CONSTRUCTION OF ROBOTIC STRUCTURES USING LEGO MINDSTORMS NXT KIT

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Abstract. *One of the major challenges of the modern educator is to teach the theoretical lessons with practical examples that can be taught in the classroom or teaching laboratories. The application of these examples will address a major problem for students in engineering the difficulty of understanding and seeing how a mechanical and/or mechatronic device functions in everyday life. This requires the use of tools that enable the construction of different prototypes of low cost to assist in student learning. Another challenge to educators is the need to motivate students during the lessons and of these ways is the presentation of models that students themselves can make and develop. Within this context this paper presents a pedagogic proposition based on the use of LEGO Mindstorms kits as a laboratorial tool in robotics lessons. The objective is to develop new teaching methodologies with the use of these LEGO kits in order to motivate the students and also to promote a higher interdisciplinary, by proposing projects that unify different disciplines from the curricular grids. The robot LEGO kit Mindstorms NXT, used in this paper is composed of a programmable logic controller with 32-bit microprocessor with USB 2.0 and Bluetooth, four input ports and three output ports; set Lego Technic; 3 servo motors, a touch sensor, an ultrasonic sensor, a sound sensor and a light sensor. This kit also includes software programmable that use the software platform from LabView. This paper reports about development of activities to build prototypes of parallel robotic structures using the LEGO kit Mindstorms. It was possible to analyze a broad range of mechanisms such as mechanism of five bars, planar robotic platforms and three-dimensional structures with spherical, prismatic and rotation joints allowing the interface between different knowledge areas of engineering such as mechanical design, electrical and sensor, solid mechanics, dynamic, control and programming. In this paper are presented the parallel structure 5R with the analysis of motion and singularity positions, the structures Delta, Hexa, CaPaMan and 6-RSS in which the movement mechanisms were analyzed. The development of these prototypes allows a complete visualization of problems in mechanisms such as singularities, settings in which the structure loses control, flexibility, assemble problems, collision problems and determination of operation limits and facilitate the understanding, visualization and motivate the student. Thus these Mindstorms and Technic kits can be used as a tool for prototyping robotic initial short-term implementation and low cost.*

Keywords*: Mechatronic, Robotic Structures, LEGO robots, LEGO Mindstorms.*

1. INTRODUCTION

The use of new technologies in the teaching and learning processes is currently on the increase. Educational robotics has made remarkable progress in several educational environments. In spite of the use and the versatility of such an educational tool it is not employed on a very large scale in Brazil, chiefly due to the equipments' high costs. Current problem has motivated the development of current research comprising a low cost solution to implement educational robotics in Brazilian schools.

Today, there are several educational kits on the market, specially designed for education, in which the student is required to have fun with these kits at the same time learning the basics of robotics. This proves to be a useful tool for learning because it not only allows the students to connect with new technologies, such as fostering the mental development of the same areas of interest in creating new technologies and logical reasoning like Artificial Intelligence and Robotics.

The Artificial Intelligence and Robotics areas are interconnected in order to develop methods or efficient algorithms that allow providing "intelligence" mechanism developed by humans. Since the beginning the human imagination has always been led astray by the idea that machines would ever be able to think and understand the universe through their own means and replace humans in tasks. Much of this imagination has always been expressed in movies or series that ended up influencing generations to dedicate themselves to research and discovery of new forms of robotic mechanisms to provide intelligence as well as the discovery of new mechanisms with much more capacity and, consequently, with a better support for new algorithms and reasoning methods (Figueira, 2008).

One of the major challenges of the modern educator is to teach the theoretical lessons with practical examples that can be taught in the classroom or teaching laboratories. The application of these examples will address a major problem for students in engineering the difficulty of understanding and seeing how a mechanical and/or mechatronic device functions in everyday life. This requires the use of tools that enable the construction of different prototypes of low cost to assist in student learning. Another challenge to educators is the need to motivate students during the lessons and of these ways is the presentation of models that students themselves can make and develop.

Aiming to meet these needs was developed in Massachusetts Institute of Technology (MIT, 2011) a programmable bricks used by LEGO® in the kits Mindstorms®.

Thus, this paper reports about development of activities to build prototypes of parallel robotic structures using the LEGO kit Mindstorms. First is presented the kit LEGO MINDSTORMS NXT® and its relationship with the mechatronics and multibody system robotics. After the planar parallel structure 5R is presented with the analysis of motion and singularity positions. Finally, the structures Delta, Hexa, CaPaMan and 6-RSS were presented.

2. ROBOTIC AND THE KIT LEGO MINDSTORMS NXT®

The new LEGO brick is called "NXT" and has been upgraded from a 16-bit to a 32-bit processor. NXT is at the heart of the next generation of the LEGO MINDSTORMS "toolset" and is designed for novice to expert robotics enthusiasts. The NXT microprocessor can be programmed to exhibit autonomous behavior using either a PC or a MAC. After building a robot, users create a program with easy-to-use, feature LabVIEW software from National Instruments which works with a graphical language. The users can program robots and actively interact with them during programming through sensors. The new system features an improved, intuitive, icon-based drag and drop environment for "building" programs; 18 building challenges with clear, step-by-step instructions help new users create robots ranging from humanoids and machinery to animals and vehicles. Users with Bluetooth® enabled computer hardware can transfer their programs to the NXT wirelessly, or anyone can use the included USB 2.0 cable to connect a computer to the NXT for program transfer. The inclusion of Bluetooth technology also extends possibilities for controlling robots remotely, for example, from a mobile phone or PDA. In addition to the new NXT brick, standard kits include three interactive geared servo motors that feature built-in rotation sensors (sensitive to one degree out of 360°) for precise control. A new ultrasonic sensor enables a robot to "see" obstacles, measure distances and respond to movement. A sound sensor enables robots to respond to sound commands with sound pattern and tone recognition. An improved light sensor actually permits color differentiation and an improved touch sensor reacts to contact or release allowing robots to "feel" their surroundings, Fig. 1. The new tool set no longer relies upon LEGO building blocks but rather is based on stylized elements from the LEGO TECHNIC® building system to ensure robot designs will be sturdy, durable and authentic looking (LEGO Education, 2011). All this at a cost of around R$ 2.500,00 in Brazil.

