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Virtual Interface With Kinect 3D Sensor for Interaction With Bedridden People: First Insights

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ABSTRACT

The human-machine interaction has evolved significantly in the last years, allowing a new range of opportunities for developing solutions for people with physical limitations. Natural user interfaces (NUI) allow bedridden and/or physically disabled people to perform a set of actions through gestures thus increasing their quality of life and autonomy. This paper presents a solution based on image processing and computer vision using the Kinect 3D sensor for development of applications that recognize gestures made by the human hand. The gestures are then identified by a software application that triggers a set of actions of upmost importance for the bedridden person, for example, trigger the emergency, switch on/off the TV, or control the bed slope. A shape matching technique for six gestures recognition, being the final actions activated by the Arduino platform, was used. The results show a success rate of 96%. This system can improve the quality of life and autonomy of bedridden people, being able to be adapted for the specific necessities of an individual subject.

KEYWORDS

Bedridden People, Kinect, Natural User Interface, Shape Matching

1. INTRODUCTION

The human-machine interaction has evolved significantly allowing nowadays to develop appropriate solutions to support people who have a certain type of physical or cognitive limitation. The development of natural and intuitive interaction techniques called Natural User Interfaces (NUI) allow people who are bedridden and/or have a physical disability to perform a set of actions by means of gestures thus increasing their quality of life (Lopes et al, 2015; Mendes, 2009; Buxton, 2009). Following this trend current technologies allow a great freedom of interaction between human and machines although there are still several gaps that need to be addressed. The possibility of bedridden people to interact

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with electronic devices naturally is still far from maturity. This project aims to contribute to this gap and enable the bedridden people to perform actions autonomously through technology.

There are thousands of people around the world depending upon external assistance to perform basic activities and it is estimated that this number will increase in the forthcoming years. If there is a field in which science and technology can and should play a central role it is precisely the field of health and wellbeing of people. In the particular case of electronics and computing there is still a set of systems that can be developed as a means to improve the quality of life of bedridden people. Considering this necessity, the prototype presented in this paper makes total sense in today's society where there is an aging population increase. The solution implemented is based on image processing and computer vision through the Kinect 3D sensor.

The goal of this project is to allow the user (a bedridden person who depends upon external help) to interact, in a very intuitive and natural way, with a computerized system equipped with the Kinect 3D sensor using six hand gestures to perform a set of basic actions that are fundamental for bedridden people, such as, switch on/off the TV, call the emergency help, control the bed inclination, switch on/off the light, among others. From the point of view of the user the solution should be an intuitive and minimalist application that presents several benefits related essentially with an improved quality of life but that could also bring added value, due to its capacity, to save patients confronted with life-threatening situations (allows to call emergency help). An algorithm of shape matching was considered for the hand gesture recognition (Yam et al, 2004; Ren et al, 2013; Altman, 2013).

This paper is organized in 6 sections. Section 2, State of Art, presents studies and solutions of existing bedridden assistive technologies as well as the added value of the presented solution to improve the quality of life of bedridden persons. Section 3, System Architecture, shows, among others, the hardware and software used in the solution developed including also the user interface. Section 4, System Development, describes the process of obtaining the sensory device information and its conversion as well as the methods applied to recognize hand gestures. Section 5, Experimental Results, presents the tests performed with several subjects to validate the system and finally, section 6, Conclusion and Future Work, enunciates the final considerations presenting the system limitations and further possible developments.

2. STATE OF ART

The possibility of living and undertake basic daily activities without being dependent on others increases considerably the quality of life of bedridden people. In line with this major concern several systems have been being developed in order to support the daily life of bedridden people. Furthermore, the increase of life average expectancy also implies, on one hand, a higher pressure to develop new technologies that allow elderly people to preserve as possible a normal lifestyle, and, on the other hand, the commercial market itself looks at this area as a business opportunity which it is important to boost the development of new solutions. In fact, there are several projects to this end ranging from devices for home automation used to control blinds, lighting, TVs, phones, among others, to hospital systems that function as supplements for people with motor disability. One of these projects proposes a system facilitating the daily activities of the elderly people with poor mobility and that can be used in their own room for tasks, such as turning on or off electrical devices, without any need to touch these devices or even without their remote controls. The system detects and alerts the elderly when there is a risk of falling out of the bed, when the elderly presents some unusual symptoms or when he or she needs assistance. This system consists of a Kinect 3D sensor monitoring abnormalities and detecting gestures searching for any signal of help (Booranrom et al, 2014). Moreover, with the goal of helping people who are bedridden and debilitated physically to live independently, a system was developed to control electrical devices. The system also uses the Kinect 3D sensor and may be controlled from a bed through hand gestures or voice commands (Ichimura & Magatani, 2015).

