Design and Testing an Artificial Arm Microsystems in Virtual Environment

E.D. Franti, A. Zafiu, A. Plavitu, M. Teodorescu, P. Schiopu

Abstract— In this paper is presented a virtual environment that was designed in order to develop and test different architectures for Artificial Arms microsystems. The utility of the virtual environment is significant because testing different structures of Artificial Arms and microsystems architectures and then selecting the best option is much cheaper when it is used a virtual environment compared to the option of testing different hardware implemented microsystems. The virtual environment also allows the user to evaluate the performance/cost ratio for each microsystem correlated with the type of the Artificial Arm that was used.

Keywords— artificial arm, microsystems, virtual environment.

I. INTRODUCTION

CONTINUOUS technological progress of the last decades had and is still having an undebiable impact on medicine. During the last centuries, as the technology increased, prostheses have been created and thus better models of building them were set, but a number of issues remain unresolved such as:

- Specific to each individual design challenges;
- Low reaction speed of command and control system attached to the Artificial Arm;
- low accuracy of control system;
- the quality of interfacing with human body
- low degree of freedom for Artificial Arms compared to the replaced limb.

Prostheses for the arms, differ from other total prothesis by the complexity of reconstructed joint function, as well as the consequences of increased risk of damage of these medical devices with time. Prostheses that have a series of multiple joints may be subject to multiple changes as a result of their placing on the market, as was found for artificial arms for shoulder and elbow. To obtain an optimal level of safety and health protection and to reduce problems related to the design of these devices, the notified organism must examine these devices before they are put into use (both the design file that includes clinical data used by the manufacturer in support of announced performance, as well as design and manufacturing changes subsequent to their placing on the market). Studying and understanding the components and the dynamics of movement of articulated elements also implies the study of movements that occur in these joints. Joint movements in the human body are made in several joints simultaneously, so-called „chain joint". The movements type and the shape of the articular surfaces are closely interdependent. Knowing the shape of the articular surfaces can be deduced the movements in that joint. The possible movements are: sliding, spinning and rotation. Slipping means displacemet of the articular surfaces that are brought into contact, together with friction, without their removal and takes place in plane joints. Spinning or tumbling means circular movement of articular surfaces so that with every new phase of motion other parts are brought into contact. Rotation is a circular motion, characterized by the twisting and movement of the mobile bone cell around its longitudinal axis. If the axis is out of joint, rotation is accompanied by movement. Given the above presentation, we have designed a system that allows the design and analysis of Artificial Arms with a virtual environment. The initial result of the design is a virtual prothesis that can be analyzed using a simulator. The virtual Artificial Arm design system has been developed in a modular way. Each module has well defined tasks:

- module for generating action virtual environments,
- module for describing virtual Artificial Arms
- module for describing Artificial Arms
- module for describing the controlling program
- module for coordinating and synchronizing the operation of the components of the simulation environment.

Design and implementation methodology of Artificial Arms is complex and expensive, requiring numerous tests before the patient can control the artificial limb properly. To control the artificial limb the patient needs a long time, because with training he can learn in time to control the Artificial Arm even at a very fine level. For patients in rural areas, the ploblem is more difficult because they have to bear additional costs of travel and time required. In this direction software environment presented in this paper is helpful because it can substantially reduce patients' costs and also helping them to train in order to develop the necessary skills for effective use of the Artificial Arm. This virtual environment also helps to design a quality Artificial Arm without the need for patient movement from the place where he lives.

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II. THE VIRTUAL ENVIRONMENT

A. The Virtual Environment Module

Software module „ virtual environment” allows the user to generate, configure and modify the various working environments that will be used for testing the prosthesis and the controlling programs designed for them. The virtual environment is composed of:

- 3D graphics engine;
- elements for interaction between the operator and graphic scene components;
- the mode for collecting graphic scene parameters (eg. „reading” current parameters of joints);
- the mode for modifying the components characteristics of the scene by transmission of new parameters for graphics scene (eg. new angles for joints).

