DEVELOPING INTELLIGENT WHEELCHAIRS FOR SERIOUS DISABLED PEOPLE BASED ON EYE-BLINKING

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Abstract— The life in society of a person who has serious disability is very complicated and one of the most serious problem is the dependency of other people to do basic things like to move inside his own house. In some cases, the patient loses, permanently or temporarily, the control over his body, except of his eyes, despite of being in a perfect state of conscience, which allows the development of approaches to provide him with the ability to control an electric wheelchair and consequentially move by himself. In this paper is proposed and tested a non-invasive system, based on image processing, to allow the locomotion of handicapped patients into a known place through eyes-blinking. In order to do it, an approach to perform eyes and blink detection is presented, as well as a security wheelchair navigation based on a path-planning using potential fields. Conclusions about the proposed system are presented, indicating that the system worked successfully.

Keywords— Intelligent Wheelchair, Serious Disability, Eyes-blinking detection, Path-planning.

1 INTRODUCTION

Nowadays, it is possible to observe a growing search for assistive technology for disabled people, which results in increase of investment and research in this area. In general, assistive technologies improve the life quality of people who has some kind of disability, whether this deficiency linked to basic senses or any other mental disorder, physiological or anatomical.

The most part of the technology developed aims to use the response of less affected senses to provide, even partially, better living conditions for the person. However, in individuals with serious limitations, the communication is impaired, making other people help less effective, once that is very hard to express their will.

According to (Cavalieri, 2007), the neuromotor disorders are a major cause of problems associated with communication between individuals with disabilities. However, in a significant number of cases, these people maintain a perfect state of consciousness, which allows some techniques are developed to provide them the means by which they can communicate effectively (Cavalieri, 2007). In turn, the communication capacity can also be used as a tool for the control of locomotion, since the handicapped can at least manifest his desire. This type of technology can bring, among other consequences, the social inclusion of the handicapped, improving the quality of life, and reducing psychological problems.

The use of robotic wheelchairs has proven to be a feasible solution for this task and several works have been developed in this area, for example (M. Lee, 2003a) used approaches based on voice, (M. Lee, 2003b) used a Brain-Computer Interface and (Matsumoto, 2000) used a face and gaze pose. However, in these works the handicapped controls the wheelchair directly, which is not possible when the person has a severe motor disability. In these cases, the control of the wheelchair can become wearing or even impractical, being necessary in such cases to provide the wheelchair with the ability to perform tasks autonomously as possible to see in (Parikh, 2007), (Celeste, 2006) and (De La Cruz, 2011).

Some neurological diseases not rare, as the brainstem stroke, present as symptom the permanent or temporary loss of voluntary muscles control, except the eyes, which are controlled by a different region of the brain (Medeiros, 2002). In this case, the individual, despite conscious can voluntarily just look in the desired direction and blink.

Solutions such as the localization and/or tracking eyeball using image processing, as in (Arai and Mardiyanto, 2011) and (Gajwani, 2010), or the use of biological signals (Vidaurre et al., 2011), associated with specific computing resources, are identified as feasible for this type of disability.

When the technology is based on the use of biological signals, it is necessary to make use of electrodes arranged on the handicapped skin surface. Considering the physical and psychic limitations of most of these patients, the use of electrodes becomes invasive and uncomfortable for such individuals. On the other hand, some devices based on image processing have large restrictions on the distance of the camera from the face of the handicapped, making its use is still uncomfortable for him, despite having no direct contact with his face. An example is in (Ishiguro and Rekimoto, 2010) that positioned the camera in glasses, which can cause great discomfort and consequent rejection by the user. In (Gajwani, 2010) is also presented a work that makes use of a camera very close to the user.

Another problem found in this area is the fact that the amount light present in the environment can influence the results obtained with image processing, and at the same time be uncomfortable for the user. Cameras equipped with infrared light has been considered as a solution to this problem. In some cases, the pupil reflection of such light is also used for the detection of the eyes, as in (Ji, 2002). However, according to (Krolak and Strumillo, 2008), most users is not fully satisfied with this type of technology and suggest improvements. Besides that, the use of this method requires a camera equipped with this type of lighting.

