A Study of a Handrim Sensor for a Power-Assisted Wheelchair

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ABSTRACT

The power-assisted wheelchair (PAW) is a hybrid of the conventional manual wheelchair and the electric wheelchair. The PAW is designed to mitigate the physical work of a wheelchair user by detecting human power and using a driving motor to create a supplemental force that corresponds to the detected power. Currently, various types of sensors for PAWs have been commercialized. This includes the use of circular connectors and force sensors, rotation of the driving part and battery together but without a circular connector, and the detection of torsion between a rigid body and a gear. This study proposes a method that uses a noncontact inductive sensor to transmit rotating handrim signals to a fixed controller without rotating. The rotating part uses metal of a specific geometric shape. An inductive sensor (LDC1000, Texas Instruments), which is an inductance-to-digital converter, is positioned in the fixed part to identify the user's driving intention by detecting handrim movements. We designed the sensor part and manufactured a prototype to test its performance. The test results showed that the proposed method can be used in PAWs because it can output reliable signals according to handrim movements. The proposed sensor method can sense the movements of a handrim accurately without using circular connectors.

KEYWORDS

Power-assisted Wheelchair, Inductive Sensor, handrim activated, PAW, Wheelchair,

1 INTRODUCTION

Wheelchairs are commonly configured for manual or electric power. Manual wheelchairs may be occupant-powered, with each drive wheel having a concentric handrim that may be gripped by the occupant to rotate the drive wheel to drive the wheelchair. By contrast, the power-assisted wheelchair (PAW) is a hybrid of the conventional manual wheelchair and the electric wheelchair. The PAW is designed to mitigate the physical work of a wheelchair user by detecting human power and using a driving motor to create a supplemental force that corresponds to the detected power [1–5]. The core technologies of the PAW are a sensor for detection of manpower, sensor signal transmission, a power train, a battery, and compact assembly.

Yamaha Motors, which was one of the first companies to commercialize the PAW, developed the JWII, JWX-2, and JW-swing models [1]. Yamaha detected rotating handrim movements by using a force sensor, and transmitted that force to a controller located in a fixed part that is not rotated using a circular connector. A circular connector, which is located in the center of the axis and transmits sensor signals to a controller, needs rigidity that can guarantee durability for long-term use. Recent products from Yamaha use noncontact sensors that employ magnetic materials rather than early-model force sensors.

A running wheel from Ulrich Alber that uses e-motion comprises a complete drive part including an electric motor, power supply, control, and drive part, which are adapted to rotate together by themselves [2]. This model has no use for a circular connector that transmits the signal from a rotating handrim. A torsion sensor that uses elastomers for handrim detection has been updated and modified to the

ISBN: 978-1-941968-17-8 ©2015 SDIWC

structure that ensures soft handrim movements similar to those of the Yamaha PAWs. The driving wheels on both sides, which are developed by Alber, do not communicate with each other and operate independently. Tailwind developed a wheelchair that uses a rigid body and a mechanism in which all parts such as sensors, motors, and the power supply are fixed to the body. The wheel structure is similar to that of manual wheelchairs [3]. To detect the movement of the handrim, a gear part that is connected to the wheel axes is moved. Through this movement, a user's intention can be determined.

In recent years, various types of sensors have been studied for PAW[6–9]. The present study proposes a method that uses a noncontact inductive sensor to transmit rotating handrim signals to a fixed controller without rotating. The rotating part uses metal of a specific geometric shape. An inductive sensor (LDC1000, Texas Instruments), which is an inductance-to-digital converter, is positioned in the fixed part to identify the user's driving intention by detecting handrim movements. We designed the sensor part and manufactured a prototype to test its performance. The test results showed that the proposed method can be used in PAWs because it can output reliable signals according to handrim movements.

2 DESIGN AND PROTOTYPING

Inductive sensor technology is noncontact short-distance sensing technology that can detect a conductor's location in high resolution, even in environments where dust, oil, and moisture are found. When current flows through the coils or spring, a magnetic field is generated in the surrounding area. Then, if a conductor approaches the surrounding area, changes in the magnetic field occur. Position changes and movements can thus be measured. This study employed a noncontact inductive sensor to avoid patent infringement. Once a user moves the handrim, a conductive target moves linearly as a result. The inductive sensor

