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# HUMAN MOTION DETECTION BASED ON INTELLIGENT WHEELCHAIR DURING SITTING PROCESS

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Abstract. *Intelligent wheelchairs are helpful transportation tools for the elderly with lower limb impairment to move in daily lives. However, during the attempts of sitting to the chairs, it was dangerous for users who were insufficient to control their body very well, since the wheelchair may slip or overturn due to the position offset. In order to achieve effective aid for an intelligent wheelchair in the process of users sitting to the wheelchair, an experiment setup was proposed, in which laser sensors and gyroscope sensors were employed to detect the motion of users during sitting process. The methodology of motion detection was described specifically, and the model between sitting gesture and sitting position was built in this paper. The sitting process with different situations was analyzed, and the results of experiments and simulation show effectiveness of the proposed model.*
**Keywords:** Intelligent wheelchair, Motion detection, Laser sensors, Gyroscope sensors

1. **Introduction.** With the aging problem becoming serious, the number of elderly with mobility problem is increasing dramatically. It is a heavy burden to the family and society, because the elders have to ask others for assistance in their daily activities. How to improve their capabilities of self-care has been concerned for the society.

The intelligent wheelchair, a simple and efficient transportation tool, is appropriate for elder people with mobility problems. In 1986, the first intelligent wheelchair was developed in British [1]. After that, many countries began to invest in the research of intelligent wheelchair. Intelligence Laboratory of MIT developed WHEELESLEY, a semi-autonomous robot wheelchair, which was mounted on various sensors and controlled by computer. The intelligent wheelchair of VAHM project in French had three operational modes: manual operation, semi-automatic, and full-automation. In 1996, Spain began to research STAMO. In order to enable users to control the wheelchair more easily, the project focused on modularity and flexibility of the system. And it had many human-machine interfaces: brain drive [2], hand gesture recognition [3], sitting postures [4], intelligent joystick [5], and Eye-Gesture [6]. At the present stage, intelligent wheelchair owned the capability of obstacle avoidance, path planning, human-machine interaction, and so on.

However, there are some problems that while users are sitting to the wheelchair, the position offset of wheelchair and the impact from users may cause the wheelchair to slip or overturn. In order to achieve effective aid for an intelligent wheelchair in the process of users sitting to the wheelchair, an experiment setup was proposed to analyze the impact between users and chair. The model between sitting position and sitting gesture was built, and the effectiveness of the model was verified.

The remainder of this paper is organized as follows. Section 2 introduces the construction of experiment setup and the experiment procedure. The features of experiment data were analyzed, which were collected by the proposed detection methods during the process of sitting, in Section 3. Section 4 describes the modeling approach and verified the effectiveness of the model that between sitting motion and sitting position. Section 5 is the conclusion of this paper.

## 2. Experiment Setup and Procedure.

**2.1. Experiment setup.** Figure 1 shows the apparatus for measuring sitting motion. There are six gyroscope sensors fixed on the tester. Four of the sensors are put on the tester's shanks and thighs respectively to detect the posture of lower limbs. One sensor is fixed on the waist and the other sensor is fixed on the chest of tester. Both sensors are used to detect the posture and impact of tester during sitting process.