At this paper is proposed a non-invasive and very simple system to allow a person who is able to control only his eyes to move by himself using an electric wheelchair. It is done using image processing to detect eyes-blinking with a low cost camera positioned in a comfortable distance from the user; a path planning based on harmonic functions, which allows a secure path for the wheelchair; and a very simple interface where the user only need to blink his eyes when the desired position is selected.

All these steps are presented with more details in section II. Then Navigation system is presented in section III. The experiments and results are presented and discussed in section IV. Finally, conclusion remarks are presented in Section V.

2 System Overview

A system was developed to aid in locomotion of serious disability people based on eye-blinking. The steps involved in this system are presented in the block diagram shown in Figure 1 and will be discussed in greater detail in the following subsections.

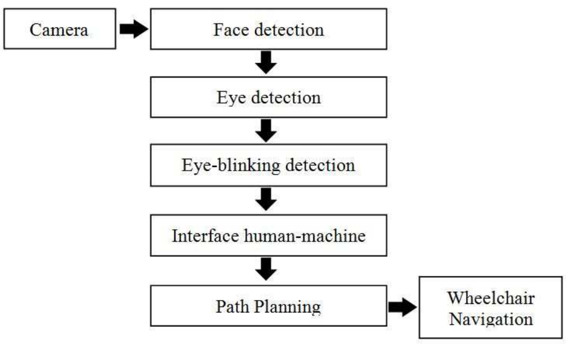

Figure 1: Block diagram of the system.

2.1 Face Detection

Face detection is a very important part of the system and it must precede the projects of eye detection, since it is possible to reduce the search area of the image, reducing the computational cost and the harmful effects of background processing.

There are a lot of algorithms for face detection. In this project it was used in this project a method proposed by Viola-Jones in (Viola, 2001) due to its good performance and processing speed. This algorithm is composed of three parts. The first one is the representation of the image in a feature space based on Haar filters. This is done with the aid of the "full picture". The second one is the assembly of a classifier based on Boosting able to select the most relevant characteristics, and, finally, there is a cascade combination of these binders.

The "integral imaging" $ii(x, y)$ is defined in (Viola, 2001) as

$$ii(x, y) = \sum_{x' \leq x, y' \leq y} i(x', y'), \qquad (1)$$

where $i(x, y)$ is the original image with size $R \times C$ pixels, $1 \leq x,\ x' \leq R$ and $1 \leq y,\ y' \leq C$. Through the "integral imaging" is possible to calculate the sum of any rectangle within the image quickly. Thus, a set of characteristics can be obtained by the difference between the sum of rectangular pixel regions.

The features used are called Haar-like features and can be seen in Figure 2.

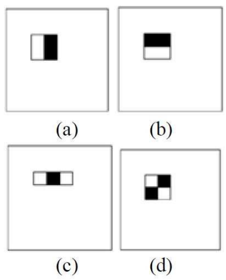

Figure 2: Haar-like features.

The training set of Viola-Jones is formed by samples of the type (x_n, y_n) with N samples, where x_n is an image of size 24×24 pixels and $y_n = 0, 1$ is the class label. In this set, $y_n = 1$ corresponds to a face image and $y_n = 0$ is a non-face image. As the total number of features is large, the Viola-Jones uses an algorithm of machine learning called *AdaBoost* to select the most important features. In each iteration of *AdaBoost*, a set of weak classifiers h_j is adjusted to minimize the classification error. Each of the classifiers corresponding to a characteristic $f_j(x_n)$, where $j = 1, \ldots, J$, and J is the total number of characteristics. Given a threshold θ_j and a parity p_j, the classification rule can be given by

$$h_j(x_n) = \begin{cases} 1, & \text{if } p_j f_j(x_n) > p_j \theta_j \\ 0, & \text{otherwise} \end{cases}, \qquad (2)$$

in which parity p_j indicating the direction of the inequality.

In order to improve the performance, a combination of *AdaBoost* classifiers is done in the cascade form. So, a false negative rate close to zero is obtained.

The features selected in training are staggered of the minimum size to the size of the image to which the face can be detected, since the position of the face is not known.

