Competency-Based Education in the Design of Medical Rehabilitation Devices: a Case Study

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Abstract — *This paper discusses how concepts associated with Competence-Based Education are applied in Biomechanical project teaching at the Mechanical Engineering Department of the University of Minho.*
The key factor is that the principal actor in the learning process should be the student. Cognitive theory states that knowledge learned and applied in a realistic problem solving context is expected to be remembered and used properly when needed later. In fact, these problem-based learning/teaching strategies, case methods and simulations are useful tools for an effective teaching since students must become active participants rather than passive observers. Students must make decisions, solve practical problems and analyze the achieved results. For this purpose, the paper presenst a summary of the research and parallel teaching activities related to the design of medical and rehabilitation devices in order to increase the quality of life of individuals and the added value of the end products, keeping in mind the present efforts that are being undertaken in the European Union. This task is being carried out at the University of Minho, School of Engineering, which gathered senior researchers from the department of Mechanical Engineering and MSc graduation students from the Integrated Master course in Biomedical Engineering, in the specialization area of Biomaterials, Rehabilitation, and Biomechanics. The design of medical rehabilitation devices needs the integration of knowledge from different backgrounds and scientific areas, with expertise in the various phases of mechanical engineering design involving advanced numerical simulation techniques, who will develop complementary activities to achieve the project goals. The establishment of a solid basis of work and the collaboration between the several working groups are also a goal and motivation for the MSc students involved. The paper also summarizes the most relevant projects developed in the scope of the Curricular Unit Design of Medical and Rehabilitation Devices of the Integrated Master course in Biomedical Engineering. It also be presents and discusses with more detail a case study related to the conceptual design of a feeding device to assist motor or mental handicapped people.

Index Terms — *Competency-based education, Biomechanical project, Medical and rehabilitation devices.*

INTRODUCTION

To reduce the potential healthcare costs arising from a rapidly aging industrial world population, the problem of sustaining independent living for the elderly and persons with low to high levels of disabilities must be addressed. Fundamental knowledge of functional development, change in functional capacity during development and alteration of functional abilities post injury or disease is a focal point of medical rehabilitation research.

Medical rehabilitation research is directed towards restoration and improvement of functional capability lost as a consequence of injury, disease and congenital disorder of children and adults. The mission research is to improve the ability of medical rehabilitation to restore or improve function through research on: (1) functional problems associated with diminished mobility; (2) body systems response to lost function; (3) adaptive behavior systems modifications to functional loss; (4) treatment intervention effectiveness in restoring function; (5) assistive devices that replace or enhance function, and (6) outcome measurement systems that provide an integrative method for tracking functional change over time in many different domains [1].

This paper focus on the development of assistive devices that replace or enhance function, which is the scope of the Curricular Unit Design of Medical and Rehabilitation Devices of the Integrated Master course in Biomedical Engineering, specialization area of Biomaterials, Rehabilitation, and Biomechanics. The concepts associated with Competence-Based Education are applied in this Curricular Unit using the methodology of problem-based learning/teaching strategies. The students are active participants rather than passive observers in the Biomechanical project learning process, because the knowledge is learned and applied in a realistic problem solving where the student must make decisions, solve problems and analyze the achieved results. A summary of the research and parallel teaching activities related to the design of medical and rehabilitation devices, and, with more detail, a case study related with the conceptual design of a feeding device to assist motor or mental handicapped people it will be presented in this paper.

OVERVIEW OF THE MEDICAL AND REHABILITATION DEVICES

There are many examples of assistive devices for people with manipulative and locomotive disabilities. These devices enable disabled people to perform many activities of daily live, thus improving their quality of life. Disabled people are increasingly able to lead an independent life and play a more productive role in society.

