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A New Measurement Method of a Radial Pulse Wave Using Multiple Hall Array Devices

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This study investigated the radial pulse waveform obtained by a medical pulsimeter sensor. A pulse-sensing part array consisting of multiple Hall devices was located over a skin-contacting part with a hard magnetic material. The periodic movement of the magnetic material of the skin-contacting part affected the magnetic field in the pulse-sensing part array and was detected by multiple Hall devices. The analysis of a radial pulse waveform that is measured noninvasively by detecting the changes of the magnetic field can be used to develop a new diagnostic algorithm of oriental medical apparatus.

Keywords : pulsimeter, multiple Hall array devices, pulse-sensing part, radial pulse wave

1. Introduction

Currently, most medical detecting sensors for body pulse are either invasive types, which detect the changes in the blood pressure by injecting tubes into the blood vessels, or noninvasive types, which use pressure sensors [1-2]. Particularly, the pulsimeter sensor, which uses pressure sensors, has been researched many times due to its noninvasivity. There are three categories of pulsimeter sensor: medical, automatic, and pulse wave measuring [3-5].

The medical pulsimeter sensor includes a pressure-sensing sensor with a silicon layer, which is adhered closely to the upper skin at the radial artery and closes up a tight air layer to sense the pressure change of the air layer depending on the vibration of a pulse wave [6]. A silicon gel transfers the pressure change of the air layer. A pressure-measuring plate is affected by the transferred pressure by the silicon gel. A silicon gum is adhered to the front side of the upper skin and fixes the pressure-sensing sensor to the skin of the examinee. A fortified plastic plate is adhered to the back side and transfers the variable pressure from the back side of the pressure-sensing sensor fixed to the skin of the examinee.

The silicon layer and silicon gel, which are in front of the pressure-measuring plate, eliminate any cold feeling and unnecessary stimulus of the metals. However, the conventional pulsimeter sensor comprised of pressure sensors suffers the disadvantages of unnecessarily closing up the air layer tight, which transfers the pressure changes indirectly to the pressure-measuring plate and results in inaccurate pulse measurement. The location of the pulse in different patients cannot be determined and the exact pulse cannot be measure quickly with the conventional pulsimeter sensor using pressure sensors [7].

Oriental medical doctors have diagnosed the three pulse locations over the radial artery on the wrist and classified them as Chon, Gwan and Chuck. “Gwan” is located on the coronal process of the radial artery on the wrist. “Chon” is located on the spot 1~1.3 cm from Gwan toward the palm of the hand. “Chuck” is located on the spot 1~1.3 cm from Gwan toward the elbow. The doctor places the index, middle and ring fingers on the examinee’s Chon, Gwan and Chuck locations with three different degrees of pressing, that is, moderate (the “Bu” state) hard (the “Jung” state), and light (the “Chim” state) [8].

Oriental medical doctors feel the pulse with one pressure sensor, which is a disclosed invention for measuring the three regions of Chon, Gwan, and Chuck simultaneously with three pressure sensors [9]. To solve the problems of the conventional pulsimeter sensors, the present feature is directed to a pulsimeter sensor using multiple

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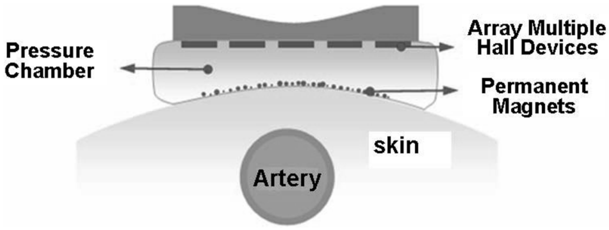

Fig. 1. Schematic of a cross-section of one form of the radial artery pulsimeter's pulse-sensing and skin-contacting parts by using multiple Hall devices and permanent magnets, respectively. The pressure chamber between the skin-contacting and pulse-sensing parts is full of air.

Hall devices and array nano-magnetic sensors composed of giant magnetoresistance-spin valve (GMR-SV) and magnetic tunneling junction (MTJ) devices [4, 5, 10, 11]. To achieve the objectives of the proposed invention, a pulsimeter sensor was characterized by using multiple Hall devices and including a skin-contacting part, formed with a hard magnetic material in contact with the skin to examine the pulse. In the pulse-sensing part, a pulsimeter sensor is located some distance from the skin-contacting part and formed as an array type of unit cells with two or more Hall devices. In the spatial part, a pulsimeter sensor is located between the skin-contacting and pulse-sensing parts, as shown in Fig. 1. The pressure chamber between these two parts is full of air. Fig. 1 shows a schematic of a cross-section of one form of radial artery pulsimeter's pulse-sensing and skin-contacting parts by using multiple Hall devices and permanent magnets, respectively.

