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The Feasibility Assessment of Using a Kinect-Tablet Integrated System to Improve Electric Wheelchair Reversing Safety

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Abstract. The purpose of this study is to develop a Kinect-tablet integration system (KTIS) and then assess its feasibility to improve electric wheelchair reversing safety. The KTIS system comprises hardware components, including a Kinect®, tablet PC, voltage adapter, and collision sensing strips, and software components, such as OpenNI, PrimeSense, CL_NUI, Windows 7, Skype, and the self-developed KinectEduApp program. The KTIS system activates the rear-view monitor screen when reversing, emits an alarm if a collision is likely to occur, and automatically sends a distress text message to the caregiver's mobile phone. This study adopted the counterbalanced within-subjects design and invited two students with cerebral palsy to participate in the testing. The results indicate that KTIS can significantly help the users avoid obstructions ($p < .01$). Following the test, feasibility analysis was conducted to evaluate the functions and features of the KTIS system and its extended application in Ergonomics.

Keywords: Ergonomics; Depth sensor; Electric wheelchair; Reversing safety; Human-computer interface

1. Introduction

Discussions on car-reversing safety issues have primarily focused on preventing tragedies where children are hit by reversing cars. The Royal Automobile Association of South Australia Inc. (RAA) indicated that modern cars excessively emphasize fashion and aerodynamics, resulting in a poor rear vision field and reducing the rear-view visibility. In Australia, an average of one child per week becomes victim to this type of car accident. Installing vehicle auxiliary cameras and ultrasonic sensors can increase the driver's awareness of obstructions or children behind the body of the vehicle [1].

In addition, Fennell launched the "KidsAndCars" movement in Kansas in the U.S., which advocates the installation of a rear-view camera in all new cars. When the "Cameron Gulbransen Kids" traffic safety law was passed in Kansas in 2008, vehicle rear-view safety standards and rear obstruction or person detection methods gained official attention for the first time [2]. A sample survey conducted in the U.S. in 2010 found that the Reversing Visibility Index for general vehicles averaged approximately 13.3%. Although this has improved significantly in the last 10 years, there is still room for future improvements [3]. The U.S. Department of Transportation announced a new requirement in December 2010, that is, to reduce blind spots when reversing and to protect pedestrian safety behind vehicles, the installation of a rear-view camera must be standard for all vehicles sold on the U.S. market after 2014 [2]. A vehicle reversing alert system is an auxiliary device to eliminate rear-view blind spots, enable motorists to distinguish the reversing position and direction, and most importantly, prevent hitting the children or pedestrians behind the car.

The general reversing radar system currently installed in cars uses ultrasound reflection to activate the alarm. In 2006, the Crimestopper Security Products Inc. developed a vehicle reversing assistance camera that was integrated with the rear-view mirror and would automatically activate when the car was driving in reverse [4]. However, this system did not include the ultrasonic reversing radar system mentioned previously. Ultrasonic sensors can detect rear obstructions and provide feedback. Additionally, the car reversing camera

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assists by providing a rear-view video recording, and, although the camera cannot provide real-time feedback, it provides the driver a clear view behind the vehicle [5]. However, the car reversing radar and rear-view monitor must be employed together to achieve the best result. Vehicles with one of these electronic systems are currently available on the market; however, the two products have yet to be integrated into a single system. In the future, car reversing assistance systems will become a standard feature for new cars, and this product type will move toward integration.

The electric wheelchair usage rate has increased substantially. Therefore, the issue of how to employ the newly innovated technologies to design safer electric wheelchairs has become crucial. However, the safety design of current electric wheelchairs still contains flaws; specifically, all electric wheelchairs sold on the market have a reversing function without a reversing safety alert system. Therefore, the purpose of this study is to improve electric wheelchair reversing safety by developing an integrated Kinect-tablet integrated system (KTIS). A scenario test was conducted on electric wheelchair users with cerebral palsy; based on the test results, the feasibility of KTIS future commercial application in Ergonomics was also evaluated.