Listed below are the titles of the main projects that were offered within the Curricular Unit mentioned, regarding the design of assistive devices for people with manipulative and locomotive disabilities:

- Active and passive system for shoulder rehabilitation;
- Standing frame for rehabilitation of children with mental deficiency;
- System to help dress and undress activities of disabled individuals in wheel chairs;
- Active and passive system for the wrist rehabilitation;
- Feeding device to assist motor or mental handicapped people.

Shoulder rehabilitation device project

The aim of this project was to develop a new device for the rehabilitation of the shoulder. To accomplish this objective, in first place a survey of the physiological characteristics of the shoulder was carried out, regarding the different types of movements provided by this joint and its most common pathologies.

The idea behind this project came from the analysis of an existing equipment, the Rotater [2]. A device was then developed that fulfills all the characteristic features needed for rehabilitation mechanisms, regarding safety and comfort, as well as being capable to provide an adaptive rehabilitation which is quite useful during all stages of recovery. To accomplish this latter issue, one of the important aspects on this design was the fact that it should be able to rehabilitate the patient in an active and passive scheme, i.e. the device must rehabilitate the shoulder when the patient is unable to exercise it, also enabling the operator or supervisor (usually a physiotherapist, a medical doctor or any other health or rehabilitation professional) to control the rehabilitation procedure to permit the patient to perform some force to improve and/or accelerate the recovery (commanding and controlling the torque developed by the motor that moves the rehabilitation shoulder device).

Therefore, a new system was proposed that adapts an existing arrangement (where the patient exerted his strength by using the other arm), to which a motor was attached to act the mechanism to exercise the shoulder of the patient, without exerting any force during the rehabilitation procedure. Figure 1 shows the 3D modeling of the device designed for passive and active rehabilitation of the shoulder.

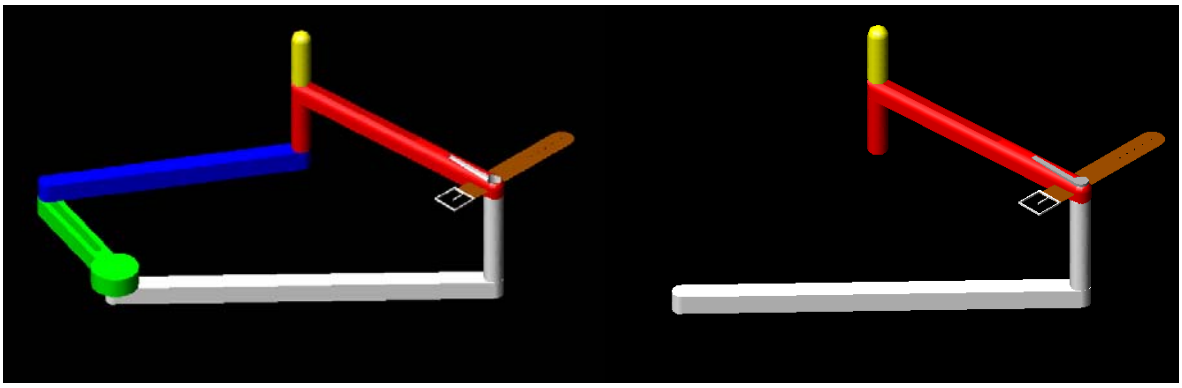


FIGURE 1
CONFIGURATION OF THE SHOULDER REHABILITATION DEVICE: (LEFT) ACTIVE DEVICE AND (RIGHT) PASSIVE DEVICE

Standing frame project

A standing frame is a mechanical or mechatronic equipment that aims to correct the inability of individuals to assume the vertical position. The available standing frames do not enable an easy positioning and placement of the individual on the device, do not permit full mobility (inside and outside buildings), are not versatile, modular and do not allow children to have occupational activities during treatments. The standing frame developed here and to be used in the treatment of children mental handicapped, takes into account the drawbacks mentioned above and it is perfectly adapted to this specific targeted individuals. The main features of the developed equipment is the modularity, being easily operated and used, especially when the handicapped, and family, need to travel and need to carry with them the standing frame. Figure 2 illustrates the 3D models developed for the standing frame in two different perspectives, where the most important mechanical components can be observed.

