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An Efficient Electronic Wheelchair Seat Balancing Maintain Methodology Applying Smart Sensors

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Abstract

In this paper we propose a new solution which utilizing the Gyro Sensor and Tilt Sensor in real-time controlling the balance of wheelchair seat. The existing wheelchair systems have the risk of falling when users go uphill because of the uneven weight allocation. But when applying our new method, the wheelchair seat can automatically adjust to maintain the balance therefore provides a safer and more stable ride. In order to adjust the seat correctly, we calculate the seat angle using Tilt Sensor. However, due to the law of inertia when wheelchair is moving there is deviation in output value of Tilt Sensor. To solve this problem, a Gyro sensor is used for measuring the acceleration and get the correct value of tilting angle. Through various experimentations we can prove that by taking advantage of Gyro sensor and Tilt sensor combination, the system is able to determine the correct seat angle in both cases when the wheelchair moving or not. We also tackle the power consumption issue in wheelchair, by using ZigBee sensor module to retrieve terrain information in advance and controlling the balance by two motors thus the overall power consumption for seat balancing is reduced significantly.

Keywords: *Seat Balance, Gyro Sensor, Electric Wheelchair Control System, ZigBee Communication, BLDC Motor Drive.*

1. Introduction

In the recently, mobile devices and wearable device [1] are advertised a variety of development was highlighted as a significant field of sensors. A previous research of the balance of the electric wheelchair seat system is the position value of the tilt sensor to be checked in real time, with purpose keeps the balance of the seat. However, a sensor connected to an electric wheelchair and checks the balance to be maintained after some period, because the environment does not respond quickly to the change. In addition, the electric wheelchair climb a hill when an electric wheelchair because it does not offer the speed of movement, even before the system works the balance seat in electric wheelchair and climb a hill may be overturned. We are using sensors, such as the area of the sensor module to check the hill, send back the information to the electric wheelchairs system, and apply information to compute of terrain to safely, and keeping the balance seat allows the wheelchair can go up this road. This system is very important when the wheelchair go to the steep terrain. It can keep the balance for electronic wheelchair seat in the real-time. And it can significantly reduce ability be overturned of wheelchair. User can use this device more safety and comfortably. We have a problem with this system. Depending on the slope of road, the wheelchair seat is always kept balance, so motor always operate. The commercial wheelchair uses 2 motor and we need 2 motor for adjusting balance of the seat. As a result, the power consumption of wheelchair is doubled. We have to resolve this problem by using a sensor[2] and normally, the switch is turned off, when the device receive signal about slope of terrain from sensors, the switch can be turned on. By

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applying this system, we have reduced wastage of battery, and the balance of wheelchair seat can be adjusted efficiently. In addition, the combination utilization of Tilt Sensor and Gyro Sensor is a compelling solution for a safer electronic wheelchair system which is adaptive and reliable in various terrain scenarios especially the uphill landscape.

2. Related Works

2.1. Seat Balancing Electric Wheelchair System

(a) (b) (c)

Figure 1. (a) Invacere of USA (b) Permobile of Sweden (c)Heartway of Taiwan

A various studies have been conducted on electric powered wheelchair topic. The automatic wheelchair balancing and adjusting are being focused and released by many corporations. Although the products are mostly expensive, the price is justified by many advantages over original wheelchair like easy to used, more comfortable thanks for the auto-balancing method. As showed in Figure 1, user can adjust the position and tilt the seat like he want just by clicking a button. The wheelchair is able to well - adjusted depending on users' preference and physical characteristics, all via simple control buttons. These kind of products are being sold widely in United States, Sweden, and Taiwan, where the terrain are fairly smooth. But it is not the case in Korea since the landscape here often has high slopes and as a result the wheelchair has much more difficulty in maintaining the balance and safety, especially while going uphill and downhill. The shortcomings of the electric wheelchair systems lay in the seat balancing matter.

