40 years. Most of the victims are children. Having considered the fatality of these accidents and the availability of efficient interventional tools to counteract them, this study approached the problem by deploying a miniature biodegradable origami robot in the stomach, guided to a wounded location, where it had the ability to remove a lodged battery, patch and effectively administer drugs directly to the wounded location, and eventually dispose itself on-site by biodegradation or digestion.

Stomach simulator:
In this study, a physical environment for testing the performance of our robotic system, comprised of an artificial esophagus and a silicone stomach that feature a biologically-comparable stiffness and folded lining inside was developed (Fig. 1). The artificial organs provide a nonperishable, realistic, cost-effective environment for iterative tests of the structure and function of the robot, and allow easy parameterization of the artificial environment, such as the size of the organs and location of the damaged area. The stomach was reproduced environment using a template silicone mold technique to be mechanically analogous to the real tissues. In this study, emphasis on the mechanical attributes of the stomach such as structure,

stiffness, friction, fluid viscosity, and color, while omitting other properties such as temperature, pH, peristaltic motion of the esophagus, or volumetric dynamics of the stomach.

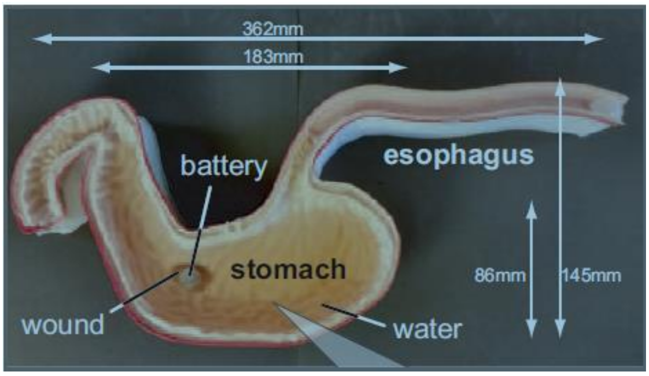
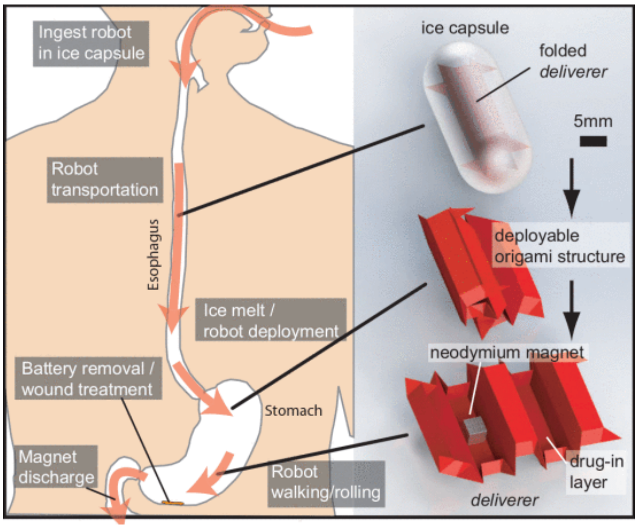


Fig. 1



In general, the stomach is filled with gastric fluid and the walls of both the esophagus and the stomach are lubricated with mucosa secretion and body fluids. Though the viscosity of gastric fluid can be variable, when the stomach is filled with water, its viscosity can be approximated as 1 centistoke.

Robot Design:

Two types of origami robots, referred to as the battery remover and the drug deliverer, respectively, were developed for the treatment of stomach inflammation. The origami designs were chosen to fold the robot such that they can be embedded in ice capsules which can be swallowed, carried to the stomach and dissolved. The robots are controlled by an electromagnetic actuation system. The actuation system consists of 4 cylindrical coils, inclined 45◦, distanced 25 cm each center to center, surrounding the center of the work stage, and placed at the lower hemisphere. By running currents, a magnetic field of various strengths and directions can be generated on the work stage. In real clinical applications one can employ a combination of ultrasound, X-ray, and an array of hall effect sensors to localize the position of the battery and the robot. The following sections explain various aspects related to robots used