Mechatronics can be defined as the integration of knowledge in the areas of mechanics, electronics and computing. According to Rosario (2005), formation in mechatronics should be based on: i) solid fundamentals and as extensive as possible, ii) systemic and multidisciplinary approach involving mechanics, electronics and computing, and iii) learning based on experimentation, in order to eliminate the gap between purely academic project and the real world, with its limitations and compromises. It is understood, therefore, that a course of modern mechatronics engineering students should be offered to its activities capable of developing these design skills in the real world, multidisciplinary teamwork, communication and time management and activities (Simões *et al.*, 2006; Silva *et al.*, 2009).

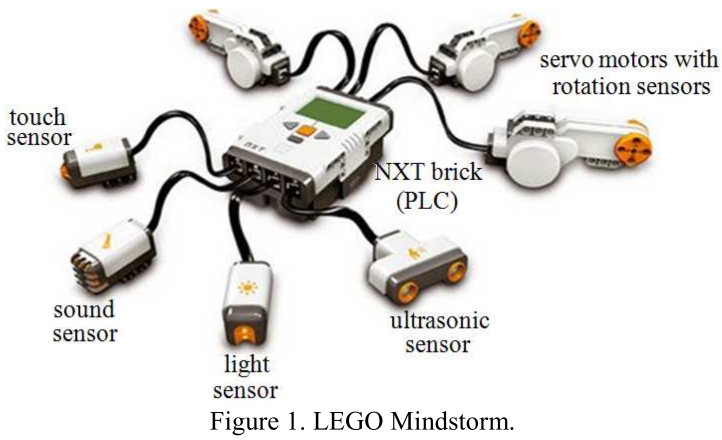


Figure 1. LEGO Mindstorm.

In this way, the Fig. 2 shows the relationship between the LEGO Mindstorm kit and Mechatronics. The student can apply to robotic structure concepts of mechatronics, with the construction of mechanical part using a set of LEGO pieces technique, sensors allowing interaction with the environment, programming the robot to give it intelligence and finally a processing unit, PLC (programmable logic controller), to connect the parts.

These LEGO Mindstorm kits allow the construction of the multibody system like parallel robot structure. The multibody system consists of a structure composed of segments that can be rigid or flexible, connected together by joints.

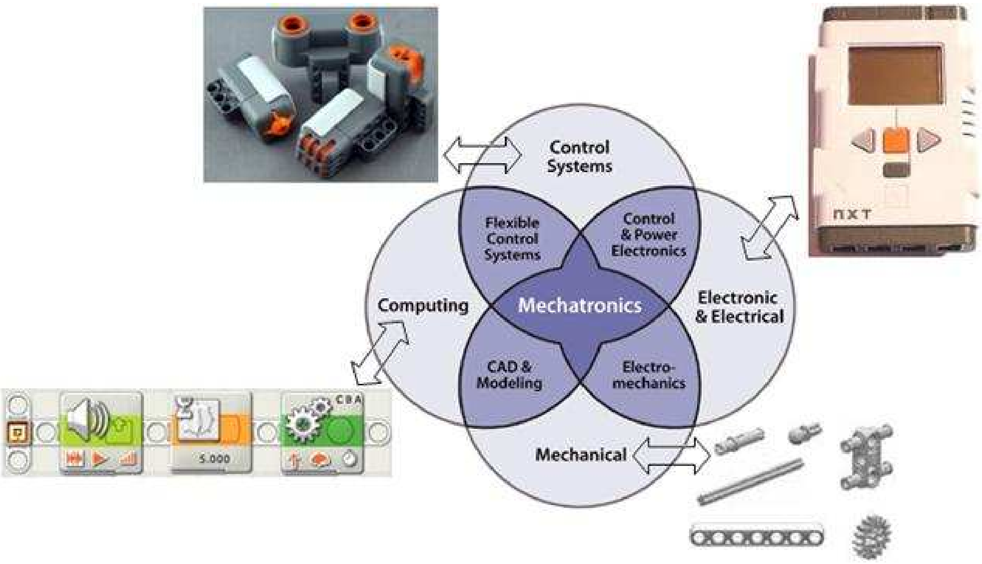


Figure 2. Relation with Mechatronics and LEGO Mindstorm.

A multibody system that has been widely studied in recent years is the so-called parallel manipulator. A parallel manipulator typically consists of a moving platform that is connected to a fixed base by several serial chains, called limbs. Features of such system can be better stiffness and payload capacity with respect to the serial architectures, and high velocity and acceleration during the operation (Tsai, 1999; Gonçalves, 2009). Furthermore, errors in the joints are not cumulative, which contributes for its overall accuracy. Due to their characteristics they have been studied extensively both from theoretical and practical viewpoints. Prototypes have been conceived and built together with the development of theoretical investigations on kinematics and dynamics, but the cost and time to develop these prototypes is high. The attention are focused to a number of possible industrial applications such as manipulation, packing and assembly/disassembly machines, motion simulation, milling machines, toys and sensors. However, they have some disadvantages such as small and complex workspace with internal singularities and the complexity of their forward kinematics (Macho et al., 2008; Gonçalves and Carvalho, 2008). For undergraduate teaching, one of the difficulties is view the function and understands the parallel structures in robotics, your workspace, singularities and collisions between the segments. The use of the LEGO kits allows for easy viewing of these problems.