2.2. ZigBee Module for Wheelchair Seat Balance

A variety of wireless sensor modules are used for the system. The wireless network connections used are Wi-Fi, Bluetooth and ZigBee. Wi-Fi [3] IEEE 802.11b is a wireless communication standard which enable high power transmission. Using the 2.4GHz frequency band, the laptop and computer around the range can connect wirelessly to the AP. In addition, the speed of wireless Ethernet could be up to 600 Mbps providing an obstruction-free condition within the range of 500m. In 1994, Bluetooth [4] was developed by Ericsson, it is a short-range wireless communication technology which is used and applied in various types of device such as PC peripherals and mobile devices and even eliminate the use of USB connection. From Bluetooth version 1.0 till today, the transmission speed goes from 1Mbps to 25Mps and even continue rising rapidly. Finally, ZigBee [5] is a connection protocol widely used for low-power sensor network. Because of low-operation and limited transmission rate of 250 kbps, it is being used in many places such as home automation and factory automation. The wireless communication technology ZigBee itself is a non-functioning sensors, it is conjunction with the sensor to provide a variety of information. ZigBee supports around 65000 sensor nodes, and the possible short-range wireless communication between nodes is ten meters. In ZigBee controlling used node ID for observation range. In order to use ZigBee, the system should have some characteristics such as limitation of power and low transferring data size.

3. Maintaining System in Balance Seat

3.1. System Architecture for Wheelchair Seat Balance

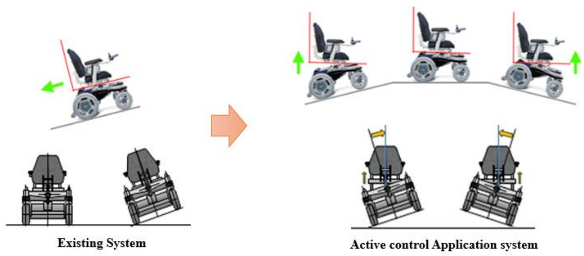

Figure 2. Maintain Seat Balance of Electric Wheelchair System

As show in Figure 2 when going uphill, the seat can adjust to balancing by control the tilting. Some systems can only adjust front and back but this wheelchair system can allow user to adjust all four directions: left, right, front and back. The two motors used for adjusting the seat in X-axis and Y-axis can be used separated or simultaneously working to help the seat move around various angles. The ability to do variety of direction enable the wheelchair to keep balancing seat no matter how the terrain changes. Because of that the seat can always be secure in horizontal. In order to maintain the balance, the existing system using the two equations (1), (2) below to calculate the tilt angle in X-axis and Y-axis. X_{max} and Y_{max} is the tilt value for X, Y directions when the sensor has maximum output voltage value. X_{min} and Y_{min} is the minimum value of sensor because it does not start from 0V. The parameters X_{val} and Y_{val} are the current output voltage value in X and Y direction. S_{max} is the maximum tilting angle value that can be measured by the sensor. In this paper, the angle tilt sensor applied the valid range X, Y direction, plus or minus 15°.

$$X_{angle}=\frac{(X_{val}-X_{min})}{(X_{max}-X_{min})}S_{max} \quad (1)$$

$$Y_{angle}=\frac{(Y_{val}-Y_{min})}{(Y_{max}-Y_{min})}S_{max} \quad (2)$$

Figure 3 show how the sensor angle value is obtained in real time, which is based on operation behavior of X-axis and Y-axis motors. However, due to system nature, the motor does not have adjustable speed, so the motor cannot support turn right or turn left.

We can use the relay module to turn right or turn left the motor, but it has to be forced to stop. Therefore, if you go up the ramp at rapid pace, the wheelchair falling get happen. In this paper, the motor speed can be adjustable by applying motor drive, the speed of the motor can be controlled depend on the seat position. By using BLCD motor, the motor speed could enable to identify the location of the motor. Furthermore, by using sensor and ZigBee collected information to identify the location, it would be more effective for the electric wheelchair to adjust the seat and cope with the current terrain quickly.