Robot Architecture

In the first phase, the remover removes a battery from the inflammation spot to prevent further damage of the stomach wall while the robot is in a capsule shape. The remover, featuring a minimum supporting structure, is folded in an elliptic cylinder package (F1 = 3 mm, F2 = 1 cm, 1 cm long) and frozen. The shape allows rotational motion even after the encapsulating ice melts. The structure contains a diametrically oriented cubic neodymium magnet (edge length a = 3.2 mm) attached at the center of the robot's structure. The remover is fixed in an ice capsule for easy swallowing and digestion, expected for the short-lasting stay in the stomach. After the patient swallows the ice capsule using water, the remover travels by rolling in the stomach, actuated by controlled magnetic fields and guided to the location of the battery. It then grabs the battery by magnetic attraction, and dislocates it from the inflammation site. The magnet battery distance changes over time due to ice melting, altering the magnitude and direction of torque transmitted to the battery, thus enabling diverse lift postures. In order to induce maximum torque for lifting the battery, the magnet should be oriented planar to the battery (instead of perpendicular to it). The ice dissolution approach enhances the probability of a proper attachment, as the magnet steadily reorients itself while the ice melts to maximize the connection strength. Magnet reorientation while melting also reduces the risk of the magnet and battery magnetically pinching the mucosa. After the battery and remover are removed from the body through the gastrointestinal tract, in a subsequent phase, the deliverer is sent to the stomach. The role of the deliverer is to walk in the stomach and patch the inflammation site by landing on it, releasing a drug to the damaged area through the robot's body degradation. In order to effectively administer the drug, the deliverer should have a wide surface area covering the inflammation when deployed from the ice capsule. An origami technique is used to design the body as an accordion shape. This body structure enables the robot to compactly fold inside the ice capsule and expand 5 times when deployed. The deliverer consists of 5 trapezoidal boxed segments which can be stacked and configured as a hexagonal cylinder by folding. The front and back of the robot are designed to be point symmetric such that it induces asymmetric friction force along the body axis. The robot can locomote even when flipped. A cubic neodymium magnet is contained in the second segment. The magnet is oriented along the longitudinal axis of the body to induce an asymmetric moment of inertia under a periodic magnetic field application. The magnet is concealed when the body forms a hexagonal cylinder in an ice capsule.

Ice capsule transportation

Ice capsule transportation has various advantages over other approaches such as encapsulation by gelatin or sugar. First, it is safe and reduces friction while sliding through the esophagus by peristalsis. Second, it disappears quickly and completely in vivo by melting once it reaches the stomach, and thus it doesn't hinder the robot's motions unlike other materials, which was realized to be critical. Third, it is easily produced. The ice capsule is 27.0 mm long, almost the same size as the 000 standard pill size (length= 26.14 mm, diameter= 9.97 mm), and it melts in water on the order of a minute to a few minutes depending on the temperature. The size is determined such that the capsule (mass w = 2.55 g) sinks in water considering the robot's weight (wr = 0.578 g), and is subject to scaling down for children's use. For freezing an ice capsule robot, first a capsule was 3D printed from ABS material. Then, the capsule was placed in a silicone mold, molded it, and retracted the capsule from the mold such that the mold retained a capsule-shaped hollow space inside. Finally the robot was put in the hollow space, filled it with water, and froze it in a freezer. Material selection For in vivo use, the robot's body needs to be composed of biocompatible and biodegradable materials. The deliverer's body is made of 5 different layers polyolefin structural layer (biodegradable (BD)), (2) organic structural layer (pig intestine wall, Eastman outdoors, BD), (3) drug including layer (simulated by oblate, PIP, water dissolvable), and (4) actuation layer for self-folding. Choosing differing biodegradable layers allows for layer degradation at different time scales such that they fulfill their operational requirements at designed time sequences.