Therefore, one of the important limitations of parallel mechanisms is that they may lead to singular configurations in which the stiffness of the mechanism is lost. The physical meaning of a singularity in kinematics refers to those configurations in which the number of degree of freedom (dof) of the mechanism changes instantaneously. The kit LEGO permits visualize this problem.

The concept of singularity has been extensively studied and several classification methods have been defined. Gosselin and Angeles (1990) suggested a classification of singularities for parallel manipulators into three main groups. The first type of singularity occurs when the manipulator reaches internal or external boundaries of its workspace and the output links loses one or more dof. Second type of singularity is related to those configurations in which the output link is locally movable even if all the actuated joints are locked. Third type is related to linkage parameters and occurs when both first and second type of singularities is involved. Tsai (1999) classify the tree type of singularity by: inverse singularity; direct singularity and combined singularity respectively.

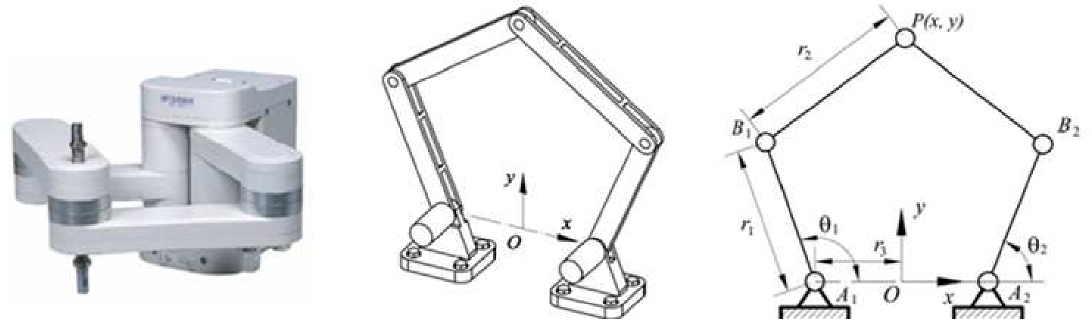
One of the most important characteristics of manipulators is the workspace. The workspace is the set of position and orientations configurations in which the end-effector is controllable and workspace determines geometrical limits on the task that can be performed. The workspace of parallel kinematic mechanisms has in general a complex volume shape. Again the use of LEGO kits allows the visualization the workspace and its different configurations with the change of the parameters of the structure under study.

Thus, this paper use the LEGO Mindstorm Kits to facilitate the teaching of robotics and visualization of singularities, wokspace and understanding the functioning of robotic three-dimensional structures.

3. THE PARALLEL STRUCTURE 5R AND THE SINGULARITY STUDY

Close to or in singular configurations parallel manipulator becomes uncontrollable. In these configurations, the mechanism tends to lose its stiffness while gaining extra degrees of freedom. Physically, when the mechanism is in a singular configuration, the structure cannot resist an external wrench applied to the end-effectors (mobile platform), therefore may collapse (Gonçalves, 2009; Tsai, 1999).

The five-bar manipulator is a typical parallel manipulator with the minimal degrees of freedom (d.o.f), which can be used for positioning a point on a region of a plane, Fig. 3(a). A 5R parallel manipulator consists of five bars that are connected end to end by five revolute joints, two of which are connected to the base and actuated, as shown in Fig. 3(b).

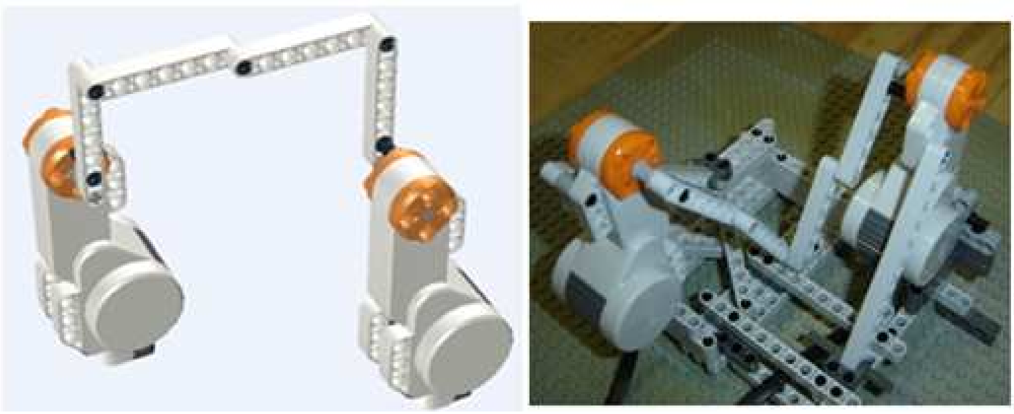


(a) (b) (c)

Figure 3. (a) Robot 5R Mitsubishi Electric; (b) The 5R Parallel Manipulator; (c) Kinematics model (Liu *et al.*, 2006a).

