Pressure Mapping System Development Based on Intensity Modulated Fiber Sensor

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Abstract
The development of smart-mat as a pressure mapping sensor has received great interest. These sensors have been used for variety of human needs, from medical to smart-house. The main objective of this research is to point out the feasibility and effectivity of mapping fiber sensor subjected to a load given to a certain area to the pressure distribution on the mat surface. The proposed pressure distribution fiber sensor was made by sandwiching partially scratched polymer optical fiber to form a web. Five strands of partially scratched fiber were inserted sandwiched horizontally in a rubber mat and the other six strands were sandwiched vertically. As the mat is loaded, optical fiber sandwiched underneath the load is bent resulting in light attenuation. Analyzing the attenuation light from both sides using matrix method, a contour area representing pressure distribution can be constructive.

Keywords : fiber optic sensor, modulated fiber sensor, pressure mapping

1. Introduction
Pressure mapping is measurement and visualizing pressure experienced by any point on a surface. Now days, pressure mapping can be found in many applications from biomechanics, smart-building, agriculture, defense and security. Using pressure mapping system, one can quantify and visualize the feel of wearable product as well as what the body experiences resulted from either an external force or internal force. Among them are applications for visualizing foot print. Davis et al. has been designed to simultaneously measure the vertical pressure and the anterior–posterior and medial–lateral distributed shearing forces under the plantar surface of the foot. This device uses strain gauge technology and consists of 16 individual transducers arranged in a 4x4 array each with a covering measuring area of 2.5 cm x 2.5 cm [1].

Various sensor technologies have been used to build pressure mapping system, i.e., piezoresistive sensors, piezoelectric sensor, resistive sensors, and capacitive sensors [2] [3]. Among them, piezoelectric-based polymers sensors are much used these days. Many distributive shear and pressure sensors have been developed using that use an integrated-capacitive sensor and strain-gauge sensor. Despite its superiority in term of elasticity, this sensor suffers from many problems caused by its susceptibility to electrical interference because of its high impedance as well as its high sensitivity to temperature.

In recent years, optical fiber sensors (FOS) have received much attention mainly due to their unique properties such as immune to electromagnetic field interference, small size, and most importantly it can be installed hazardous area where electric-based sensors cannot do. In addition to that, FOS are also known for their sensitivivity and high dynamic range [4]. Making use of the basic properties of light
propagating in optical fiber, many class of fiber optic sensors have been developed. Among them are those manipulating the change in light intensity coming out of the fiber as portion of the fiber is subjected to physical or chemical change. The type of these fiber sensors (intensity modulated sensors) were introduced in the early 60's [5-10].

Pressure mapping system built based on intensity modulated fiber sensors have been developed by many different researchers. Most of them were made by exploiting macro-bending loss. Macro-bending in pressure mapping pad can made by laying optical fiber in between three cylindrical rods at which one rod are placed above the interspace of the other two rods [11], by laying fiber in between two series of teeth or by crossing series of perpendicular fibers such that as a crossing point is subjected to a vertical force a macro-bending occurs. Using normal silicate optical fiber used for optical communication or polymer optical fiber, however, loss will occur only bending radius is equal or less than its corresponding critical radius. This means than large force or pressure has to be applied. This paper proposed a novel method to build a pressure mapping system, that is pressure mapping system built with sensing element consist of partially cut polymer optical fiber. Unlike that we developed previously [11], the fiber pad built in this system is thinner than that previously build based on macro-bending loss [4].

2. Methods

Figure 1 is an illustration of partially cut plastic optical fiber. Series of partially cut were made using a sharp blade. In order to control the depth of cut, the blade movement in vertical or horizontal directions is controlled using micrometer. In this work, the distance between two cuts is 2.5 mm. Basic principle of the sensing element unit (sensing cell) is as follow. The side of the fiber containing a series of partially cut is faced downward. If no downward force applied, the cuts remain close (Figure 1.a). As a downward force applied at a point at the fiber above the cut, that cut or nearby cuts will open to form V-shape mouth. The larger the force, the larger the angle of the V-shape and therefore more light will radiated out through the V-gab.