A team of researchers from the Republic of Korea has developed an intelligent bed that it is basically a robotic system used to help patients to live independently in bed. The bed is equipped with two robotic arms and a set of pressure sensors connected to the mattress. The pressure distribution on the mattress is used to estimate the posture of the patient and adequate support is provided by the robotic arms (Seo et al, 2011).

Another observed project uses a depth camera to monitor bedridden people and to prevent accidents in hospital beds. A bed alignment map is used to analyse the patient's body. The depth camera is used to locate the bed and estimate its surface. The system develops metrics to estimate occupancy of the bed, the body shaking and the position in which a person sleeps (Martinez et al, 2013).

Starting from the premise that patients spend most of their hospital stay in unmonitored beds, thus causing risk situations in terms of safety, health and quality of life of the patient, it was developed a solution that proposes a monitoring system for bedridden people. The system is based on the Kinect depth information to estimate 3D edges of the bed, the bed height and other parameters, to prevent, for example, the patient form falling from the bed, and to assist with getting in and out of bed. This prevention function is achieved via an alarm that is activated whenever there is any abnormal situation (Li et al, 2014).

Apart from the previous mentioned devices, several other solutions were developed, such as a system for monitoring the weight of bedridden people (Silva et al, 2011), a system for patients' monitoring (Kittipanya-ngam & Way, 2012), a smart mattress for bedridden patients (TVI24, 2012), a mechatronic system meant to boost the quality of life of bedridden patients (Alexandre & Pereira, 2014) or a system used for monitoring the status of patients placed in hospital beds using unobtrusive depth sensors (Banerjee et al, 2014).

While technology can greatly improve a person's quality of life, ethical questions about person's privacy also rise. When cameras and sensors are used to monitor people 24 hours a day, this could be considered an invasion of people's privacy. The solutions presented in this paper are invasive technologies and none of them are specifically programmed for satisfying only the necessities of the bedridden people, which is the main advantage of the proposed solution. The proposed system is based on gestures that can be adapted to help and satisfy the necessities of the bedridden people. Moreover, this system is intended to be as intuitive, non-intrusive, and as low cost as possible. On the other hand, it is known that the Kinect 3D sensor has poor performance when lighting conditions are not ideal as it is a sensory device that should be used preferably indoors and in favourable lighting conditions (lighting conditions can disrupt the system's efficiency), so opting for this solution in order to reduce the cost of the system could cause some constraints. In order to counteract this drawback, future modifications to the developed algorithm will be considered to reduce this issue.

