Guidance of a Wheelchair for Handicapped People by Head Movements

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Abstract

This paper shows a guidance system of an electrical wheelchair for handicapped people by head movements. A color face tracking system has been developed in order to calculate the head movements of the user and, depending on it, some commands are generated to drive the wheelchair properly. The system is non-intrusive and it allows visibility and freedom of head movements. It is able to learn the face features of the user in an automatic initial setup, working even for people of different races. It is adaptive and, therefore, robust to light and background changes for inside environments. It has been tested with several users and the results are given.

Keywords: Face tracking, skin color segmentation, handicapped people, human machine interface, guidance of a wheelchair

1. Introduction

A kind of human-machine interaction which is very interesting is tracking the direction a person is looking at. This information can be required for several applications: automatic focus [Canon, 95], teleconferencing with improved visual sensation [De Silva et al.,95], faces identification in security systems [Sun&Poggio, 98], gaze driven panorama image viewer for virtual reality systems [Stiefelhagen et al. 97], lips readers [Meier et al. 97], assistance to the mobility of disable people [Heinzmann&Zelinsky 97], etc.

The Electronics Department of The University of Alcala has been working, for more than 6 years, on artificial means to assist the mobility of handicapped people. Nowadays, an electronic system is being developed, within SIAMO project (Integral System for Assisted Mobility) [Mazo et al.,98], in order to guide a multi-functional wheelchair for disabled or elderly people (Figure 1). This project includes an alternative guidance, by head movements, for cases of severe disability.

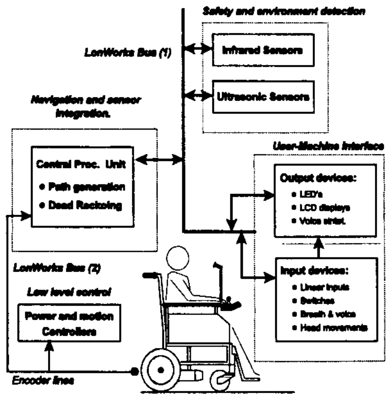

Figure 1. SIAMO Project

At present, a wheelchair prototype is working using this guidance method. A 3D simulator has been designed as well, just to help the users to adapt themselves to the system in a secure way.

Here, we present the global system architecture and the explanation of the methodology we have followed for its design. Likewise, some experimental results are given and, finally, some conclusions about its permormance have been taken out.

2. System architecture

Figure 2 shows the general system architecture. Through a CCD color micro camera, placed in front of the user, the face images are acquired. These images are digitized by a frame-grabber and loaded in a PC Pentium memory. To locate the head in the image, an original skin color segmentation algorithm has been used, called UASGM (Unsupervised and Adaptive Skin Gaussian Model) [Bergasa et al., 99].

This method segmentates any person's skin, even of differents races, under changing light conditions and random backgrounds. To do this, a stochastic adaptive model of skin colors in a normalised RG color space has been used.

The model is initialized by a clustering process. This divides the chromaticities of an image in a number of classes (k) between one and a maximum value (K). At each step, the k cluster centers are estimated using an approximate color histogram. After that, these centers are adjusted employing a competitive learning strategy (Vector Qantization algorithm [Kohonen, 95]) in a closest center sense. Finally a clustering quality factor is calculated for each topology. The process is repeated adding a new cluster center in each step until the maximum number of classes. The maximum quality factor gives the number of classes that best fits the histogram. This calculation is known as "clustering validation problem". With this number of classes the skin cluster is located depending on the distance between the center of the clusters and a master skin color position. Then the skin class is modelled by a Gaussian function $N(m_S, C_S)$ and the parameters of the model are adapted by a linear combination of the known ones using the maximum likelihood criterion.

Experimentaly it has been shown that the results, obtainded by UASGM, respect to the optimum number of classes in the clustering process, improve the results given by the following methods: FHV (Fuzzy Hypervolume), Evidence density and MDL (Minimum Description Length), and equalize these others: MML (Minimum Message Length) and GMM (Gaussian Mixture Modeling), reducing the computing time in every case. All these methods are based on EM (Expectation-Maximization) algorithm. An explanation of such methods and the data sets used in the comparison can be found in the reference[Roberts et al.,98].

On the other hand, with UASGM method, we have obtained better results than applying the GLVQ-F (Fuzzy Generalized Learning Vector Quantization) one [Karayiannis et al, 96], which utilized the very known FCM (Fuzzy C-Means) algorithm. It also improves the stochastic model shown in [Stiefelhagen et al.,97] as ASGM uses initialization of the model suitable for the user.