3D graphics engine is designed to graphically display prosthesis. OpenGL was chosen as the graphics engine because it allows access of video cards graphics functions. OpenGL is a description language of three-dimentional objects and it allows description oftheir shape, their position, direction and degree of illumination, and the apparent position of the viewer and its movements. The virtual environment will allow the operator intervention to modify the status of Artificial Arm by visual operations such as „grabbing” a part of the prothesis and its translation or rotation within the constraints set by the prosthesis model. Virtual Artificial Arm will be „equipped” with the ability to determine the joint parameters at any time. This facility is equivalent in the real world with the addition of a set of sensors on the joints of the Artificial Arm so that states can be determined in each joint, and consequently the overall state. This set of sensors is used to determine the equations of motion that should be passed to the Artificial Arm in order to perform a reconfiguration „described” via direct interaction between the operator and the prothesis within the virtual environment. Sensors are used for learning predetermined sets of movements. Artificial Arm parameters can be coded and, by a command equivalent to „start” of certain actuators of Artificial Arm, the reconfiguration of the Artificial Arm is viewed without operator’s direct intervention. How to modify the attributes of joints at a certain time is specified by equations of motion submitted to the virtual Artificial Arm for each actuator.

Validating the performance of these movements automatically transmitted is made via sensors attached to virtual Artificial Arm. The functions that were implemented in this module were:

- **window resizing function** allows the image to be displayed correctly regardless of window’s size. For implementation 4 functions were necessary as described below:
- **„loading an image into memory” function** – loads a raw image type (binary) into memory, an image that will be used for texturing, then releases the memory.
- **„initialization” function** - initiation of vectors „v_elements”, „v_elements2”, „theta”, „theta2” , „beta” , „beta2” used for the upper limb joints angles and corresponding leg .
- **function for „testing depth”**;
- **function of „drawing the background”** is the function that draws the background, the background in which prothesis and joints are vizualized and tested. The background is a cube with 5 sides - the front side is missing.

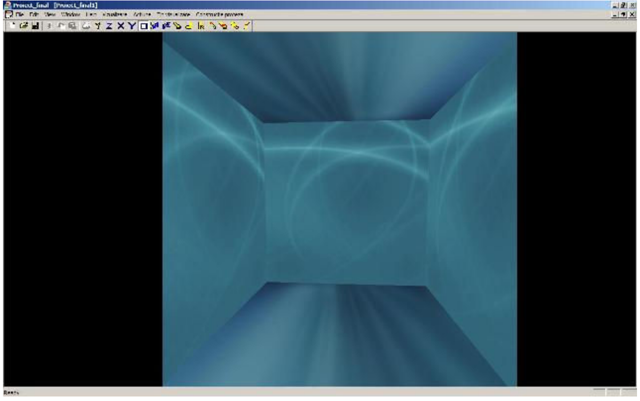


Fig. 1 The 3D virtual environment

B. Virtual Artificial Arm Module

Joints can be classified according to several criteria:
By the mobility:

- Sinarthrosis – fixed joints that allow no movement
- Amfiarthrosis – semi mobile joints
- Diarthrosis (synovial) – mobile joints

By the number of the component bones:

- Simple, made of two bones
- Compound, made of several bones

By the number of axes of rotation:

- Uniaxial – motion occurs around a single shaft/axis
- Biaxial – motion occurs around two axes
- Three axes - motion occurs around three axes

By the shape of the articular surfaces:

- Plane joints - only allow for sliding movement
- Gliomas, which allows flexion – extension movement, very low and the movement of lateralitate
- Trohoide joints - only allow rotation movement
- Condiliene joints - a bone has two articular surfaces, such as knee joint
- Joints in the saddle, concave in a way and convex in the other way. Allow flexion – extension movements, abduction Ellipsoidan joints – allow flexion – extension movements, abduction
- Sphenoid joints – allow greater mobility, flexion - extension, abduction, rotation.

Motion amplitude can be determined by the articular surfaces ligament, or periarticular muscles. Joints with a single rotating axis, or more than one axis (degrees of freedom). Joint axis is a theoretical line around which movement takes place. Possible movements in these types of joints are:

- Flexion – approaching of two segments
- Extension – moving away of two segments
- Adduction - a limb or segment is approaching / moving away from the body plan

- Circumduction - successive execution of the four movements above , describing a truncated cone
- Pronation - rotation of limb, whereby the thumb or toe moves closer to the body
- Supination – rotation of the limb, whereby the thumb or toe moves away from the body.