2. Experimental Method

A detailed description of the preferred form of the proposed pulsimeter is provided below with respect to the accompanying Fig. 1. A magnetic material of a skin-contacting part of the proposed invention can be composed of submicron particles like magnetic micro- or nano-beads [12], and their locations can be changed easily depending on the vibration of the pulse. It is preferable that the magnetic nano-particles are Co, Fe_3O_4 or Fe_2O_3. The thick magnetic films are ribbon-type magnetic pads or small circular plate-type magnetic chips. In the case of using the ribbon-type magnetic pads for a hard magnetic material, plastic (or rubber) bonded magnets of 200~300 Oe are placed at a 3 mm distance from the pulse-sensing part. The size of the ribbon-type magnetic pads is determined by the pulse-sensing part. For example, the ribbon type magnetic pads can be shaped with 5 stripes, each of size 1.0×12 mm^2. This gives the advantage of enabling the skin-contacting part to be fixed with 10 grooves made by stripes of the magnetic pads. Especially, it is preferable that the surface of the skin-contacting part is made of soft materials that do not press the skin.

The proposed radial artery pulsimeter comprises a pulse-sensing part of an array type using a magnetic sensor as a minute unit cell. This minimizes the time required to search for the locations of the pulse and to measure the spatial characteristics of the pulse completely. Therefore, all 28 qualities of the traditional pulse diagnosis can be evaluated [11].

The Hall device used as a magnetic sensor can be shrunk by a semiconductor lithography process [13]. It is largely unaffected by movements of the examinee and various applications can be designed such as wrist watches, rings and IC chips as a wearable (portable) pulsimeter. Furthermore, while pain is induced by the pressure applied to the skin in the conventional pulsimeters using pressure sensors, the proposed apparatus receives the pulse through a mechanically soft, hard magnetic material of a skin-contacting part that does not generate any pain. The permanent magnets, with a diameter of 1.5 mm, height of 2 mm and surface magnetic field of 200 Oe maintained at a constant displacement of 54 pieces, are shown in Fig. 2(a). The printed circuit board (PCB) pulse-sensing part mounted with multiple Hall devices corresponding to permanent magnets is shown in Fig. 2(b).

Next, the unit cell of the pulse-sensing part array can be a Hall device, regardless of its structure. Many studies on

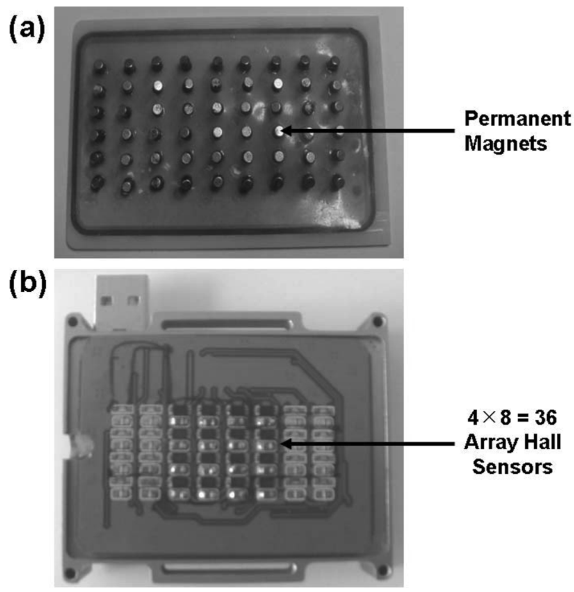

Fig. 2. (a) Permanent magnets with a diameter of 1.5 mm, height of 2 mm and surface magnetic field of 200 Oe maintained at a constant displacement of 54. (b) PCB pulse-sensing part mounted with a multiple $5 \times 9 = 45$ array of Hall devices corresponding to the permanent magnets under it.