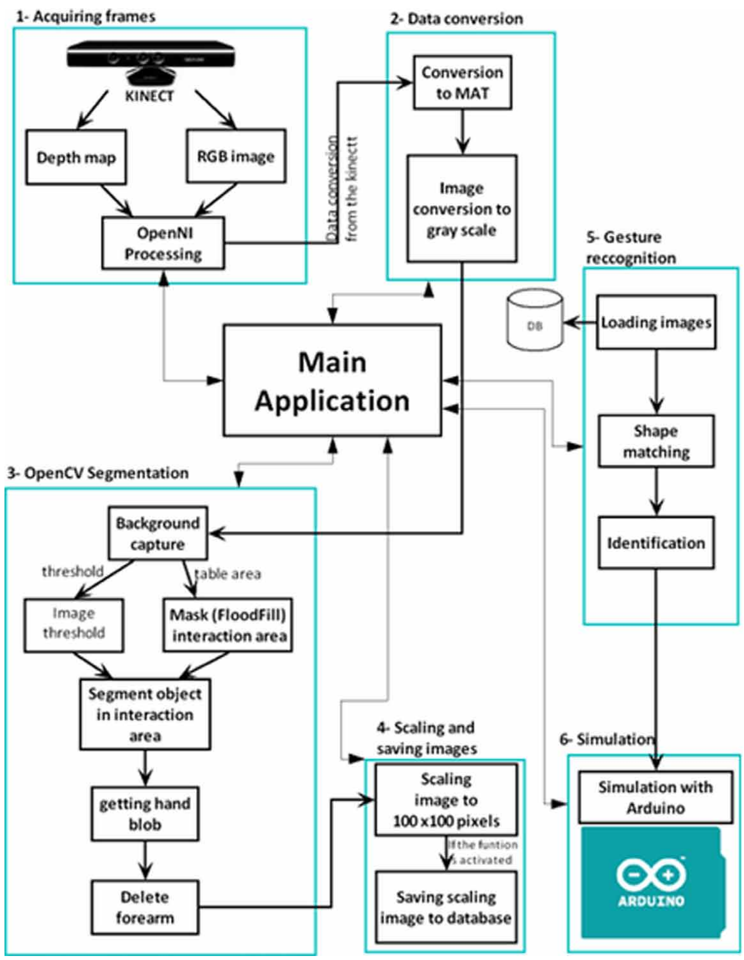
3. SYSTEM ARCHITECTURE

The designed system comprises several software and hardware tools. Figure 1 presents the system architecture.

Fig.1 shows the access to the sensory device (Kinect) used to obtain information in a raw state, and the respective pre-processing, so that it can be manipulated by the system (1-Acquiring frames). After the data conversion to a format suitable for handling through the OpenCV library functions (2-Data conversion), the image segmentation is performed to extract the characteristics necessary to the solution (3- OpenCV Segmentation), followed by image scaling to a suitable size. It is possible to record these scaled images in a folder so they can be used for inclusion in the valid gestures' database (4- Scaling and saving images). Finally, it is performed the hand gesture recognition by comparing the current image with the database class of images (5- Gesture recognition). The simulation of the prototype was made with an Arduino based architecture (6- Simulation).

The hardware used to develop the prototype (Figure 2) includes a personal computer (PC) used to program the system, the Kinect 3D sensor (Cruz et al, 2012; Xing et al, 2013; Galna et al, 2014;

Figure 1. Scheme of the system architecture



Hernández-López et al, 2012; Shotton et al, 2011) as a source of information, and an Arduino based architecture (Figure 3) to simulate the system.

The system was implemented in a MS Windows environment considering the following software:

- Development environment: Microsoft Visual Studio 2010;
- Programming language: C ++ in the approach of object-oriented;
- Access of the sensory device: OpenNI (Cruz et al, 2012; Campos, 2013; Skeletal Tracking, 2014) framework;
- Image processing: OpenCV library (HP, 2005);
- Simulation and testing the operation of the system: Arduino IDE.

The prerequisites for the development of the proposed solution/system interface include the following:

- The user interface should be minimalist or preferably hidden;
- The user should use the system naturally;

Figure 2. Kinect device connected to a PC

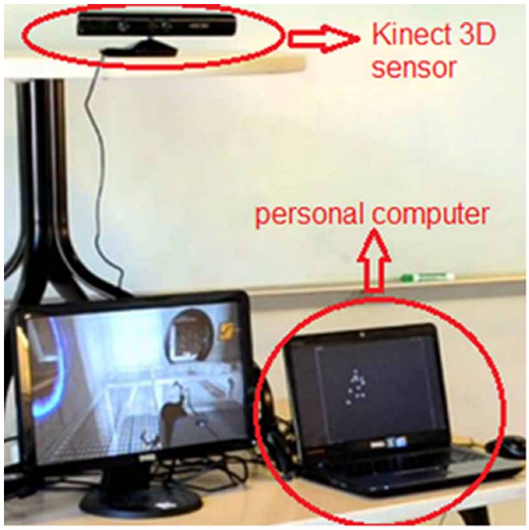
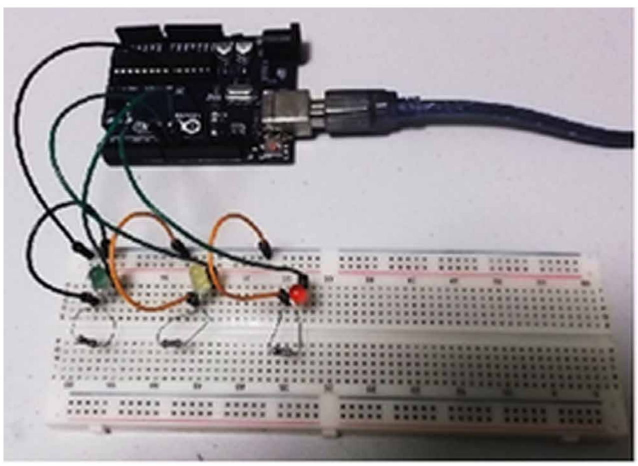