WALKING MOTION CONTROL FOR THE DELIVERER

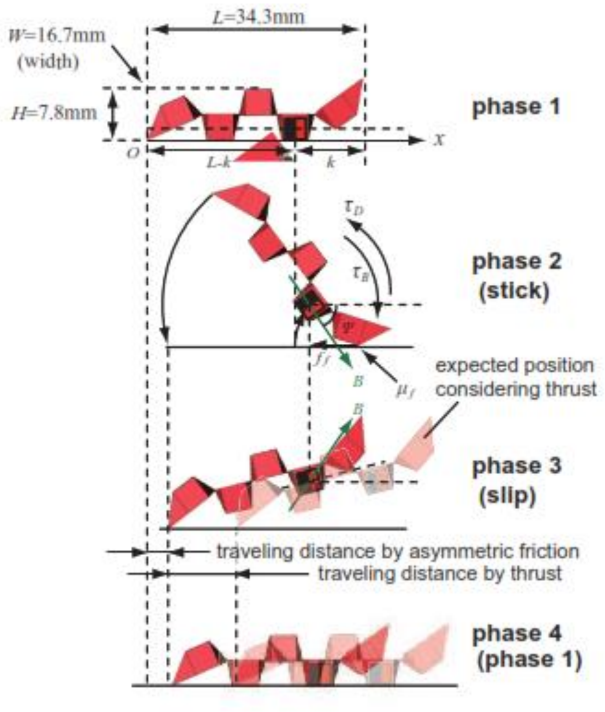


Fig. 2

The walking motion is designed based on stick-slip motion on ground. The robot acts underwater and thus experiences effects from moving in a low Reynolds number environment. Fig. (2) illustrates the walking motion of the deliverer seen from the side. The walking motion is easier to control than the rolling motion with higher precision. The magnetic field is applied at 5 Hz in the direction along which the deliverer is actuated (the positive x direction in the figure) oscillating through four angles (Ψ, Ψ/2, -Ψ/2 and -Ψ; Ψ = 1.1 rad is the angle from the horizontal plane). When such an alternating field is applied, the deliverer can "walk forward" due to the combination of thrust, asymmetric frictional force induced by the shape between front and rear, and asymmetric mass balance of the body. More precisely, one step motion consists of three distinctive phases; (phase 1) the body is laid on the ground; (phase 2) the body points down following a downward-oriented magnetic field; (phase 3) the body points up following an upward-oriented magnetic field. From phase 1 to phase 2, the deliverer lifts up the rear while the front is still in contact keeping the anchor position against thrust and exploiting the friction (stick motion). The center of mass, assumed to be at the location of the magnet, travels forward a distance ~ k(1-cos Ψ), where k = 8.7 mm is the distance between the center of the magnet and the front edge. From phase 2 to phase 3, as a turn of magnetic field occurs instantly, and due to the relatively low Reynolds environment with negligibly light body mass compared to the magnet mass, the body is expected to rotate about the magnet keeping the height of the center of mass (slip motion). Due to the body balance shifted to the front and also depending on the frequency of B, the posture does not completely catch up to the magnetic field, compared to the posture in phase 2. Considering the thrust that acts to push the body backward, this angle of magnetic field pointing up is minimized. From phase 3 to phase 4 (which is the same state as phase 1), the deliverer exploits friction and low stroke, and enables further body travel. The body length is L = 34.3 mm, the height H = 7.8 mm, and the width W = 16.7 mm. The traveling distance D in one cycle without considering thrust is kinematically — derived and is,

$$D \approx L - k\cos\Psi - (L-k)\cos\left(\sin^{-1}\left(\frac{k\sin\Psi}{L-k}\right)\right).$$

With this function, the walking speed of the deliverer is estimated to be 2.98 cm/s. Our experimental result shows the walking speed to be 3.71 cm/s. The difference is due to the influence of thrust.