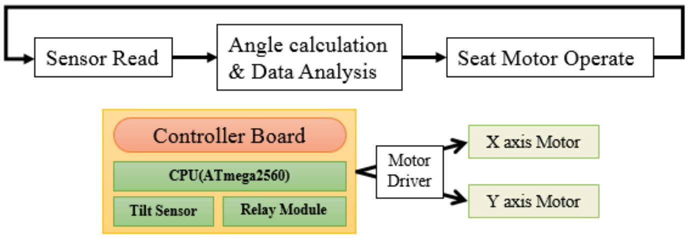

Figure 3. System Operation Procedures for Balancing Seat

3.2. Motor Drive for Wheelchair Seat Balance

We have to solve existing systems problems: turn right, turn left direction and speed of a non-stop function, the encoder can be given to know the position values. As before, in order to maintain the balance seat of the BLDC motor [6] was used, in real time the speed can be controlled. In order to control the desired speed, motor requires a voltage is proportional integral (PI), which is usually supposed the speed controller is used. In proportional integral of speed controller, proportional gain is referred to K_{ps}, integral gain is referred to K_{is}, as in equations (3), (4) below:

$$K_{ps}=\frac{J\omega_{cs}}{K_T} \tag{3}$$

$$K_{ps}=K_{ps}\omega_{pi}=K_{ps}\frac{\omega_{cs}}{5}=\frac{J\omega_{cs}^2}{5K_T} \tag{4}$$

w_{cs} is the angular frequency of the speed controller gain cross $\omega_{pi}(=K_{is}/K_{ps})$ is PI corner frequency. ω_{pi} is set to be small, the degradation occurs in the normal characteristic, and if set too high, the overshoot is generated. So, usually select $\omega_{pi}=\frac{1}{5}\,\omega_{cs}$. In equations (3), (4), J refer to an integer of the mechanical inertia of the motor drive system, K_T is torque constant. In order to control the torque of AC motor such as three-phase at the same time, control the size and stature of current without the need for a BLDC three-phase [7], you can control the size of the current. Output torque of the phase current proportional to the intensity DC of phase current is I_{dc}, DC input current is proportional to normal control the size of phase current. Figure 4 illustrates configuration of the speed controller.

The electric current output of speed controller I_{dc}^* is sent to an electric current controller to control the voltage of the electric motor in this case, the control method of the “Triangle wave comparison PWM technique [8]” is used. “Hysteresis technique [9]”, part of the implementation is simple and fast, but the response rate, hysteresis technique band, due to its breadth and weight lifting switching frequency disadvantage of changing the seats, a wheelchair to control the risks, and can be in the to response is a bit slow but switching frequency in a certain way in that they can maintain their sense of par comparison uses PWM techniques. Thus, the conventional electric wheelchair seat to control the motor On/Off if expression is controlled, in this paper Seat for controlling the electric wheelchair motor speed is adjusted according to the situation. The BLDC drive method generally used, but a triangular wave comparison PWM method is used, the errors the motor operation could not occur. In order to control the electric wheelchair seat should be understood position value of the motor by using the encoder to identify the position of the motor. The motor we used an optical incremental encoder with Totem Pole outputs were used. Optical encoders are widely used mainly as low-cost, and the number of pulses per revolution (PPR) with the same spacing of the slit with a moving board [10] and each of the other three pulse for distinguishing three slits in the fixed board is composed. In order for the light signal to the LED and the photo transistor incoming receive is composed. As shown in Figure 5, the value used by the incremental encoder was used as a cycle of pulse.

