MICRO SCANNING LASER RANGE SENSOR FOR PLANETARY EXPLORATION

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Abstract

This paper proposes a new type of scanning laser range sensor for planetary exploration. The proposed sensor has advantages of small size, light weight, and low power consumption with the help of micro electrical mechanical system technology. We are in the process of developing a miniature two dimensional optical sensor which is driven by a piezoelectric actuator. In this paper, we present the mechanism and system concept of a micro scanning laser range sensor.

1. Introduction

As increasingly many missions are being proposed for the moon and planet explorations, autonomous navigation technology for spacecraft in deep space is getting more important than ever. In recent years, many researchers have been extensively studying and developing planetary landers or rovers for unmanned surface exploration of planets[1][2][3][4][5].

In a planetary exploration mission, it is important for a lander to land in a plain and safe place. A planetary rover is also required to travel safely over a long distance in unknown terrain without collision with big stones, rocks etc. Hence, it is necessary for a lander or a rover to recognize the terrain on the planetary surface.

There have been developed various kinds of sensors for this purpose[6][7][8]. However conventional sensors have many problems with weight, size, power consumption, reliability, etc. In this paper, we propose a scanning laser range sensor using micro electrical mechanical system (MEMS) technology. A two dimensional optical scanner is one of the most promising devices to recognize the three dimensional terrain. So we are in the process of developing a miniature two dimensional optical sensor which is driven by a piezoelectric actuator. The scanner system consists of two elements, a resonator and a piezoelectric actuator. The resonator has two typical vibration modes, twisting and bending mode of the torsional spring. Actuating the resonator with piezoelectric element at the resonance frequency leads to the resonant rotating vibration of the resonator with large amplitude. When the piezoelectric actuator is driven simultaneously with both the resonance frequencies, optical beam reflected on the mirror of the vibrating resonator is scanned in two perpendicular directions. The proposed technology will remarkably reduce the weight, size, and power consumption compared with the conventional sensor.

This paper is structured as follows. In Section 2, the concept of recognition sensor is discussed. Then a scanning mechanism is described in Section 3. In Section 4, a method to obtain range image by a micro scanning laser range sensor is explained. Final Section is for discussion, conclusion, and future work of the research.

2. Concept of Recognition Sensor

Several sensors and methods have been proposed to recognize the terrain on the planetary surface; for example, a laser range finder, stereo vision etc. However, conventional laser range finders have problems with weight, size, power consumption, reliability, etc. for the purpose of scanning the terrain area. It is difficult and takes a long time to find correspondent points in stereo vision methods. Hence, we have proposed a new type, of two dimensional optical scanner sensor.

Figure 1 shows the concept model of the proposed recognition sensor, which consists of an optical scanner device, a micro lens, a laser diode, a photo detector, a piezoelectric micro actuator to drive the scanner, driver circuits, and signal processing circuits. Target size, weight, and power consumption are shown in Table 1.

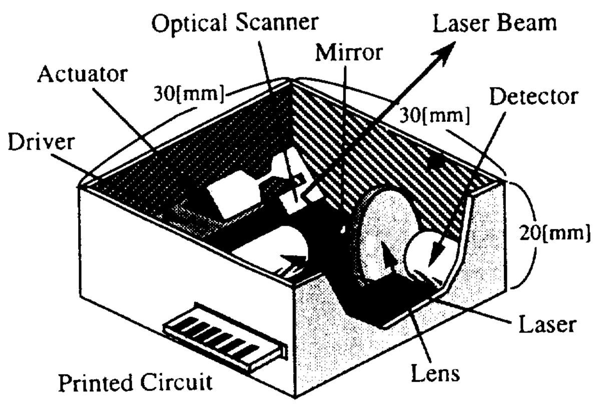

Figure 1. Concept of Recognition Sensor

Table 1. Specification of LRF

Laser Range Finder	size	weight	power
Conventional LRF (Rotating Mirrors)	20[cm] (L) 20[cm] (W) 20[cm] (H)	15[kg]	100[W]
Advanced LRF (Polygon Mirrors)	15[cm] (L) 15[cm] (W) 15[cm] (H)	3[kg]	60[W]
Micro LRF (Piezo-Mechanism)	target 3.0[cm] (L) 3.0[cm] (W) 2.0[cm] (H)	target 0.5[kg]	target 3[W]