Virtual Artificial Arm software module allows the user to generate into the virtual reality one or more Artificial Arms with different architectures and modes of coupling according to the handicap of the persons to use them. The module has a library that contains:

- Rigid elements specific to the Artificial Arms described by the main dimensional characteristics that can be adjusted when selecting such an item. Various dynamic restrictions (speed and/or degrees of rotation) could be associated to these rigid elements.
- Joints specific to Artificial Arms described by size that can be adjusted when they are selected and degrees of freedom which may have restriction of movement associated with:
  - o Ranges of values for angles;
  - o Ranges of values for shifts;
  - o Maximum speed and acceleration;
- Prostheses in the form of kinematic chains composed of rigid elements and joints.
- Equations of motion that are associated with joint elements.

Association of these equations takes into account existing constraints for each joint and rigid element. Information is stored in a database of virtual prostheses. The module allows as well the definition of new elements that can be added to the database.

„Virtual Artificial Arm " module has a module of calculation that consists the movements associated to the kinematic chain joints in order to calculate them on each individual item and report during simulation when reached or exceeded the dynamic and/or static limits required to the components.

To design and assemble prosthesis in the virtual environment these steps must be followed:

- identifying the necessary elements already in the database;
- describing the new elements and adding them to the database;
- adding all the necessary mechanical elements to a project associated to the Artificial Arm;
- resizing components;
- adding restrictions to the joints;
- creating links between components;
- choosing the equations of motion associated with the joints:
  - o Rotation
  - o Translation
- adjusting constraints on each joint so that all constraints that are occuring along the kinematic chain (speed and acceleration) to be meet.

During designing process the results are viewed in a virtual environment, aiming to follow closely the anatomy and kinematics of physiological movements.

For projects where there is a real prosthesis or prototype prosthesis, connecting the sensors and actuators to the computer system is useful. The actuators can be controlled via computer, and the condition is monitored continuously. The Artificial Arm allows manual reconfiguration of the kinematic chain. Reconfiguration is continuously monitored by sensors associated with Artificial Arm and transformed into equations of motion.

This Module gives user the following features:

- To view the five types of joints;
- To view and test one or more prostheses (related to joints of the human body) of the library of elements already built;
- To build a virtual prosthesis, choosing from the library of elements the desired items to meet data requirements;
- To remove a particular constructive item or more of the prosthesis (related to joints of the human body);
- To adjust the size of prosthesis:
  - ▪ Normal adjustment (on all three dimensions);
  - ▪ Adjust on X, Y respectively on Z.
- testing various dynamic restrictions (speed and/or rotations) associated with the joints:
  - ▪ Ranges of values for angles;
  - ▪ Ranges of values for shifting;
  - ▪ Maximum speed and acceleration.
- To select different modes for viewing the scene:
  - ▪ On the X, Y, Z, respectively normal view;
  - ▪ Rotating stage left, respectively right;
  - ▪ Aproaching, respectively distancing to/from the object chosen for viewing and testing (zoom);
- To select various modules such as:
  - ▪ Viewing the axes for the object chosen to view and test;
  - ▪ Viewing information related to the chosen object (picture type);
  - ▪ Information on how to use the program;
  - ▪ General information about the project.

The classes used are as follows:

- **CaboutDialog –** derived from Cdialog class (class automatically generated)
- **UseKeys -** derived from Cdialog class (class added)
- **CchildFrame –** derived from CMDIChildWnd class (class automatically generated)
- **CmainFrame** - derived from CMDIFrameWnd class (class automatically generated)
- **Cproject finalApp –** derived from CWinApp class (class automatically generated)
- **Cproject finalView** – derived from CView class (class automatically generated)
- **Cproject finalDoc -** derived from Cdocument class (class automatically generated)
- **CInterface** - built to include functions from VELLEMAN K8000 library
- **CHard_test** – derived from Cdialog class (class added)

The function for **"axis marking"** allows axis viewing and is constructed of 3 lines corresponding to the three axes X, Y, Z.

This function was added for better visualization of the movement that applies on objects.