2. Method

2.1. KTIS System Planning for Electric Wheelchairs

The KTIS system used in this study comprised Kinect®, a tablet PC, voltage adaptor, collision sensing strips, and LED lights. The tablet PC and voltage adaptor were placed under the user's feet and were visible from the front. The tablet PC is the information exchange centre for the rear-view assistance monitor screen. The purpose of the voltage adaptor is to provide power for the Kinect®, tablet PC, and LED lights. The collision strips affixed to the pipes are used to detect objects behind the wheelchair and are visible from the back. If the wheelchair collides with an object when reversing, the LED lights activate and a text message is sent automatically to a caretaker via Skype.

A tablet PC was used instead of a notebook computer to reduce the device size and provide a touch-screen function to facilitate control. The collision sensor strips and LED lights were designed to objectively record the collisions made by the testers. In addition, Kinect's detection angle can be moved up or down by 27° to monitor the location of obstructions.

Next, we describe the operational function structure for the KTIS electric wheelchair system. The tablet PC captures the image and field depth information from the Kinect® via the USB link. When the system detects objects (obstructions) within the detection area, the computer issues an alarm to alert the user. If a collision occurs, the system sends a text message via Skype to request assistance. To achieve these functions, we installed OpenNI 1.0.0 for Windows, released by PrimeSense (the OpenNI API is used by Kinect® to capture images and 3D field depth data, and can be downloaded from OpenNI.org), PrimeSense 5.0.0 for Windows (this program is Kinect's driver and can be downloaded from OpenNI.org), CL NUI Platform 1.0.0.1210 (this software controls Kinect's vertical oscillation function and can be downloaded from codelaboratories.com/nui), and Skype API for Windows (this software allows text messages to be sent via Skype and can be downloaded from developer.skype.com). We also used C# language to write a user interface application for Windows-KinectEduApp to serve as the interface program between users and the tablet PC, and to display information captured by Kinect® on the Windows 7 tablet PC. The screen interface allows the users to see the rear-view image and configure features and functions that can be detected in the detection zone.

The KTIS system control program framework interface and monitoring screen was developed by this study. The data captured by Kinect® can be transferred to the tablet PC Windows 7 operating system via USB. The control program written for this study then translates the captured data into feedback information for the wheelchair user. The control program uses "start" and "stop" buttons to turn the Kinect® control program on or off. After the control program is activated, the system can show real-time colour monitoring and 3D field images of the area behind the wheelchair. The users can upload audio alarm files via "Audio File," set a warning distance via "Warning Distance," adjust the obstacle's resolution size via "Min. Pixels," adjust the sound volume via "Sound Volume," adjust Kinect's oscillation angle via "Motor Degree," and set the obstruction detection distance to activate the system's distress text message function. As part of the text message activation function, when the wheelchair is within the set distance from an obstruction, a dialogue box pops up for 30 s. If no action is taken within 30 s, the system sends the distress text message. This design is an emergency strategy to assist the users when they are unable to operate the wheelchair after a collision.

In the screen display area, functions, such as whether to display the colour image, field depth image, red warning zone, and wheelchair reverse guidance line, can also be configured. In the content display area, the font type and guidance line width and length can be set. In the Skype text message area, the cell phone number, to which the message is sent, can be set and the text message processing status can be displayed. The KTIS system values configured by this study were adjusted for optimal results prior to conducting the tests and were not readjusted by the users. However, if the user experienced any problems, they could report the problems to the research assistant, who would then readjust the setting values and restart the entire scenario test.

2.2. Design of the Test Experiment

This study adopted the counterbalanced within-subjects design and invited two students with cerebral palsy to participate in the testing which was divided into four steps. The two test participants were arranged to complete the first cycle of Steps 1, 2, 3, 4, and next to complete the following cycle of Steps 3, 4, 1, 2. There were 5 times testing separately in above cycle.