For this work, it was used a Viola-Jones algorithm available on the website of MathWorks. In figure 3 can be seen the result of the application of Viola-Jones algorithm.

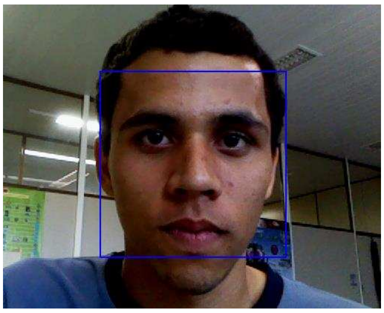

Figure 3: Face detection using the algorithm of Viola-Jones.

2.2 Eyes detection

In this paper is proposed an eye detection system based on analysis of densities histograms of the binarized image as presented in (Santos, 2012).

In order to reduce the effects of the light influence, a histogram adjustment was used on the face image of the individual before turn the image binarized with a threshold that can be adjusted by a non-disabled person when the system is initialized.

In binarized image is calculated histogram density black pixels in the horizontal direction. Therefore, a count is made of the number of black pixels in each image line.

The analysis of this histogram enables to correctly identify some areas of the face, including the eyes, that are evidenced by the peaks of the histogram, as can be seen in figure 4b.

By the geometry of the face, it can be considered that eyes are in the upper face, as is used in (Krolak and Strumillo, 2008). Thus, the search is performed only on the top of the image, eliminating the peaks corresponding to the nose and mouth. With this, it is easy to notice that the two highest peaks on the upper region is the representation of the eyes and eyebrows.

To find these peaks an average filter was applied to smooth the histogram, and then the points where the derivative is zero were determined as a peak.

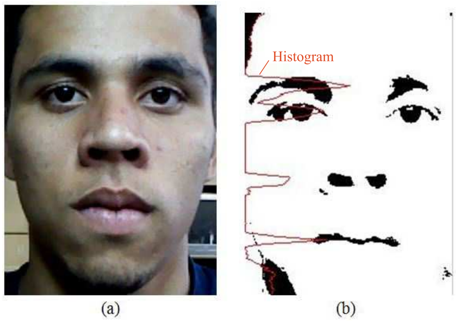

Figure 4: (a) Photo of an user face and (b) horizontal histogram in binarized image.

Once located by analysis of the peaks, the eye region is selected and then and a new density histogram is calculated, but now in the vertical sense. This application generates a histogram pattern with other peaks at the eyes region. Through the combination of both histograms, each eye is easily detected. In figure 5 is shown the result of eye detection (in blue), the horizontal (red) and vertical histograms(green).

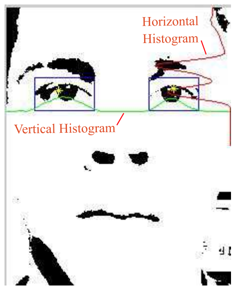

Figure 5: Eyes detection (blue), horizontal histograms (red) and vertical (green).

2.3 Eyes-blinking detection

The step of eye-blinking detection consists to identify the state of the eyes (opened or closed). This is done through the analysis of pixels dispersion at the eyes region.

In figure 6 is possible to see that the distribution of black pixels in the vertical direction is more dispersed around the average (blue line) when eyes is open (6a) than when they are closed (6b), it allows to determine the state of eyes.

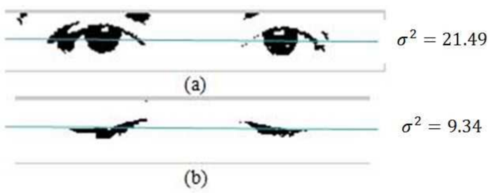

Figure 6: Dispersion of eyes pixels around the average for the eyes opened (a) and eyes closed (b).

The dispersion of the pixels was measured by calculating the variance, which is defined in (Kay, 1951) as

$$var(y) = E[(y - E[y])^2], \quad (3)$$

where $E[.]$ represents the averaging and y the vector of points with component lines of each black pixel of the image of the eyes.