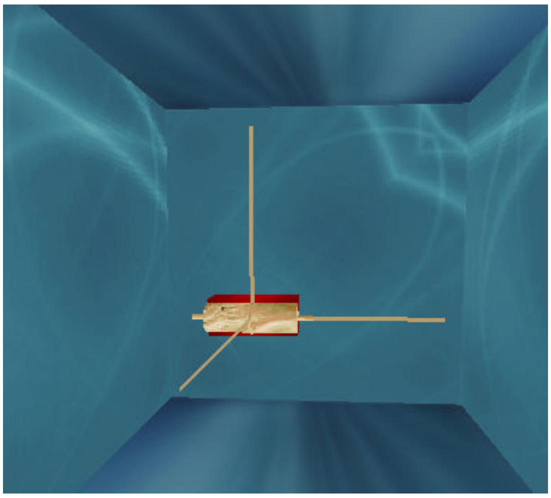


Fig. 2. Drawing the axes applied on elbow joint

"Drawing the upper limb" function. This function builds the upper limb and allows it virtual mobility (you can test the joints related to the upper limb). You can also view the axes for each joint, you can view additional information related to the upper limb. From the menu you can choose one joint at a time, joint that can move under the restrictions implemented for each joint. These movements can be observed in the real world by lighting a blue LED if the joint is moving in the positive direction and a red LED if the joint is moving in the negative direction. A joint can be acted at a time from the real environment and this motion be referred to in the virtual environment by reconfiguring the kinematic chain. This is possible by use of **"read-ReadADchannel ()"** reading function (this function is located in the library of functions given by the acquisition card VELLEMAN K80000).

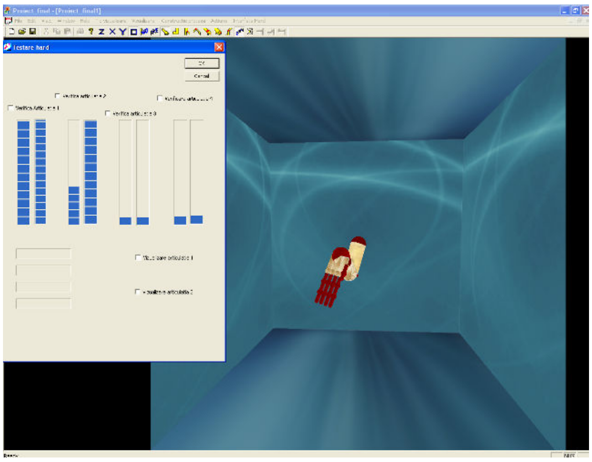


Fig. 3. Configuring the virtual Artificial Arm

C. Command and Control Module

Command and Control Module has access to the information provided by the sensory system of virtual and/or real Artificial Arm, processing signals by the default algorithms of the virtual Artificial Arm's model and develops series of new commands in the form of new equations of motion. These are sent to both Artificial Arm and virtual Artificial Arm to enable models' validation in both the virtual and the real environment. "Virtual Artificial Arm" module takes the orders and calculates the new parameters of the prosthesis. At the end of each step of the simulation, the new configuration is taken using the sensors of the virtual Artificial Arm and compared with the desired parameters.

D. Syncronization Module

Sync engine implementation was done using DirectX9 interfaces (support for. NET). DXControl class is dealing with presentation, being the interface between the 3D model and user interaction (mouse movements, etc.) For application ergonomics a room control has been chosen by polar coordinates, and that was provided by BioArcBall class, which is activated when the left button of the mouse is pressed and, depending on the variation of its position, the view matrix for the display of the whole scene is shown. This is obtained from 3 vectors representing the position of the observer, the point that he is looking at and the relative vector of the up direction related to him. At the basis of the display there is the BioModel class that performs reading from Milkshape 3D format (application's native) and its synchronization using DirectX interfaces. Note that internally this class supports the division of objects and their animation based on framework (with wrists size - 4 weights on a bone for each point), multitexturing, etc. however, in order of not having the need for the achievement of an intermediate file format with conversion into two directions (application/Milkshape), its use was chosen for only the unitary synchronization of each component of the human body and the achievement of a layer to read a text file that contains a description of the framework (minimum and maximum rotation angles, etc.). Bone class is the only information of shifting to the wrist (Wrist). The latter contains the model to be rendered as well as the rotations applied to it, then the translation is done according to the bone. Each joint contains a list of children who go out of it and who will be affected by any geometrical transformation applied to the parent joint (the product of transformation matrices). A rotation is composed of a rotation angle and a vector around which the rotation will be done, the result being a matrix. Finally, synchronization is done starting with the parent node which is a wraper for the Wrist class and continuing with its children. **F**ramework description is based on a template that contains information on how the bones are being settled (translations they are giving to the wrists) as well as the degrees of freedom of movement (axes and possible rotation angles - min / max). Reading from the file is recursive, each Wrist object having a constructor that receives a Stream as a parameter from where it loads its structure and will instantiate the same way every child of his (and therefore the input file is also a tree structure). The interface also allows the attachment and configuration of sensors and determining how they affect joints rotations.