A kinematics model of the manipulator can be developed as shown in Fig. 3(c), (Gonçalves and Carvalho, 2009). Each actuated joint is denoted as A_i ($i = 1, 2$), the other end of each actuated link is denoted as B_i and the common joint of the two legs is denoted as P, which is also the output point. A fixed global reference system O_{xy} is located at the center of A_1A_2 with the y axis normal to A_1A_2 and the x axis directed along A_1A_2. For the structure symmetry, one have $OA_1 = OA_2 = r_3$, $A_1B_1 = A_2B_2 = r_1$ and $B_1P = B_2P = r_2$. In the structure built with LEGO bricks relations length of the bars are: $A_1B_1 = A_2B_2 = B_1P = B_2P = 6M = 48mm$ and $A_1A_2 = 12M = 96mm$.

For the workspace was the largest possible and the bars do not collide with each other they were placed in different planes as well as the motors, Fig. 4. Figure 4(a) shows the design and assembly done in software LEGO® Digital Designer® (LDD, 2011) and Fig. 4(b) the built prototype with LEGO®.

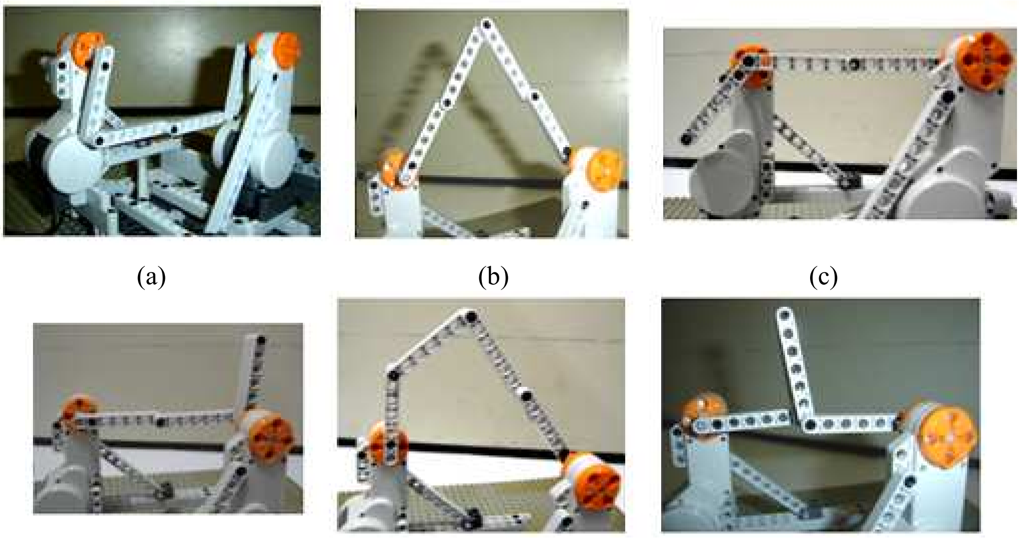


(a) (b)

Figure 4. (a) 5R Mechanism; (b) Prototype assembled with LEGO®.

In this structure the direct singularities occurs when A_1B_1P or A_2B_2P is completely extended or folded. These singular configurations are complex configurations where the actuators cannot resist applied forces and/or moments on the moving platform and this loci singularity are inside on the workspace. The singularities due to inverse kinematic model correspond to the configurations in which the moving platform loses one or more degrees of freedom. These singularity occur when A_1B_1 is parallel to B_1P or when A_2B_2 is parallel to B_2P. These singularities determine the boundary of the workspace.

The singularity positions illustrated in Fig. 5 were obtained from the initial positioning of the 5R mechanism free of singularity and the movement of the servomotors to the loci of singularity (Gonçalves, 2009). In these configurations or close, Fig. 5, the structure locks or loses control.



(a) (b) (c)

(d) (e) (f)

Figure 5. Singularities configurations of 5R mechanism built with LEGO®.

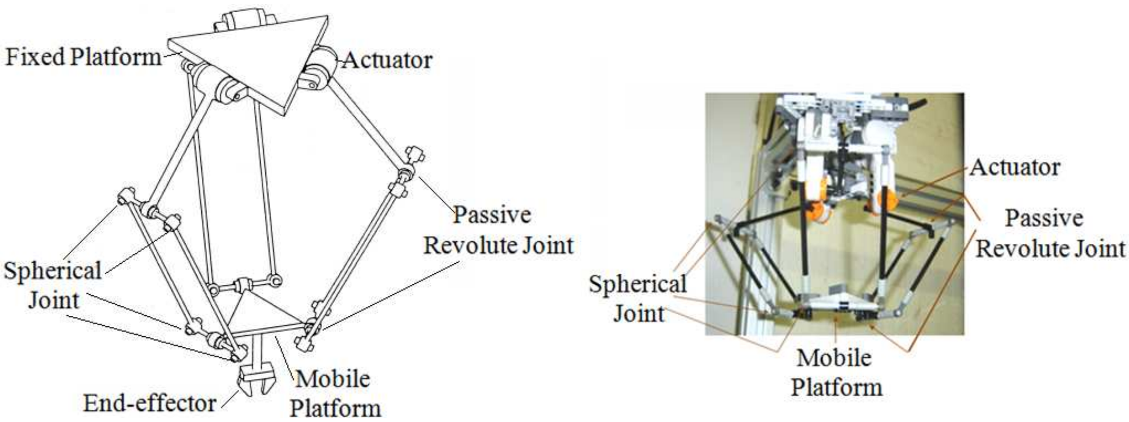
4. CONSTRUCTION OF THREE-DIMENSIONAL PARALLEL STRUCTURES.

This section will describe some three-dimensional robotic structures developed with LEGO Mindstorm kits. The purpose of these assemblies with LEGO is to show the functioning of these structures facilitating student understanding in the applications of these structures in the discipline of robotics.