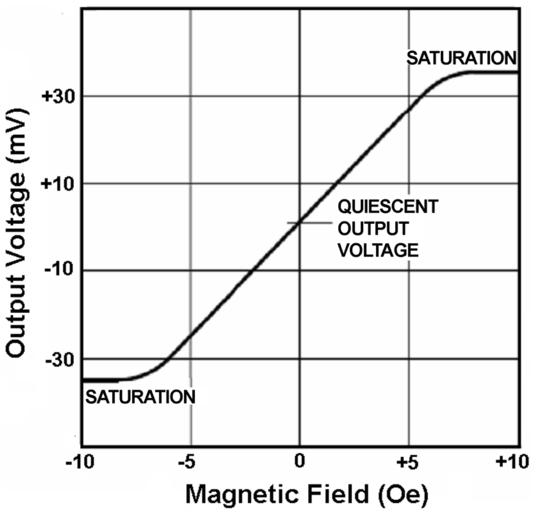

Fig. 3. Output voltage versus magnetic field for the commercial, A3515- and A3516-type Hall device with a high sensitivity of 2.5-5 mV/Oe and a linearity in the magnetic field and temperature range of from –10 Oe to +10 Oe and from –40°C to +150°C, respectively.

the applications of these devices as next-generation memory devices have already been conducted by semiconductor memory manufacturers [10, 11]. Therefore, matters relevant to the proposed pulsimeter are only briefly described here. A Hall device, which is used as a unit cell 22 in the proposed pulsimeter, is usually called a semiconductor Hall sensor, showing Hall effects. The characteristics of Hall voltage versus external magnetic field for the used Hall sensor are shown in Fig. 3. The commercial, A3515- and A3516-type Hall sensor has a high sensitivity of 2.5-5 mV/Oe and a linearity in the magnetic field and temperature range of from –50 Oe to +50 Oe and from –40°C to +150°C, respectively.

3. Results and Discussion

The pulsimeter was characterized by arranging minute unit cells of the pulse-sensing part appropriately. It was not only possible to elucidate the time characteristics of the pulse by a pulse wave measurement, but also the spatial characteristics of the pulse by measuring the widths, lengths, degree of pulse palpation and so on. In the final form, it is preferable that a spatial part is a constant pressure chamber, which maintains a predetermined pressure, as in shown Fig. 1. In the proposed pulsimeter, any means can be used to maintain a predetermined space and transfer changes in the magnetic field by the magnetic material of the skin-contacting part to the pulse-sensing part.

We measured the signals at the "Chon", "Gwan", and "Chuck" regions using the product testing of the radial pulsimeter system comprised of multiple Hall devices. The signals passed through the voltage-detecting hardware system induced a differential input, automatic zero set, noise filtering, high power gain and output attenuation, and output with 12-bit resolution at 30 FPS (frame/s). The results were simulated with a predetermined computer processing, and obtained through an acquisition process of three-dimensional (3D) pulse images using the product testing of the radial pulsimeter system comprised of multiple Hall devices, as shown in Fig. 4. By the computer processed, 3D signal images detected by the radial pulsimeter, one point pulse can be selected to analyze the temporal pulse wave.

Fig. 5 shows multiple pulse signal forms of measuring time (seconds) versus temporally typical signal of multiple points pulse obtained from the analysis for an arbitrary 3D pulse image of multiple positions of small permanent magnets. The preferable forms of the radial pulsimeter have been described above. However, the radial pulsimeter cannot be defined only by the described forms herein. The radial pulsimeter described herein is generally applicable and executed as various modified forms by those skilled in the art. For example, materials and numerical values for a skin-contacting part, pulse-

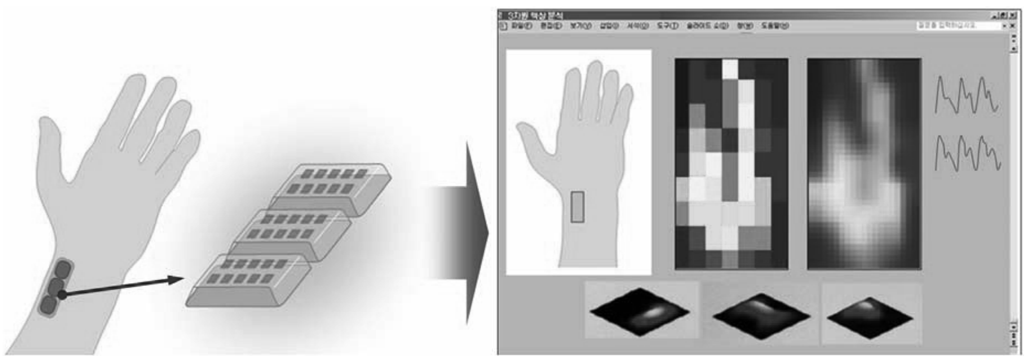

Fig. 4. Acquisition process of 3D pulse images for the "Chon", "Gwan", and "Chuck" regions using the product testing of the radial pulsimeter system with multiple Hall devices.