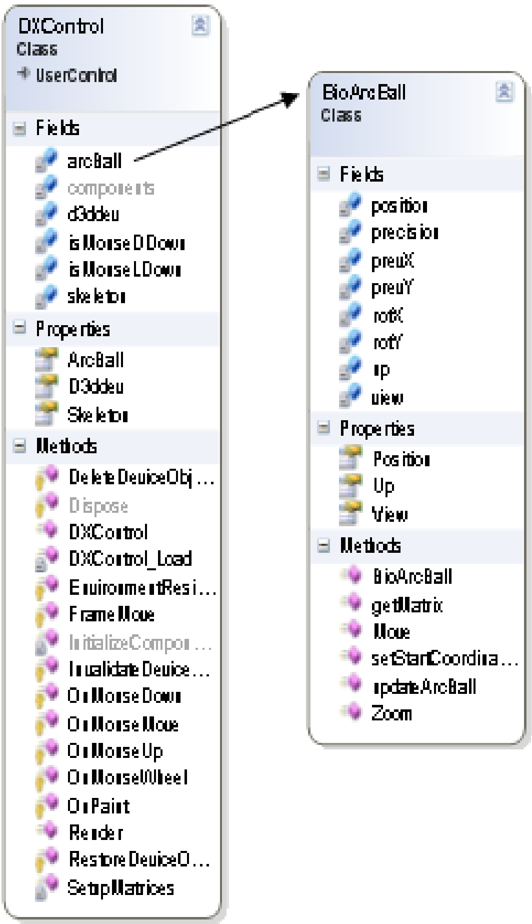


Fig. 4. DXControl and BioArcBall classes’ structure

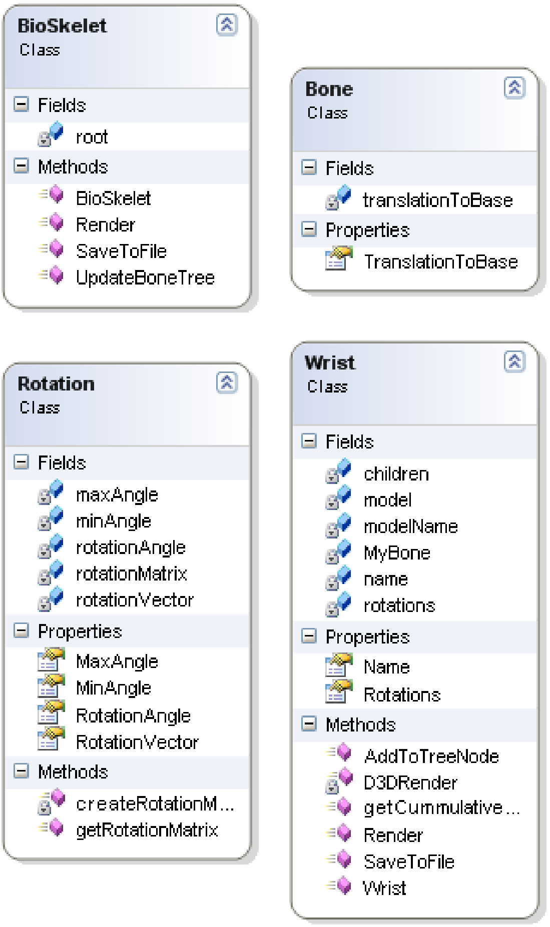
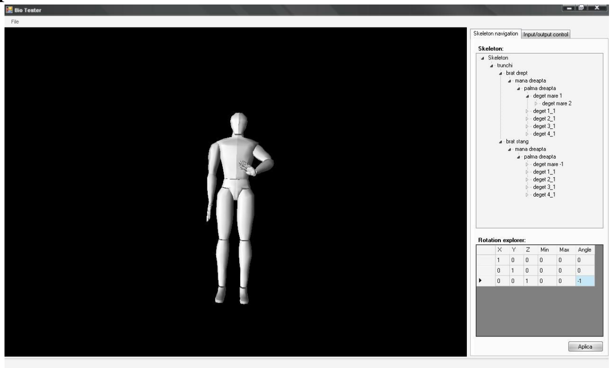


Fig. 6. BioSkelet, Bone, Rotation and Wrist classes’ structure

E. *The Graphical Interface*

Graphical interface for visual feedback allows the patient to visualize how its actions are performed by a computer in the virtual environment. The movements are controlled / checked by data read from sensors placed on the Artificial Arm and are based on information read from miosensors. Interface provides real-time operation, for implementation using technologies that offer response speed to commands in real time: DirectX and OpenGL.



