Movement and Postural Noncontact Bioinstrumental Sensor – a Genetic Alghorithm Based DSP Implementation

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Abstract— **The paper presents further details of implementation of a laser sensor system used to determine the movements, position and distance to a target without any physical contact. The sensor system generates a laser plane, uses a video system to extract position and distance information, all controlled by a DSP system. A genetic algorithm is used to compute the body position with respect to the video camera. Several possible applications of the bio-instrumental sensor are discussed.**

I. Introduction

Designing high performance computers and other "intelligent" systems imposes, from the interaction point of view, the understanding of the subject's emotional state, physical and psychological state. The computer or system ability to sense and respond to the user's state helps them to better adapt to the user's needs and also, to develop the naturalness of human-computer communication.

Moreover, the human efficiency in the activity related to the human-computer interaction (or, more general, human-machine interaction) is directly dependent on both the subject's state and the capability of the systems to recognize the specific needs of the user in order to change their response accordingly. Unfortunately, *acquiring* and *interpreting* this kind of information is very difficult and, as a consequence, all the actual systems have only a limited ability of communication. Current strategies for user's state acquisition are either obtrusive (only a small part of them are not) or, the data, captured by the systems, consist in low level useful information (keystrokes, mouse and joystick movements).

In real life, what provides real substance and naturalness to face-to-face interaction and communication beyond the speech (through voice inflexion, pitch, timbre, etc) is the body activity of the people, [1]. Much more, a "sensitive computer" can use the body movement and the position of the body, linked to the artifacts from the environment, in order to assess the state of the person such as: nervousness, lack of attention or interest, motor fatigue and agitation, confusion etc.

The final goal of the human computer interface is to identify the subject's state in a real world environment, characterized mainly by: *open-recording*, *event-elected* and *internal feeling* state, [2].

To respond to the previously presented requirements a non-contact laser system was introduced, [3], [4], in order to continuously establish the distance between the observation point and the subject and to determine the subject posture.

This paper discusses further detailed aspects related to the implementation of the independent system controlled by the TMS320C6416 DSP, presenting new results in exploiting the bio-instrumental sensor.

II. The Sensor Operating Principle

The principle of operation is to generate a laser plane at a constant angle from the horizontal plane, considered as reference. The laser plane is projected on the body of the subject, determining the apparition of a laser line, as shown in Fig. 1. The sensor system is composed of a laser scanner, an interface unit, a video camera and a software program, running on a DSP platform, that controls the scanner, acquires the images and extracts the distance/position information. The video camera acquires images from the area where the laser plane hits the target (in our case, the person's torso). With this camera, the software gets two consecutive images: first, with the laser diode on, with a line of laser light that appears on the target and the second, with the laser diode off. Subtracting the two images we get, as a result, only the projection of the laser line. Based on this operating principle, the extraction of the laser line becomes a very fast task – a major advance of this system, even if, in order to determine the distances, images are used. If the object is far away, the extracted laser line will be close to the top part of the image. In the opposite situation, it will be closer to the bottom part of the resulting image – see h_1 versus h_2 in Fig. 1. At this point, one knows the angle between the laser scanner and the horizontal plane, the position in space of the video camera and the extracted shape of the laser line on the subject torso, arm, etc, respectively. Then, the depth information of each point on the extracted laser line can be calculated using some basic geometric formulae. Based on these values, one can determine exactly the real 3D subject body position with respect to the camera, as well as aspects concerning person's posture or movement.

III. Details of the Hardware Structure

The block diagram of the proposed bio-instrumental system is depicted in Fig. 2.

The designed set-up has two components: the electro-mechanical scanner and the DSP system used to control the