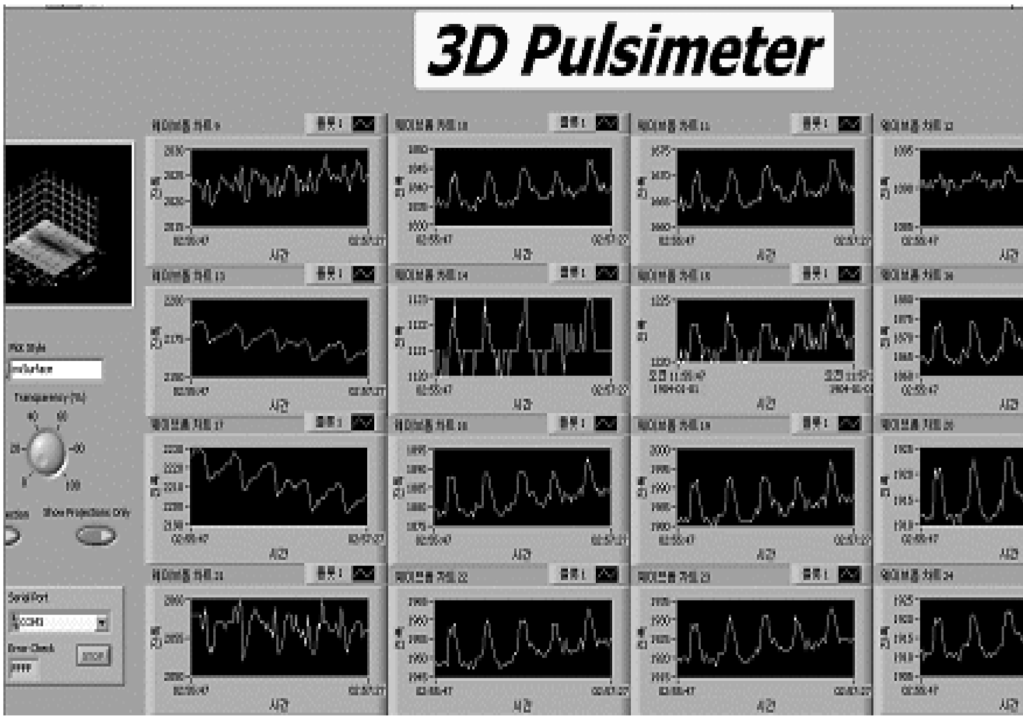

Fig. 5. Multiple pulse signal forms of measuring time versus temporally typical signal of multiple points pulse obtained from the analysis for an arbitrary 3D pulse image of multiple positions of small permanent magnet.

sensing part and spatial part can vary according to the technical opinion of the radial pulsimeter. A conventional pressure sensor can be adhered to the skin-contacting part, separately from the magnetic materials, and this can constitute the only function of the pressure sensor.

By forming a pulse-sensing part array with magnetic sensors such as Hall devices, over the skin-contacting part, which consists of a magnetic material, the proposed pulsimeter increases the integrity of sensors, thereby minimizing the time to search for the pulse. It is widely applicable to portable pulsimeters, as shown in Fig. 6.

In the constant pressure chamber, the distance between the skin-contacting and pulse-sensing parts can be determined based on the magnetic strength of the permanent magnets and the magnetic sensitivity of the unit cell, as shown in Fig. 2. For the magnetic material of a permanent magnet with a magnetic strength of 200~300 Oe, the preferred distance is maintained as 1~3 mm. Furthermore, when a pressure controlling apparatus is adhered to the constant pressure chamber, it is possible to obtain easily the three pulse qualities of the "Bu", "Jung", and "Chim" states of the traditional pulse diagnosis. However, to show the function of the pressure controlling apparatus properly, it is necessary to embody the pulsimeter sensor according to the proposed multiple Hall array devices. This apparatus such as a wrist watch or bracelet transfers the increased pressure to the skin-contacting part intact when the pressure of the constant pressure chamber is increased, as shown in Fig. 6.