4.1. Delta Manipulator

In 1988 Clavel introduced a three degree of freedom (dof), three identical legged manipulator he called “Delta”. This device is shown in Fig. 6. Its end-effector executes pure spatial translation (Clavel, 1991).

As shown in Fig. 6(a), the kinematic chain of the Delta parallel manipulator is composed of three identical serial kinematic chains that share the base or fixed platform and the mobile platform. For each serial chain (from the base to the end-effector), the links are coupled by an actuated revolute joint and the passive revolute joints. The Fig. 6(b) shows the built LEGO Delta manipulator.



(a) (b)

Figure 6. (a) Delta manipulator sketch; (b) Delta manipulator built with LEGO®.

During the experimental tests of the Delta structure built with LEGO® the mobile platform always remained parallel to the base, Fig 7(a-c). Figure 7(d) represents a singularity configuration in which the segments are aligned.

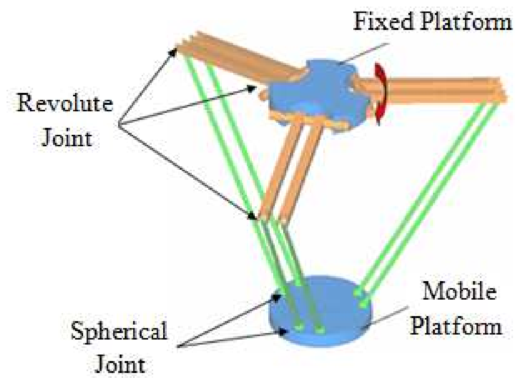
(a) (b) (c)

(d)

Figure 7. (a-c) Sequence of moving the Delta manipulator; (d) Singularity configuration.

4.2. Modified Hexa Manipulator

The modified Hexa mechanism consists of six elementary kinematic chains. All these chains are identical and consist of one arm, one rod, one passive revolute joint and a spherical joint. The base of the modified Hexa robot is fixed with the ceiling of the supporting frame and all the 6 motors are placed in this base. Each motor is then attached to an arm and directly actuates it. In this way, each kinematic chain, though having three joints in it, has only one active joint in its base, while the rest of two are passive. With these six chains, it is possible to achieve six degrees of freedom at the mobile platform, Fig. 8 (Pierrot, 1998).



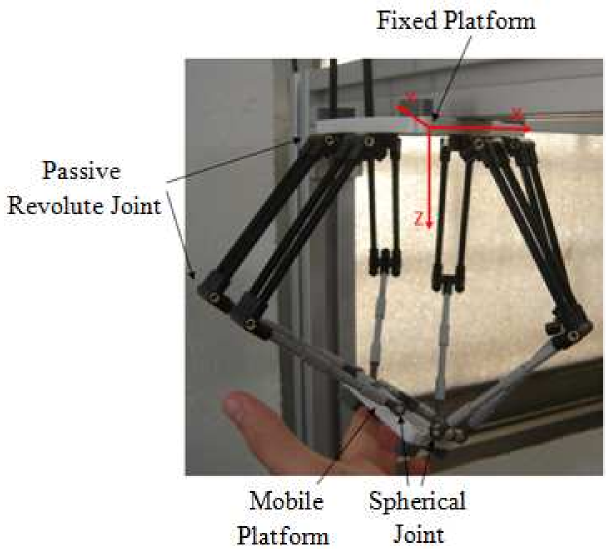


Figure 8. (a) Modified Hexa manipulator sketch; (b) Modified Hexa manipulator built with LEGO®.

Figure 9(a-d) show a sequence of moving the modified Hexa manipulator and it is possible to see the potential to tilt the mobile platform. Figure 9(e) shows a configuration singularity of modified Hexa when the segments are aligned and the manipulator loses control. Since Fig. 9(f) represents a configuration in which the collision hap between segments.

