Toward Gesture Controlled Wheelchair: A Proof of Concept Study

Noriyuki Kawarazaki
Dept. of Robotics and Mechatronics
Kanagawa Institute of Technology
Kanagawa, Japan
kawara@rm.kanagawa-it.ac.jp

Dimitar Stefanov
Faculty of Engineering
Coventry University
Coventry, U.K
d.stefanov@coventry.ac.uk

Alejandro Israel Barragan Diaz
Dept. of Robotics and Mechatronics
Kanagawa Institute of Technology
Kanagawa, Japan

Abstract –**This study focuses on the early stages of developing and testing an interactive approach for gesture-based wheelchair control that could facilitate the user in various tasks such as cooking and food serving. The proposed method allows a user to hold an object (tray, saucepan, etc) with both hands and to control at the same time the wheelchair direction via changing the position of his/her arms. The wheelchair control system contains an image sensor directed to the user's arms. Sensor signals are processed via an image-recognition algorithm and the calculations for the arm positions are used for the computation of the wheelchair steering signals. Thus, the wheelchair direction depends on the arm positions and the user can control the wheelchair by moving his/her arms. An initial wheelchair prototype, operated by the intentional motions of one hand, was built and was tested by several initial experiments.**

Keywords – Wheelchair interface, Gesture recognition, Depth image sensor, Natural interaction library

I. INTRODUCTION

The research on novel assistive systems for people with movement disabilities is a growing research area driven by the requirements of the end-users and their expectations for living at home independently. The needs of physically challenged people and the difficulties that they might encounter while performing daily living tasks, such as reaching a cupboard, opening a door, or changing TV channels have been an object of various recent research studies [1], [2]. The individual sets of essential movement tasks vary from person to person and depend on the specifics of the user's impairment, environment, culture differences, lifestyle, age, and physical condition. Recent technology advances made possible the design of better devices for assistance in movement. Current research efforts are focused on the development of innovative means of transportation, novel systems for human-wheelchair interaction and environmental control, and new technology for assisting in tasks related to household activities, sport, and social interaction, etc. Wheelchairs with systems for analysis of the surrounding environment and automatic obstacle avoidance have been reported in various new studies, e.g. the TAO project [3], the Rolland project [4], and the Robotic Wheelchair project [5]. Such solutions improve user's experience and increase movement safety. Recent progress in face tracking techniques and voice recognition enabled the development of new interfaces for control of electric wheelchair as an alternative of the standard joystick [6]. The idea for hand gesture control of assistive technology has been explored for more than two decades but the practical application of such systems has been delayed due to their sensitivity to motion artifacts and illumination variations and low gesture recognition rate against cluttered and dynamically changing backgrounds [7], [8]. Some recent studies have investigated the application of the Kinect sensor for human motion recognition and wheelchair control [9], [10], and [11].

In this research, we introduce an approach for gesture control of the wheelchair direction. The proposed control system contains an image sensor that monitors the zone where the user's arms are located. The signals of the sensor are analyzed via a special algorithm that recognizes the images of the user's arms and produces signals for controlling the wheelchair direction that are based on the calculated arm positions. This way, the user can change the wheelchair direction by intentional arm motions. The proposed system could facilitate the wheelchair users in tasks that require manipulation of an object with both hands and steering of the wheelchair at the same time, for example, kitchen tasks that require moving a pot during cooking or moving plates from the stove to the table for meal serving. An initial evaluation of the proposed algorithm was done by a simple experimental setup that contained a depth image sensor and implemented an image-recognition algorithm that referred to the OpenNI natural interaction library. The experiment in this early stage was limited to control of the wheelchair by the gestures produced by one hand. Some initial results from the testing of the experimental wheelchair control algorithm are also presented.

This paper is organized on the following way: The concept of the gesture control system is explained in section II and the simplified algorithm used in the prototype system is commented in section III. In section IV, the structure and the

978-1-4673-6024-1/13/$31.00 ©2013 IEEE

components of the experimental system are presented. Section V explains on the gesture control system and Section VI describes the experiments and experimental results. Future plans are discussed in section VII.