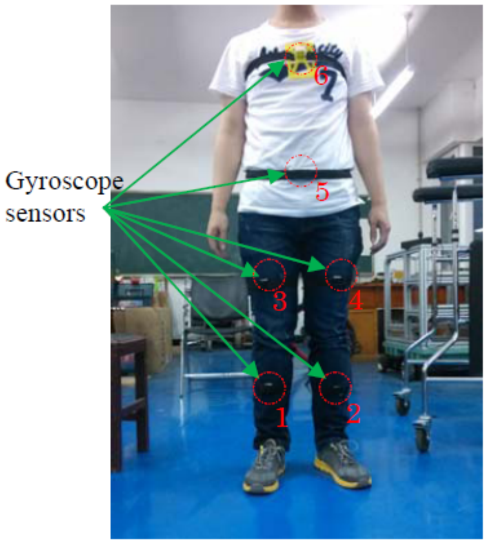


FIGURE 1. Experiment setup

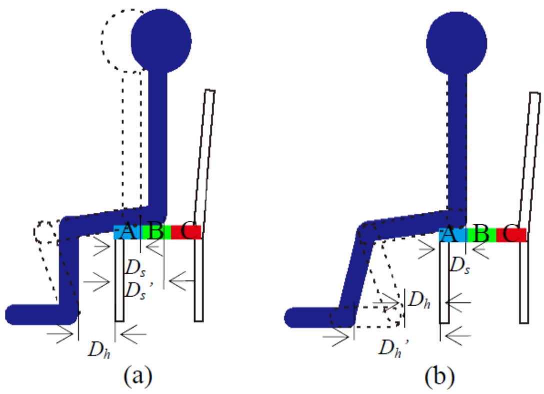


FIGURE 2. The procedure of experiment

**2.2. Experiment procedure.** In order to analyze the influence elements of sitting process, a series of experiments were designed. Two determinants are changed in the experiments. One is the sitting position $D_s$, the other is the distance $D_h$ between tester's heel and the begin point of chair. In the first group, the distance $D_h$ remained the same with different $D_s$, shown in Figure 2(a). In the second group, the position $D_s$ is maintained constant with different $D_h$, shown in Figure 2(b). In the experiments, the distance $D_h$ is set on 5, 15, 25cm respectively. The sitting area A of chair is 0-15cm, B is 15-30cm, C is 30-45cm. The combinations of $D_s$ and $D_h$ are listed in Table 1.

Table 1. Grouping of experiment

| $D_s$ \ $D_h$ | 5cm | 15cm | 25cm |
|---|---|---|---|
| A (0-15cm) | C1 | C4 | C7 |
| B (15-30cm) | C2 | C5 | C8 |
| C (30-45cm) | C3 | C6 | C9 |

## 3. Experimental Result and Analysis.

**3.1. The feature of sitting motion.** The data of the 5th gyroscope sensor on the waist, shown in Figure 2, is chosen to analyze the impact between tester and chair, because of its conspicuousness. And the acceleration is selected to represent the impact force.

Figure 3 shows the experiment data of the condition C1. Because of the condition, the tester impacted on chair only once. After the impact, the amplitude of acceleration manifests decay.

