

Tongue Operated Electric Wheelchair

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Abstract—In this paper, we propose a tongue operated electric wheelchair system to aid persons with severe disabilities. Real-time tongue facial gesture is detected and estimated from a video camera pointing to the face of the user. The tongue facial gesture is used to control the wheelchair. Our system is a non-contact vision system, making it much more convenient to use. The user is only required to move his/her tongue to command the wheelchair. To make the system easy to drive, the system is also equipped with a laser scanner for obstacle avoidance. We also mount a 2D array of vibrators on the chair to provide the user with the information of the response from his/her tongue movement and the status of the system. We are carrying out user tests to measure the usability of the system.

I. INTRODUCTION

Tongue operated wheelchair project is amid to benefit severely disabled person in order to improve their mobility. For our current assistive wheelchair system the target users are tetraplegia patients (i.e. lacking fine motor control skills); they don't have ability access and control the robotic wheelchair using conventional methods, such as joystick or chin stick. For this group of users being able to move around freely is immensely important to their quality of life. There are quite a lot of research applying technologies such as using voice controlled [1], the eye control access method [2] and a head gesture controlled wheelchairs [3]. An overview of such systems can be found in [4]. Very few works can be found in exploring the use of explicit tongue gestures for communication and control. Researchers, who have tried using tongue as input device, used complex system by instrumenting the tongue with metallic piercings or magnetic attachments [5], [6], [7], [8], [9]. The sensor attached to tongue within the mouth can then be detected either by a dental retainer worn in the mouth or by a separate device worn outside the mouth. These tongue augmentations are obtrusive and marginally acceptable to the disabled people [10].

In this paper, we propose to use a video camera to estimate the tongue movement, the motion gestures are used to steer an electric wheelchair (Fig. 1). Typical tongue gestures are shown in Fig. 2. Based on tongue gestures the operations of our wheelchair are defined as “right turn”, “left turn”, “start and move with speed”, and “stop”. The “stop” operation causes the wheelchair cancel all commands and come to a halt.

To make the system more usable, our tongue gesture operated wheelchair system consists of three important modules: estimating the tongue orientation based on



Fig. 1. Our electric wheelchair fitted with a) a camera (logitech 9000, 30fps), b) a SICK Laser scanner S300, c) a laptop (CPU Pentium M 1.6 GHz, RAM: 1GB) and built in sound unit, d) vibrotactile motors (8 coin-motors controlled by PWM generated by micro-controller).

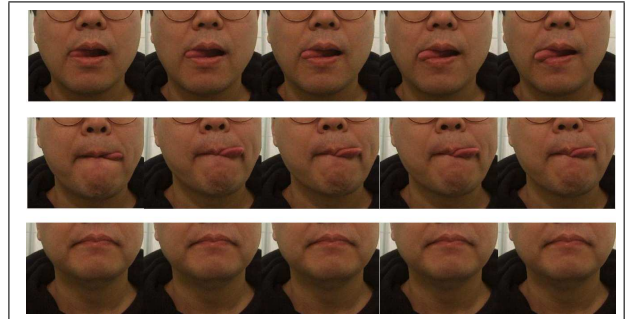


Fig. 2. Sample facial images from the user with tongue facial gestures; [Top to bottom row] left turn, right turn and move forward commands to tongue operated wheelchair system.

mouth images for direction for control parameters, an obstacle avoidance based on laser scanner and a vibrotactile feed back for used. Errors can occur due to incorrect recognition so the user is informed of the selected action so that he/she can correct the error by repositioning his tongue gesture. To do so the wheelchair is also equipped with a real-time feedback vibrotactile system.

II. SYSTEM ARCHITECTURE AND SENSORS

A. System Architecture

Sensor data acquisition, joystick reading and motor commands are performed by software modules. Sensor data is collected via a serial port and USB in a lap-

top with XP operating system. The software modules are developed in C/C++ and Java. The real time video is acquired from web camera from which direction parameters are extracted based on tongue gestures. These parameters are provided to main micro-controller in order to steer the wheel chair. Vibrators are used to inform the user the current state of the system. The designed vibrotactile patterns along with extracted tongue gestures are shown in Fig. 1.