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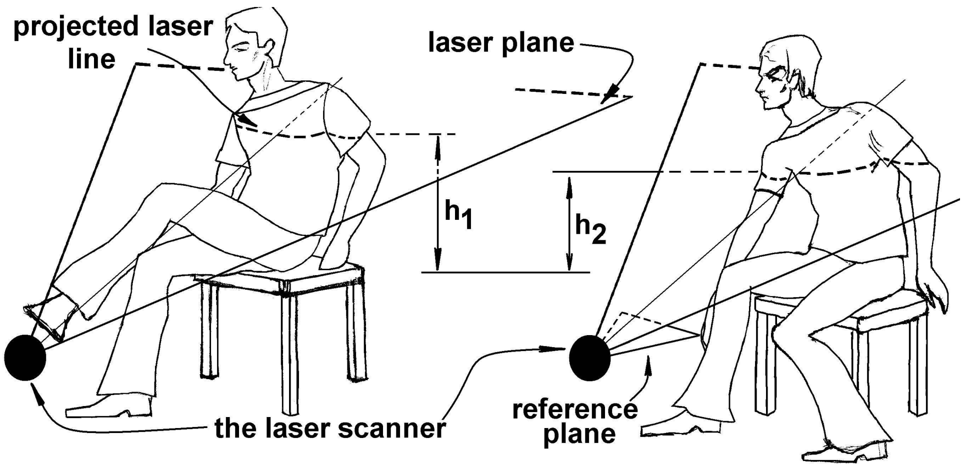

Figure 1. The distance determination for two different subjects positions

scanner, acquire the image and extract the distance. The scanner has a low-power laser diode and a mechanical system with six mirrors disposed on a plate, in hexagonal configuration. The position of each mirror can be controlled individually by a mechanical system – in this mode all the six mirrors can be set in order to generate the laser plane with the same constant angle, related to the reference plane, usually the floor, in the 3D space. The engine spins with a constant rotational speed of 5 rotations per second.

The entire bio-instrumental scanner system is controlled by a DSP, the TMS320C6416, operating at 600 MHz. The imaging daughter card belongs to the TMS320C6000TM Imaging Developer's Kit that comes with TMS320C6711 DSK board.

Mainly, since this application deals with images and all these type of applications are considered data-intensive and computing-intensive, the TMS320C6416 DSP was chosen because its: high computing power (supplied by: the architecture, execution speed – 1.67 ns cycle time versus 6.7 ns for TMS320C6711-150 and by the type of the processor – very long instruction word processor), large on-chip memory (its L2 cache has 8 Mbits versus 512 Kbits for TMS320C6711) and to the efficient data transfer mechanism (possibility of accessing 64 bits of data at a time, enhance direct memory access (EDMA) peripheral and efficiently transfer of data from/to off-chip memory).

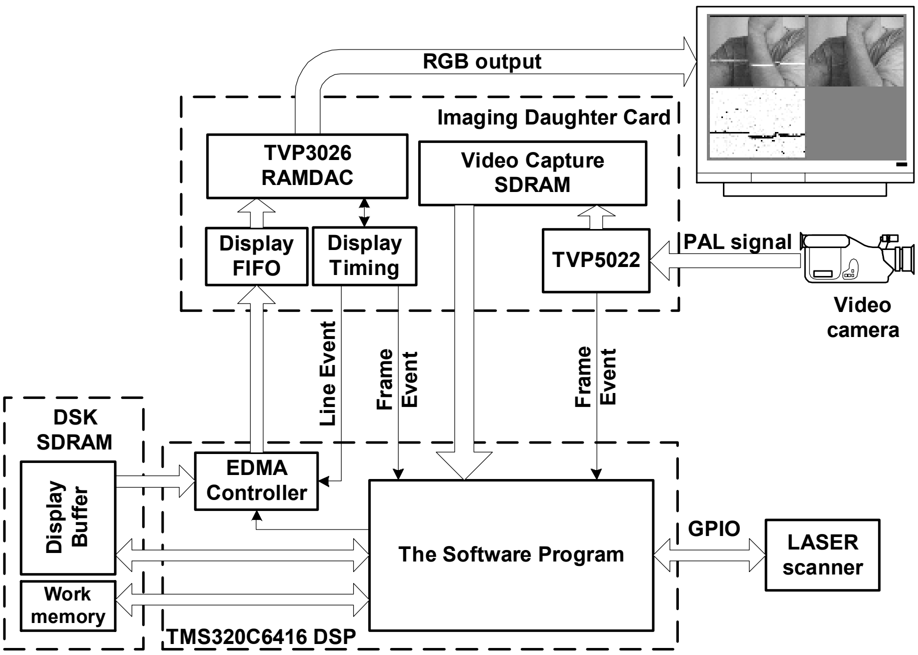

Figure 2. The bio-instrumental hardware block diagram and the system data flow

All the images used to derive the laser line are acquired with a professional Sony™ camcorder (TRV78E). A similar result was obtained with a web CCD. The main difference between the two alternatives consists in the superior resolution of the first one, which generates a higher accuracy. The same imaged area is spanned into 576 lines by the camcorder and only into 320 using a webcam. Using the camcorder the system was able to evidence even the respiratory activity extracted from the subject chest movements.