Figure 3. Assembly device simulator

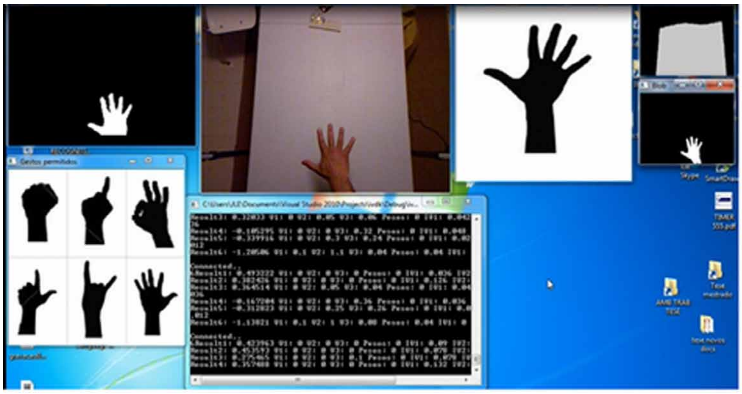


- The system should not be omnipresent in the life of the user;
- The system should be functional and it must allow the bedridden patient to interact with the environment without noticing the electronics that surrounds him.

Considering the programmer mode, the prototype has an interface composed of several images and an output console used to allow program improving as well as to detect possible program errors (Figure 4).

As previously mentioned, the Kinect 3D sensor has poor performance when lighting conditions are not ideal. So, the testing with the 3D Kinect sensor avoided the exposition to intense light rays as well as with low lighting conditions. Anyway, the fact that the device is positioned vertically in relation to the area where the hand moves and at a closed fixed distance prevented the lighting conditions from having a significant effect on the tests performed.

Figure 4. Programmer interface for the developed prototype



4. SYSTEM DEVELOPMENT

The development process undertaken in this project can be organized into six major steps, as shown in Figure 5.

The Kinect 3D sensor provides data in various formats being the depth sensor data the data collected under this project.

The Kinect 3D sensor data is collected through the OpenNI tool. The context object is the main object of the OpenNI which contains the full state run of the OpenNI tool (Xruz et al, 2012; Campos, 2013; Graebling et al, 2007; Zeng & Zhang, 2012). After converting the depth map into a native OpenCV format (HP, 2005) the histogram normalization is performed which is then used to generate a matrix with 256 levels (Gray image, Figure 6) that acts as the basis for all subsequent tasks.

Figure 5. Project development stages

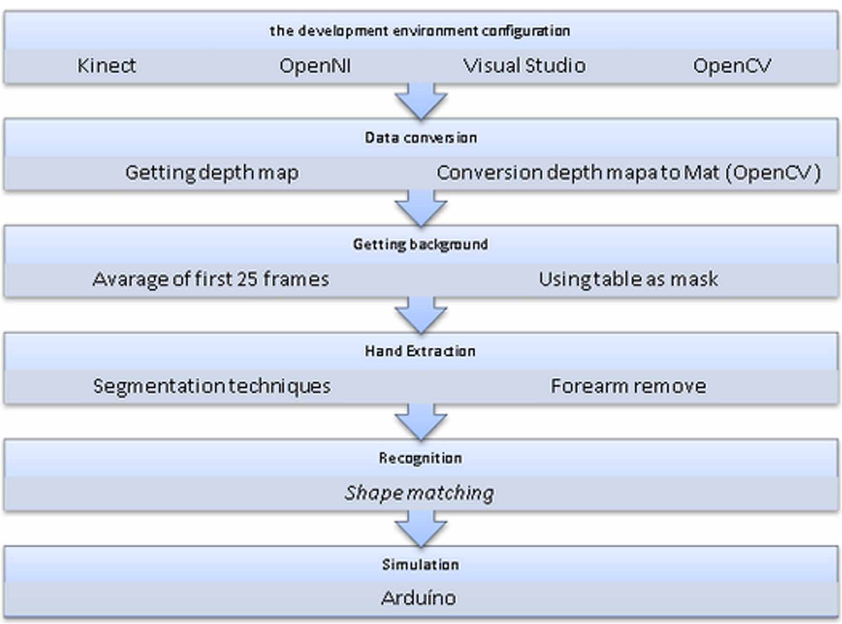
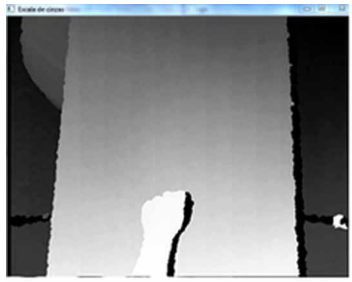