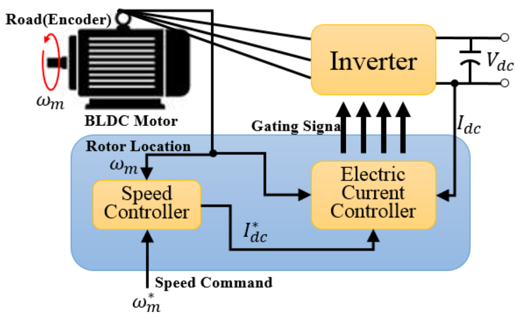

Figure 4. Speed Controller System Using Electric Current Controller

$$I^*_{dc} = (K_{ps} + \frac{K_{is}}{s})(\omega^*_m - \omega_m) \quad (5)$$

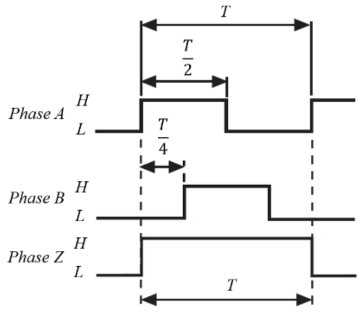

Figure 5. Phases A, B, Z Using in the Incremental Encoder

Pulse A and pulse B per first PPR (Pulse per Revolution) at regular intervals, the output is T=360° when called, and pulse A is High when pulse is B=90°, after that B can be is High. In this case, the forward (CW) can be determined A is Low when pulse B is 90° then in the opposite direction after the High (CCW) can be determined. In other words, when the forward and reverse direction A is when the first B is high. This sequence has a current motor in the forward direction can be seen whether the reverse cognitive. Based on the location of the rotation pulse Z used to be read through the nose, the insides of the position value is total power block disappear. In order to prevent this, the ROM portion of the storage ATmega or the SD card storing the values in real time scheme. As shown in Figure 6.

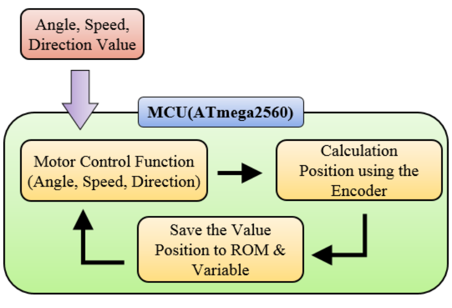

Figure 6. The Motor Controller Operating

Angle, speed, direction, and a value associated with a motor control MCU to control spending, the motor based on the MCU motor behavior. When the motor behavior, motor mounted encoder to determine how it was moved, and the value stored in an internal variable is ROM. Finally, the motor control function as many times as you wish, determine whether the behavior of the motor, the motor, and motor operation up to the desired position, the motor operates up to where you want it, you want to operate the motor.

3.3. Sensors for Wheelchair Seat Balance

We check the balancing of the seat using Tilt Sensor and Gyro Sensor. A Tilt Sensor (1), (2) uses the propagation angle, the value is obtained at the reading speed of 1ms.

Figure 7. Angle of the Seat Determination Test

On the existing system, tilt sensor measures the angle of the seat. We found one error through experimentation. When the wheelchair is moving and then stop, the laws of inertia can be applied. Due to the law of inertia, the wheelchair can be halted and the tilt sensor can be got mistake the angle. To resolve this problem, we use an additional Gyro Sensor. Because of the acceleration of inertia, using Gyro Sensor's law can solve this problem. In the equation (6) M_{res} is the resolving power, V_{ref} is the voltage of Gyro sensor, S_{sen} is the sensitivity of the Gyro, S_{res} is full resolution power when the value of angular velocity change 1, S_{deg} and is the rotation angle of the sensor.

$$\frac{V_{ref}}{M_{res}}\left[\frac{mV}{bit}\right] * \frac{1}{S_{sen}[mV/(°/S)]} = S_{res}\left[\frac{(°/S)}{bit}\right]$$

$$S_{res}\left[\frac{(°/S)}{bit}\right] * \frac{\pi}{180°} = S_{deg}\left[\frac{(rad/s)}{bit}\right] \quad (6)$$

For example, we used ATmega2560 with resolution power of 1024, Gyro Sensor voltage scale is 3.3V, and sensitivity is 2mV, then apply in the equation (6) we have equation (7) as below:

$$\frac{3300}{1024}\left[\frac{mV}{bit}\right] * \frac{1}{2\left[\frac{mV}{(°/S)}\right]} = 1.611\left[\frac{(°/S)}{bit}\right]$$

$$1.611\left[\frac{(°/S)}{bit}\right] * \frac{\pi}{180°} = 0.028\left[\frac{(rad/s)}{bit}\right] \quad \textbf{(7)}$$

We calculate the value based on when the wheelchair is stopped, the acceleration caused by the movement is calculated on the Gyro Sensor, and so the error does not occur in controlling the seat. If (Acceleration <= 1°) Gyro Sensor can measure the acceleration of the moment and if it is less than 1°, tilt sensor can measure the current angle of the seat. After measuring the angle of the seat, as shown in Figure 6, Gyro Sensor and along with Tilt Sensor can maintain the balance of the seat and reduce the error.