Thus, the variance is a measure that indicates, in general, how their values are far from the average, which leads to a higher variance of position of the black pixels located in the region of the eyes when the eyes are opened. Thus, we attributed a threshold variance, for which values above this indicate that the eye are opened, and values below indicate that the eye are closed.

In order to distinguish voluntary from involuntary blinks was analyzed how long the eyes remained closed.

This system works with a camera positioned in a comfortable distance to the user and no special camera is required, a basic web camera is enough.

2.4 Human-machine Interface (HMI)

Once the system is able to detect eyes-blinking, it was introduced an interface, shown in Figure 7, in order to allow the user to express his wish through the eyes-blinking.

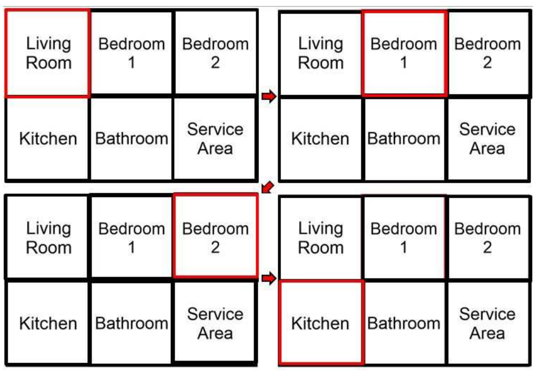

Figure 7: Human-Machine Interface.

The interface is very simple, the selection (red square in figure 7) is changing place by place with an interval of about one second and the user just need to blink the eyes when the name of the place that he wants to go is selected.

This interface allows an individual who has control only over the eyes movement to indicate where he want to go.

2.5 Wheelchair Navigation

People with severe neuromotor injuries have a lot of difficult to control a wheelchair, so the system must be easy and with a high level of autonomy, enabling the wheelchair to navigate to the destination without any participation of the user or another person on the control. This autonomy can not be applied to anywhere, once that some places can bring difficult situations even to non-disabled people. However, considering the handicapped's house or another known place where the person is used to stay, the system can autonomously control the wheelchair from the user's position to a desired place.

In robotics, the process of setting an adequate and secure path to the robot from a initial point to a goal point is done by the navigation. According to Arkin (Arkin, 1998), the navigation architectures are qualitatively classified in deliberative, where the robot plan the action before starting the navigation; reactive, where the robot navigates reacting to the environment; and hybrid that combines both ideas.

Once the environment is known, it is possible to create a map and it can be used to define the robot attitudes in an optimum way. It's is done using the deliberative architecture through a path planning. Latombe (Latombe, 1991) classified the path planning in three big groups: road maps, cell decomposition and potential field. For the problem presented in this article, it was applied a potential field method in order to planning a path to the wheelchair.

3 Path Planning using Harmonic Functions

The path planning is done generating an artificial potential $U(q)$ to each position q that the robot can be on the map. This potential is obtained combining an attraction potential, that leads the robot to the goal point not considering the obstacles, with a repulsion field that take the robot away from obstacles (Khatib, 1986). So, this potential field exerts a force that leads the robot to the obstacles and, at the same time, takes it away from the obstacles. This force is calculated through the negative gradient of U in the position q

$$F(q) = -\nabla U(q). \quad (4)$$

However this combination can generates local minima that would be a big problem to a person that has a lot of difficult to control the wheelchair directly. So, in order to avoid this problem, it was used a method based on harmonic functions which generates the potential $U(q)$ in order to satisfy the Laplace equation

$$F(q) = -\nabla^2 U(q) = 0, \forall q \in \Omega, \quad (5)$$

where Ω is the navigable region. Once the dimension of the state q is normally greater than two, the Laplace equation is better represented by

$$F(q) = -\nabla^2 U(q) = \sum_{i=1}^{n} \frac{\partial^2 U(q)}{\partial x_i^2}, = 0, \forall q \in \Omega, \quad (6)$$

where n is the dimension of q. Any potential function $U(q)$ that is solution of the equation 6 is called harmonic function.

To solve this equation is necessary to define the boundary condition to $\partial\Omega$. There are some solutions for this problem in the literature, but the classics are still more used (Molina, 2014), as the Dirichlet (Connolly et al., 1990) and Neumann (Feder and Slotine, 1997) conditions.