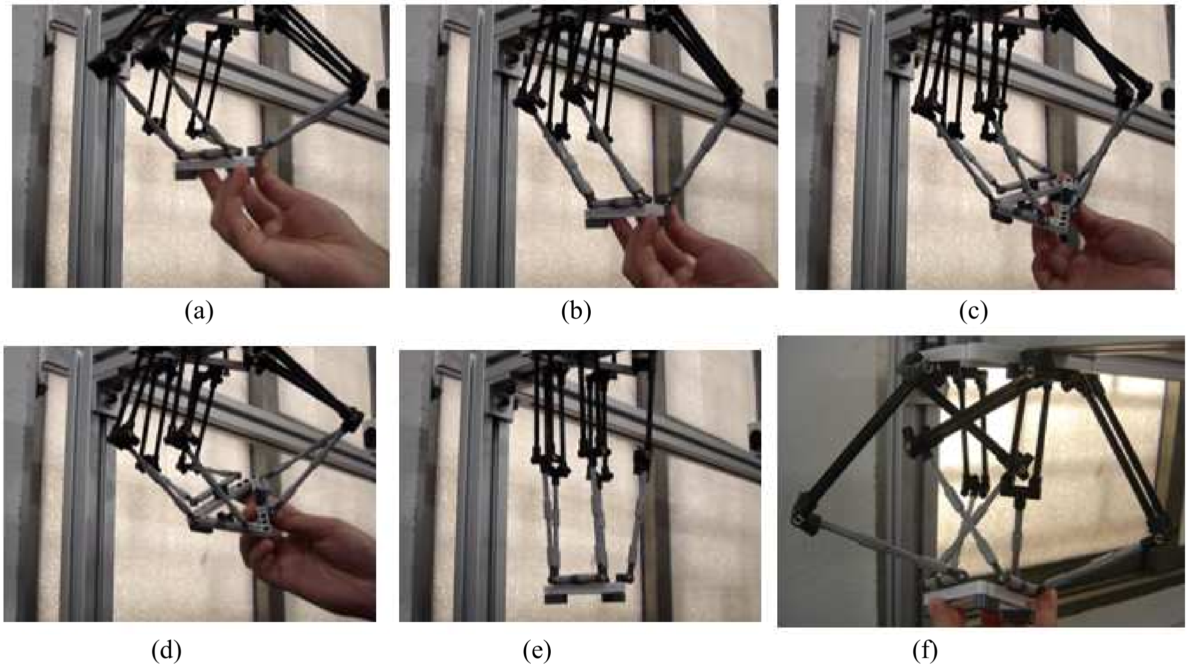


Figure 9. (a-d) Sequence of moving the Hexa manipulator; (e) Singularity configuration; (f) Collision between segments.

4.3. CaPaMan (Cassino Parallel Manipulator)

CaPaMan (Cassino Parallel Manipulator) is a 3 degree of freedom spatial parallel manipulator that has been designed at the Laboratory of Robotics and Mechatronics, in Cassino. It is composed by a fixed platform that is connected to a mobile platform by means of three leg mechanisms (Carvalho *et al.*, 2008). Each of these is composed by an articulated parallelogram, a prismatic joint and a connecting bar, Fig.10(a). The centers of the bases of these mechanisms are arranged at the vertices of an equilateral triangle in the fixed platform, so that the planes containing them, form angles of 120°, thus giving the symmetry properties of the manipulator, Fig. 10(a).

To construct the CaPaMan using the kit LEGO Mindstorms NXT limiting construction was to construct a passive prismatic joint, Fig. 10(b), with minimum clearance, Fig. 11.

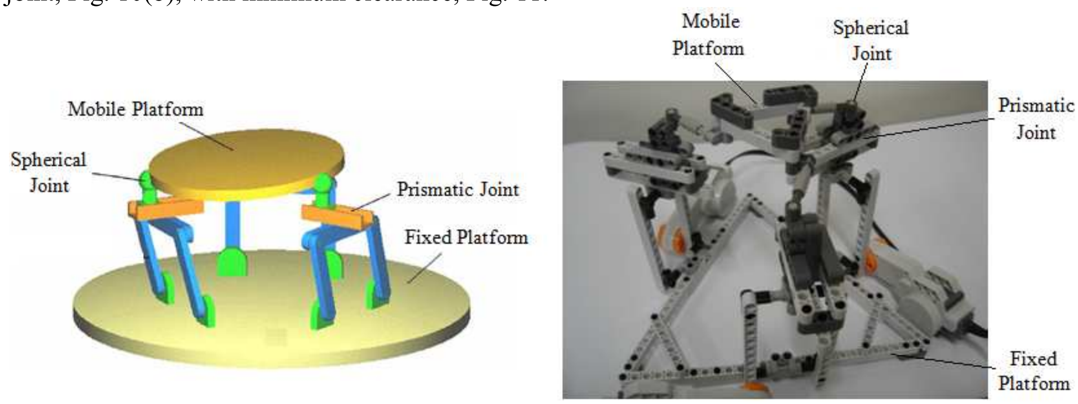


Figure 10. (a) CaPaMan sketch; (b) CaPaMan built with LEGO®.

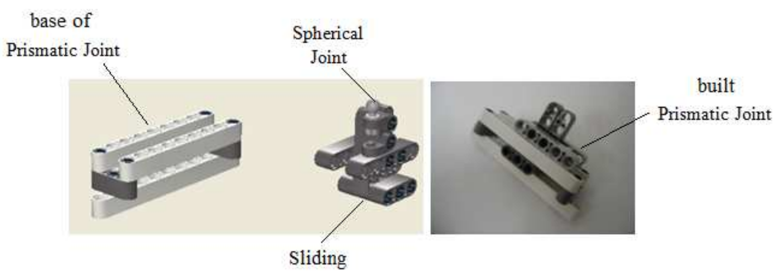
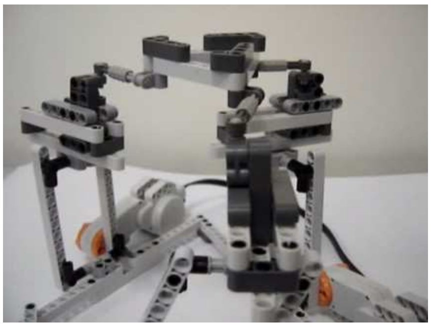
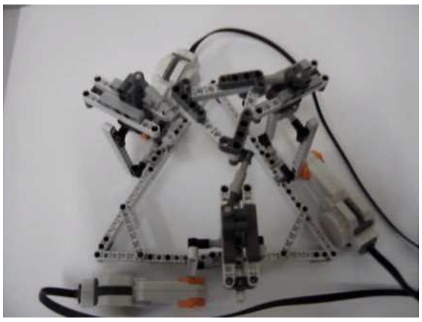
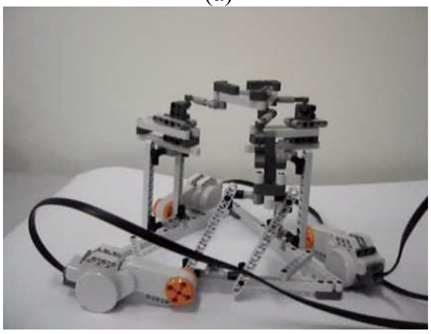
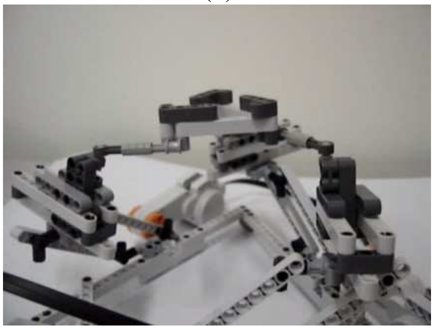


Figure 11. Prismatic Joint.