4. Balance Seat using ZigBee System

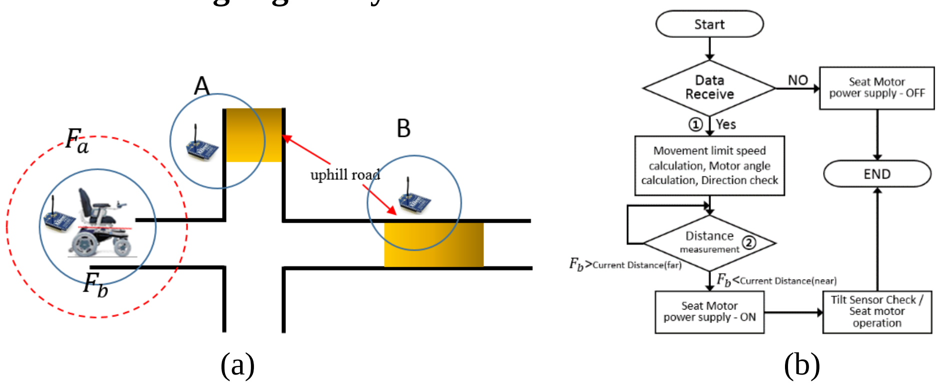

Figure 8. (a) Coverage of Wheelchair and Sensor Module (b) The Wheelchair Motion Sensor Operation Flowchart

We are using a sensors, a more stable and less battery consumption is intended to develop a balanced system seat. We use only use the Zigbee sensor, instead of just the terrain's tilt sensor measured values of module. The experiment XBee (Zigbee) Module is commonly used throughout the module, and with the Frequency Band 2.4 GHz. The RF Data Rate 250 kbps, and transfer of each product performance differ, but 30m ~ 1.6Km to transfer. We are based on the role of different XBee modules. The use of an electric wheelchair is outside the effective range of the XBee modules using a range up to 1.6Km was used. To reduce the power consumption as much as possible, instead of the wheelchair detects by itself, XBee module with the maximum range of 100m is used to recognize the terrain beforehand. Figure 8 (a) shows the wheelchair moving while communicating with XBee sensors to locate the ramps on the landscape. The wheelchair sensor communicates with two other XBee in the area A and B. The data is exchanged via transmitting signal around the range F_a and from that the wheelchair can measure the distance. F_b is minimum distance between the sensor module and the wheelchair when the power supply is cut off (OFF) and the power supplies for the seat balance (ON). Figure 8 (b) represents the sequence behavior of the sensor operating in wheelchair. While the wheelchair XBee cannot detect the signal and not connect, the power supply to seat balancing motor can be cut off. When the data has been received by XBee, the wheelchair analyze the data of MCU, then calculate the movement limit speed, motor angle and check direction. Follow by that, the wheelchair can measure the distance. Figure 8(b) - ② indicates that while F_b is bigger than current distance the power supply for seat motor is kept cut off till F_b is smaller than current distance means the area is near then the power supply for seat motor is on. If the distance between the sensors is getting closer, the wheelchair can apply the previous calculated tilting value by tilt sensor go uphill safely. After the sensor modules distance exceeds the range means the wheelchair is back to the ground, the power supply to seat motor is cut off. By obtaining the necessary information in advance by using sensor, tilt sensor can work more reliably and efficiently in energy consumption. Figure 8 (b) - ① show the measurement method of distance between XBees.

$$17.32\sqrt{\frac{d_{km}}{4f_{ghz}}} = r_m,\ \frac{r_m}{d_{max}}100 = A_p \quad (8)$$

Equation (8) is used to get the radius distance. d_{km} is the the distance between two XBee. f_{ghz} represents the frequency of the XBee, 17.32 is a constant to calculate the radius between two XBee. d_{max} and d_{min} are the maximum and minimum capable of transmitting distance while r_{max} and r_{min} are the maximum and minimum radius. By using the mentioned parameters, we can calculate and obtain the current position r_m in real time and the distance A_p can also be measured.