X	Y	Z	Min	Max	Angle
1	0	0	0	0	0
0	1	0	0	0	0
0	0	1	0	0	-1

Fig. 5. The graphical interface for synchronization module

III. TESTING AN ARTIFICIAL ARM CONTROLLER

Designing an intelligent Artificial Arm includes designing and testing of the following components:

- mio-sensors that detects muscle signals from the patient
- actuators that perform operations specific to the human muscles, resulting power and precision;
- position and pressure sensors that generate feedback signals for the Artificial Arm control;
- a controller that collects data from miozensors, processes them (filtration and amplification) and then commands the actuators of the Artificial Arm according to an algorithm that was programmed to follow. The controller’s role is essential because it must recognize correctly not only the signals from miosensors but from the position and pressure with feedback information sensors as well. Inside controller various libraries of motion algorithms are implemented so that the Artificial Arm to be able to move as close to natural as possible. All these algorithms are tested in virtual environment for different architectures of Artificial Arms and different configurations of the environment in which they act.

Command and Control Module has access to the information provided by the sensory system of the virtual and/or real prosthesis, processes signals by the default algorithms from the virtual prosthesis model and develops new series of commands in the form of new equations of motion. These are transmitted both to the real and to the virtual prosthesis to allow the models' validation in both the virtual and the real environment. "Virtual prosthesis" module takes orders and calculates the new parameters of the prosthesis. At the end of each step of the simulation, the new configuration is taken via the virtual prosthesis' sensors and is compared with the desired parameters.

From the development platform, the command information of the virtual "muscles" is transmitted to the computer where it will be taken by the "Virtual Patient" program. Hardware Interface module and development platform, together with a common set of electrodes are shown in the figure below.

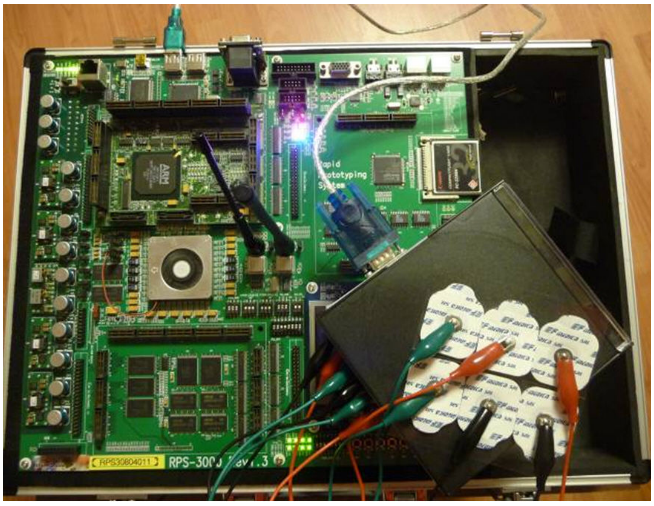


Fig. 7. The development Platform RPS-3000

Development Platform RPS-3000 type could be missing from the assembly if the direct command of an experimental Artificial Arm is not wanted and if the simultaneous processing of 10 signals can be retrieved by computer.

A. Interconnection between Virtual Arm and Artificial Arm

The algorithms of virtual and real prostheses are correlated with the synchronization algorithm which**,** through the virtual environment, is able to display the model of the virtual or real prosthesis. Elements that make up the prosthesi's control system are both passive and active. Active actuators are represented by high-precision engines. To function as real as possible and without risks of accidents, security passive features/elements were added to the prosthesis. Passive actuators are represented by a group of transducers and sensors that interact directly with the command module, offering real-time information about status, current position and surrounding obstacles. The Command Module has the possibility to take decisions independent of human will when necessary. For prosthesis equipped with intelligent interface, system's control is done without human intervention, based on information gathered by transducers. These ones, translating the analog information from sensors, are sending information to the control Module. Control Module evaluates the parameters and engages the active elements in order to achieve movement of the prosthesis elements.

Sensors integrated in the prosthesis are:

○ **electromagnetics** - which complements the fastening system being located inside.

○ **of proximity** - detect objects approaching the prosthesis, being located on the external shell.

○ **of pressure** - ensure the functionality of mechanical systems; are located in the interior.

○ **rotating or angle** - they are located on joints and determines the movement and position of each component. The information is transmitted in real-time to the Command module.

