In-pipe wireless micro robot

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Abstract—We have been developing an In-pipe Wireless Micro Robot for inspection of the inner surface of pipes, in collaboration with DENSO, Toshiba and SANYO under the Japanese national R&D project ‘Micromachine Technology’ of METI. The micro robot consists of many devices, a CCD camera for visual inspection, an actuator for locomotion, control circuits for system control, a microwave antenna and a photovoltaic device for energy supply and communication. The robot moves in a 10 mm diameter pipe without wire and observes the inner surface of the pipe. Through the project, the technologies of the component devices and the system have been developed. Several important results have been obtained on both technologies. For the device technologies, high-performance micro component devices have been developed. For the systematization technologies, the functions, simulation, packaging and assembling of the system have been studied. Through the development of the micro robot, we have successfully confirmed the wireless in-pipe locomotion and wireless image data communication of 2 frames per second.

Keywords: Wireless; micro robot; in-pipe inspection; image data communication; microwave.

1. INTRODUCTION

We have been developing a micromachine system for inspection of the inner surface of thermoconduction tubes of power plants under the Japanese national R&D project, the Industrial Science and Technology Frontier Program (ISTF), Research and Development of ‘Micromachine Technology’. In our previous work, we developed a wired in-pipe inspection micromachine which moves in a curved pipe and detects cracks in the pipe [1], as a primary prototype of the system. With a diameter of 5.8 mm and an overall length of 20 mm, it fits inside 8 mm piping, and is inertia-driven [2] while searching for cracks in pipe walls using an eddy current sensor. The machine consists of an eddy current sensor, an inertial mass, a piezoelectric stacked actuator, a base, radiation fins and three clamps. The

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wires are used for energy supply and signal monitoring of the eddy current sensor. Through the development of the prototype micromachine, problems unique to micro technology were identified. The biggest problem was wiring for the power supply and signal monitoring. Even with a diameter of wire as thin as 18 μm, the weight of the wire is too heavy enough for the 1 g micromachine and the hardness of the wire is too great for the machine, so the wire limits the movement of the machine. In our previous work, we proposed a wireless energy supply method utilizing microwaves, and we developed a 15 mm diameter in-pipe wireless locomotive mechanism whose power was supplied from outside by microwave. Through the development, we could successfully realize the wireless in-pipe locomotion [3]. Therefore, we planned the wireless in-pipe micro robot shown in Fig. 1.

The figure shows the wireless in-pipe micro robot under development. The robot consists of a CCD camera for inspection, an actuator for locomotion, control circuits for system control, a microwave antenna and a photovoltaic device for wireless energy supply and communication. The robot moves in a curved pipe at 20 mm/s by the actuator, inspects the inside of the pipe and transmits the observation data to a host computer. The required power of 650 mW is provided from the outside via microwaves and light. We are developing the micro robot in collaboration with Toshiba and SANYO. The system will be completed in 2001. The R&D current status of the component devices and the systematization are discussed in this paper.

2. COMPONENT DEVICE TECHNOLOGIES

2.1. CCD micro camera module

The CCD micro camera module has been developed by Toshiba. The CCD camera module consists of several functional devices, such as a mirror, a mirror rotation mechanism, a focusing mechanism, a micro lens, a 100 000 pixels CCD and a CCD imaging data transmission circuit. These devices have been integrated to achieve a 9.2 mm diameter CCD micro camera module. The mirror rotation mechanism and focusing mechanism have electrostatic actuators which are operated at 80 V. The lens is mounted on the inner cylinder of the focusing mechanism. The circuit, which consists of many LSI chips and discrete elements, has been packaged in a block of $4.4 \times 5.2 \times 11.5 \text{ mm}^3$ by using new three-dimensional assembly technology [4].