Development of Active Catheter, Active Guide Wire and Micro Sensor Systems

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Summary

Active catheters and active guide wires which move like a snake have been developed for catheter-based minimally invasive diagnosis and therapy. Communication and control IC chips in the active catheter reduce the number of lead wires for control. The active catheter can be not only bent but also torsioned and extended. An ultra miniature fiber-optic pressure sensor, a forward-looking ultrasonic probe and a magnetic position and orientation sensor have been developed for catheters and guide wires. These moving mechanisms and several sensors which are fitted near the tip of the catheter and the guide wire will provide detailed information near the tip and enable delicate and effective catheter intervention.

Introduction

Conventional catheterization requires certain human skill because doctors have to control the tip of the catheter or the guide wire by moving it from the outside of the body. Furthermore, doctors monitor the position of the

tip of the catheter or the guide wire using X-ray radioscopy and angiography but the information obtained is insufficient because the image observed is two dimensional and there is no detailed information about the vessel wall near the tip.

Active catheters and active guide wires have been developed for controllable steering^{1, 2, 5}. The tip of the catheter is controlled from outside the body and moves like a snake utilizing a multi-joint mechanism with distributed shape memory alloy (SMA) actuators. Active catheters can perform several motions, not only bending but also torsional, and can extend by changing the configuration of the SMA actuators and bias springs.

First, designs and mechanisms of active catheters and active guide wires are described, then the circuit integration and development of fiber optic pressure sensors, forward-looking ultrasonic probes and magnetic sensors to obtain information near the tip of the catheters or the guide wires and that help the steering of the catheters or the guide wires are described.

Figure 1 Active catheter which has integrated communication and control (C&C) circuit.

Active catheter

Multi-link active catheters which move like a snake in blood vessel have been developed for minimal invasive diagnosis and therapy^{1,2}. Distributed NiTi shape memory alloy (SMA) coils are utilized as actuators for movement in multi-degrees of freedom. As shown in figure 1, CMOS integrated circuit chips which have flexible polyimide-based interconnect leads are incorporated within each links to control the motion with three common lead wires³.

Active catheter which can not only bend but also torsion and extend is shown in figure 2. Batch assembly using nickel electroplating and acrylic electrodeposition was applied to fabricate this catheter of which outer diameter is 1.4 mm⁴.

A bending of 60 degree was obtained by the current of 80 mA at 32 mm length. A torsional rotation of 70 degree was obtained with a current of 80 mA at 7 mm length. Outer tube is formed after fabricating active mechanisms for use in blood vessels. The outer tube consists of evaporated parylene (Poly-para-xylylene) membrane and biocompatible polyurethane (Pellethane) which is used for conventional

catheters. The surface temperature was below 41°C when the bending mechanism was actuated by a current of 80 mA in water at 38°C.

Active Guide Wire

An active guide wire of 0.5 mm diameter has been developed (figure 3)⁵. It can bend in one-direction using one SMA actuator which was fabricated using photolithography from a TiNi SMA sheet. The active guide wire is very flexible because it consists of the meandering SMA actuator and the coil spring. The guide wire bends to over 60 degree (length of bending mechanism is 5 mm) by applying current of 50mA in the air at 25°C.

Fiber Optic Pressure Sensor

Small diameter (125μm) fiber optic pressure sensor shown in figure 4 has been developed for catheter use⁶. A micromachined thin diaphragm is formed at the end of an optical fiber and the deformation by the pressure is detected interferometrically. This fiber-optic sensor is electrical hazard free and its signal is not affected by an electromagnetic interference.

Forward-looking Ring Array Ultrasonic Imager

A forward-looking ultrasonic imager has been developed for catheter use (figure 5). Piezoelectric PZT ceramic transducer array was made at the end of a catheter. Improved 1-3 composite piezoelectric transducer, built-in integrated circuit and micro relay for multiplexing the drive pulse are being studied as integrated ultrasonic imager at the end of catheter^{7,8}. Although the resolution is relatively low and monochrome, ultrasonography does not need flushing with saline and continuous monitoring is possible. Furthermore, a three-dimensional image and images of the surrounding blood vessel can be obtained.

Magnetic Sensor System for Detecting Position and Orientation of Catheter Tip

A sensor system for detecting the position and orientation using the Earth's magnetic field and an AC (10 kHz) magnetic field gener-

ated by two source coils which are located near the human body has been developed (figure 6)⁹. Real-time information about the position and the orientation and map of the blood vessels makes three dimensional navigation possible. Three-axis MI sensors (magneto-impedance effect sensors) for measuring the Earth's magnetic field and AC magnetic field are mounted on the catheter tip. On the display, the position and orientation of the catheter tip will be superimposed on the three-dimensional map of the blood vessels obtained using X-ray helical CT or MR angiography.

Conclusion

Active catheters and active guide wires which move like a snake utilizing distributed SMA actuators have been developed for catheter-based minimally invasive diagnosis and therapy.

Active catheters can have bending, torsional and extending mechanisms. A novel batch as-

Figure 2 Bending, torsional and extending active catheter. A) Bending mechanism. B) Torsional mechanism

Figure 3 Active guide wire using a flat meandering SMA (TiNi) actuator. A) Tube type (polyurethane was used for tubing), B) Skeleton type

sembly method for active catheters which connects SMA actuators, a liner coil and lead wires using nickel electroplating and acrylic electrodeposition was developed for low-cost assembly.

Fabrication methods for the outer tubes of

the active catheters using parylene and polyurethane were developed.

Several integrated circuits and sensors have been developed for catheters and guide wires. Communication and control chips reduce the number of lead wires needed to control the ac-

Figure 4 Fiber-optic ultra miniature (125μm outer diameter) pressure sensor.

Figure 5 Forward-looking ring array ultrasonic probe mounted at the end of the catheter.

tive catheter. A forward-looking ultrasonic probe and magnetic sensor mounted at the tip of the active catheter are useful for navigation of the catheter and for reduce x-ray exposure. These moving mechanisms and several sensors are fabricated at low cost using micromachin-

ing and can be disposable. Future multi-functional active catheters might provide information as virtual reality to the doctor, making doctor feel as if he or she is inside the human body, and enabling delicate steering and operation of the catheter.

Figure 6 Magnetic sensor system for detection of position and orientation of catheter tip.

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