Steve Park <Seminar Paper Review> EN.600.446 CIS2
Team #12 04/04/2014

✧ **Paper 1: "*Interactive force-sensing feedback system for remote robotic laparoscopic surgery*"**
Authors: Mack Ian, Ferguson Stuart, Rafferty Karen, Potts Stephen, Dick Alistair
Presented at: Transactions of the Institute of Measurement & Control. June 2012, Vol. 34 Issue 4, p376~387.

✧ **Paper 2: "*Design and evaluation of an encountered-type haptic interface using MR fluid for surgical simulators*"**
Authors: Teppei Tsujitaa, Kazuya Saseb, Atsushi Konnob, Masano Nakayamab, Xiaoshuai Chenb, Koyu Abeb and Masaru Uchiyama
Presented at: Institute of Fluid Science, Tohoku University, 2-1-1 Katahira Aoba-ku, Sendai 980-8577, Japan

A. Intent

The development of complicated robotic system opened new opportunities for minimally invasive surgery. 'Da Vinci' and other surgical robotic systems significantly reduce the size of incision required to perform the operation, which means much shorter recovery time. Although there is increasing prevalence of robotic incorporation in various surgical operations, there is no such robotic system designed for laryngeal surgery through mouth. Traditional laryngeal surgery involves one surgeon to hold the endoscope camera steadily to view the area of interest for the other surgeon. Because the airway of a human is not so large, there is line of sight problem when two surgeons should work together within very small space. In addition, the surgeon who is holding the endoscope must stay steadily while the other surgeon operates. It is very difficult to hold the camera for entire duration of the operation which may last few hours due to fatigue and hand tremor. The traditional method also lacks depth perception, as the surgeon looks only at the display from the endoscope camera. Currently, surgeon fits various sizes of cylindrical tube down to the patient's throat to obtain the sense of depth and scale, during which the patient's throat might get damaged.

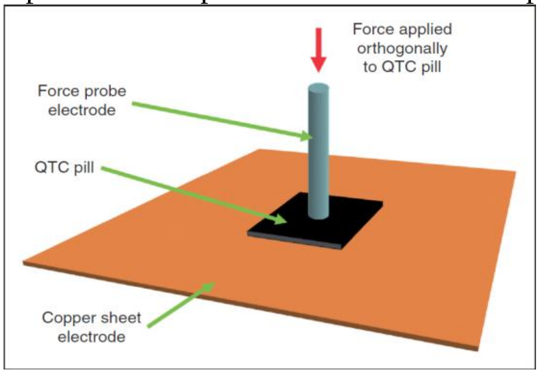
To overcome the drawbacks of current method, Robotic Endolaryngeal Flexible (Robo-ELF) scope is designed to hold and manipulate pose of the endoscope steadily inside of the patient's body. The current Robo-ELF prototype is driven by a controller with only on/off states, bulky size, and two-handed operation method. Better type of joystick would have gradual reading of input, compact size, one-handed manipulation, and haptic feedback. The paper number 1 discusses force sensing mechanism with ATC composite and its implementation in surgical robot system. The paper number 2 analyzes novel approach to provide haptic feedback using Magneto-Rheological (MR) fluid. Paper 1 investigates force sensing mechanism which can be mounted on the scope or robot possibly, while the paper 2 shows the unique MR fluid property under different magnetic field which can be utilized in the controller to provide direct haptic feedback.

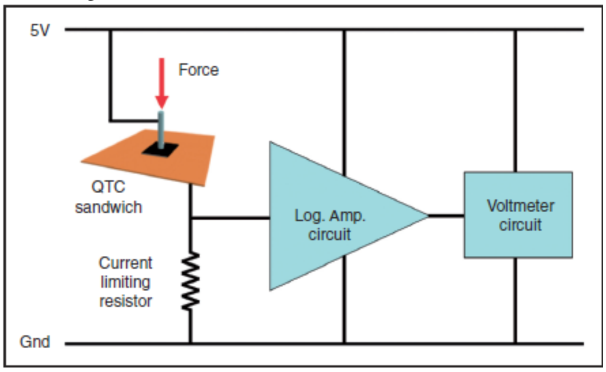
B. Technical Summary (all the figures used are from the papers listed at the top)