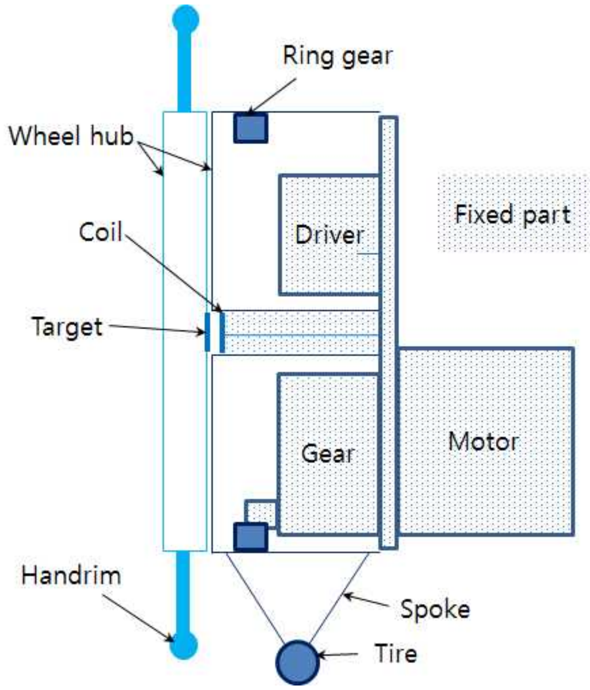

Figure 1. Block diagram of the proposed PAW wheel using an inductive sensor.

fixed to the body can detect target movements to identify the user's driving intention. Since the mechanism proposed in this study is positioned at the fixed part, which is not rotated, the mechanism does not need a circular connector for signal transmission.

Fig. 1 shows the wheel mechanism designed for the PAW. As shown in Fig. 1, the fixed part that is not rotated consists of a motor driver, gear module, motor, and inductive sensor that includes PCB coils. The rotating part consists of the handrim, wheel hubs, and the target to which the inductive sensor responds. The target is made from aluminum.

In the proposed mechanism, the rotation of the motor is transmitted to the wheel hub via the gear module and the ring gear, and then, the wheels are rotated. Since the output of the inductive sensor should be constant even during wheel rotation, the center of the coil for the inductive sensor was arranged to be parallel with the rotating axis of the wheel. This is because the output of the inductive sensor is proportional to the target.

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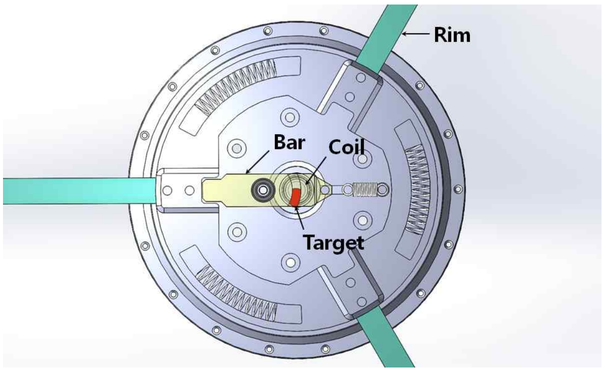
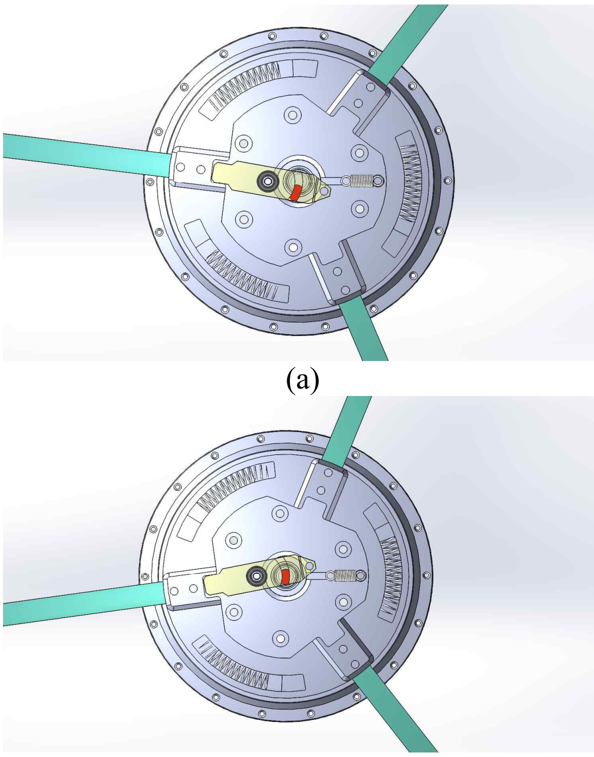


Figure 2. Configuration of detector for Handrim movement using an inductive sensor.

Fig. 2 shows the wheel hub structure to which the inductive sensor is applied. Because of the spring positioned between the wheel hub and the handrim, the handrim can be moved flexibly up to 8º to both sides. The sensor coil at the center of the wheel is fixed, and target position changes depending on the handrim movements. Since the maximum sensing distance where the coil can detect inductive objects was designed to be 3 mm, no conductive objects should be found within 3 mm of the coil. Thus, the bar to fix the target was made from plastic material. Because the output changes according to the area overlapped as the target and coil moved in parallel, a vertical distance between the target and the coil should be maintained constantly. The bar is a structure that can be physically separated from the handrim to prevent handrim movements from affecting the vertical distance between the target and coil. When the handrim is not moved, the bar should stay at the same position at all times, which is why tension is applied by a spring at the opposite side of the fixed axis of the bar.