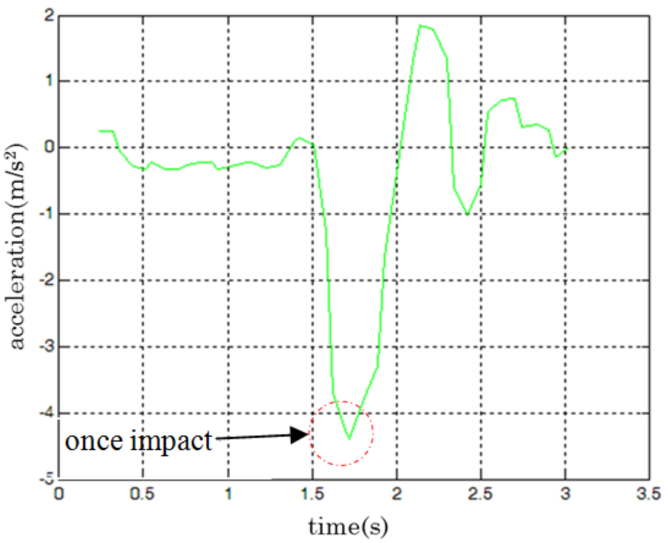


Figure 3. The data of C1

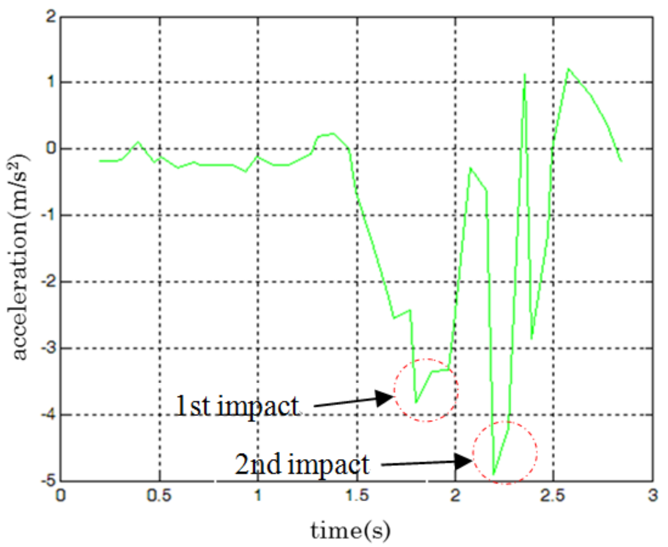


Figure 4. The data of C3

Figure 4 shows the experiment data of the condition C3. In this condition, the tester impacted on chair twice. The first impact appeared when the tester's hip contacted with the seat of chair. The second impact appeared when the tester's upper body contacted with the back of chair. After the second impact, the amplitude of acceleration also manifests decay.

3.2. **The influence of sitting motion caused by distance $D_h$.** Figure 5 shows the experiment data of C1, C4 and C7. In sitting area A, as the distance $D_h$ increases, the maximum amplitude of acceleration is growing slowly. $D_h$ contributes to the amplitude of acceleration tinily.

When the sitting position area is C, the distance $D_h$ makes more contribution to the amplitude of acceleration shown in Figure 6. According to the experiment data, the impact that tester suffered is in positive correlation with distance $D_h$. And as the $D_s$ increases, the coefficient of correlation is enlarged.

3.3. **The influence of sitting motion caused by the position $D_s$.** Figure 7 shows the experiment data of C1, C2 and C3. When the position $D_s$ enlarges, the maximum