II. THE CONCEPT

In this research, we refer to a wheelchair user with well preserved arm movements who is able to propel a manual wheelchair and to manipulate objects by hands. It is also assumed that the wheelchair can be driven either manually by the user or by small electric motors coupled with the driving wheels. Electromagnetic clutches are used to couple and decouple the motors from the wheels. During indoor and outdoor usage, the wheelchair is propelled by the user by applying forces to the push rims. In that mode, the motors are disconnected from the wheels and the wheelchair performs as a standard manual wheelchair. The wheelchair can also operate in a "gesture control mode" where the wheelchair is driven by the motors and the wheelchair movement direction is set by the position of the user's arms. The gesture control mode allows the user to control the wheelchair by intentional arm movements and to perform at the same time kitchen tasks which require holding objects with both hands. The gesture control algorithm is presented in Figure 1.

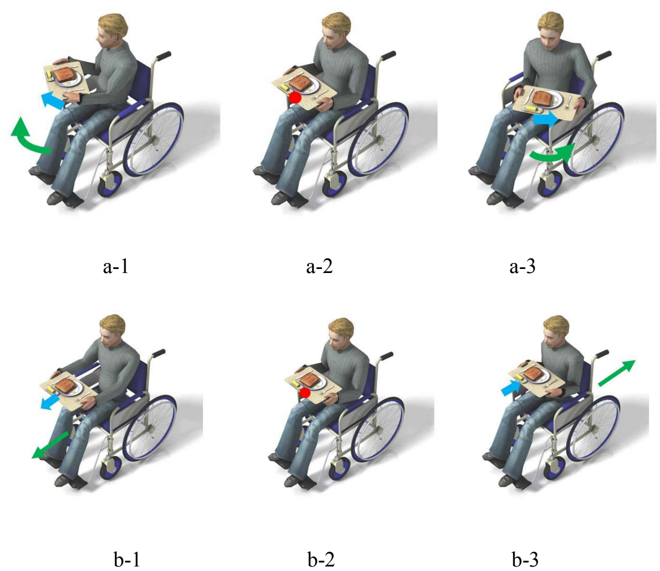


Figure 1 Arm positions and wheelchair movement directions

The position of the arms is detected by a position sensor (not shown on the figure) that is attached to the wheelchair frame and senses remotely the zone where the user's arms are located. When the arms are in a "neutral" position (see Figure 1, positions a-2 and b-2), no control signals are sent to the motors and the wheelchair does not move. If the user moves his/her arms to the left (Figure 1, position a-1), the wheelchair rotates to the left. The wheelchair turns to the right when the arms move to the right (Figure a-3). By analogy, the stretching of the arms causes forward wheelchair movement (Figure 1, position b-1) and the flexion of the arms toward the body (Figure 1, position b-3) causes backward wheelchair movement. The algorithm is intuitive and allows easy wheelchair control. When the wheelchair runs in a gesture control mode, the electromagnetic clutches connect the motors with the wheels.

The gesture recognition module continuously analyses the arm positions and turns the gesture control mode when it identifies that an object is held with both arms. The system switches back to a manual mode when the gesture monitoring system detects that the user's arms are far from each other or outside the active zone of the vision sensor. In most cases, the wheelchair is used in a gesture mode for relatively short periods and runs at a low speed on a horizontal kitchen floor, which reduces power demands to the gesture control module and allows its compact design based on a small-sized battery and electric motors.

III. SIMPLIFIED ALGORITHM

In order to explore the viability of the control algorithm described in the previous section, we designed a simple system for wheelchair control that was based on the recognition of the gestures, performed by the right arm of the user.

To initiate the gesture control mode, the operator places his/her right hand in a preliminary defined area of the image sensor viewing zone and performs there a "start gesture" by moving his/her hand toward the sensor and returning it back. The user executes the gesture with stretched fingers and a palm facing the vision sensor, as shown in Figure 2. After the recognition of the start gesture, the system memorizes the same arm posture for further referencing to it as the "neutral position". During the gesture control mode, the wheelchair is driven by the electric motors. When the arm is in a neutral position, the motors do not work and the wheelchair does not move.