- *Step 1*: Control the interfering variables, such as lights, electric wheelchair power, and operating experience, and provide instructions before administering the test.
- *Step 2*: Conduct a baseline test using wheelchairs without the KTIS system installed. Participants practiced basic operational control of the electric wheelchair for 10 min to familiarize themselves with the movement controls. Participants completed the wheelchair reversing test on the testing route. The entire process was recorded and scored by the research assistant (by observing whether the LED lights were activated).
- *Step 3*: Install the KTIS system and implement the formal experiment. Perform the tests using the electric wheelchairs with the KTIS system installed after the baseline tests. Participants practiced basic operational control of the electric wheelchair for 10 min to familiarize themselves with the movement controls. Participants completed wheelchair reversing tests on the testing route. The entire process was recorded and scored by the research assistant (by observing whether the LED lights were activated).
- *Step 4*: Check and recovery the above control variables and testing route.

2.3. Test Route Planning and Participants

The wheelchair reversing route was S-shaped and had five obstructions. The experiment participants were two students with cerebral palsy from the Hualien Special Education School for the Mentally Retarded of Taiwan. Cerebral palsy is characterized by muscular dysfunction, and the two participants were unable to freely turn or look behind themselves. When collisions occurred, the collision strips on the rear square pipe triggered LED lights. The participants were awarded five points for having no collisions throughout the entire course and one point was deducted for each collision that occurred. In addition, all obstructions used in this test posed no danger to the participants. The brown border on the floor indicated the testing bounds where the electric wheelchairs should not cross. The red “S” line was the wheelchair reversing route. The entire test process was recorded and scored by the on-site research assistant, and the Sign test was adopted for statistical analysis.

3. Results and discussion

3.1. Successful Delivery of KTIS Data

When the electric wheelchair was within 30 cm of an obstruction, the KTIS successfully activated an alarm. When the electric wheelchair collided with an obstruction when reversing, the KTIS system successfully sent an automatic text message to a designated person via the Skype software on the tablet PC.

3.2. Student Case 1 Test Results

We used the repeated measurements of the Sign Test statistical method to investigate whether the score differences for the initial baseline and post-KTIS installation test results for student case 1 had a .01 level of significance. The significantly higher number of "+" symbols compared to "-" symbols in Table 1 was not caused by probability ($p = .008 < .01$). This indicates that installation of the KTIS system assisted the electric wheelchairs users in avoiding obstructions when reversing.

Table. 1: Results of the Sign Test conducted on Case 1 to identify differences before and after KTIS installation

The X Test	1	2	3	4	5	6	7	8	9	10
With KTIS(intervention)	4	5	3	4	5	5	4	5	4	5
Without KTIS(baseline)	2	1	3	3	2	2	3	2	4	3
Sign	+	+	0	+	+	+	+	+	0	+

$^{**}p = .008 < .01$

3.3. Student Case 2 Test Results

We used the repeated measurements of the Sign Test statistical method to investigate whether the score differences for the initial baseline and post-KTIS installation test results for student case 2 had a .01 level of significance. The significantly higher number of "+" symbols compared to "-" symbols in Table 2 was not caused by probability ($p = .004 < .01$). This indicates that installation of the KTIS system assisted the electric wheelchairs in avoiding obstructions when reversing.

Table. 1: Results of the Sign Test conducted on Case 2 to identify differences before and after KTIS installation

The X Test	1	2	3	4	5	6	7	8	9	10
With KTIS(intervention)	3	3	4	4	5	5	4	5	4	5
Without KTIS(baseline)	2	3	2	3	2	3	3	2	3	4
Sign	+	0	+	+	+	+	+	+	+	+