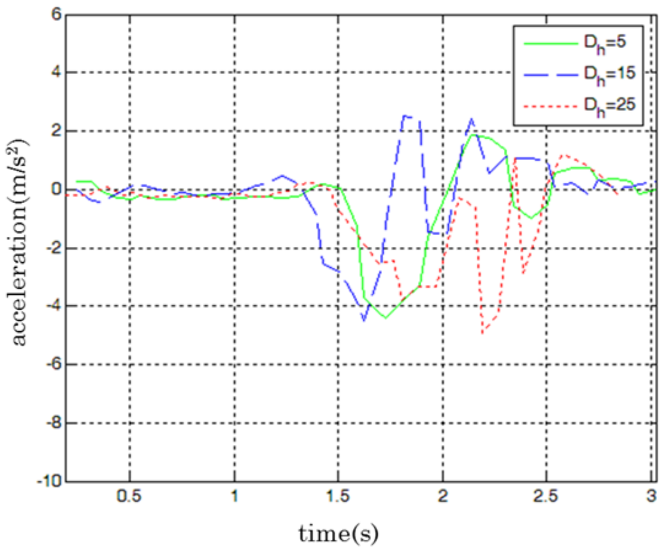


FIGURE 5. The data of C1, C4 and C7

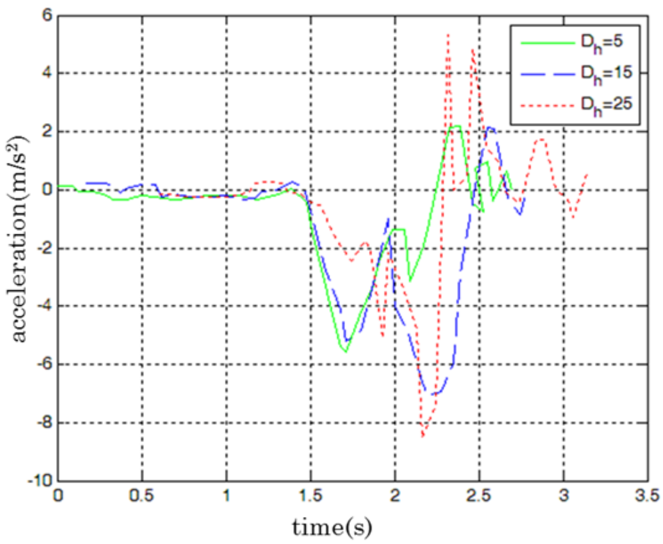


FIGURE 6. The data of C3, C6 and C9

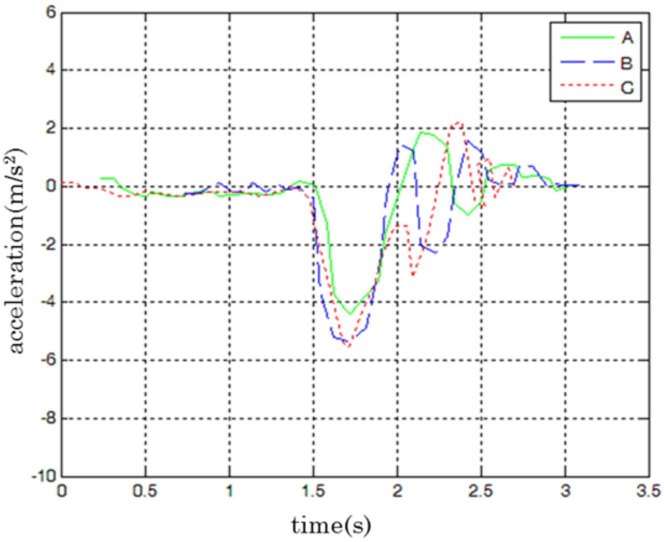


FIGURE 7. The data of C1, C2 and C3

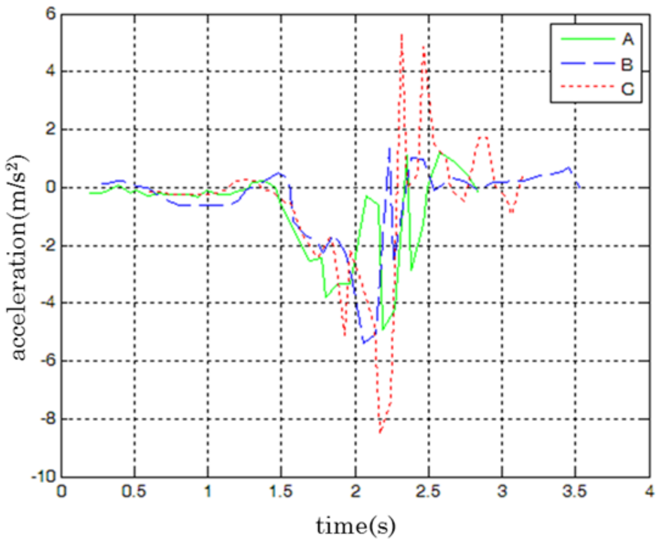


FIGURE 8. The data of C7, C8 and C9

amplitude of acceleration is growing. And it is more obvious when distance $D_h$ increased, shown in Figure 8. The position $D_s$ is also in positive correlation with the impact that tester suffered. And as the $D_h$ increases, the coefficient of correlation is enlarged.