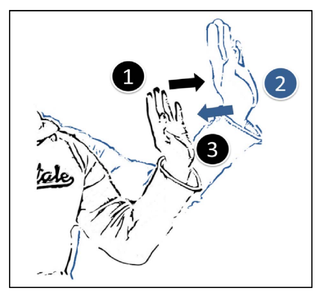


Figure 2 Starting gesture

The user sets the wheelchair movement direction by moving his/her hand away from the neutral position. If the hand is moved to the left, the wheelchair rotates to the left. In the same way, the wheelchair rotates to the right when the hand is moved to the right. Stretching the hand beyond the neutral position causes forward wheelchair movement, while the bending of the arm and moving the hand closer to the body causes a reverse movement. This way, the wheelchair direction can be controlled easily by changing the position of the user's hand. The wheelchair stops when the user returns his/her hand into the neutral position. The gesture recognition mode can be turned off if the arm is moved outside the hand recognition zone. The algorithm for changing the wheelchair direction is illustrated with Figure 3.

To avoid false positives caused by unintentional slight motions around the neutral position, we expanded the area around the neutral position (noted as a square on figure 3) and adjusted the control algorithm to stop the wheelchair when the user's hand is within the same stop area.

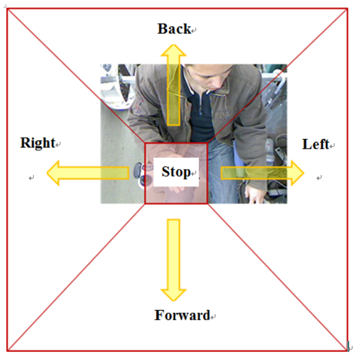


Figure 3 Algorithm for setting the wheelchair direction and control areas

IV. STRUCTURE OF THE PROTOTYPE SYSTEM

Figure 4 shows a picture of the wheelchair and the modules of the gesture recognition system mounted on it. The prototype wheelchair system consists of the following components:

1.YAMAHA JWX-1 Active wheelchair
2. ASUS Xtion PRO Depth Image Sensor
3. Depth sensor mount
4. TOSHIBA Dynabook, Intel i5–560M 2.66 GHz processor with Open NI and NITE HML Toolkit installed on it [12], [14]
5. Silicon Labs CP210x USB to USART Bridge.

Figure 4 The prototype system and its components

The block diagram of the prototype system is shown in Figure 5.

The position of the user's arm is tracked by a depth sensor whose signals are processed with a special image recognition algorithm that runs on the PC computer. The hand tracking information is used for the calculation of the signals for the wheelchair control. The signals of the computer are transferred to a special module (denoted on figure 5 as WCC) via wired serial connection. The WCC module converts the computer's commands into signals with the same characteristics as the joystick signals and the wheelchair controller responds to them on the same way as the joystick signals. The WCC module also can switch the input of the wheelchair control box to allow control of the wheelchair either from the joystick or from the computer. When the wheelchair will be used in a gesture mode, the computer sends a special command to the WCC that disconnects the joystick and enables the control from the computer. The joystick control mode can be restored if the power of the wheelchair is switched off and on again.

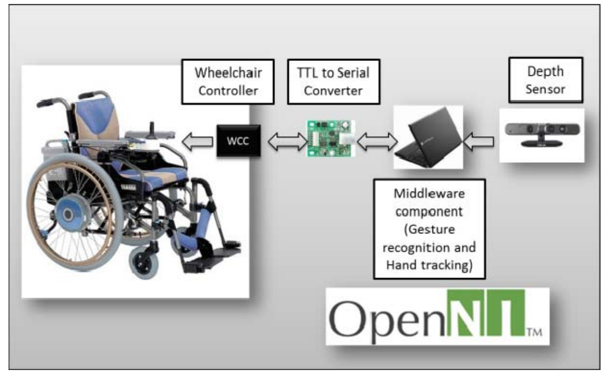


Figure 5 Block diagram of the prototype system

Further information about the components of the wheelchair control system is provided below.