B1. Force sensing (Paper 1)

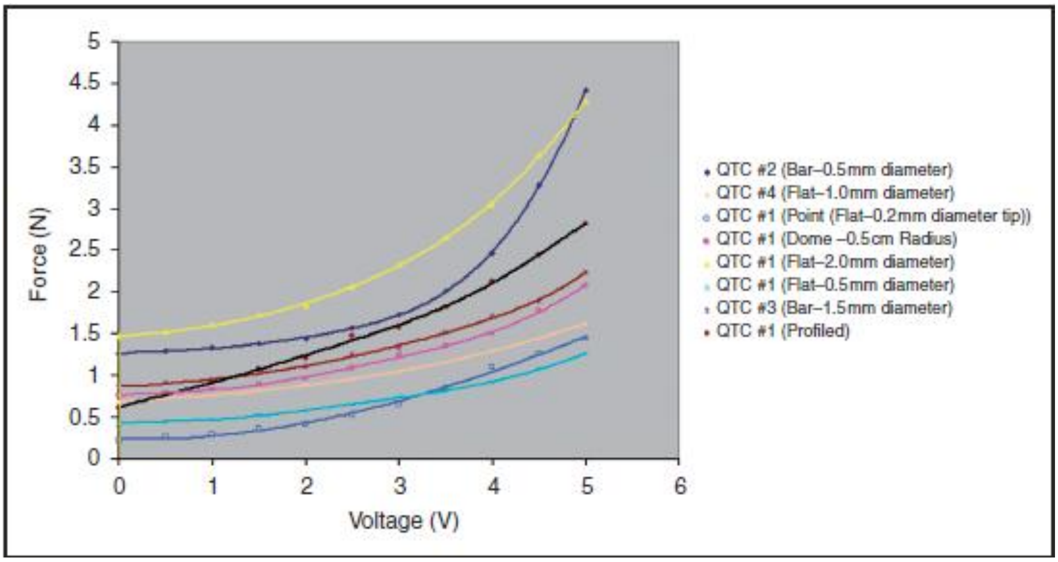
There are many different methods to measure the magnitude of applied force. Some include strain gage and photo-resistor which detects how much optical fiber deflected due to the force. Among these, the paper picks QTC composite for several advantages: the QTC pills (cubic structure 3.6 by 3.6 by 1 millimeter) is a dollar each, QTC are small enough to fit inside of any surgical instrument, it has large range of force detection at least 20 N, it does not necessitate complicated circuit system, it does not have to be near the contacting point to sense the force.

To test how well the QTC composite respond to the applied force, a test rig with electronic scale is developed. QTC is placed in between the fixed copper sheet electrode and current limiting resistor to complete the circuit. The circuit also includes logarithmic operational amplifier to linearize the output of QTC.



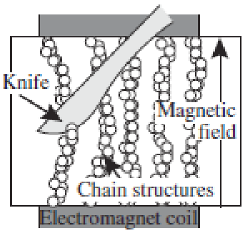


Above two figures describe the test rig set up. (Both of the figures are from paper 1). The experiment with same set up is repeated with different tip shapes which have significant effect on the linearity of the output reading. If the tip shape is too sharp, it can cause too much concentrated stress. The result shows that the initial force required to give a reading and force measuring range were reduced as the area of the force probe electrode gets smaller due to increase in stress.



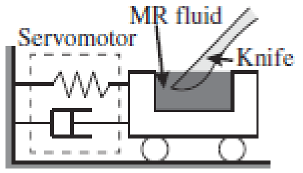
The output of the QTC is not totally linear, although logarithmic op-amp is used in the circuit. But, the QTC composite clearly shows different voltage reading for varying force magnitude.