Figure 6. Working basis image (Gray image)



To obtain the background image twenty-five frames are captured by the sensory device just after the system start-up. In each iteration pixels are added to an accumulation matrix for each captured image and, at the end of the twenty-five frames the average value of each pixel is calculated. The result is the background image, Figure 7.

After obtaining the background image, a pre-processing is made with the OpenCV function FloodFill. The FloodFill is applied to the central pixel. This procedure is performed to obtain the user interaction area. In the case of this prototype the interaction area is a table. Afterwards the hand extraction is obtained through the OpenCV functions.

The process of hand extraction is achieved through the following steps:

- Obtaining of contours from the binary image (Figure 8);
- Filling of the contours with white (Figure 9);

Figure 7. Background image

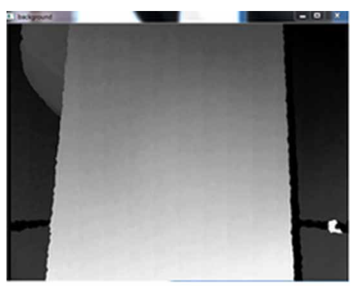


Figure 8. Image with frame contours

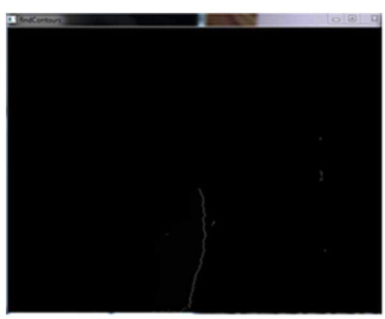
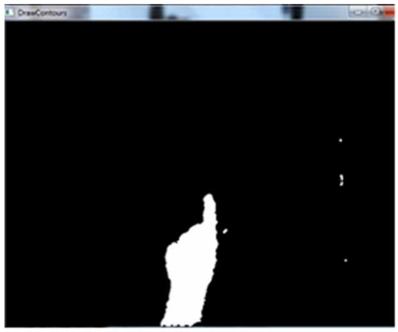


Figure 9. Image with filled frame contours



- Acquiring image moments and extracting the centre of mass of each contour;
- Deleting all contours with smaller areas;
- Obtaining the final image that contains the most central contour of the frame, Figure 10.

Although, considering that the hand contour in the final image it is too long it was necessary to remove the extension of the forearm. The elimination of the forearm is obtained according to the following sequence of steps:

- Obtaining of the hand contour and its respective filling;
- Once found the points of the contour, determining of the smallest area of convex polygons (convex hull), Figure 11;
- Determining of the convex defects (the sequence of points of the contour placed between two vertices of the convex hull), Figure 12;
- Summing up all convex defects found and their average. This value will give an estimate of the hand palm centre;
- Assuming of that the palm is similar to a circle, it is possible to find the centre using the three points obtained previously to define a circle with a valid radius. Thus, the palm centre is obtained;
- To stabilize the palm the centres obtained in previous iterations are considered;
- With the palm centre obtained a circle is drawn around the centre (Figure 13);
- Everything that is positioned below the drawn radius is eliminated from the contour. This procedure eliminates the forearm, Figure 14.