Figure 12 shows the sequence the movement of the CaPaMan. During the simulation sponsored by orderly movement of the three motors was verified visually that the workspace hit by the terminal element is small.

(a) (b)

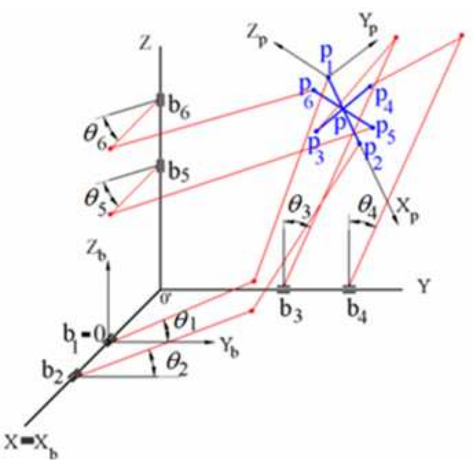
(c) (d)

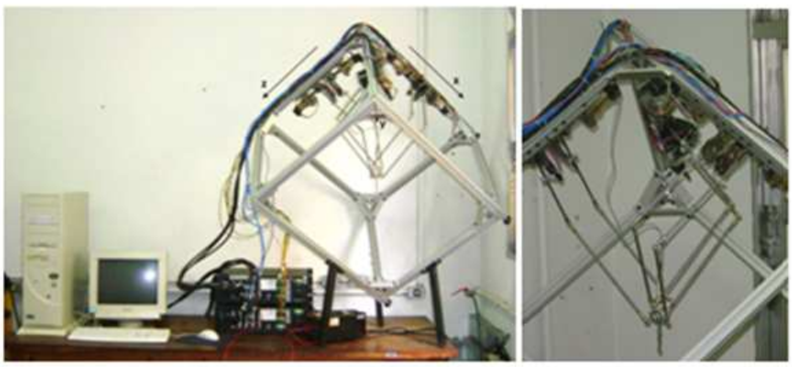
Figure 12. Sequence of moving the CaPaMan manipulator

4.4. The 6-<u>R</u>SS Parallel Manipulator

The 6-<u>R</u>SS parallel architecture is a 6 degree of freedom manipulator, which is characterized by a base and a mobile platform, connected by six *RS-SS* segments, where the R-joint is on the Cartesian axes, two joints by axis, that has been designed at the Laboratory of Robotics and Automation at Federal University of Uberlândia, Brazil, based on the work of Jacquet (Jacquet et al., 1992) as shown in Figs. 13 and 14. The Cartesian system is the base of the structure where the actuators are mounted, reducing dead loads. The links can be constructed by light and resistant materials that make then rigid, with low inertia and in a modular construction. One extremity of S*S*-segments is connected to the platform, consisting of a virtual cube, where the *S*-joints are tied on the center of its faces. Kinematics variables are the input angles α_i ($i=1$ *to* 6) of the *R*-joints. The studied structure has the *RS*-segments and the *SS*-segments the same length and $|b_1b_2| = |b_3b_4| = |b_5b_6| = |p_1p_2| = |p_3p_4| = |p_5p_6|$, Fig. 13.

Figure 14(a) show the 6-<u>R</u>SS parallel manipulator sketch and Fig. 14(b) the 6-<u>R</u>SS built with LEGO®.





(a) (b)

Figure 13. (a) The 6-<u>R</u>SS generic configuration; (b) The built prototype of a 6-<u>R</u>SS parallel manipulator (Gonçalves e Carvalho, 2008).

The great difficulty in assembling this structure using the kit LEGO® was the making of the mobile platform, Fig. 14. Figure 15 shows a sequence of movements of the structure manually.