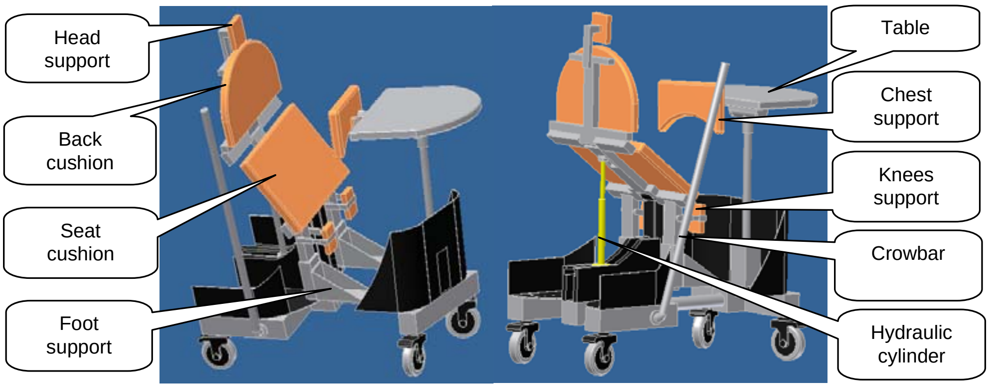


FIGURE 2
OVERALL 3D VIEWS OF THE DEVELOPED STANDING FRAME

Dress and undress aid device project

The main objective of this project was to design and develop a device to help individuals with paraplegia to dress and/or undress. The whole design was based on the procedure for dressing or undressing pants and for individuals with a maximum weight of 120 kg. The proposed solution is a system to be adapted to a common wheelchair, which will have a ramp or a hydraulic pump that be driven by the handicapped individual. Therefore, the individual can elevate her/his legs through a crank or pump, and using a vest and a simple device (attached to the back of the wheelchair) may also elevate the pelvis to pull up or down the pants. The designed alternative to enable the lifting or lowering of the handicapped legs provides a more extensive use of the device, since the use of the pump can cover other handicapped individual groups, as is the case of amputees. Figure 3 displays the 3D modeling of the designed helping device, where the major components are also depicted.

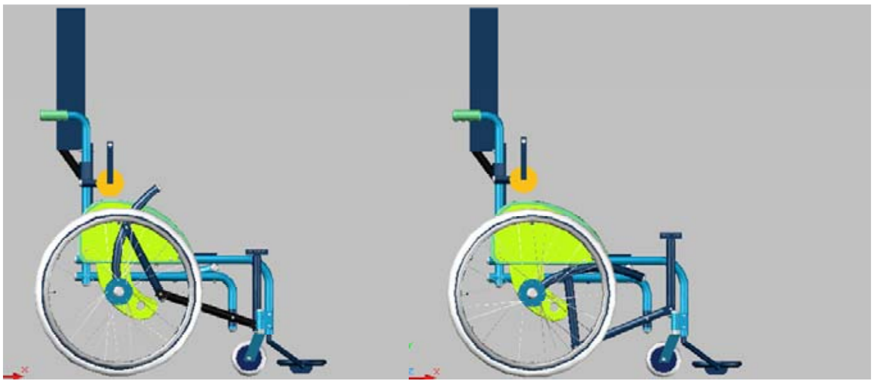


FIGURE 3
SCHEMATIC REPRESENTATION OF THE LIFTING SOLUTION FOR THE HANDICAPPED LEGS (USING PULLEYS): (LEFT) MINIMUM POINT AND (RIGHT) MAXIMUM POINT

Wrist rehabilitation device project

The rehabilitation of the wrist involves a good number of complex movements. Although there are several systems and devices to carry out the rehabilitation of this particular human articulation, there is a lack of a mechanical device to carry out this purpose to provide passive and active rehabilitation movements during the recovery process. Presently it is considered that the current rehabilitation is somewhat confined to an occupational therapy. There is, however, an equipment whose operating principle was the basis for this project development, because its application was promising in the context of rehabilitation, since it could cover all the movements that would be expected in the process of rehabilitation. This equipment is called Powerball® [3].