Fig. 3 shows the changes in target position according to changes in handrim angles. When the handrim is moved in the clockwise direction, the inductive sensor will indicate the minimum value because it produces the farthest distance between the target and coil. On the other hand, when the handrim is moved in the counterclockwise direction, the inductive sensor outputs the maximum value because the area overlapped between the target and the coil is the largest. To make the sensor output value linear according to the changes in handrim angles, a target shape should also be considered. To achieve this, a target's shape follows an arc shape whose radius is the travel distance of the bar. This is carried out in order to have a constant rate of change in the cross-section area overlapped between the coil and target per unit angle. As explained above, a design was created to apply the inductive sensor to a PAW, and a prototype was manufactured for testing, as shown in Fig. 4.



(a)

(b)

Figure 3. Variations in the target's position according to change in handrim angles: (a) when pushing the handrim clockwise and (b) when pushing the handrim counterclockwise. In the (a) state, the output of the inductive sensor will be at a minimum, whereas it will be maximum in the (b) state.

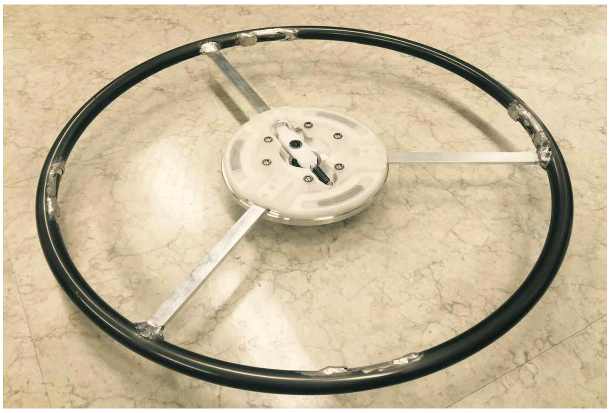


Figure 4. Prototype to test the inductive sensor.

3 TESTS AND RESULTS

To implement the inductive sensor, an inductance-to-digital converter called the LDC1000 (Texas Instruments) was employed. According to the guidelines provided by the manufacturer, a 10-mm diameter PCB coil was designed, and a parallel capacitor that is run by a resonator was added. Fig. 5 shows the manufactured PCB coil. The inductance-to-digital converter outputs the equivalent parallel resonance value and inductance value as a digital format according to changes in distance between the coil and the target. The equivalent parallel resonance, which has a 16-bit resolution, is proportional to the distance between the coil and the target, which can be used as proximity data.

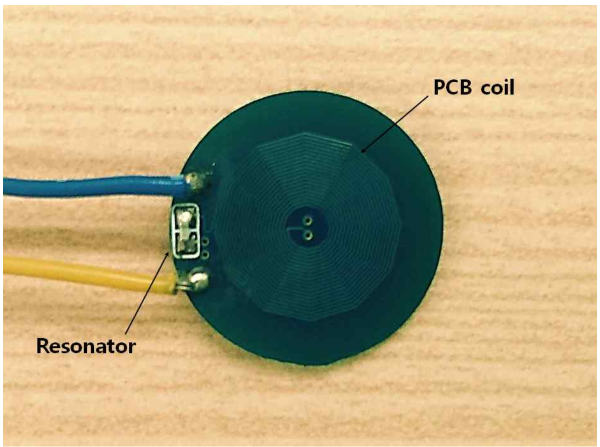


Figure 5. Manufactured PCB coil for inductive sensing.

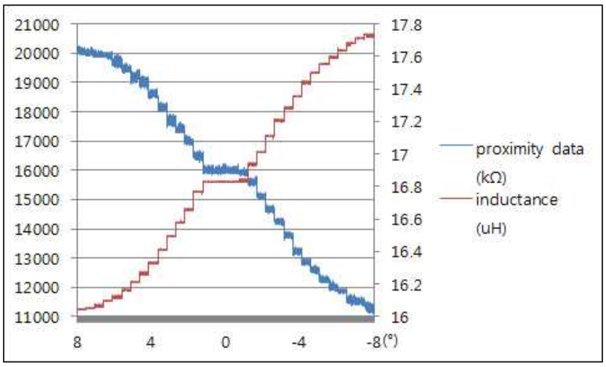


Figure 6. Sensor's output value according to the angle change of the handrim.