IV. THE SOFTWARE IMPLEMENTATION

All the processing functions are implemented into an endless loop contained by a task function – of DSP/BIOS thread type.

Each acquired image has 576 lines and 768 pixels per line. On the imaging daughter card (IDC), a FPGA circuit together with the TVP5022 (decoder chip, see Fig. 2) acquires images (the input data is digitized in the 4:2:2 format), filters, splits the input signal in three different streams (Y, Cr and Cb) and saves the data into the video capture SDRAM, in the internal IDC memory. The IDC can acquire the images at a maximum rate of 30 frames/sec.

Using the Image Data Manager (IDM) API function, [5], the images were brought from the Imaging Developer's Kit (IDK) memory into the L2 internal memory. The IDM efficiently moves data in the background using EDMA peripheral. The main advantage of the IDM API subroutine is given by the fact that the DSP programmer can make abstraction of the: double buffering EDMA requests and pointer updates, [5].

The captured image stored into the video capture SDRAM, from the IDC daughtercard, is kept in two different fields (odd and even fields). Each field has three separate blocs (Y, Cr, Cb). Based on the generic template presented in [5], an application driver was developed. In the application driver, both stored fields are merged into one image, stored in the on-chip cache. In order to obtain a fast image processing algorithm, the resulting image is a gray one, obtained only from the acquired information stored in the *luma* buffers (only the Y fields).

The system acquires, synchronically with the diode laser's states (on/off), two consecutive gray images and stores them into two buffers. In the absence of noise, all pixels of the first image, which differ from the corresponding ones in the second image, describe the laser line which appears on the user's body torso. The procedure used to extract the distance to the subject is designed to disregard the noise due to the small user movements in between two acquired frames.

In order to have a clear, real time supervision of the system evolutions and the result of image processing algorithms (the 3D contour extraction – the laser line extraction), an output image containing both acquired image and the result is formed and displayed on a RGB monitor. After the software program composes the output image into the *Display Buffer*, an EDMA controller copies each line of the display data from the *Display Buffer* to the IDC (*Display FIFO*) when the EDMA is triggered by the Line Event (HSYC – horizontal synchronization), see Fig. 2. The copied line information is displayed through the TVP3026 circuit.

The bio-instrumental sensor we have designed is intended to determine the distance between the subject and the laser diode and also to interpret some kind of body language expressed by the subject. In order to provide complex information regarding both the torso *movements* and *posture* detection we have looked for efficient feature extraction algorithms.

In this respect, modern stochastic optimization techniques involving evolutionary computation such as genetic algorithms proved to be a solution, [6]. Such algorithms attempt to simulate Darwin's theory of natural selection and Mendel's work in genetics on inheritance: the stronger individuals are likely to survive in a competing environment. Using such algorithms one can obtain robustness and flexibility.

The genetic algorithm was developed using the C++ Code Composer compiler facilities, implementing the philosophy suggested by GALib, [7]. For our application, each chromosome has two genes, encoding the position of an image pixel. We have implemented the binary string format for chromosomes.

We have used, for the beginning, the standard simple genetic algorithm, [6]. This algorithm uses non-overlapping populations and optional elitism. For each generation, an entirely new population is created by selecting individuals for mating from the previous population, according to a specified selection method. The stopping criterion is given by the condition that the ratio between the maximum and the minimum values of the individual fitness exceeds a specified value, in our case 0.98.

The fitness function was designed to provide information about the number of image pixels in the vicinity of the selected image point (pixel) weighted by the distance between the point and the bottom of the screen. To reduce the influence of noise, the pixels having in their vicinity less than a specified amount of adjacent pixels are ignored.

After a large number of tests, the most efficient crossover operator proved to be the three-point one, while the most effective selection scheme proved to be the Stochastic Remainder Sampling Selection. We have also initialized the population randomly, but distributed uniformly in the four quadrants of the image to ensure the rapid detection of the laser line segments.

V. RESULTS

For the tests we have run, the average number of generation for convergence is 200, for a population of 100 individuals, with no elitism, 0.9 probability of crossover and 0.001 probability of mutation, with an approximate run time of 3 seconds. In Table 1 we show, for a processed image, the final stage of the genetic algorithm evolution for four different initial populations, indicating: the final best six individuals of the population (coordinates of the associated image pixels and corresponding fitness), the number of generations for convergence and the final solution (the lowest laser line position on the captured image).