The PowerBall® has, in theory, a very simple working principle: a ball with carefully balanced weights, so it could rotate around their axes, is forcing to create a centrifugal force effect. The PowerBall® operates as a gyroscope with its kinetic motion allowing the recovery and strengthen of the wrist joints. One of the objectives of this project is to evaluate and assess the limitations of this equipment and to suggest a possible improvement, to generalize its application to more wrist and other body parts pathologies. Three-dimensional models of the developed device can be observed in Figure 4.

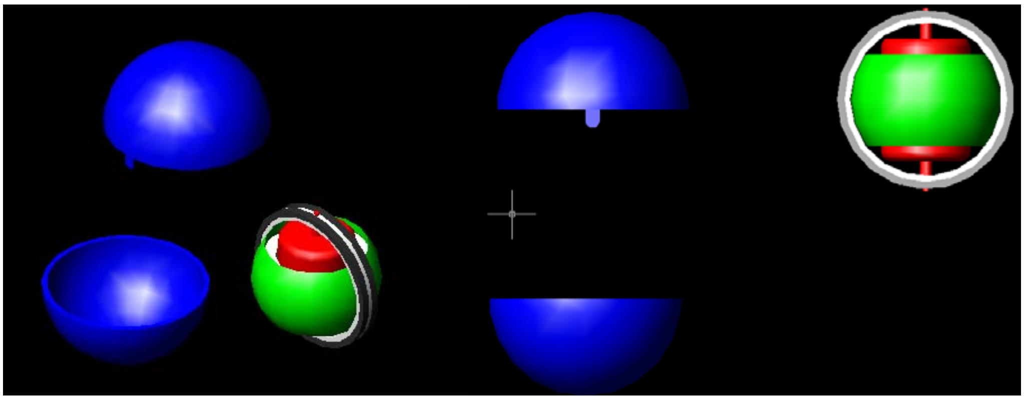
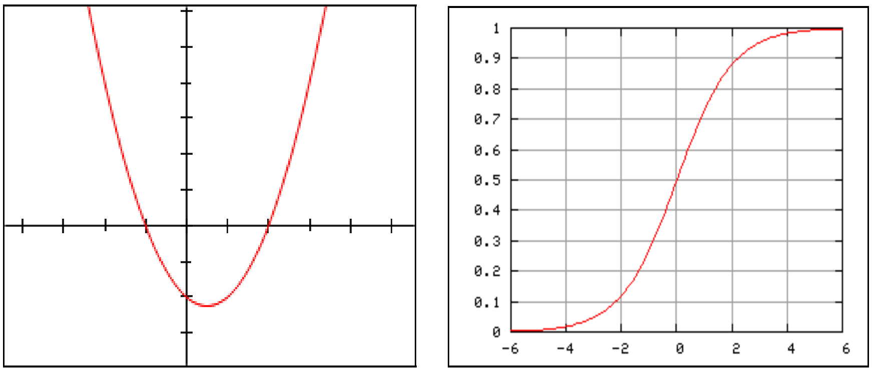


FIGURE 4
3D MODELS OF THE DEVELOPED WRIST REHABILITATION DEVICE

Feeding aid device project

The main motivation for this project is that the eating process is one of the most important activities in everyday life. Eating activity influences many aspects of our overall medical, physical, and social well being. Gustafsson [4] evaluated the psychological effects of self-feeding and found that disabled individuals who attained their goals of self-nourishment had a heightened sense of control, security and hope for the future. The inability to feed oneself has been linked to shame for human incompetence, decreased self-esteem and feelings of panic or fear. This information supports attempts to study feeding devices that assist individuals unable to feed themselves.