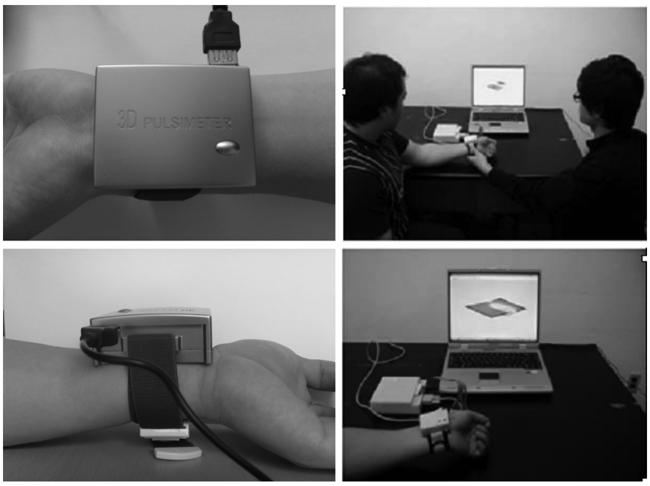

Fig. 6. Four photographs of the clinical product testing of the pulsimeter using multiple Hall devices. The product testing of the proposed radial pulsimeter and the measuring features, which are a wrist watch or bracelet, transfer the increased pressure to the skin-contacting part intact when the pressure of the constant pressure chamber is increased.

Finally, Fig. 7 shows the signal of one point obtained by the compositional analysis of the colored 3D images of the product testing of the radial pulsimeter. The spatial change of the pulse height in the arterial pulse incurred

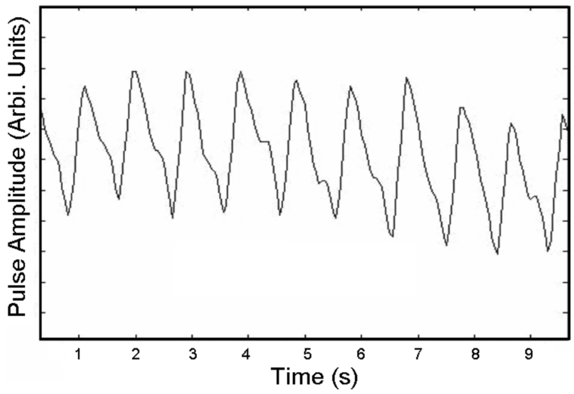

Fig. 7. Typical pulse waveform of one point obtained by the compositional analysis of 3D images of the clinical product testing of the pulsimeter using multiple Hall devices. Example of measuring time (seconds) versus temporally typical signal of one point pulse obtained from the analysis for an arbitrary 3D pulse image of one position of small permanent magnet.

one permanent magnet within 1 mm. This example of the measuring pulse signal confirmed its reproducibility and ability to provide much information for oriental medical diagnosis.

This study presented the results for the advanced application of a commercially available device for a 3D wearable pulse diagnostic apparatus. To resolve the subtle and subconscious arterial pulse, the real spatial data will be obtained through future research and development. This research has examined a noninvasive, medical pulsimeter sensor using Hall devices. By forming a pulse-sensing part array with a Hall device as a magnetic sensor, over the skin-contacting part which consisted of a hard magnetic material, the pulsimeter increased the integrity of the sensors and elucidated the spatial characteristics of the pulse which cannot be determined by the conventional sensors. Furthermore, it reduced the time required to search for the pulse and is widely applicable to portable medical diagnostic apparatuses [14, 15].

4. Conclusion

This study has presented a noninvasive, medical pulsimeter sensor using multiple Hall devices. By forming a pulse-sensing part array with magnetic sensors such as Hall devices, over the skin-contacting part which consists of a hard magnetic material, the proposed invention increases the integrity of the sensors, and reduces the time required to search for the pulse. Multiple pulse signal forms of measuring time versus temporally typical signal of multiple points pulse are obtained from the analysis for an arbitrary 3D pulse image of multiple positions of small permanent magnet. Product testing of the developed radial pulsimeter applied to a wrist watch or bracelet reveals the transfer of increased pressure to the skin-contacting part intact. The proposed device is widely applicable to portable pulsimeters.

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