Robot deployment via capsule melting

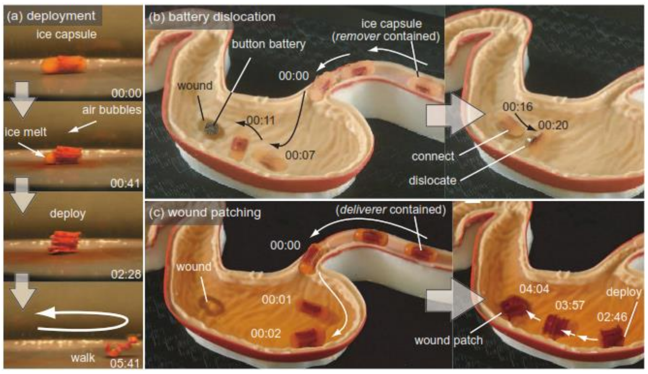
The dissolution of the ice capsule and the deployed robot's visually guided to the button battery location. The ice capsule then connected to the battery, and subsequently dislocated the battery (00:16~00:20). Note that during the operation, the ice melted and continuously reduced the distance between the magnet of the deliverer and the battery, assisting torque inductions of different magnitudes and angles. After the ice capsule connected to the battery, they could be discharged out of the body through the gastrointestinal tract. subsequent walking motion are demonstrated in Fig. 3 (a). The deliverer was deployed in the stomach as an ice capsule that facilitates the robot transportation by lowering friction with the walls of the esophagus and by preserving the robot's structure and properties. Melting the capsule was tested in liquids at a room temperature of 20°C. The dissolution time varies depending on the water temperature. According to our measurements, it took ~ 3 min at 22° C, and ~ 1 min. The deliverer was employed in the artificial stomach for the treatment of the artificially-created ulcer and showed the result in Fig. 3 (c). In this proof of concept experiment, an ice capsule was transported through an esophagus (00:00) and melted in water. Once the robot regained the original form, it showed a stable motion underwater under the application of a magnetic field.

Ice capsule's roll and foreign body dislocation

The ice capsule dislocating a button battery from the battery-caused inflammation site is shown in Fig. 3(b). As soon as the ice capsule that contained the deliverer was manually transported to the stomach (00:00), the capsule was actuated for rolling motion by an external magnetic field.

In the stomach

The deliverer regained the target body form (02:46), walked (03:57), and patched (floated over the target location) over a simulated ulcer (04:04). Sometimes air bubbles hindered deliverer from deployment, and thus it needed to let tumble for a short duration (between 02:46 and 03:57). We iterated the process 5 times and obtained an average duration of procedure completion of ~ 5 min. The demonstration proves the concept that a biodegradable artificial robot can be dispatched into the artificial stomach to accomplish a mechanical task for a medical purpose.



Discussion:

In this study origami robots that are ingestible and can be controlled to move, manipulate, and accomplish clinically-relevant tasks, such as removing a foreign body and patching a wound in the stomach were presented. Contributions include the design and fabrication of laminated biodegradable drug-including sheets for the robot's body, a method for ice encapsulation for robot delivery, control, actuation of rolling and locomotion under water, physics models for these motions, and experimental testing in a realistic artificial environment. Our approach requires limited on-board electronics. These minimalist robots enable minimally invasive clinical intervention, and greater flexibility and control in the choice of composite materials to fabricate biocompatible and biodegradable robots that can operate in vivo. Additionally, origami capabilities enable reconfigurability for minimal space occupancy and for accomplishing versatile mechanical tasks controlled by an external remote magnetic field.

LUCAS SYSTEM

The LUCAS chest compression system has been helping lifesaving teams around the world deliver high-quality, Guidelines-consistent compressions; in the field, on the move and in the hospital. With over 12 years of clinical experience, we proudly present the third generation LUCAS device, built on the LUCAS legacy. The LUCAS chest compression system has improved features to facilitate maintenance and handling and allows for new insights through easy, wireless access to device data

CPR is difficult to do well. Manual CPR training can help and it's expensive and cumbersome to schedule and track. LUCAS is simple and easy to use with minimal training, keeping the cost of ownership low.

MEDICAL REMINDERS

This is an Android-based application in which an automatic alarm ringing system is implemented. It focuses on doctor and patient interaction. Patients need not remember their medicine dosage timings as they can set an alarm on their dosage timings. The alarm can be set for multiple medicines and timings including date, time and medicine description. A notification will be sent to them through email or message inside the system preferably chosen by the patients. They can search doctor disease wise. The patients will get the contact details of doctors as per their availability. Also the users can see different articles related to medical fields and health care tips. The system focuses on easy navigation and good user interface. Many such Medical Reminder Systems have been developed where a new hardware is required but in our work we have made an attempt to develop a system which is economical, time-saving and supports medication adherence.

Advantages:

The users will get the notifications through SMS also. It will provide the information about the medicine timings. The scheduled appointment with the doctor with the contact details including visiting time, venue and availability at different hospitals in case the appointment is missed at the scheduled place. The new appointment will be set accordingly.