As the security of the patients is one of the most important point to assure, the Dirichlet boundary condition was used, because this method favors the robot to be far from the obstacles once that it generates a potential that always tends to the normal vector in relation to the obstacles in boundary regions besides guaranteing, mathematically, the absence of local minima in resulting potential.

It is done defining a constant value to the boundary region, $\partial\Omega$

$$U(q) = k, with k = constant value, \forall q \in \partial\Omega. \quad (7)$$

The Figure 8 shows the result of this method application.

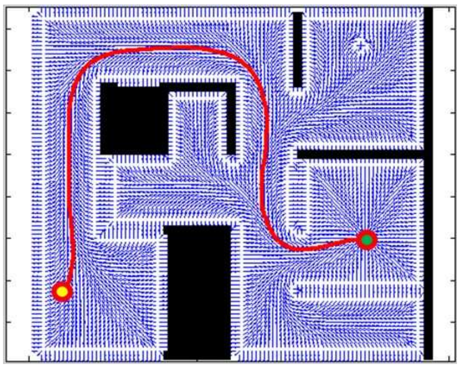

Figure 8: Path-planning based on potential fields with Dirichlet boundary condition. The yellow point is the initial position and the green one is the goal position.

In order to do the robot follow the planned path, a control was implemented to define the linear and angular velocities. This control is represented at the followings equations:

$$V = V_{max} \cdot tanh(K_v \cdot \rho) \cdot |cos(\theta_{erro})|, \quad (8)$$

$$W = W_{max} \cdot tanh(K_w \cdot \theta_{erro}), \quad (9)$$

where V and W represents the linear and angular velocities respectively, V_{max} and W_{max} are the maximum velocities, ρ is the distance from the robot to the goal point, K_v and K_w are proportional constants and θ is the angle between the robot and the direction of the potential field in the actual robot position.

4 Results

The eyes-blinking detection system was developed by us in (Santos, 2012) to help the communication of disabled people. For it, the person should blink when the desired alphabet letter was selected. Good results were obtained, confirming that the system works well.

The eyes-blinking detection was applied now to select a desired place where the user wants to go. This system, as well as the human-machine interface, were developed in the software *Matlab R2010a* and they were applied to control the robot *pioneer P3DX* as a way of simulate an electric wheelchair, since it is very expensive and we already have the *pioneer* as a test platform. As a consequence of using the robot, the user can't be on board and the tests were realized with a non-disabled person. However, this article is focused in show a non-invasive methodology to help serious disabled people and the real tests will be realized in future works.

To simulate the real situation, a computer was placed on the robot and the user sat on the floor at a distance of about 60cm to webcam, as possible to see at figure 9.

Figure 9: Camera can be positioned in a comfortable distance to the user.

Many experiments were performed choosing different goal points through the eyes-blinking and comparing the planned path with the result of the pioneer odometry. Figures 10 to 13 show the result of two experiments, whereupon figures 10 and 12 represent the planned paths to different goal points and the figures 11 and 13 represent the correspondents trajectories executed by the robot. This trajectories were ploted based on odometry results.

Figure 14 shows some video frames of the robot executing the trajectory.

Through the analysis of the results is possible to see that the system worked well. The goal points were chosen through eyes-blinking with cor-

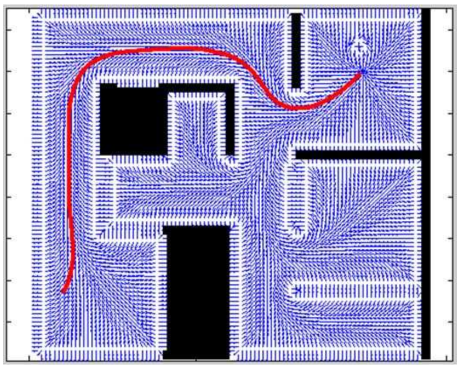

Figure 10: Planned path from living room to bedroom 1.