5. Experiments and Results

5.1. Battery Power Test using Sensor

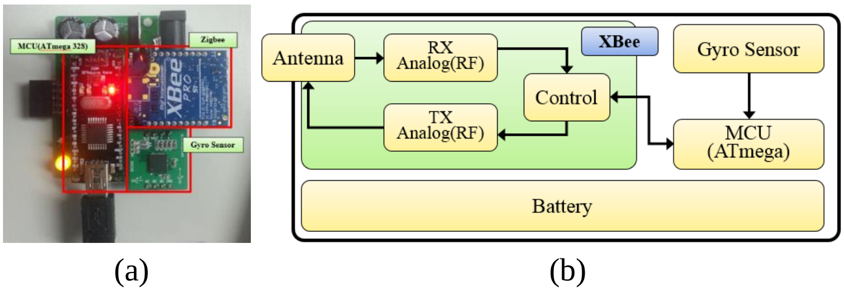

Figure 9. (a) The Sensor Module System for Identifying Terrain (b) Functional Structure

Figure 9 illustrates the XBee module used for detecting landcape. (a) is the actual development of the module, (b) is a configuration of (a) diagram showing the function. The Xbee Antenna and signal to the give and receive a radio transmitter and receiver. The Xbee Control MCU through the received data, or through the Gyro Sensor XBee reads data using an electric powered wheelchair, gives information to transmit. The terrain's tilt sensor to measure the value of the slope of the terrain for each module is 500ms can be send it to you by measuring. Tilt value is first installed when the value of the measurements, and using an equation (6), cumulative value, and angle measures. Our sensors are wired, not used in the wireless environment. We are communicating with the battery to reduce the power consumption to a minimum. In the first place, landscape, measure the outgoing XBee sensor module, instead of receiving a low battery consumption radius is very small. And the nature of the data to be sent continuously, so the radius is lower than the receiving XBee when transmitting the power consumption is small. Electric wheelchair instead of send and receive more than the radius of the XBee's high power consumption. We are constantly sending data, receiving, more appropriate than this power, but big the impact simulation. Simulation conditions were excluded standby power. The battery is usually portable mAh uses the unit. We use the battery capacity, and how to use XBee can be measured. Using an equation (9), the battery power consumption used in a wheelchair XBee mA the data received by 55 mA and data transmitting station, the power is 215 mA. The battery capacity is usually 2000 mAh when evaluating the Figure 9 and get the same results.

$$\text{Battery Capacity}(mAh)\ /\ (\text{RX or TX Currnet})(mA) \quad (9)$$

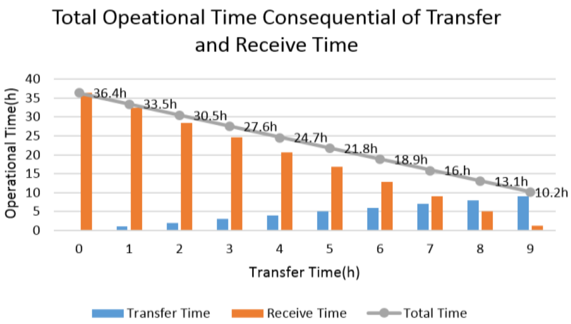

Figure 10. XBee Transmitting and Receiving Power Consumption

The Figure 10 shows a time graph of total operational time and as we can observe from it, the significantly decreasing time leads to dramatically battery reduction. We used electric powered wheelchair using XBee to minimize the power consumption. For maintaining the balance of the wheelchair, usually power supply to motor has to be cut off. But because the motor brake is still operates even if the power supply is blocked, there is no error when seat moving. By using the above method, the use of two motors and sensor is when it is necessary. Because of the new method, the operational time of motors can be extended to 1.5~ 2 times more with the same battery.

5.2. Evaluating the Sensor using in Wheelchair Seat Balancing System

We perform two experiments to exam the effect of the sensor in wheelchair balancing system. Figure 11 shows the result of sensor angle measurement while Gyro Sensor is applied and not applied, respectively.

In case of wheelchair standstill, Gyro Sensor is not applied and due to the law of inertia tilt sensor tilt forward and the result is displayed about. The tilt sensor tilt from 0° to 7° result in an error of wheelchair seat moving. In contract to that, when Gyro sensor is applied, the tilt sensor value can be measured. From the Figure we can see that when applied Gyro sensor, value of tilt sensor remains constant. Thus the problem of wheel chair seat error moving is eliminated. Figure 12 below shows the test result of tilt sensor values with and without using Gyro sensor in the scenario of wheelchair moving uphill.