3. Scanning Mechanism

3.1 Two Dimensional Optical Scanner

A miniature two dimensional optical scanner is shown in Figure 2. The developed optical scanner[9] consists of two elements, a resonator and a piezoelectric actuator. Here the center of gravity is shifted from each rotational axis P and Q. So the resonator has two typical vibration modes, twisting and bending of the torsional spring as shown in Figure 3. Actuating the resonator with a piezoelectric actuator at each resonance frequency leads to the resonant rotating vibration of the resonator with a large amplitude. The resonance frequency f is described by the following equation.

$$f = \frac{1}{2\pi}\sqrt{\frac{K}{\ell}} \qquad (1),$$

where K and ℓ denote stiffness of torsional spring and rotational inertia moment of resonator respectively. As a result, optical beam reflected on the mirror of the vibrating resonator can be scanned in the two directions of θ_T and θ_B .

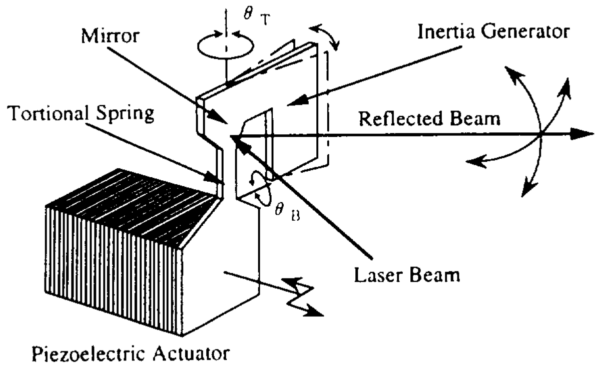

Figure 2. Structure of Scanner Sensor

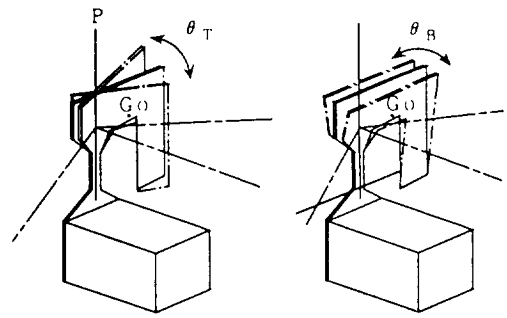

Figure 3. Resonance Vibration Modes

3.2 Piezoelectric Micro Actuator

A multilayered piezoelectric actuator is often used because it is easy to realize miniaturization and high speed response of the actuator. However the multilayered type requires high voltage over 100 volts to obtain several microns amplitude of the resonator. It is needed to avoid generating heat at the miniature devices. The new actuator[10], which is called moonie, is developed as shown in Figure 4. The actuator consists of a multilayered piezoelectric actuator and metal plates fixed on the top of the actuator. The plates has shallow cavity to transform and magnify the radial strain of the actuator into the axial strain.

When the piezoelectric actuator generates the strain in X direction as the axial strain by supplying electrical field, the contraction strain in Y direction is produced. The plate is deformed by the contraction strain as shown in Figure 4(b). So a magnified strain in X direction can be obtained.

Applying the moonie actuator in the two dimensional optical scanner, low voltage driving, less than 10 volts can be realized. It can reduce generate heat at the actuator and driving circuits.

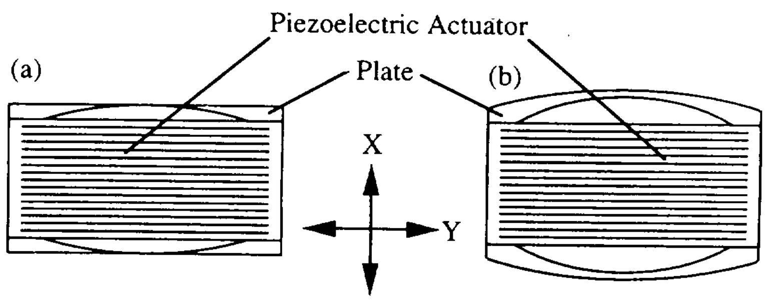

Figure 4. Structure of Moonie Actuator

3.3 Scanning Angle Detection

It is necessary to detect the scanning beam angle for making three dimensional terrain map of planetary surface. In the developed resonance type sensor[11], the phase difference between the scanning orientation and driving voltage wave form is 90[deg] which is constant regardless of the oscillation frequency and amplitude. So it is possible to detect the scanning angle by monitoring the driving voltage to the actuator. The scanning angle is calculated by the following equations:

$$\theta_T(t) = \pm \theta_0 \sqrt{1 - \left(\frac{V_T(t)}{V_{0T}} - 1 \right)^2} \qquad (2),$$

$$\theta_B(t) = \pm\,\theta_0 \sqrt{1 - \left(\frac{V_B(t)}{V_{0B}} - 1 \right)^2} \quad (3),$$

where Vo is maximum amplitude of the driving voltage wave form to the actuator and θ_0 is maximum scanning angle of the scanner.