A. Wheelchair

As explained in sections II, for testing of the algorithm we need a wheelchair that allows dual usage as a manual wheelchair (for indoor movement) and as a motor-driven wheelchair (for the gesture control mode). For the experiments we used a wheelchair, model JWX-1 from Yamaha, whose motors are embedded into the hubs of the rear wheels. Each wheel has a special mechanical clutch that connects or disconnects the power from the motor to the driven wheel. When engaged, the clutches connect the motors with the wheels and the wheelchair performs as a standard electric powered wheelchair. In this mode, the wheelchair is controlled by the user via the joystick. If the clutch is disengaged, the motors are separated and the wheels can be driven by the user via the push rims, i.e. the wheelchair operates as a manual wheelchair. The user can select the powering source mode by a special lever that changes simultaneously the positions of the clutches of both wheels. During the gesture mode, the motors are connected mechanically with the drive wheels and the wheelchair controller is powered.

B. Depth Image Sensor

The image sensor provides information about the arm position and acts as an interface between the user and the wheelchair control system. We used an Asus Xtion PRO Live depth image sensor that allows precise 3D tracking and hand gesture recognition and integrates three sensors [13]:

- A camera-based RGB Sensor that can detect three color components: red, green and blue.
- A depth sensor based on an infrared projector and a monochrome CMOS receiver that work together. The sensor is insensitive to the visible light and can provide 3-D information.
- Two built in microphones that provide audio input. In this

experiment, the microphones are not used.

Main specifications of the used depth sensor are presented in Table 1.

Table 1 Main specifications of the Xtion PRO Live sensor

Effective Distance (when using OpenNI)	Between 0.5 meters and 3.5 meters
Effective Angle	58º horizontal, 45º vertical, 70º diagonal
Interface/Power	USB 2.0
Sensor	RGB & Depth
Audio	2 x built-in microphones
Development Platform	Visual Studio .NET 2008, 2010
Middleware	OpenNI/NITE
Programming Language	C++/C# (Windows) | C/C++ (Linux)
Supported OS	Win 32/64: XP, Vista, 7 | Linux 32/64: Ubuntu 10.10
Dimensions	1.5" x 7" x 1.9" | USB Cable Length: 5.5 feet

C. Depth sensor mount

The depth sensor was attached to the wheelchair via a special mount designed as an aluminum arch-shaped frame that allowed the fixation of the sensor in different positions around it. Both ends of the frame were fixed to the wheelchair through connecting joints that enabled its axial translation and swiveling. For these first experiments, the size of the sensor mount was intentionally increased to allow positioning of the depth sensor in a very wide area. The experiments gave us useful information about the optimal sensor position which will allow us to design a new smaller mount unit.

V. GESTURE RECOGNITION PROCESS

We used the OpenNI open source SDK Natural Interaction library (OpenNI) to develop the gesture recognition software and its middleware components [14]. Originally, the Natural Interaction library had been created to promote the development of software for interaction via speech, hand gestures and body motion in a natural way.

A block diagram of the gesture-based wheelchair control processes is presented in Figure 6. After powering of the vision-processing unit, it initiates a procedure for recognition of a hand-shaped object in the image. When a hand-shaped object is found in the images produced by the depth sensor, the system starts to track its position by initializing a procedure for analysis of the depth of the recognized object and comparing the results with the predefined images of the "starting" gesture in the OpenNI library run by the Gesture Generator. The "starting" gesture (see Figure 2) is recognized after the completion of intermediate stages. This process is illustrated in Figure 7.