To be possible to develop the mechanical system of an aid device, it is of paramount importance to know the natural feeding trajectory. For that reason, an experimental analysis of the feeding movement was performed and it was concluded that the trajectory is not linear: it approaches to a parabola or even to a Sigmoid function (see Figure 5).



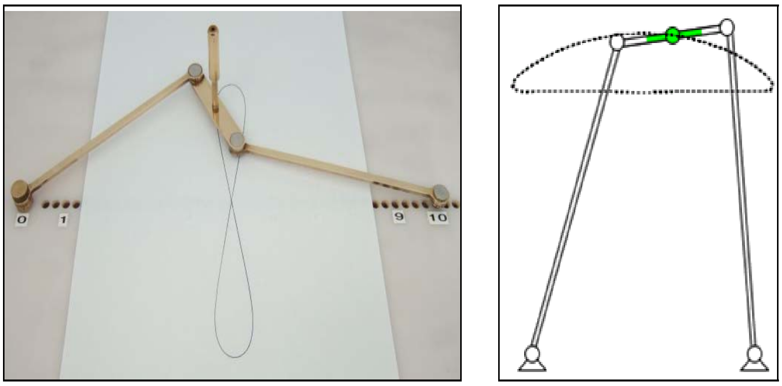
(A) (B)

FIGURE 5
(A) QUADRATIC FUNCTION; (B) SIGMOID FUNCTION

This path is the most appropriate for the use in a mechanism with a motor, since it transmits a continuous and progressive movement. However, it is essential to find a suitable mechanism to replicate this trajectory with a driven motor only. Besides, it is fundamental that it can be possible to stop the mechanism in a specific point to allow the patient's feeding. It is still desirable that the described trajectory is cyclical and that it should incorporate the individual's mouth in one of the trajectory points. For that it was necessary to select the most appropriate mechanism to accomplish these requirements.

It was first considered the Watt mechanism (see Figure 6A). This four-bar linkage returns a trajectory in form of "eight", which could satisfy the initially imposed conditions. However, the mechanism of Watt presents two problems: first, the point that describes the intended trajectory it is the medium point of the central bar (coupler link), which represents a physical obstruction for placing the spoon; second, this mechanism is driven by a bar with an alternate motion (input link), which requires the change of the rotation of the motor; this aspect does not satisfy the needed requirements. Despite these problems, the difficulty to maintain the horizontal position of the spoon during the whole trajectory still exists.

Further, it was studied the possibility to use the Chebyshev mechanism (see Figure 6B). This returns a "half moon" trajectory that is much easier to maintain the horizontality required for the spoon during the trajectory. However, this mechanism presents the same problems as the previous one, because the point that describes the trajectory is the medium point of the central bar (coupler link), also requiring an alternate driving motor.

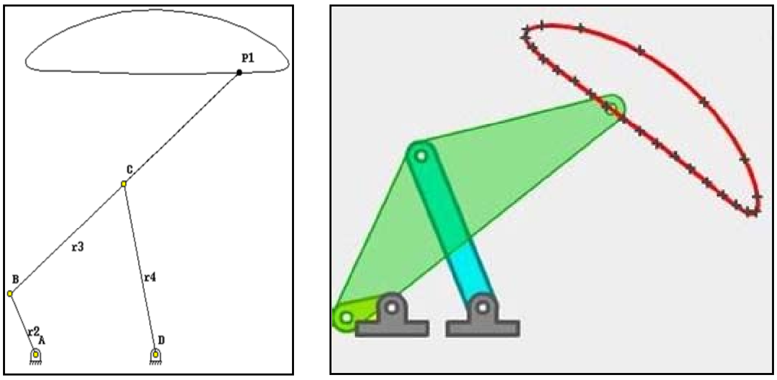


(A) (B)

FIGURE 6
MECHANISMS: (A) WATT AND (B) CHEBYSHEV

In this project, the Hoekens mechanism (see Figure 7A, a variation of the Chebyshev mechanism) was also analyzed with the advantage of having the trajectory defined by the end of one bar (point P1 of Figure 7A). With this mechanism it is possible to fulfill the two main system requirements: to perform the trajectory with the intended end point, while the mechanism is driven in only one rotation direction, since the driven bar carries out a motion of 360°.