The use of the estimation theory for tracking and for information fusion in computer vision is well known [Crowley&Coutaz, 95]. On the skin blob some parameters are calculated to track the face: center of gravity (x,y), horizontal (h) and vertical (v) size of the face, being able to obtain the face position and orientation.

A zero-th order Kalman filter is used to estimate two independent state vectors: one for the horizontal variation (X_h =(x,h)) and other one for the vertical variation (X_v =(y,v)). Two independent state vectors have been utilized because, in our application, the user can do only horizontal and vertical head rotation movements. Then we can take into account that the horizontal and vertical movements are independent: horizontal size depends on

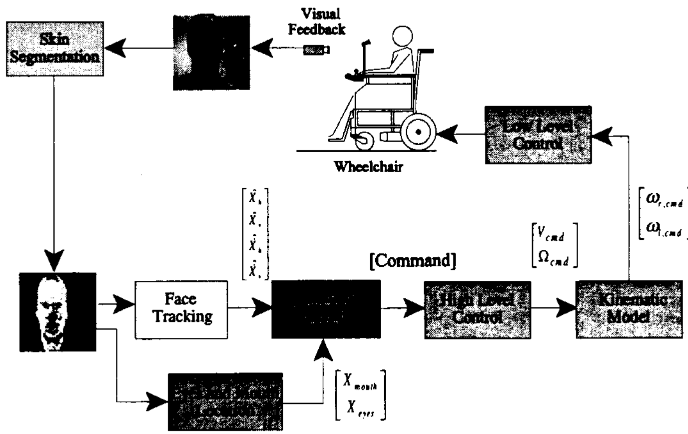

Figure 2. Architecture of the guidance by head movements

the x center position and vertical size on y center. The horizontal and the vertical size of the face are calculated as two parameters because the aspect ratio of the face can change with rotations. The state vectors (X_h,X_v) and their covariance matrices (C_{Xh}, C_{Xv}) are estimated in a recursive process composed by three phases: predict, match and update.

Estimated state vectors($\hat{X}_h$, $\hat{X}_v$) and theirs derivatives ($\hat{\dot{X}}_h$, $\hat{\dot{X}}_v$) are introduced in a command generation state machine. Each state codifies one of the next commands: turn right, turn left, increase speed, decrease speed and no command. State transitions of the machine are achieved analysing the activation of some fuzzy conditions of input variables, based on thresholds. These are calculated in the initial setup. Likewise, using the information given by eyes and mouth position (X_{eyes}, X_{mooth}) the special commands on/off and forward/backward will be obtained. These positions are calculated by the hollows analysis on the skin blob and imposing some geometrical restrictions. The hollows appear in the blob because there are in the face some features like: eyes, mouth, eyebrowes, etc, that have different colors respecting to the skin.

Figure 3 shows the actions that generates the commands. For that, we have followed a criterion of simplicity in the fulfilment of these actions and in the robustness of their detection. Therefore, if the user turns the head to the right the wheelchair will turn to the same direction. This happens as well if he/she turns his/her head to the left. Head rising involves the increment of the wheelchair speed, and when the user bows it, this will decrease the speed.

Every time he/she winks an eye the wheelchair changes its state on/off; when lips are hidden it changes again for the command forward/backward. It is necessary to keep the special actions for at least two seconds just to let the special commands activation. Doing this, wrong commands are avoided as a consecuence of normal blinks. On/off commands allows the user to activate or desactivate the system by themselves, so when it is in the off state, it can make any kind of movement being secure of the fact that no other command will be activated.

Table 1 presents the way in which the system recognizes action the user has made, paying atention to some fuzzy conditions in the evolution of the state variables. Analysing the activation of these fuzzy conditions and their derivatives the commands are generated.

In figure 4 we can see an example of the rigth command activation for a sequence of right progressive rotations made by the user (30°, 60°, 90°). Here, the evolution of the state variables and their derivatives is shown.

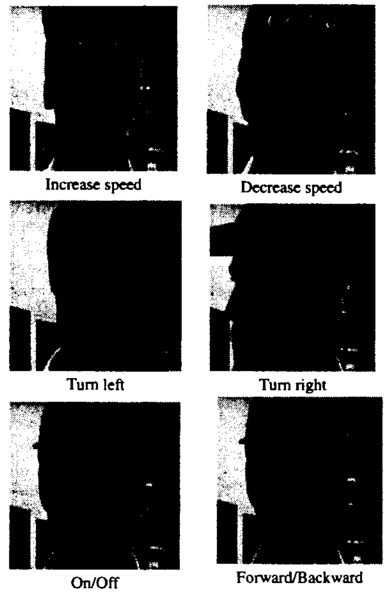

Figure 3. Actions that generate the commands

Then, the values of the state variables for the "no command" position can be regarded as (x_R, y_R, h_R, v_R). These last varibles are used as well as reference positions in the calculation of the fuzzy conditions to do the states machine transitions.