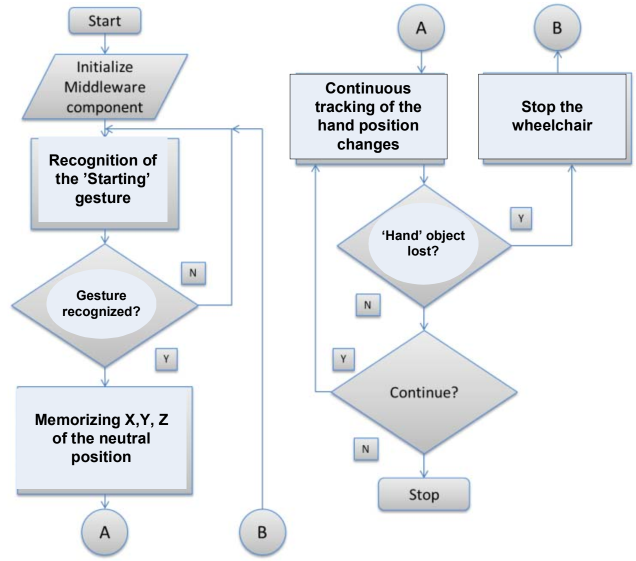


Figure 6 Gesture recognition and hands tracking process.

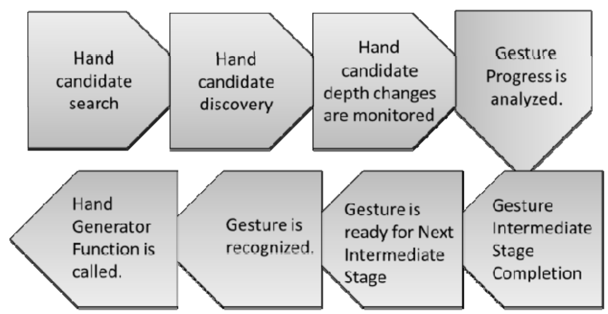


Figure 7 OpenNI gesture recognition process.

After the completion of the recognition of the "starting" gesture, the intermediate stage is completed and the co-ordinates x, y and z of the current position of the hand are memorized to be used in the next procedures as the co-ordinates of the reference (neutral) position. The system begins to track the 'hand' object by analysis of the image information from the depth sensor and compares the current position of the 'hand'-object with the memorized co-ordinates of the reference position. The differences between the current and the reference co-ordinates are computed continuously and used for calculation of the direction and the magnitude of the hand movement. The control algorithm issues a "stop" command to halt further wheelchair motion if the "hand" object cannot be found in the depth sensor image. Such situation occurs when the user moves his/her hand outside the recognition area with the intention to stop the wheelchair or in the cases when the sensor has lost the object. In such cases, a new hand gesture recognition process is initiated.

B. The Wheelchair Control Strategy

The sensing area of the depth sensor was divided virtually into five zones as shown in Figure 3. Depending on the zone where the hand was located, the algorithm produced commands for movement of the wheelchair in forward and backward direction, or for its rotation “on place” (around the centre of the rear wheels axle) to the right or left. Experimentally, the “stop” area was defined as a 12 cm square around the neutral position.

VI. TESTS AND RESULTS

The prototype system was assessed by a few experiments. Five subjects without physical disabilities (aged from 19 to 27 years; three men and two women) participated in the tests described below.

A. Gesture Recognition Test

With this set of trials we aimed to explore the recognition accuracy of the prototype system. We compared the performance of the system for the recognition of the “starting” gesture for 3 different angular orientation of the depth sensor. The sensor was rotated sequentially to 30[deg.], 40[deg.], and 50[deg.]. For the experiment, the computer was disconnected from the wheelchair controller. The subjects were asked to sit in the wheelchair and to perform the “starting” gesture 100 times for each sensor orientation. The recognition result for each test was recorded.

The recognition rates for each sensor orientation are shown in Table.2. The best average recognition rate was 90.6%. It was achieved when the sensor was inclined on 30[deg] toward the plane where the user’s hand moved. A snapshot of the depth sensor image while a person is performing a “starting” gesture is shown in Figure 8.

Table 2 Recognition rates of the “starting” motion

SUBJECT	SENSOR ANGLE		
	30 [deg.]	40 [deg.]	50 [deg.]
Subject A	97%	96%	25%
Subject B	100%	81%	26%
Subject C	100%	81%	5%
Subject D	95%	93%	87%
Subject E	61%	75%	78%
Average	***90.6%***	85.2%	44.2%