## 4. Modeling and Verification.

4.1. **Modeling.** According to the experiment data, the distance $D_h$ and the position $D_s$ are important elements for sitting process. However, the gyroscope must be fixed on the users, and it is very inconvenient. The laser sensor, a non-contact sensor, is selected to detect the users' position and posture. The lower limbs are considered as two-link model, shown in Figure 9. On the basis of geometry, the following equations can be got:

$$L = D_s + D_h + y \tag{1}$$

$$L_1 = l_{11} + l_{12} \tag{2}$$

$$y = H \tan \theta_1 \tag{3}$$

$$l_{11} = \frac{H}{\cos \theta_1} \tag{4}$$

$$L_2^2 = L^2 + l_{12}^2 - Ll_{12}\cos\left(\theta_1 + \frac{\pi}{2}\right) \tag{5}$$

where $L_1$ and $L_2$ are the length of users' shank and thigh respectively, $H$ is the height of chair ($H \leq L_1$), $D_h$ is the distance between users' heels and chair ($D_h \leq L_2$), $D_s$ is the sitting position of seat, and $\theta_1$ is the angle of shank. The five equations can be consolidated as Equation (6).

$$\begin{aligned} &D_s^2 + \left[2D_h + 2H\tan\theta_1 - \left(L_1 - \frac{H}{\cos\theta_1}\right)\cos\left(\theta_1 + \frac{\pi}{2}\right)\right] D_s \\ &= L_2^2 - D_h^2 - (H\tan\theta_1)^2 + (D_h + H\tan\theta_1)\left(L_1 - \frac{H}{\cos\theta_1}\right)\cos\left(\theta_1 + \frac{\pi}{2}\right) \end{aligned} \tag{6}$$

The $L_1$, $L_2$ and $H$ can be measured. The sitting position $D_s$ is determined by $D_h$ and $\theta_1$. The $D_h$ and $\theta_1$ can be obtained by the laser sensor as shown in Figure 10. The laser sensor is mounted under the seat to detect the distance of users' shanks.

$$D_h = D_0 - a \tag{7}$$

$$\theta_1 = \arctan\left(\frac{D_1 - D_0}{h}\right) \tag{8}$$

where $D_h$ is the distance between users' heels and chair, $a$ and $h$ are the position of laser sensor, $D_0$ is the detected distance of user's shank before sitting, and $D_1$ is the detected distance of user's shank during sitting movements processing.

4.2. **Model verification.** In the experiment, the length of tester's shank $L_1 = 47$cm and thigh $L_2 = 43$cm. The height of chair $H = 35$cm. The distance $D_h$ changed from 0cm to 25cm, and angle $\theta_1$ changed from 0° to 45°. According to distance $D_h$ and angle