$^{**}p = .004 < .01$

3.4. Discussion

Results of the tests conducted in this study indicate that the KTIS system can improve electric wheelchair reversing safety. Installation of the KTIS system enhanced the electric wheelchair reversing safety of the participating cerebral palsy students. We also conducted a feasibility assessment based on KTIS features, functions, and future application in Ergonomics. There were three main advantages of the KTIS system, that is, 1) wheelchair rear-view monitoring; 2) wheelchair reversing danger alarm; and 3) the system can be configured by the user. The KTIS system has two primary functions: 1) serve as a monitor, alert, and rescue integrated system; and 2) use Skype to conduct remote wireless emergency rescue requests. Furthermore, the KTIS has two commercial applications in Ergonomics: 1) use KTIS as the reversing safety assistance system for electric wheelchairs or mobility scooters; and 2) use KTIS as the standard issue or optionally installed car reversing assistance system. The above evaluation results demonstrated that the KTIS system's three features, two output functions, and two commercial applications in Ergonomics can all be feasibly applied to enhance car reversing safety for immobile or disabled people. These systems can be preinstalled when manufacturing the automobile, replacing the current rear-view monitor screens and ultrasonic reversing sensor systems, or be developed as a consumer-installed safety assistance system.

Although the KTIS system has feasible commercial applications in Ergonomics, the results of this study indicate that the product design must be adjusted to promote the system for commercial use. For example, the Kinect® system and tablet PC must be adjusted to use the DC power system provided in most cars instead of relying on a power adaptor. In addition, Microsoft CEO Steve Ballmer announced at the 2012 Consumer Electronics Show that Microsoft would launch a Windows operating platform-compatible Kinect® sensor in February 2012, provide a free software development kit (SDK) for developers to download, and collaborate with corporations such as Toyota and American Express to research and develop various Kinect® application products [6]. This should improve the smoothness and convenience of the KTIS system's integrated operations.

4. Conclusions

Although all electric wheelchairs have a reversing function, they do not have a reversing safety system. This study developed a Kinect® and tablet integrated system to address this limitation. The system comprised hardware, including a Kinect®, tablet PC, and voltage adaptor, and software, such as OpenNI, PrimeSense, CL_NUI, Windows 7, Skype, and self-developed KinectEduApp. The system can provide car reversing rear-view monitoring, activate alarms within a specific distance before collision, and send or cancel distress text messages when the wheelchair is extremely close to an obstacle. The results of experimental condition tests conducted on two students with cerebral palsy confirmed that the KTIS system significantly assisted the participants in avoiding obstructions behind their wheelchairs ($p < .01$). Results of the evaluations conducted after the tests suggested that KTIS can serve as a reversing safety assistance system for electric wheelchairs or mobility scooters, and be used as the standard issue or optionally-installed vehicle reversing assistance system. For electric wheelchairs and mobility scooters, the KTIS system can simultaneously perform monitoring, alert, and distress call functions. The Windows 7 touch-screen platform allows easy consumer configuration and provides power for the Kinect® and tablet through a voltage adaptor. For general vehicles, the Kinect® can be installed as a car reversing assistance system. Additionally, Kinect® data can be transferred to the driver panel using a USB, and appropriate KTIS system settings can be configured based on the user's individual needs.

According to the above practice described, the significant contribution of the KTIS system for contemporary ergonomics was summarized as follows: 1) The Kinect-Tablet Integrated System (KTIS) can be used as reversing safety assistance system on the ergonomics practice of electric wheelchairs; 2) The electric wheelchair with KTIS can provide custom-oriented settings for the various users, as well as provide users for rescue requests via Skype; 3) The KTIS can provide the better integrated design of sensor and rear-view monitor for contemporary ergonomics; 4) The KTIS can also be used as reversing safety design of ergonomics for mobility scooter or general vehicles.

Previous studies indicate that rear visibility devices still have significant room for improvements [3]. Various U.S. state governments are also recognizing the importance of vehicle rear-visibility safety standards and rear-obstruction detection methods, and have declared that rear-view cameras must be standard issue equipment for all vehicles sold in the U.S. market after 2014 [2]. Vehicles with reversing radar and a rear-view monitoring systems installed are currently available on the market; however, the two products have yet to be integrated into a single system [5]. Adopting KTIS as the reversing assistance equipment for electric wheelchairs, mobility scooters, or general vehicles would promote the development of more diverse car reversing safety assistance systems to allow consumers to integrate various functions in one system.

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