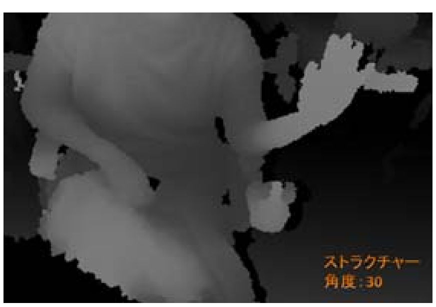


Figure 8 A depth-sensor image

B. Steering Performance tests

We conducted initial tests to evaluate the steering efficiency of the developed control system. At the beginning of each test, the wheelchair was placed in the start position. Participants were asked to sit on it, to perform a ’starting‘ gesture, and to navigate the wheelchair by intentional hand movements to the goal position while keeping the wheelchair within a narrow corridor that was marked on the floor with a colored tape. The test path also included two interim points. After reaching each point, the participants needed to perform additional driving maneuvers that were explained to them in advance. Figure 9 shows the plan of the room and the test route. Each subject was asked to repeat the test three times. Before the test, each subject was instructed on the method of control and was asked to practice the ’starting’ gesture and steering by gestures for 10 minutes.

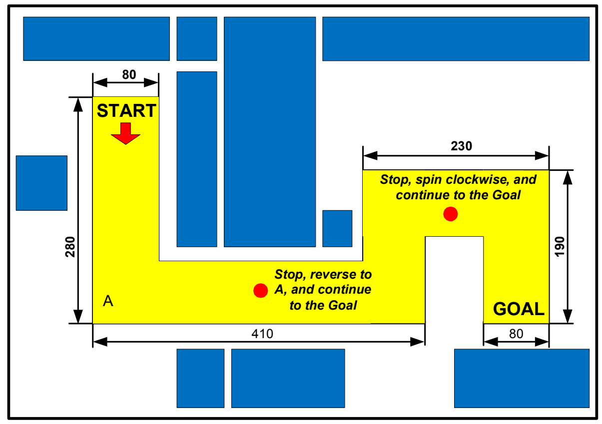
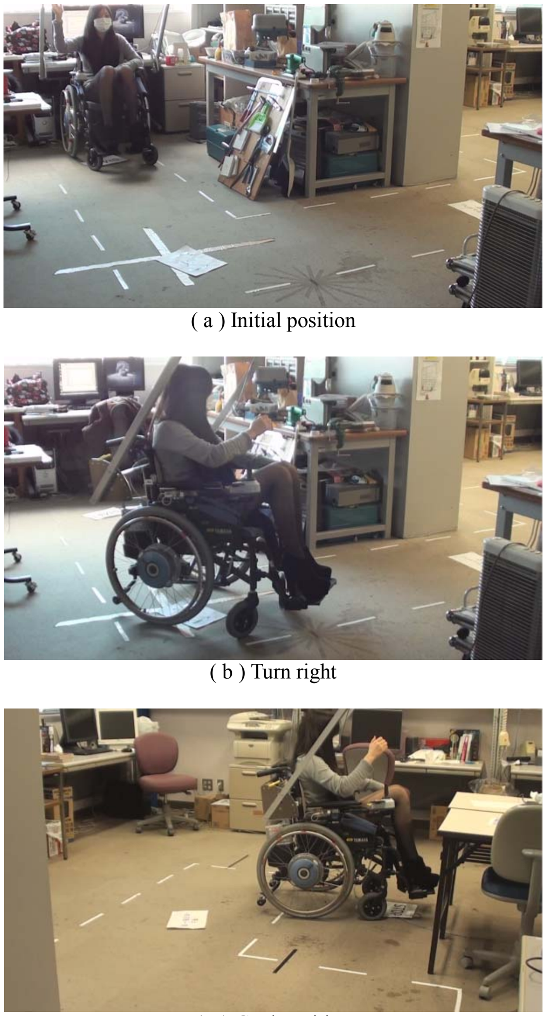


Figure 9 Wheelchair test route

All subjects reached the goal position. The average time for completion of the test was 264[sec]. Scenes from the conduced performance test are shown in Figure 10. For achieving best functioning of the system, the position of the depth sensor needs to be adjusted individually for each participant.