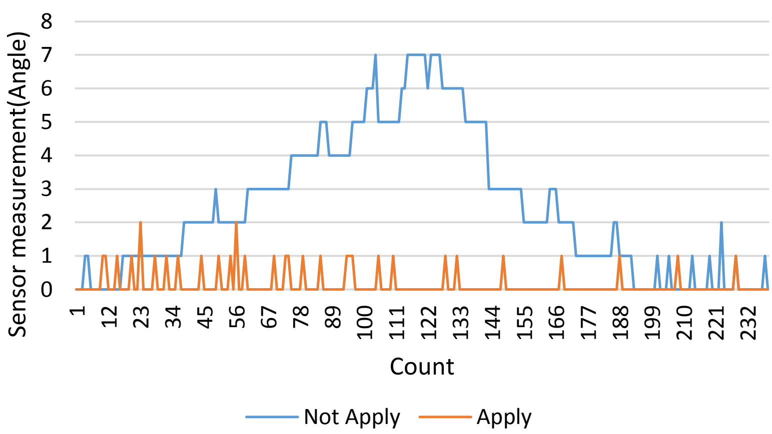

Figure 11. The Output Result in Case Gyro Sensor is Applied and Not Applied

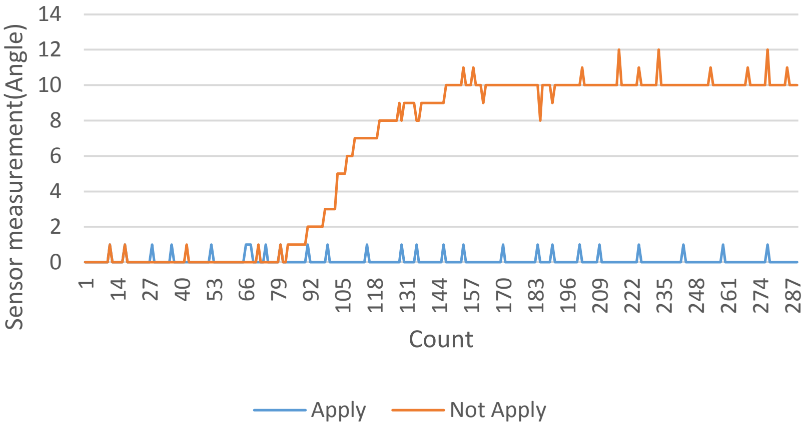

Figure 12. Comparing the Tilt Sensor Value in Case Gyro Sensor is Applied and Not Applied

As showing in Figure about we can see the angle value output of tilt sensor when the wheelchair go uphill 10°. When the Gyro sensor is applied, wheelchair seat angle always maintain in a static and unchanged range. On the opposite side, when the system is not applied, the wheelchair seat angle keep getting higher and in some case it could cause the wheelchair flip due to the unbalance allocated weight. From the result we can say that the wheelchair balancing system is not only provide more comfortable ride but also be safer for the users.

6. Conclusions

This paper presents an application of smart sensors in electric wheelchair seat balancing control system. We address the safety problem when the wheelchair go uphill and enhance reliability by maintain the seat balancing. In order to real-time control balance of wheelchair seat, we use BLDC motor to be able to calculate the position of encoder and move the seat accordingly. The inaccurateness problem caused by the law of inertia when the wheelchair is moving is resolved by using Gyro Sensor to eliminate error in calculating seat angle. The result of experimentation proves that with the use of Gyro Sensor, this system can ensure the balance and stability of the wheelchair. In addition, the experiments prove that by using Gyro sensor and Tilt sensor, the wheelchair can go safer and more reliable on the uphill terrain. Using two motors for controlling seat balancing provides a faster solution, but it also leads to the problem of additional battery consumption. However, by using Zigbee and Gyro sensors, the power using could be lessen from 1.5 to 2 times. Because Zigbee sensor module can receive the landscape information beforehand and allow the wheelchair motors to determine and operate correctly. The combination utilization of Tilt Sensor, Gyro Sensor and Zigbee is a compelling solution for a safer electronic wheelchair system which is adaptive and reliable in various terrain scenarios especially the uphill landscape. In the future, variety type of sensor can be put into trial and comparison so the wheelchair could be better adapted to many landscape scenarios.

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