B2. Force feedback (Paper 2)

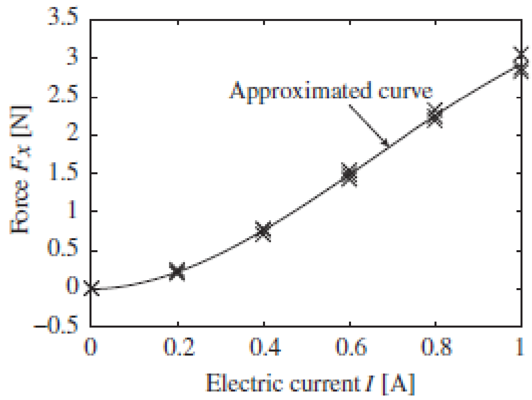


Cutting chain structures of MR fluid by a knife.

The Magneto-Rheological fluid (MR fluid) forms chain structure within itself in the presence of the magnetic field. The fluid can resist thus provide resistance force when an instrument tries to pass through. The magnitude of the resisting force can be changed by inducing various strength of the magnetic field around the fluid. Two of the biggest advantages of MR fluid haptic feedback system over any other system are that any instrument works with the fluid and that the instrument can move freely when it is not submerged under the fluid. Because the chain forms inside of the fluid due to the magnetic field, the fluid feels like a real tissue. When the surgeon tries to cut the fluid, one should feel about the same resistance force as if the one is cutting through real tissue. The biggest challenge of this model is that the MR fluid has very limited elastic range. Servomotor is attached to the fluid container and moves accordingly with the container in order to increase the range of cutting motion. The precise kinematic relationship between the servomotor and fluid container is carefully calculated with details by using Jacobean matrix in the paper. Different current is applied to the electric conducting wire to generate various strength of magnetic field. The result of the experiment is similar to the graph below.



Displaying large displacement motion by a servomotor



The force on the y-axis of the graph represents the magnitude of the sheer force required to cut through the fluid. The electric current on the x-axis denotes how much current applied to the coil to generate magnetic field around the fluid container. MR fluid can exert about 2.7 Newton under 1 Amps coil current.

C. Importance

1. QTC composite used in paper 1 shows that the force sensing mechanism does not have to be close to the contacting point, if the force can be carried through long thin rod.
2. QTC composite is very small and cheap enough to be mounted on any part of the robot.
3. The direction of the chain inside of the fluid can be controlled by the direction of the magnetic field. Therefore, the direction of haptic feedback can be adjusted to that of joystick.
4. The magnitude of the haptic feedback due to magnetic field in MR fluid can be changed quickly and effectively.

D. Relevance

	Our Project	Reviewed Paper
Similarities	The robotic system requires force sensing and haptic feedback system	The robotic system requires force sensing and haptic feedback system
	Varying magnitude of haptic feedback with multiple degree of freedom is required	Varying magnitude of haptic feedback with multiple degree of freedom is required
	Force sensing has to be far apart from where the force is applied	Force sensing has to be far apart from where the force is applied
Differences	The endoscope is flexible	Rigid instruments are used to demonstrate.
	The user experience haptic feedback through the joystick	The user experience haptic feedback through the cutting instrument

E. Critique

Strength:

- Paper 1
  1. The sensitivity of the QTC composite is very strong (only small amount of initial is required for the composite to produce readable change in output voltage).
  2. The QTC composite is very compact and cheap (only $1 per 3 mm^3 cube).
  3. The QTC force sensor can be far apart from where the force is applied. Long thin beam can be implemented to carry the load from the point where the force is applied to the force sensor.
  4. This method does not use any of X-ray which can expose the surgeon to danger, while some other force sensing mechanisms do.
- Paper 2
  1. The direction of the resistance force can be easily manipulated.
  2. The magnitude of the resistance force can be quickly adjusted by applying various current through the coil around fluid container.
  3. The instruments can move around freely when it is not submerged in the fluid.

Weakness:

- Paper 1
  1. The voltage reading of QTC composite under different forces is not linear.
  2. The force applied at the end of the flexible instrument cannot be measured.
- Paper 2
  1. The maximum resistance force MR fluid can exert is only about 2.7 Newton.
  2. Different direction of haptic feedback is possible but only one at a time. All the chain structure in the fluid is parallel to each other.
  3. The magnitude of resisting force varies with cutting angle, which is very hard to be adjusted.