Figure 10. Final image

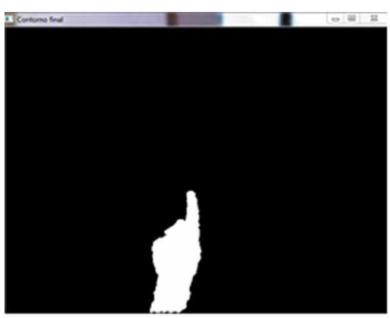


Figure 11. Convex hull

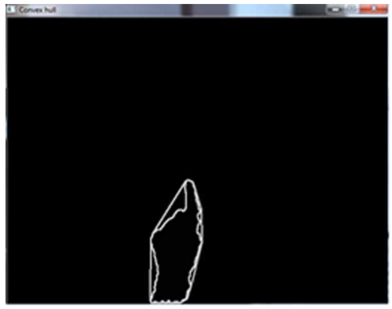


Figure 12. Convex defects

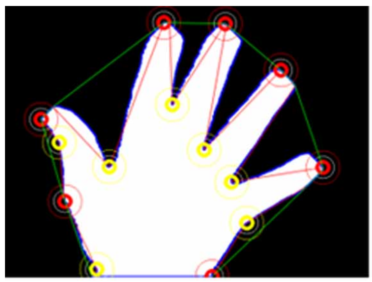


Figure 13. Circle centred on the palm centre

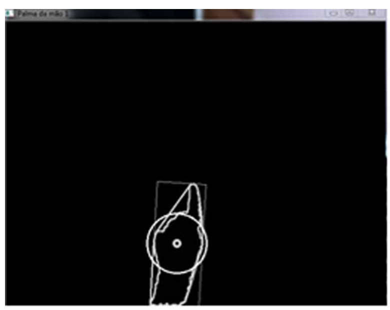


Figure 14. Hand contour after removal of the forearm

As can be seen in Figure 15 the hand contour occupies less than one sixth of the entire image. This would hinder significantly the recognition of hand gestures.

Depending on the distance from the hand to the sensory device the hand extraction algorithm will return images with different dimensions. To prevent it a scaling was applied to a predefined size (100x100 pixels) to all processed images, as in Figure 15.

The gesture recognition (Anjo, 2012; Cárdenas, 2015; Oliveira & Castanheira, 2014; Barbosa & Silva, 2009; Mendonça, 2013; Guangsong, 2013) was based on a matching algorithm. The matching algorithms relate to examples of patterns with a new standard in order to determine a degree of similarity between them. With the shape matching algorithm, satisfactory results were obtained in terms of the recognition of hand gestures. The standards provided are hand images already processed. The shape matching algorithm receives characteristics as a binary image of a processed hand and compares it with several images from each class of gestures. The implementation of the gesture recognition has been achieved as follows:

- Upon application start-up, all the sample images are loaded. Each image is stored in a vector associated with a class of gesture;
- To identify each image, it is calculated the similarity to every image in the database (Figure 16). To calculate the similarity between two images, the OpenCV function matchShapes is used;

Figure 15. Final images scaled to the size of 100x100 pixels

Figure 16. Example of an image class for a specific gesture

- For each comparison made, a value is returned. Depending on the similarity of the value returned, it is checked if this value is in a predetermined range. Every time that the comparison with a sample image class is in this range a variable is incremented. This procedure is used to compose the final value comparison with the class of gesture;
- After comparison with all the class images of gestures a final value is found, and it is assigned to a certain class of gestures.

There are six gestures to be identified. Each of these gestures must be associated with a specific action that makes sense to bedridden people. The chosen gestures are shown in Figure 17.

The simulation with Arduino IDE was carried out is the last part of the project development so that all gestures that trigger actions could be identified. In order to be useful to a bedridden people every gesture should enable or disable a particular fixture as the light or television, be used to activate an emergency alert or call the nurse or to allow a patient to control the inclination of the bed, among others.

The prototype was used in a simulation of the activation of electrical devices via an Arduino based architecture. There were used three different colour LEDs that allow the system to test the operation of the six hand gestures (Table 1).

The module developed in Arduino IDE used a class that allows serial communication. When a particular gesture is recognized a code is sent via the serial port so that Arduino IDE can identify and perform a certain action (to switch a particular LED on or off).

5. EXPERIMENTAL RESULTS

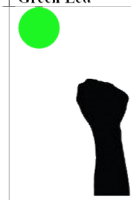
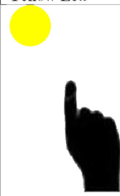
In this section, there are presented the results obtained with four different subjects in order to validate the efficacy of the gesture recognition function of the system.