Fig. 6 shows the sensor's output values according to changes in handrim angles, which are data measured by moving the handrim by 0.5º every 1 s. The data-sampling rate was 1 KHz. As shown in Fig. 6, proximity data is proportional to the distance between the coil and target but is inversely proportional to the inductance. When the handrim is positioned at +8º, the overlapping area between the coil and target will become maximum, thereby having the maximum proximity data value. On the other hand, when the handrim is positioned at -8º, the proximity data value will become minimum. A nonlinear characteristic can be found at the end part of the sensor output, which is a result of the target shape.

A flat characteristic is found in a range of +1º to -1º because the bar that fixes the target is separated from the handrim by approximately 1 mm. Since the bar cannot be moved in that range even with handrim movements, the output values do not change.

The baseline noise of the sensor is an important parameter that is related to sensor stability and effective resolution. Fig. 7 shows baseline noise of the sensor measured for 1 min while fixing the handrim. As shown in the figure, baseline drift is not generated, and the difference between the maximum and minimum values was less than 0.5% of the total resolution. With additional signal processing, we will have more reliable signals.

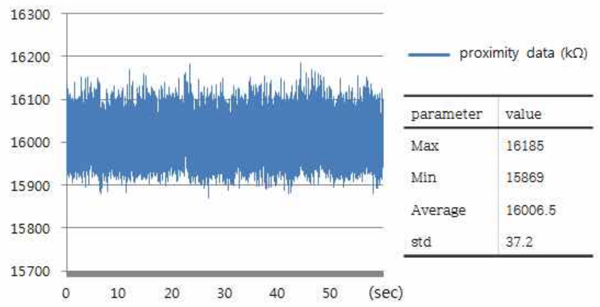


Figure 7. Baseline noise of the sensor.

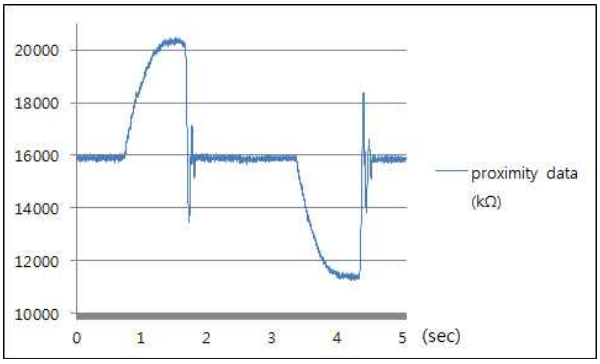


Figure 8. Expected control pattern of the handrim during PAW running.

When driving the PAW, a driver generally pushes or pulls the handrim in the forward or backward direction, followed by releasing the handrim. Fig. 8 shows the sensor output measured after the handrim is operated in a manner that is similar to real driving situations. As soon as the driver releases the handrim, the handrim returns to the neutral position. However, because bar vibration occurs because of the spring located between the wheel hub and the handrim, oscillation is generated in the sensor output. The change in values from oscillation could affect the motor, and therefore, the oscillation should be removed. Because the oscillation comprises high-frequency components, it can be easily removed by applying a low-pass filter. This indicates that the sensor output values while pushing or pulling the handrim have sufficient resolution to differentiate the user's driving intention. Therefore, the electric power can be assisted precisely according to the intensity of pulling or pushing the handrim.

Table 1. Baseline noises according to change of distance between the sensor and magnetic material.

	Distance		
	Reference	20 mm	10 mm
Max	16162	16167	16308
Min	15835	15740	15938
Average	16014.2	16000.2	16112.9
Std	57.6	52.3	57.8

Finally, we tested whether the sensor output is distorted if ferromagnetic objects approach the proposed handrim detection sensor. The distortion of the sensor output can be recognized as handrim movements, and this can result in wheelchair accidents. For the test, a strong magnet (neodymium magnet, grade N35, ø40 × 5 mm), which is not used in normal daily living, was selected. Table 1 shows the sensor output according to distance.

The baseline noises in Table 1 indicate that the sensor used in this study had constant output changes regardless of magnetic material owing to a very short sensing distance of the coil, set at 3 mm. By covering the wheel with a case, which makes the distance 10 mm between the sensor and case, this is expected to result in no malfunctions of the wheelchair owing to magnetic materials.

4 CONCLUSION

This study designed a wheel for PAWs to which inductive sensors are applied, and verified whether an inductive sensor is suitable to sense the driving intentions of wheelchair users. The test results showed that the wheel is usable in PAWs because it can output reliable signals according to handrim movements. Although part of the sensor output is nonlinear and has some baseline noise, it showed sufficient resolution and linearity. In the future, these limitations will be overcome by improving the target shape.

ISBN: 978-1-941968-17-8 ©2015 SDIWC

ACKNOWLEDGEMENT

This study was supported by the Senior-Friendly Product R&D program funded by the Ministry of Health & Welfare through the Korea Health Industry Development Institute (KHIDI). (HI14C1496)

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