Finally, the four bar linkage selected was the Burmester mechanism (see Figure 7B), which is similar to the Hoekens mechanism. The orientation of the fixed body in this mechanism relatively to the obtained trajectory is different and, due to this reason, it was considered more appropriate to the aid feeding system to be developed.



a) b)

FIGURE 7
MECHANISMS: (A) HOEKENS AND (B) BURMESTER

After the selection of the mechanism that best fits the intended trajectory, a 3D CAD model was built to permit its analysis, as shown in Figure 8.

It was necessary to consider the maximum height of the movement that allowed the correct feeding of the individual, as well as the minimum height to make possible the filling of the spoon.

Using AutoCAD®, from Autodesk, it was possible to find the appropriate relationships between the lengths of the bars that can describe the required trajectory using the mechanism of Burmester. It was obtained a length ratio of 2:1 between the fixed bar (B1) and the driven bar (B2) and of 1:2 between the fixed bar (B1) and the remaining bars (B3, B4 and B5). For the bars linkage was used rotation joints (four in the main mechanism and one in the rotation system of the food container). It must be emphasized, that having been used five bars, the mechanism of Burmester is a mechanism with only four bars; the bar of different geometry was replaced by two bars (B4 and B5) linked together.

Finally, in order to evaluate and validate the proposed feeding aid device, the motion of the mechanism was also analyzed by using a commercial software specially dedicated to these type of mechanical systems. The computational program Working Model 4D (by MSC.Software [5]) was used to carry out the kinematic analysis of the displacement of the spoon, to determine the performance of the feeding system.

After positioning all components (bars, spoon, food container and other components), the mechanism is completed with all its characteristics, that is, the kinematic pairs, the generator of the movement, the friction and restitution coefficients, etc. Once defined the characteristics of the four bar linkage mechanism, it was possible to carry out the kinematic analysis where, for the present simulation, the output variables are the position, velocity and spoon acceleration. The obtained results are presented in the figure 9, using a graphical form, according to the displacement movement of the spoon mechanism.

Based on the obtained simulation results, it can be concluded that the developed mechanical system is appropriate as a feeding aid device, because it enables to obtain the required spoon trajectory in a continuous motion.