B. Sensors

The system is equipped with a normal web camera (i.e. Logitech 900), a SICK S300 laser sensor and a vibrotactile board on the back of the chair. As a navigation aid an obstacle avoidance algorithm is also employed using SICK laser scanner. SICK laser scanner S300 is ultra compact and low power device, and works well for our purpose. For the user feed back system vibrotactile rendering based on a printed circuit board (PCB) is used. The PCB board is connected to PC using a serial port. Eight standard coin vibration motors (model No. C1026B200F produced by JinLong Machinery) are used on the back of the chair to code the current state of the system (see Fig. 1, 6). The vibration motors can rotate at a speed of 12000 RPM.

III. TONGUE GESTURE ESTIMATION AND CONTROLLING WHEELCHAIR

To control a wheelchair with tongue gestures, we need real-time gesture estimation. In our system, Locally linear embedded (LLE) algorithm [11] has been applied to characterize and visualize tongue gestures.

A personal tongue gesture gallery (PTG) stores all video frames $\{\mathbf{X}_i\}$ of personal mouth and tongue mimic. The manifold of a PTG is calculated with the standard LLE algorithm [11]. The projection of a video frame $\mathbf{X}_i$ onto the manifold by the LLE operation, $\mathbf{LLE}()$, is called the *LLE-code*, a_i , of the frame $\mathbf{X}_i$.

$$a_i = \mathbf{LLE}(\mathbf{X}_i) \quad (1)$$

Thus, each high dimensional input $\mathbf{X}_i$ is mapped to a low dimensional output a_i representing global internal coordinates on the manifold.

In the real-world operation, we have to code frames of incoming videos with the built manifold. Here we adopted two algorithms to calculate the LLE codes.

A. Algorithm I

For frame $\mathbf{Y}_i$ from the new video, we need to search for its k nearest neighbors $\{\mathbf{X}_j\}$ from the **PTG**, as measured by Euclidean distance. $\mathbf{Y}_i$ is approximated by a linearly weighted combination of its neighbors

$$\mathbf{Y}_i = \sum_j w_{ij} \mathbf{X}_j \quad (2)$$

The weight w_{ij} summarizes the contribution of the j th image to the input frame $\mathbf{Y}_i$.

Since the LLE algorithm computes a low dimensional embedding with the property that nearby points in the

high dimensional space remain nearby and similarly co-located with respect to one another in the low dimensional space, the LLE-coded of the input frame $\mathbf{Y}_i$ can be obtained by

$$b_i = \sum_j w_{ij} a_j \quad (3)$$

where $\{a_j\}$ are the LLE codes of frames $\{\mathbf{X}_j\}$.

The LLE code b_i will be used for rendering. In this way we can achieve real-time rendering of the manifold of on-line video.

The drawback with this algorithm is that for every frame $\mathbf{Y}_i$, we need to know its k nearest neighbors $\{\mathbf{X}_j\}$. Thus, we have to search over the whole gallery. It is a bit heavy for real-time mobile applications. Here we come up with a simple solution.

B. Algorithm II

After the LLE coding, we select some typical, well-representative tongue gesture frames as templates $\{\mathbf{X}_j\}$. Obviously, their LLE codes $\{a_j\}$ are also known. For the frame $\mathbf{Y}_i$ from the input video, we will match it with all stored templates

$$k \equiv \arg \max_j \mathbf{S}(\mathbf{Y}_j, \mathbf{X}_j) \quad (4)$$

where $\mathbf{S}$ is a similarity measure. It works as following, the template is divided into blocks and each block is searching for the most similar block over the mouth area of the input frame. The similarity is measured by summing up the measures of all blocks. The template k is identified because it is template k the most similar to frame $\mathbf{Y}_i$. Thus, the index k is used to retrieve the LLE-code of frame $\mathbf{X}_k$ for frame $\mathbf{Y}_i$

$$b_i = \mathbf{LLE}(\mathbf{Y}_i) = a_k \quad (5)$$

The new video frame $\{\mathbf{Y}_i\}$ is LLE-coded into $\{b_i\}$, which is used for real-time rendering.

In the current system algorithm II is used to estimate tongue movement. The LLE will specify how the tongue moves, left or right. In addition, three more mouth gestures are detected to aid to control the wheelchair. The following control operations are assigned to different types of gestures:

- left tongue out - left turn
- right tongue out - right turn
- no tongue (i.e. close mouth) - normal state/move forward
- smile mouth - start/increase speed (for 5 second) in operation mode
- open mouth - stop/ cancel all operations.