3.4 Performance of the scanner

The performance of the scanner angle is shown in Figure 5. The developed scanner can scan an optical beam in two directions with approximately 40[deg] at 4[μm] piezoelectric actuator amplitude. In this case, the resonance frequency of the resonator is 121[Hz] for twisting mode and 288[Hz] for bending mode. So the scanning speed of 242[scan/sec] and 576[scan/sec] is obtained if a to-and-fro scanning is applied. The scanning speed is adjustable by changing the resonator shape. The maximum speed is over 2000[line/s] by reducing air viscous resistance against the resonator. Two dimensional scanning pattern is determined by the ration of the resonance frequencies. Figure 7 shows an example of the scanning pattern.

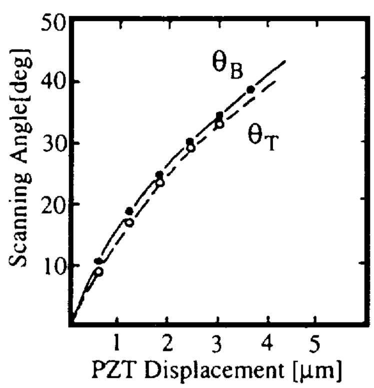

Figure 5. Scanning Angle Data

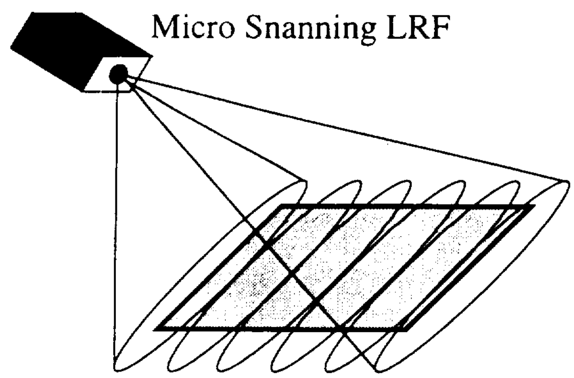

Figure 6. Scanning Pattern

4. Range Image

Laser range sensors for planetary exploration require high accuracy and high frame rate performance. This leads to using phase-comparison system by intensity modulated CW laser. The laser beams are radiated to target objects reflected and returned to the sensor with some phase shift proportional to the target distance. The intensity of the semiconductor laser is modulated at 10.7 [MHz]. The reflected beam from the object is received by an APD photo detector. The signal received by the detector passes into the detection circuit of the range and reflectance. The range is determined by the phase difference of returned signal and the reference signal as shown in Figure 7. In order to obtain sufficient sensitivity and accuracy, nearly 100 waves are integrated for each range data. The data of range and reflectance are converted into digital data by an A/D converter. Optical scanning in two dimensional directions help to obtain three dimensional terrain recognition.

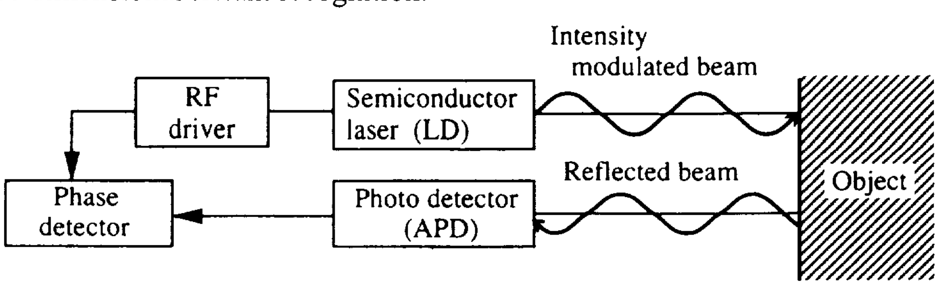

Figure 7 Range Data Measurement

5. Conclusion

This paper presents a scanning laser range sensor for terrain recognition of planetary surface. The concept of micro scanning laser range sensor is proposed with the help of micro electrical mechanical system technology. The proposed micro sensor is expected to solve some problems with weight, size, power consumption. Experimental study is under going. When the proposed sensor is used in space environment, there are some items for further study as follows: range drift due to temperature change, vibration and shock problems at launch. Those problems are under study.

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