	State Variables			
Actions with the head	h	x	v	y
No Command	E	E	E	E
Turn Right	I	D	D	I
Turn Left	I	I	D	I
Rising	E	E	I	X
Bows	E	E	D	I

I: Increase, D:Decrease, E:Equal, X:user's function

Table 1. Fuzzy conditions in the evolution of the state variables for the different actions.

As can be seen, the system is able to detect all the rotations, except for the 30° one, in the 250 samples, as the movement was made very slowly. This happens because, working with the derivatives of the state vector, the actions speed is taken into accont. It is not enough if we do only one action, but we have to execute it quickly. In this way some unvoluntary wrong actions are eliminated.

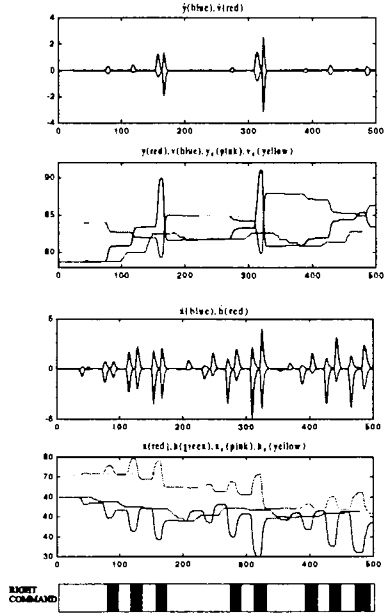

Figure 4.Examples of right command generation

The commands are sent to another state machine which implements the high level control and will generate the linear and angular speed command of the wheelchair (V_{cmd}, Ω_{cmd}), as a function of time. It works as shown in figure 5. The machine has six states: Stop, No operation, Accelerate, Deccelerate, turn right and turn left.

Starting from a rest position (V_{cmd}=0, Ω_{cmd}=0) commands such as "Forward", "Backward", "Left", "Right" give Ω_{cmd} speed a predetermined initial value and increase it until a final value, positive or negative, according to the case. Then the "Increase speed" and "Decrease speed" commands increase or decrease the linear speed, V_{cmd}, as a function of time and depending on the direction state (forward/backward), up to certain pre-arranged limits. The command on/off allows to stop the wheelchair and start the process.

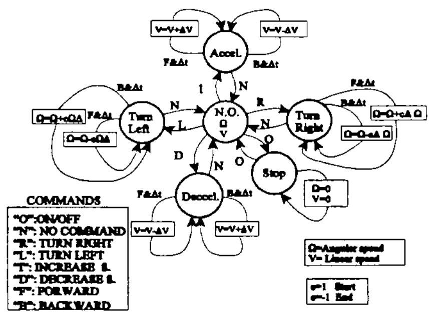

Figure 5. High level control state machine

Applying the Knematic model, the linear and angular speed become angular speeds for every wheel (ω_{r_cmd}, ω_{l_cmd}) and they are sent to the low level control. In this level a PI controller has been designed to control the velocity of each wheel.

It can be clearly seen that there is a visual feedback loop, as the human user reacts according to the current circumstances. For instance, if the system detects a right turn command, the wheelchair will turn to the right until the command finishes.

3. System layout

The system constructed on board the wheelchair presents the general layout shown in figure 6 [Garcia et al., 97]. A LonWorks Neuron chip based network has been developed, where new sensors or modules can easyly be added because of the open system nature of its design.

The wheelchair is driven by a pair of DC-motors, one in each rear wheel. The neuron chip provides an H-bridge with the PWM signal neccesary to achieve the intended angular speed in each wheel. It also provides the support to perform control tasks:

• PWM signal generation that can directly be applied to the transistors driver.

• Dead-reckoning capacities by reading the encoders signals (firmware built).

• Programmable in Neuron-C to design different control actuations. A PI controller is currently being used.

The driver nodes receive the commanded angular speeds coming from the high level control driven by the vision process. In this node the vision algorithm is processed on a PC Pentium II 400 Mhz NT 4.0. This node employs a card called PCLTA, also based in a neuron chip, to connect to the LonWorks bus. To facilitate this, Neuron C issues network variables data types allowing simple programming for information exchange through the bus.