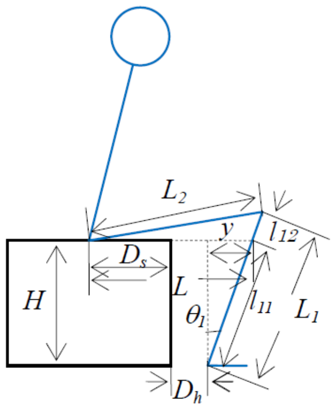


FIGURE 9. Two-link mode of sitting

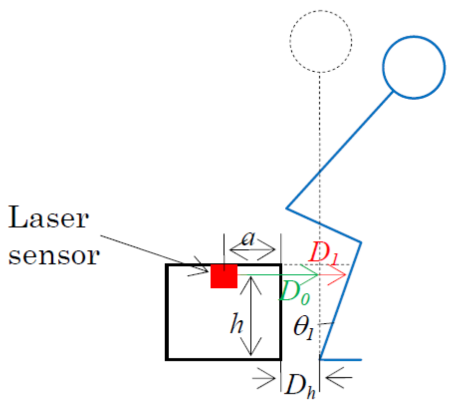


FIGURE 10. Motion detection by laser

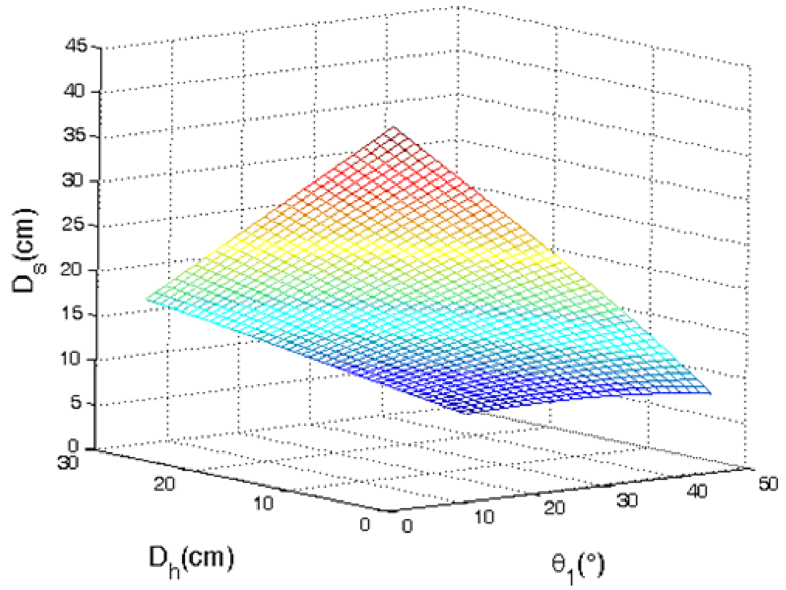


FIGURE 11. Simulation of the proposed model

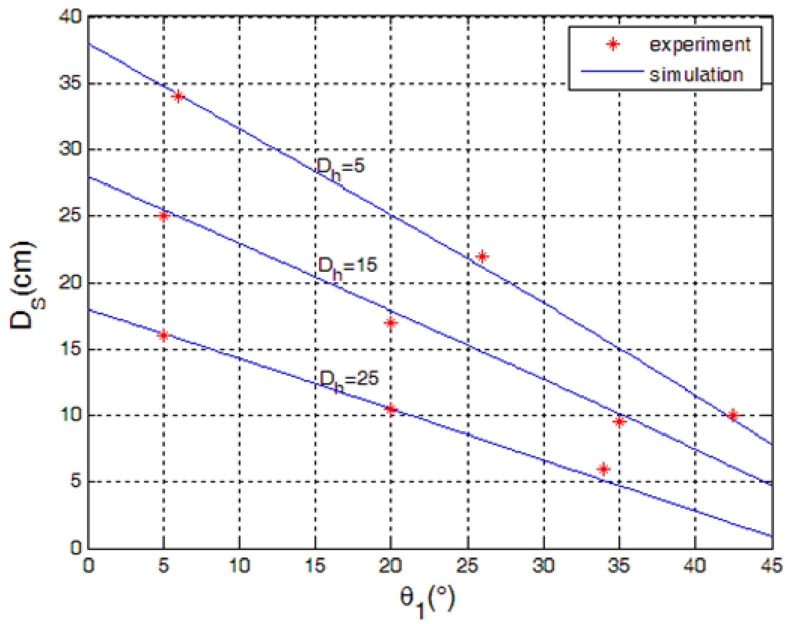


FIGURE 12. The contrast results

$\theta_1$, the sitting position $D_s$ can be obtained by the proposed model. Figure 11 shows the simulation result of the model.

According to the motion detection by laser sensor mentioned above, the distance $D_h$ and angle $\theta_1$ were obtained. And the sitting position $D_s$ was measured. The measured value of $D_h$ and simulated value of $D_s$ were compared, shown in Figure 12. The measurement of $D_h$ is almost the same as that of simulation.

5. **Conclusions.** In order to make wheelchairs with more intelligence to assist someone sitting on it safely and comfortably, the experiments were set up and the interaction between the body and the wheelchair during the procedure of someone sitting on it was analyzed in this paper. The experiment results show that the distance of someone and wheelchair correlates positively with impact force to the wheelchair. Moreover, the relationship of the sitting gesture and the sitting position was built based on the two-link mode, and the contrast results of experiments and simulation show effectiveness of the

proposed model. It is significant for developing intelligent wheelchairs with more comprehensive assistance for users.

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