From the laser line algorithm extraction point of view, even the fastest movements can be extracted, as shown in Fig. 3. The identification of some particular postures: the arm position- in front of the torso, or the torso position, is possible based on the geometric extracted curve dimension, curvature and the final

TABLE I. THE FINAL SOLUTIONS FOR FIVE INSTANCES OF THE GENETIC ALGORITHM

	(x coordinate, y coordinate) → fitness			
	Population 1	Population 2	Population 3	Population 4
Final best six individuals	(408,413) → 41.9162 (408,413) → 41.9162 (408,413) → 41.9162 (408,413) → 41.9162 (408,413) → 41.9162 (408,413) → 41.9162	(405,413) → 41.9162 (405,413) → 41.9162 (405,413) → 41.9162 (405,413) → 41.9162 (405,413) → 41.9162 (404,413) → 41.9162	(408,413) → 41.9162 (344,413) → 41.3174 (344,413) → 41.3174 (344,413) → 41.3174 (348,413) → 41.3174 (344,413) → 41.3174	(403,413) → 41.9162 (403,413) → 41.9162 (403,413) → 41.9162 (403,413) → 41.9162 (403,413) → 41.9162 (407,413) → 41.9162
Nr.Gen.	139	393	259	211
Solution	**(408,413)→ 41.9162**	**(405,413)→ 41.9162**	**(408,413)→ 41.9162**	**(403,413)→ 41.9162**

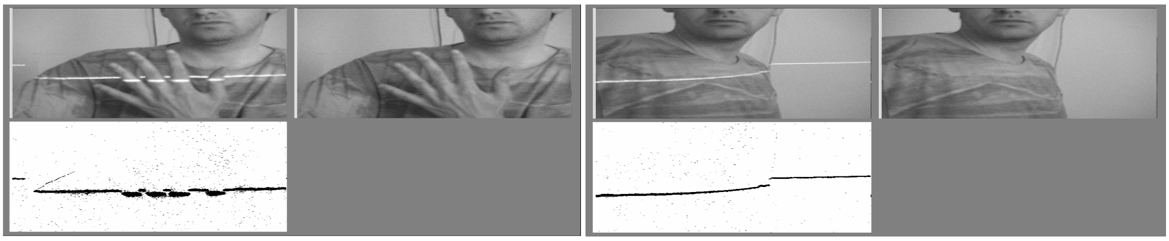

Figure 3. The system ability to differentiate the finest details and a particular body posture, maybe, reflecting the user state

position of these laser segments in the final image. Each of these postures or body positions can be related with different internal subject states that can guide a system in order to improve the human computer interaction.

The main advantage of this non-invasive system implementation for supervising the body movements and postures is due to the possibility to use it in a variety of applications such as: medicine, industry, virtual reality, entertainment – to name only few of them. In the medical field, this bio-instrumental sensor can be easily used in potential application as for example: rehabilitation, functional movement analysis, evaluation of the cognitive deficits or motion and ergonomic studies.

In the rehabilitation process, the measurements of the motion skills impairments, caused by different illness or injuries, are very important and can quantify the recovering between two medical sessions, disregarding the physician subjectivism. Using two different laser scanner systems the subject trajectory can be recorded and easily quantified in order to assess the patient rehabilitation.

The system presented in this paper can be used also in the quantitative analysis of the head tremor movements.

VI. CONCLUSIONS

In this paper a DSP implementation of a bio-instrumentation system was detailed.

Even if all imaging application is considered data and computing intensive, the software that controls the system is not very data and computationally demanding.

The system mechanical part is very simple. These characteristics make the system inexpensive, easy to manufacture and, hence, attractive for practical applications. The main drawback of the system is generated by the existence of the mechanical part in movement. But, the same system of laser sweep is intensely used in the laser printers without any reliability problems. In the end, last but not least, the entire system is very fast.

The selection of TMS320C6416 is well fitted to our application being able to perform in real time all tasks. The time between two determinations can be further improved by removing all the subroutines used to display the acquired images and the resulting ones.

As a final conclusion, based on this system, one can easily construct more complex systems used to identify the subject patterns of contextual postures able to describe the user's state.

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