We have introduced as well, advisary sounds when the commands are activated for easy control of the user through acustic feedback.

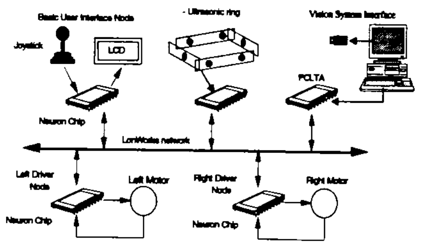

Figure 6. System layout

The final wheelchair prototype will be also provided with an ultrasonic ring to increase safety during navigation and a basic user interface compose by a joystick and a LCD.

4. Experimental results

The vision system is able to process up to 20 images per second, with a resolution of 128x128 pixels. During the testing stage great robustness exhibited in the velocity commands. However, some details are still to be fixed on the special commands. In order to increase the system controllability two switches have been included. One of them is used to activate the on/off command, while the second is intended to activate the forward/backward command. 10 commands per second are issued to the low level controller. The maximum wheelchair velocity was set to 1 m/s.

The system was tested for 5 different users in the Electronics Department's labs, after having trained on the simulator . In figure 7 we show the image of one of the users during a test. Likewise, the run performed by that user during one of the tests is illustrated in figure 8. The evolution of both the linear and angular wheelchair velocities is presented, as well. The test lasted 1000 seconds, taking 5 samples per second. In this figure the accelerations of the wheelchair during straight sections can be clearly apreciated. Also, the wheelchair decreases its speed before performing a curve. In this case, six left turns were executed, yielding great angular velocity peaks in the figure.

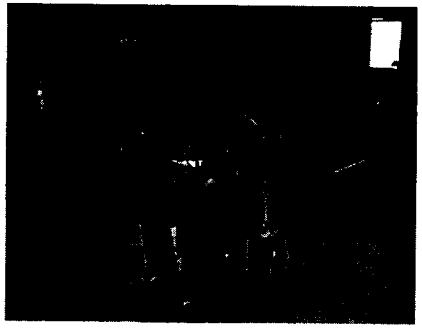

Figure 7.User doing the test

5.- Conclusions and future work

The conclusions obtained by the users after performing the test on the navigation system are presented bellow:

• It is non-intrusive, as it is passive, and there is no need for additional elements.
• Guidance complexity is decreased as more training is perfomed. We must also take into consideration that the camera is 80 cms in front of the user and, therefore, the system requires certain space for properly manoeubring.
• The simple commands set and the wheelchair response allow for easy controllability in environments where no many obstacles are present.
• Audible feedback is included to ensure proper command acknowledgement.
• The system can be interesting to assist the mobility of severe disabled people.
• It works properly in indoor environments, where suitable ilumination is provided, decreasing the performance as light conditions get poorer. In outdoor environments there is no uniform ilumination (shadows, direct sun light, etc), decreasing also the system capabilities.

In future, we intend to include an ultrasonic ring to increase safety during navitacion and an LCD. The system will be embedded on a hardware platform and a 3D model of the head will be developed in order to robustly obtain the gaze direction (not depending on the particular user) and perform the wheelchair control accoding to it.

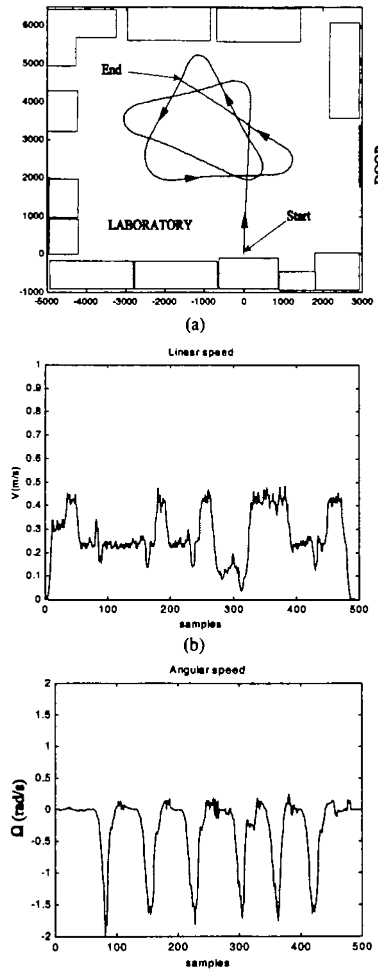

Figure 7. Example of the guidance

6. Acknowledgements

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