![Figure 1](image1.png)

**Figure 1.** Partially cut polymer optical fiber optic as (a) no force applied and (b) a force is applied.

![Figure 2](image2.png)

**Figure 2.** Schematic diagram of pressure mapping system at which two series of partially cut fibers were crossed perpendicularly: 1) rubber silicon, 2) partially cut, 3) fiber optic, 4) LDR, 5) LED.
Figure 2 is schematic diagram of pressure mapping system. Series of partially cut optical fibers were laid in x-axis and other are laid in y-axis on top the first series. For each fiber, one end is connected to the light source (light emitting diode/LED) and the other end was connected to a photodetector (LDR). Silicone rubber was then cast to form a thin pad of 0.4 cm thick such that in all points at the fiber web has the same distance to the rubber pad surface. As the mat is loaded, optical fiber sandwiched in the rubber pad underneath the load is bent. The heavier the load, the wider the V-shape will be. Consequently, more light will radiate out of the fiber through the open cut (V-shape).

3. Results and Discussion

![Figure 3](image-url)

**Figure 3.** Visualization of stress distribution experienced by rubber pad as loaded with the same mass (0.5 kg) but positioned at different position (Figure a and b) and as loaded by 1.5 kg (Figure c).
When a rubber pad or mat with specific surface area is subjected to a point load, the action force is experienced not only by the rubber at the contact point but also at its vicinity. Rubber surface just underneath the load will be pressed deeper than that located at farther distance from the contact point. Depending on the rubber elasticity, the downward pressure experienced by the rubber beyond the contact point varies with the rubber elasticity. It means that the optical sensor cells beyond the contact point are also bent resulting in light attenuation. Light intensity coming out of a fiber, therefore, reflects the pressure experienced by a point on the rubber surface.

Figure 3 shows the visualization of pressure distribution experienced by the rubber pad surface as a load of the same mass but with different position was placed on the rubber pad surface. Point position or area on the rubber surface experiencing the largest pressure is indicated with dark blue color while the one with no pressure is indicated with dark red color. The effect of force at the vicinity of the loading point is quantified by the step-like contour change from the dark blue to the dark red.

Gradual color change of all contours as shown in Figure 3 which are typically the same as those reported in other papers [4, 11, 12] suggests that the new pressure mapping system reported in this paper work well. Gradual change in color as shown in these figures shows that the V-shape cut underneath the load is open wider than those beyond the contact point. In other word, more light radiated out through the V-cut at the position of loading point than those beyond it.

![Figure 3. Visualization of pressure distribution](image)

**Figure 3.** Visualization of pressure distribution experienced by the rubber pad surface as a load of the same mass but with different position was placed on the rubber pad surface.

Simple mechanism of light radiated out the fiber used in this experiment is shown by Figure 4. As a force F is applied downward, fiber is bent, and the scratch begin to open to form a “V” shape. As parallel light with a particular mode moves toward the scratch, part of light is refracted to the V gap. Part of the light in this gap is radiated back to the fiber and other radiated out of the fiber. The percentage of light radiated out of the fiber through this gap depends on the applied force F. The larger the F, the wider the scratch is open and therefore the more the light is radiated out of the fiber.

**Figure 4.** Loss mechanism in partially cut optical fiber as it is bent by a force F

4. Conclusion
We have successfully developed a new pressure mapping system using partially cut polymer optical fiber sandwiched in an elastic rubber pad. Characterization of the pad has also been carried out. Using our computer program, we have demonstrated that pad into which the series of partially cut fiber sensors configured in a web form is buried was capable of visualizing the pressure distribution experienced by the pad surface. Simple mechanism of light radiated out the fiber in V-shape area was also described.

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