5.1 Results Obtained Upon Testing by Human Subjects

As referred previously four people were involved in testing the prototype. Each test was performed by a single individual. During the test there were 716 hand observations. The subject A contributed

Figure 17. Gestures recognized by the system

Table 1. Gestures associated with activation / deactivation of LEDs

	Green Led	Yellow Led	Red Led
Switch off			
Switch on			

with 164 observations, the subject B with 211 observations, the subject C with 190 observations and the subject D with 151 observations.

It was found that for a total of 716 observations the system correctly identified 686 and had 30 misreading's. The mean percentage of correct observations was 96%.

The gestures that feature a lower percentage of correct identification include gesture number three, with 93% correct results, and gesture number five, with 91% correct results. However even in these two actions it was obtained a percentage above 90% (Table 2).

5.2 Confusion Matrix

The confusion matrix (Table 3) allows checking the type of failure that occurs in each invalid reading.

In addition to the factors already mentioned and contributing to some of the test errors – poor placement of hands, in particular, and the use of a poor technique to perform a certain act, there are other factors that can cause errors. For example, the similarity between gestures number three and number six or, in some frames, the pulse cutting being made a little further from the hand end due to the calculation of the palm radius. Although in most of the frames it was observed a good performance.

By Table 3 it can be seen that, the gesture number one is correctly identified in all tests, the gesture number two was not identified in two samples and was misidentified in one, the gesture number three was not identified in five samples and was misidentified in six, the gesture number four was not identified in two samples, the gesture number five was not identified in ten samples and gesture number six was not identified in two samples and it was correctly identified in two samples.

6. CONCLUSION AND FUTURE WORK

This section presents the main project conclusions including its limitations and further work suggestions of development.

6.1 Conclusions

Technology has an important role to play in health and wellbeing of the elderly. We live in aging societies and it is urgent to improve quality of life for a growing population of bedridden people providing them with a certain degree of autonomy in performing daily basic actions. The goal of this project was the development of an application meant to allow bedridden people to perform basic actions by just moving the arm and performing simple standard gestures with the hand. For this

Table 2. Total results observed for each gesture

Gesture	Number of observations	Correct identification	Incorrect identification	Percentage of correct results	Percentage of incorrect results
	114	114	0	100%	0%
	110	107	3	97%	3%
	143	132	11	93%	7%
	111	109	2	98%	2%
	116	106	10	91%	9%
	122	118	4	97%	3%
totals	**716**	**686**	**30**	**96,00%**	**4,00%**

Table 3. Confusion matrix of the tests

							?
	114						
		107			1		2
	1		132			5	5
				109			2
				6	106	4	
			1	1		118	2

purpose, an application capable of recognizing hand gestures in real time was created by linking the gestures with actions that take place in the daily life of bedridden people. This system tries to reduce the impossibility or difficulty faced by such people in performing these actions.

The Kinect 3D sensor was used for the image acquisition while OpenCV library was chosen for processing images; the gestures classification algorithm used was based on Shape Matching.

There were performed experiments to test the accuracy of the algorithm recognition of the hand gestures in which was obtained a percentage of correct readings of 96%.

The good results obtained indicate that the system can be used, with further improvements, in a real-world environment.

6.2 Limitations

Considering that this was an academic project (developed under an Electronics and Computers Engineering Master dissertation in the Polytechnic of Cávado and Ave - IPCA, Portugal) and with a short time of development, some limitations can be listed, namely:

- Efficiency of the algorithms of hand extraction and gesture recognition;
- Still an under-development prototype;
- Single hand gesture recognition.

6.3 Future work

Considering the further development of this project some suggestions are enunciated:

- Improve the performance of the forearm elimination algorithm;
- Improve the performance of the gesture recognition algorithm;
- Increase the number of hand gestures database of sample images with due commitment to performance;
- Physically implementing a structure with the Kinect 3D sensor within a lamp so that the device remains invisible to the bedridden people allowing a more natural interaction;
- Create an electronic device to communicate with various electrical devices so that the patient can perform certain basic actions;
- Implementation of other gestures (programmed by end-users) than those defined in the presented design.

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