SMART WHEEL CHAIRS

Smart Wheel Chair is mechanically controlled devices designed to have self mobility with the help of the user command. This reduces the user's human effort and force to drive the wheels for wheelchair .Furthermore it also provides an opportunity for visually or physically impaired persons to move from one place to another. The wheelchair is also provided with obstacle detection system which reduces the chance of collision while on the journey. Smart wheelchair has gained a lot of interests in the recent times.

These devices are useful especially in transportation from one place to another. The machines can also be used in old age homes where the old age persons have difficulty in their movements. The devices serve as a boon for those who have lost their mobility. Different types of smart wheelchair have been developed in the past but the new generations of wheelchairs are being developed and used which features the use of artificial intelligence and hence leaves a little to tinker about to the user who uses the wheel chair. The project also aims to build a similar wheel chair which would have a sort of intelligence and hence helps the user on his/her movement.

The Da Vinci surgical System

The da Vinci Surgical System is a robotic surgical system made by the American company Intuitive Surgical. Approved by the Food and Drug Administration in 2000, it is designed to facilitate complex surgery using a minimally invasive approach, and is controlled by a surgeon from a console.

The surgeon operates on the patient from a seated position using system controls while viewing the surgical site through a high definition 3-D magnified view on a stereoscope monitor. The system is built with four robotic arms where three arms hold and operate various surgical instruments and the fourth holds numerous 3-D cameras. The surgeon can also control the device using a foot switch.

Advancements in robotic surgery have significantly improved laparoscopic (small incision) and minimally invasive surgeries where the surgeon utilizes computer-controlled robotic arms and hands for assistance. The multi-armed system can assist surgeons performing complex surgical procedures using tiny incision sites to enhance the surgeon's control, flexibility, and accuracy.

The most popular robotic surgical procedures performed by surgeons involve:

- Hysterectomies involving cancerous and benign uterus conditions
- Kidney surgeries in the treatment of kidney cancer including nephrectomy, partial nephrectomy, and nephroureterectomy that involves removal of the uterer and kidney
- Prostatectomy to treat urinary obstruction and prostate cancer
- Lung surgeries
- Cardiac surgeries involving robotic mitral valve repair
- Urologic reconstruction surgeries involving ureteral reconstruction, ureteral obstruction, pyeloplasty, sacrocolpopexy (uterine prolapse repair), uterine fibroids removal (myomectomy), and gender confirmation surgical procedures
- Endometriosis treatment
- Neck and head surgeries

Da Vinci Robotic Surgery Benefits

Due to the significant benefits the technology provides, many doctors recommend their patients undergo different types of surgeries using robots that perform minimally invasive procedures. Some of these benefits include:

- Shorter hospitalization time
- Diminished discomfort and pain
- Minimize scarring
- Smaller incision sites that reduce the potential risk of developing infections
- Quicker recovery to return to normal daily activities
- Minimal blood loss reducing the need for transfusions
- Better surgical outcomes

In addition, robotic surgery techniques help maximize surgical performance by utilizing the surgeon's enhanced dexterity using console controls, greater visualization by viewing the procedure on large monitors and more accurate precision.

The surgeon has more control than traditional surgeries and a heightened sense of dexterity that allow the doctor to operate in inside the body that has previously become inaccessible without a long incision.

Da Vinci Robotic Surgery Issues

While many patients can see the obvious benefits compared to the risks involved in undergoing robotic surgery, there are severe negative outcomes and complications involved in minimally invasive surgery using robots. Complications that can arise during the surgical procedure and afterward include:

- Increased risks associated with longer anesthesia and operating time.
- Temporary tissue swelling caused by gas used during the procedure
- Short-term nerve damage because of operating table positioning
- Injuries or complications to the patient's vision, larynx, or face when the patient is placed in an inverted position with the feet are higher than the head
- Injuries to blood vessels and organs caused by the surgical equipment or instruments
- blood pressure issues caused by gas absorption used during the procedure
- Fluctuating heart rates
- Post-surgical procedure shoulder pain
- Temporary discomfort and/or pain caused by the gas or air used during the surgical procedure

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