C. Automatic Obstacle Avoidance

The extended Circle Sector Expansion (CSE+) [12] based on a SICK laser scanner will be used for local obstacle avoidance. CSE+ is an intuitive method, which works on sensor data registered by a laser range finder. It is implemented with a depth-first approach where the

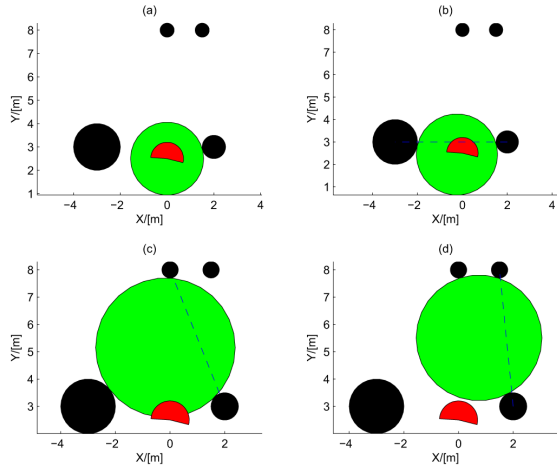


Fig. 3. CSE+ method for finding free space before a right turn. a) A circle expands from the origin of the robot until it tangents one obstacle. b) The circle expands until it tangents two obstacles. c) The circle now expands forward until it tangents three obstacles. d) Shows the next circle in the output sequence. The circle has three tangent points.

target bearing angle is used as criteria in a divide and conquer step. CSE+ is based on circle sector expansion, which is bounded by the tangent point with the circle. A circle expands until it tangents one obstacle. The tangent point divides the arc into two parts. The circle can expand in two directions; one to the left and one to the right, relative to the upper tangent point. Fig. 3 shows when the wheelchair (the half circle) is surrounded by obstacle, heading right and needs to find possible path. For the navigation of a wheelchair, it is so important to check if a passage is wide enough for the wheel chair. If the passage is too narrow an attempt to drive through may cause damage to both the vehicle and the environment. CSE+ provides a narrow passage between two circles. For wheel chair systems, it is desired to have safety margins of one meter, CSE+ move the lines one meter toward the center of the passage. By connecting the lines, it defines a corridor for the vehicle is constructed (see Fig. 4). Fig. 5(a) plots the generated output sequence and the polygons for the safety margins. Fig. 5(b) plots a possible path for the vehicle.

CSE+ has been used for path planning if the obstacles and the environment are known in advance. For our system, CSE+ will be just used for obstacle avoidance. The user will navigate the wheelchair by his/her tongue facial gestures.

D. Vibrotactile Rendering of Tongue Gestures

For all assistive systems means of interaction provided by the interface must be efficient and effective for the human user. It is extremely important to inform the user the response from the system and the status of the system. A common way to provide such a feedback is to use audio by speakers to inform the user current state of the system during control and navigation. The problem with audio is that it is quite boring and easy to attract attentions of others. The second type of feedback is more intuitive: to use a vibrator, i.e., to use vibrational stimuli on the

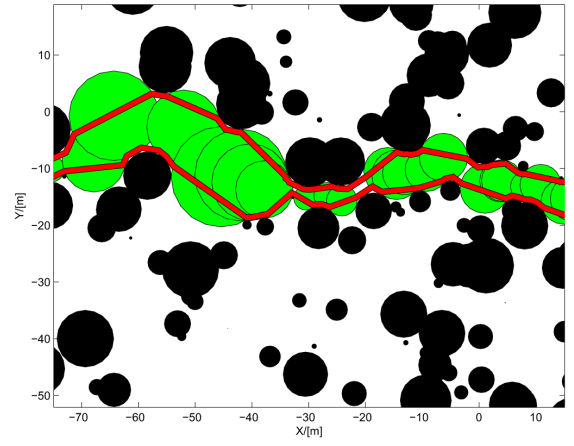


Fig. 4. Extracted corridor and safety margins by CSE+ : This figure plots the safety margins as solid polygons. The width of the polygons are 1m.