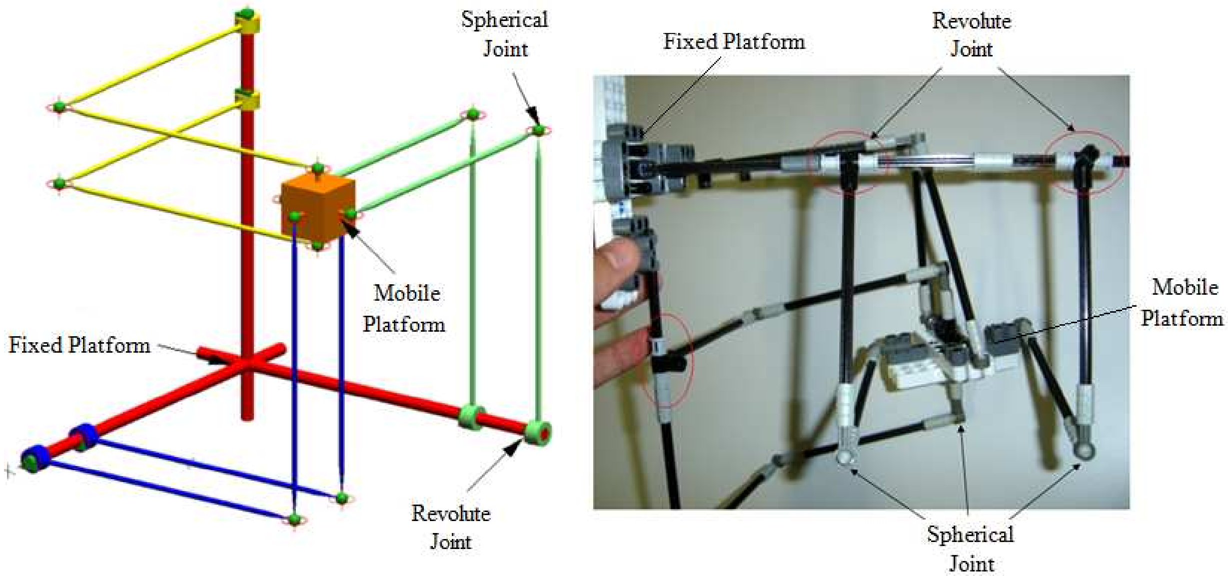
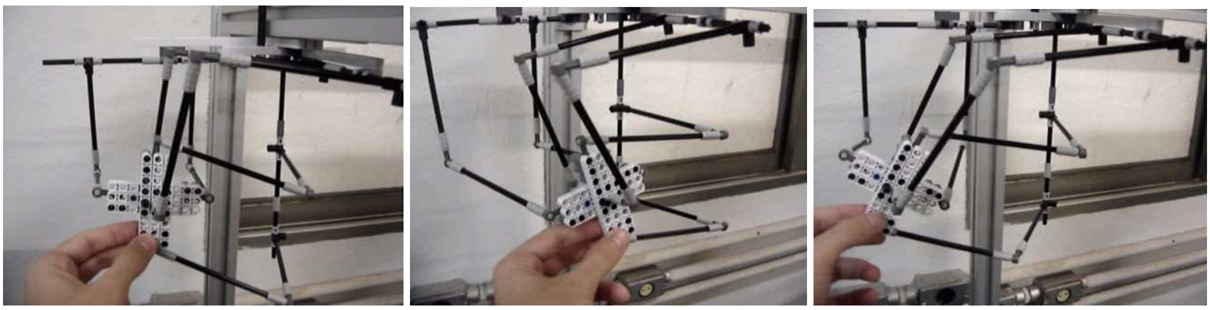
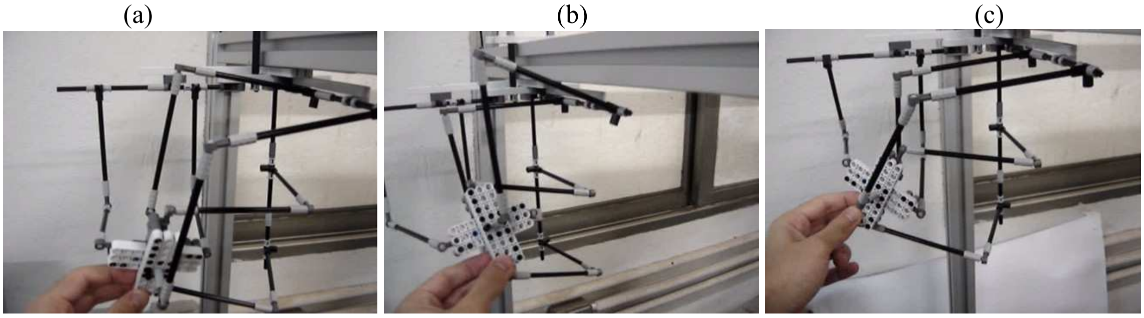


Figure 14. (a) 6-RSS sketch; (b) 6-RSS built with LEGO®.



(a) (b) (c)



(d) (e) (f)

Figure 15. Sequence of moving the 6-RSS manipulator.

5. CONCLUSIONS

This paper presented a proposal for a multidisciplinary educational course in mechatronics, specifically applied to robotics, focused on the use of Lego Mindstorm kits.

The use of Lego Mindstorm kits were able to offer the students a systemic view of mechatronics engineering, including information technology (through programming), mechanical (through experience with the use of different types of transmissions, gears, bars) and an introduction to electrical (through experimentation and activation of sensor and control). Other highlights are: reduced cost of deployment compared to traditional robotics labs, a paradigm shift in teaching methodology, with learning based on trial and encouraging the use of creativity in the solutions.

The undergraduate teaching of mechanical and mechatronic at Federal University of Uberlândia includes formal laboratory work for robotics teaching and final year projects. These activities utilize the fast development capabilities of the LEGO technical framework coupled with imagination and fun to provide the desired pedagogical outcomes.

Students have difficulty see some existing problems in robotics such as the presence of singularities, determination of the workspace and understand how works a three-dimensional structure parallel robotics. Thus the uses of kits from LEGO allowed illustrate these issues quickly, easily and with low cost.

Thus, in this work was first presented the kits LEGO Mindstorm. Next was his relationship with mechatronics. After these kits were used to demonstrate the singularities problem applied to parallel structure 5R.

As one of the great difficulty of undergraduate students is the view of the functioning of three-dimensional robot parallel structures. Thus in this paper was showed an alternative using the kits LEGO Mindstorm to facilitate the understanding of the mathematical model, workspace, collision and movement of the structure. The Delta manipulator, modified Hexa manipulator, CaPaMan and 6-RSS parallel manipulator were presented with the correspondent built model LEGO.

In this way, the use of kits LEGO Mindstorm provides complete learning solutions which cover important curriculum areas while stimulating creativity, problem-solving and team-working skills. They also motivate the students to learn so that they can improve their designs.

6. ACKNOWLEDGEMENTS

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