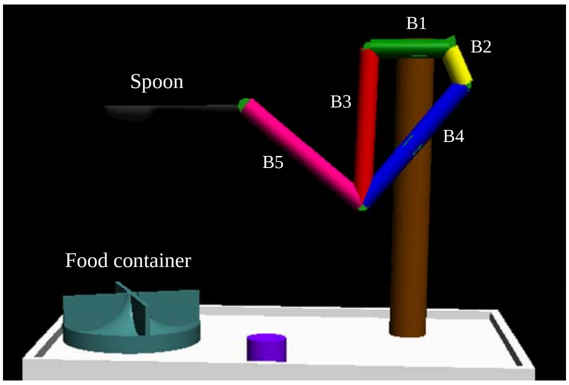


FIGURE 8
3D MODEL OF THE DEVELOPED FEEDING AID DEVICE

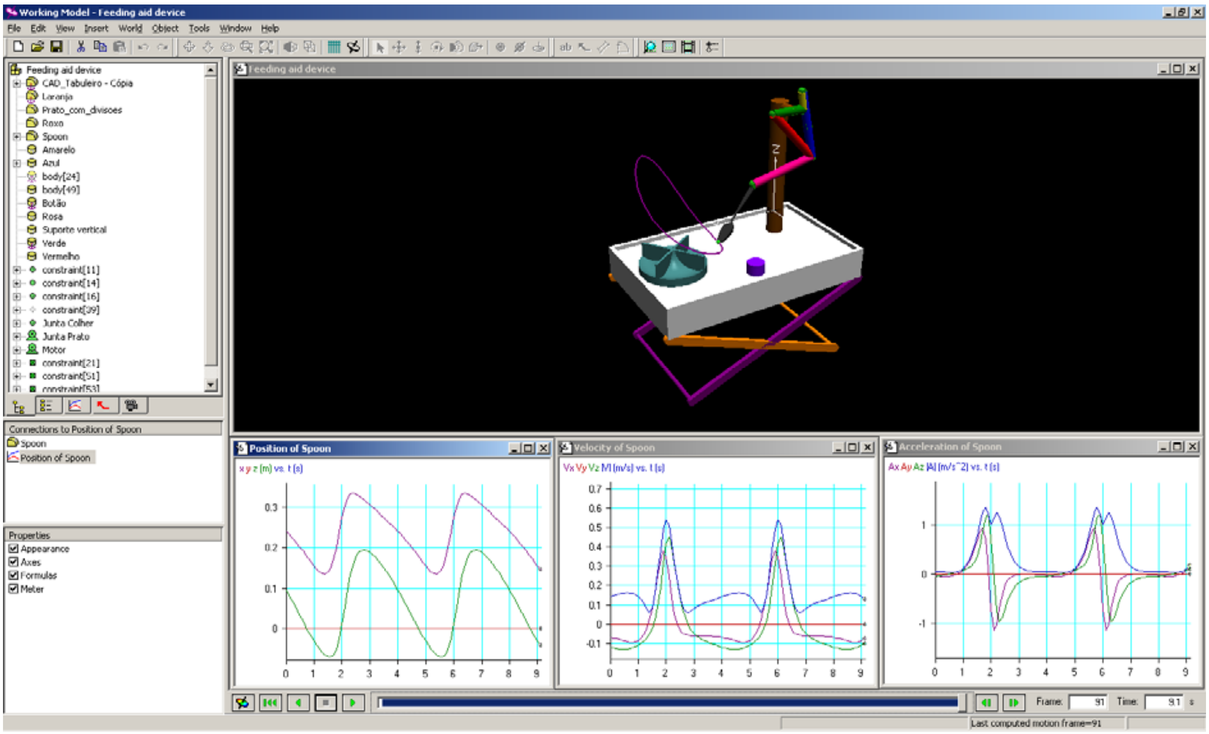


FIGURE 9
KINEMATIC ANALYSIS OF THE DEVELOPED FEEDING AID DEVICE USING THE WORKING MODEL 4D SOFTWARE (FROM MSC.SOFTWARE)

CONCLUDING REMARKS

The integration of knowledge, skills and performance relating to Competency-Based Education [6-11] in the teaching of engineering design methods for the design and development of medical and rehabilitation devices (at the Department of Mechanical Engineering, University of Minho) was implemented based on case studies. Some of these case studies have been presented and discussed in this paper, with a special focus on the design of a feeding device to assist motor or mental handicapped individuals.

The role of the teachers in this learning process, in the particular Curricular Unit of “Design of Medical and Rehabilitation Devices”, was just to tutor and to support and guide students in practice. The students were free to choose between several ways of gathering information and to decide which was the best way to accomplish the objectives for each one of the proposed case studies.

The results of the implementation of these learning methodologies were very positive, since good results have been obtained, for all students, in all assessment stages throughout the semester. The students were motivated and happy to the syllabus of the course and the skills acquired by these students were the knowledge of engineering design methods, mechanical engineering design and mechanisms analysis, the use of AutoCAD (from Autodesk) and specific motion simulation software (Working Model 4D, from MSC.Software), as well as some of the automation knowledge on the development stages. Group work, the ability to collect relevant information and the opportunity to extend the students work to R&D activities in the field of science and technology was also encouraged in this course.

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