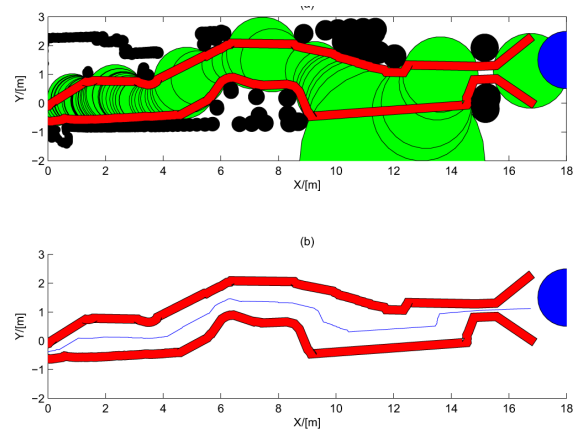


Fig. 5. Extracted corridor and safety margins by CSE+ : A proposed path from the path planner is plotted as the line between the two solid polygons. The left and right polygons form a corridor for the wheel chair.

back of the user. The vibrotactile patterns associated with the tongue gesture are depicted in Fig. 6. 8 vibrators are arranged in a 2D array, following the LLE map from the tongue gestures.

The vibration patterns are generated and controlled by a printed circuit board (PCB)(see Fig. 1(d)). The PCB containing a micro controller (Atmel ATmega16 L), is programmed to generates Pulse Width Modulation (PWM) at one of the pins and send signals to the vibration motors. By adjusting PCB's output to switch it on or off, the vibration motor fitted on the back of the wheelchair could rotate at certain frequencies and intensities. The vibrators are low-cost coin motors used in pagers and cellular phone. The vibration frequencies has been selected in a range from 100Hz to 1kHz. While mounting vibration motors on the wheelchair all precautions are made so that the vibrators must not contact the spinal cord or any other area which can be harmful to the users.

IV. EXPERIMENTS AND DEMO

Three able-bodied male subjects have participated in our experiments. All of them have previous experience

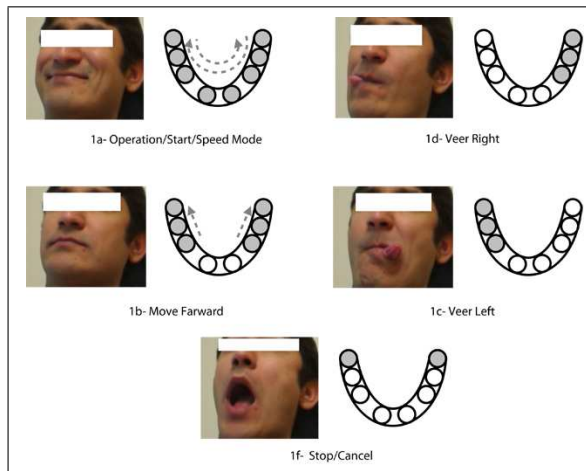


Fig. 6. Vibrator arrangement on the back of the wheelchair, which displays vibration stimuli messages corresponding to the tongue gesture. Tongue gestures control wheelchair movements and the associated vibration patterns give the user a feedback about current state of the system.

with audio and vibrational stimuli (i.e. mobile phone vibration). At the beginning of an experiment, the subject is shown the wheelchair and briefly explained the purpose of the experiments. Laser, video and vibrational sensors are pointed out and safety measures, such as the power button, are discussed.

The subjects are asked to be seated in the wheelchair and the user interface (i.e. camera system, SICK laser scanner) is connected to the wheelchair. Once the subject is comfortable with the interface. The subjects usually spend about 2 – 4 minutes for practicing before expressing an understanding of the system. The test course is designed for user tests; it includes obstacles several office tables, ranks and chairs, turns to the left and to the right, rotate right and left, and move backwards. The test phase consists of a complete navigation of the test course. The total test session time for each subject is approximately 20 – 30 minutes.

After each test session the subjects are asked to fill in questionnaire. A useful measure of user satisfaction can be made if the evaluation team's measure is based on observations of user attitudes towards the system. Thus, it is possible to measure user attitudes using a questionnaire, e.g., "Is this application interesting? 1=very boring (negative) to 8=very interesting (positive)." We will use likert style questionnaire (1-8) with the following notations:

- Usefulness: Effectiveness of the user centered tongue gesture interface.
- Control: Does this tongue based system provide control over wheel chair navigation?
- Trainability: Is the training helpful?
- AInterest: Are you interested in tongue operated assistive systems?
- Comfort: Is this application is comfortable to use?
- Easiness: Are tongue facial gestures are easy to use?

The results will be reported in conference.

V. CONCLUDING REMARKS

In this paper, we have presented a tongue gesture controlled wheelchair system. It is based on three technical modules, namely, *tongue gesture estimation*, *obstacle avoidance* and *vibrotactile feedback*. Our system provides an intuitive navigation aid for severely disabled person. Preliminary results are relatively promising suggesting that our non-contact vision based approach makes tongue feasible for natural man-machine interaction.

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