Control system of the prosthesis seeks to achieve a prosthesis movement as close to the natural movement of the foot as possible in different situations in everyday life, standing up from the chair, sitting down on the chair, traveling, climbing stairs, descending stairs. Information on intermediate positions of the prosthesis, during a specific type of motion, is provided by different sensors. We have angle sensors for detecting the inclination angle of the prosthesis towards the normal position, end position sensors for detecting ending of a moving element of the particular type of motion that had been chosen, pressing sensors, strain unit type for sensing a pressing of a certain level.

Switching between modes of motion is done with a remote control, while the rest motion sequences characteristic of each mode to be controlled by a microprocessor.

The same remote can make adjustments or programming of sequences of movement for time situations that require slightly different characteristics of motion from the run of standard sequences, the system feature.

The process of creating the Artificial Arm is done in several stages:

1. clinical analysis of amputation and determination of the minimum number of distinct commands needed to implement the basic functions of the future Artificial Arm;
2. determination of a maximal set of biosignals that can be purchased in areas close to the blunt as having potential use for controlling of future Artificial Arm;
3. choosing an appropriate set of transducers to acquire biosignals;
4. schieving a module prototype to purchase and filtrate biosignals equipped with a communication system (I2C) for connection to computer (via an adapter to a serial interface - RS232 or USB), but also with other modules to be integrated into prosthesis (it is preferably to reuse a configurable module that already has an interface implemented for purchasing a large number of signals, to avoid additional costs);
5. testing, with the achieved prototype, the patient's ability to consciously control biosignals and choosing a subset with maximum potential in terms of using it for the Artificial Arm control;
6. implementation of a dedicated signal acquisition module;
7. implementation of the virtual arm to allow patient to improve control over it in a safe environment;

8. the patient will use the acquisition module and the software application connected to it in order to control predefined sequences of moves on virtual arm.
9. mechanical construction of the Artificial Arm, depending on the patient's clinical characteristics (anatomic blunt’s shape, pair limb’s size and patient’s weight).
10. actuators adaptation to the Artificial Arm’s joints;
11. Command Module designing of actuators provided with a communication interface (I2C) for connection to computer (via an adapter to a serial interface - RS232 or USB), but also with other modules to be integrated into the prosthesis. It accepts macro commands as input data and breaks them down into sub-commands for different actuators.
12. Testing the integration of modules for biosignals acquisition and engine control through software. The simultaneous transmission of commands given by the patient to both the virtual and the real prosthesis is aimed for in order to correlate as well as possible the skills obtained by the patient (by using the Virtual Arm) with the Artificial Arm.
13. determining the deficiencies in the use of Artificial Arm (movements not covered properly) and remeding them by using appropriate combinations of biosignals that the patient can accurately control. These correlations are implemented as subcommands into the control module.
14. extending the functionality of the Artificial Arm by adding compound movements adapted to the way of using of prosthesis that the patient had already achieved (subcommands to be implemented in the control module)
15. implementation of logic that was developed using a Virtual Arm into a control mode that, based on information collected from data acquisition module, transmits macro-commands to the - actuator module.
16. Integration of the Acquisition Module, Control Module and Actuator Module into the Artificial Arm.
17. Adjusting the Artificial Arm movements through direct learning. Prosthesis’ poor postures are corrected by mechanical repositioning the actuators and registration of new values over the old values into the Actuator Module.

IV. CONCLUSION

The virtual environment achieved allows graphical modeling of Artificial Arms and allows, through a dedicated hardware interface, generation of signals similar to mioelectrical signals, which are used to control intelligent Artificial Arms. These signals, related with the movements virtually modeled, enable the study of Artificial Arms or their components in laboratory conditions, in the absence of a patient. Technological progress is also found in this area, and permanently contributes to overcoming these limitations and the development of intelligent Artificial Arms to meet more complex needs of patients. The efforts of the research team involved in this project aimed at developing both the Artificial Arms’ performance (in terms of hardware and software) and its performance in terms of its accurate response speed to direct commands (by biosignals, remote control or direct driving) or indirect commands given by the patient or the environment (through sensors or resistance). To test the Artificial Arm, complex signals were used similar to mioelectrical biosignals as well as the testing system .This system allows testing the Artificial Arm with signals coming from the virtual environment, signals that are comparable to those offered by a patient. The testing system is of great help to determine the accuracy and reproducibility of movements of the Artificial Arm’s components, and their conformity with the movements software modeled.

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