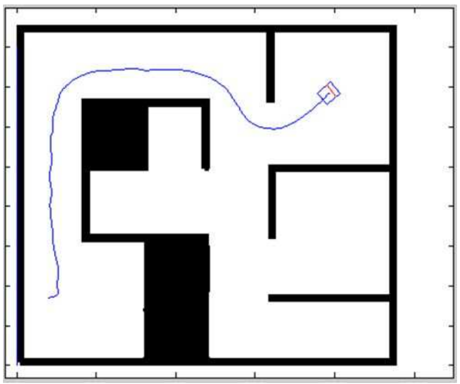

Figure 11: Trajectory executed by the robot from living room to bedroom 1.

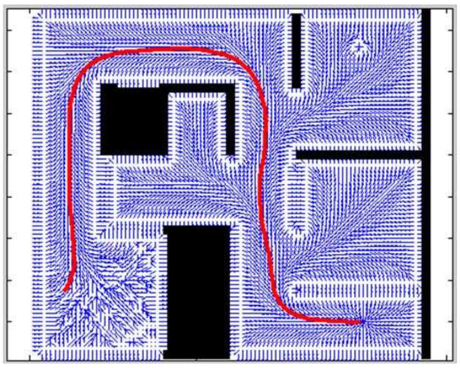

Figure 12: Planned path from living room to service area.

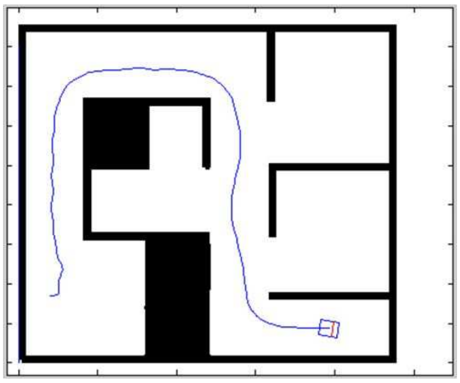

Figure 13: Trajectory executed by the robot from living room to service area.

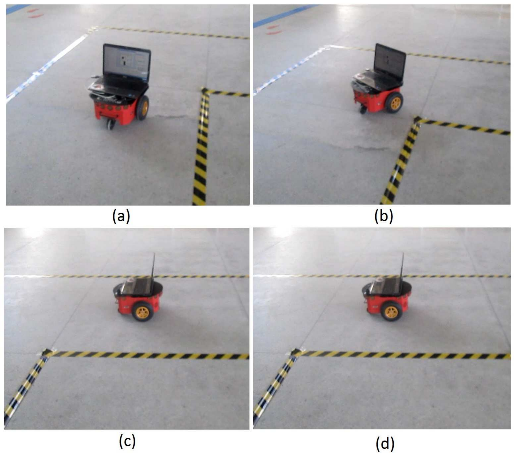

Figure 14: Video frames of an experiment.

rects detection; the planned trajectories didn't have local minima and generated security paths; and the robot developed a smooth trajectory and very close with the planned one arriving in the desired place correctly.

5 Conclusion

This paper propose a system to help the locomotion of serious disabled people based on eyes-blinking and image processing. For it, it was implemented a system composed for face detection, eyes detection, blinking detection, path-planning and a human-machine interface.

The proposed system is non-invasive, since it operates in a comfortable distance to the user, it is cheaper when compared with systems that use electrodes or special cameras and it doesn't need a special illumination. Moreover, the path-planning based on dirichlet generates a path that favors the distance of the robot to obstacles and it is very important to the user security.

The results obtained with the developed system were presented in this article and showed that the proposed approach works satisfactorily, enabling a serious disabled person to move by himself just blinking the eyes.

The rotation of the face and the use of glasses is limiting factors in the quality of the system of eyes-blinking detection. These aspects should be addressed in future works, as well as new tests, considering other possible limitations of the system.

Another point that will be considering in future works is the robot localization. Despite of the pioneer odometry system has a good precision, there is still an error accumulation. This error can be reset using landmarks as used in (De La Cruz, 2010) or the odometry can be used together with a SLAM (Simultaneus Localization and Mapping) to estimate the wheelchair pose inside the environment as used in (Cheein, 2009).

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