VII. CONCLUSIONS

We propose a gesture-based wheelchair control system for helping wheelchair users in activities that require holding an object with both hands and driving the wheelchair at the same time. The viability of the proposed approach was tested with an initial prototype that was operated with the intentional motions of one hand and utilised five motion commands defined by the hand position. The prototype used an Asus Xtion PRO Live depth image sensor whose signals were processed by a special image recognition algorithm built on the OpenNI library. The effectiveness of the gesture recognition system was clarified with several initial performance tests. Although these results corresponded to the initial system development, the average recognition rate for the recognition of the “start” gesture was 90.6%. The experiments gave us new practical experience and design ideas for improvement. In our future work, we intend to explore further the practicality of the system by various experimental scenarios. The long-term goal of this research is to build a new system based on recognition of the movements of both arms as described in section II.



(a) Initial position

(b) Turn right

(c) Goal Position

Figure 10 The performance test

ACKNOWLEDGMENT

We would like to thank Mr. Alexander Avtanski for his great help for the computer design of some of the figures presented here and Tiziana Loni whose 3D models were used in some of the pictures.

REFERENCES

[1] Dimitra Anastasiou : "A Speech and Gesture Spatial Corpus in Assisted Living", Proceedings of the eighth international conference on Language Resources and Evaluation (LREC2012), 2012.

[2] Dimitra Anastasiou, Cui Jian, Desislava Zhekova : "Speech and Gesture Interaction in an Ambient Assisted Living lab", Proc. of the 1st Workshop on Speech and Multimedial Interaction in Assistive Environments, pp.18-27, 2012.

[3] Gomi, T. and Griffith, A. : "Developing Intelligent Wheelchairs for the Handicapped". Assistive Technology and Artificial Intelligence, Applications in Robotics, User Interfaces and Natural Language Processing, Lecture Notes in Computer Science, Vol 1458 , pp. 150-78. Berlin, 1998.

[4] Röferand Lankenau, A.T. : "Architecture and applications of the Bremen autonomous chair Wheelchair". Proceedings of the 4th Joint Conference on Information Systems, Vol 1, Association for Intelligent Machinery - pp. 365-368,1998.

[5] Yoshinori Kuno, Nobutaka Shimada and Yoshiaki Shirai : " A Robotic Wheelchair Based on the Integration of Human and Environmental Observations", IEEE Robotics & Automation Magazine, pp.26-34, March 2003.

[6] Arturo Escobedo, Jorge Rios-Martinez, Anne Spalanzani and Christian Laugier : "Context-Based Face Control of a Robotic Wheelchair", workshop on navigation and manipulation assistance for robotic wheelchairs in IROS2012.

[7] K. Mohan Kumar, Dinesh Masani : "Hand Gesture Recognition for Wheelchair Control by Digital Image Processing Technique", International Journal of Communications and Engineering, Vol.04, No.4, pp.67-71, 2012.

[8] Pei JiaH. Hu, Tao Lu, Kui YuanHuosheng: "Head Gesture Recognition for Hands-Free Control of an Intelligent Wheelchair", Industrial Robot: An International Journal, Vol.34, Number 1, pp.60-68, 2007.

[9] Mohd Razali Md Tomari, Yoshinori Kobayashi and Yoshinori Kuno : "Development of Smart Wheelchair System for a User with Severe Motor Impairment", Procedia Engineering 41, pp.538-546, 2012.

[10]Theodoros Theodoridis, Huosheng Hu, Klaus McDonald-Maier, Dongbing Gu: "Kinect Enabled Monte Carlo Localisation for a Robotic Wheelchair", Advances in Intelligent Systems and Computing Volume 193, pp 153-163, 2013

[11] Wen-Fu Pan, Mei-Ying Chien and Shih-Chun Tu : "The Feasibility Assessment of Using a Kinect-Tablet Integrated System to Improve Electric Wheelchair Reversing safety", International proceedings of computer science and information technology, vol.49, pp.121-125, 2012

[12] NITE HML Toolkit, http://groups.inf.ed.ac.uk/nxt/

[13] Asus, Xtion PRO Live, http://event.asus.com/wavi/product/WAVI_Pro.aspx

[14] OpenNI open source SDK, http://www.openni.org/