LEGO application for a microelectronics powered upper limb exoskeleton.

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Abstract: In general, the main aim of education through models is based on stimulating young people's ability to think logically and use their creativity to develop practical problem-solving skills. Over time, the standard educational process has identified the need to find and use new ways of transmitting basic information in the teaching of students and this way has been quantified by the phrase - serious games. This approach allows a faster and more efficient access of users (pupils-students) to the information bases and a correct and beneficial transmission of their theoretical and practical training. Thus, in the first part of the paper a number of aspects related to educational resources based on Lego pieces and an analysis of the opportunity of their use in the processes of instruction, learning and creation are presented. In the second part of the paper, an analysis of the different variants of Lego pieces assemblies used for the development of exoskeleton shapes or for upper limb training is carried out, as well as for the study of the possibility of obtaining versatile and customized variants. In the third part of the paper, the experimental model of a microelectronically actuated upper limb exoskeleton is presented, useful in training procedures for the rehabilitation of elbow joint and wrist movements. In the final part of the paper, observations obtained from the construction of the system and conclusions regarding the use of such a demonstration-educational model in practical problem-solving skills development actions are presented.

1.Introduction.

Creativity is a very important skill that should be possessed by a country's human resources, especially in this period of the 21st century. Human creativity should be stimulated through various things, including multimedia, science and technology or the field of education and lifelong learning to improve the quality of human resources. [1]

For the development of logic and creativity skills that provide children with the ability to understand and be creative, a number of fundamental or special methods and applications can be used, but all of them can cope with the development of current techniques and technologies.

One of the most special resources in the last decade to develop and exercise creativity in children is the Lego set. These toy pieces have proven over time their intrinsic value in creating a unique learning experience for children, helping them to develop creative and structural thinking at the same time. The design of these pieces, the diversity of shapes, colours and sizes give users the freedom to build whatever they want, and the dynamics of assembly help them to think in a logical, orderly way and respecting design principles to create different figures, buildings, machines, special devices or even complex and versatile systems for different applications (games, medical recovery, learning, etc.).

Figure 1. Lego pieces [2]

Educational and training experiences are thus linked to the activity of serious play, a mechanism that offers the learning process another dimension, more enjoyable and more easily accepted by students, making it more fun, more flexible and easier to understand.

Recently, a number of important education companies and institutions have been promoting and supporting the principles of quality early learning through play for all students in countries around the world, thereby increasing global capacity to capitalize on early learning opportunities and fostering understanding and commitment to the value of serious play in education.

Recent technological advances have changed the way Lego pieces are used as educational tools, and students not only have the chance to build things that look good, or that are just models, but can create objects that work and provide solutions for highly dedicated and practical applications.
Now, coding and software applications created specifically for this purpose open a new phase in the development of the educational innovation platform, using serious games and interactive and dynamic lessons, so that children learn valuable practical as well as theoretical skills in a field dominated by technology, computing or computer-aided design.
In this highly dynamic and creative process, software applications or structures for running an experiment teach children about logic, reverse reactions and sequences. They understand through practice and repeated trials that computers also need specific instructions and that errors that occur can be controlled just as experimental steps are constructed according to certain procedures.
This has been, is and will be the reason why it is so important to simplify and ease the process of learning these skills by using and experimenting with innovative methods that are engaging, stimulating and enjoyable, like a game, for students. Only with a little enthusiasm and fun, a few hours a week, can children thus be given the tools they need to cope in an ever-growing technical and technological labour market. [2]

2. Variants of exoskeleton use for the upper limbs.

In addition to the aspects that consider the use of Lego pieces in learning, training or cognitive skills development activities, it is also possible to highlight the situations in which this set of pieces can be used for the construction of versatile structures for rehabilitation systems and/or motor training of the upper limbs. For example, impairments of sensorimotor functions of the hand are among the most common consequences of traumatic and neurological conditions affecting the central and peripheral nervous systems, such as strokes, spinal cord injuries and cerebral palsies. Due to the fundamental role that hands play during the performance of various activities, deficits in arm and hand function are severely disabling conditions that drastically reduce the personal independence in daily life and social participation of affected individuals, making rehabilitation operations one of the main priorities for these users.
Therefore, managing (through various economic, social, medical pathways) such conditions correctly and comprehensively is essential not only to ensure an adequate quality of life for users with motor disabilities but also for their families. At the same time, reducing and limiting the ever-increasing costs due to various socio-economic or widespread medical causes and perhaps not least the prolonged periods of disability can put pressure on national health systems.

Figure 2. Exoskeleton from BioRob laboratories-École polytechnique fédérale de Lausanne [3]

This is why a number of companies, research centres or universities are developing systems for the recovery/rehabilitation of functional parameters of the upper/lower limbs in order to make the construction of mobile or fixed, static or dynamic, multifunctional or strictly customized exoskeletons for complex pathologies more flexible and diversified.
An example of this is the system (fig.2) that was designed, developed and iteratively tested by BioRob laboratories at the École polytechnique fédérale de Lausanne, in collaboration with partner clinics, including health professionals (neurologists, occupational therapists, occupational therapists, occupational therapists, physiotherapists) and users suffering from motor disorders (spinal cord injuries, amyotrophies, lateral sclerosis, strokes and/or cerebral palsy) [3].
The experimental results showed in this case that the exoskeleton could help these users regain the abilities to perform independently the independent daily activities that they lost due to disabling accidents.

This system, based on a proprietary artificial tendon technology is fully wearable and portable, functionally usable in both training and utility enhancement procedures and rehabilitation/recovery of motor deficits.
Specific to this system is the feature of versatility and customization for the needs of different users as the system aims to directly assist hand functions during routinely performed major activities, with the ultimate goal of supporting, providing motor independence and accelerating recovery due to continuous and intensive use. [3]
Another example of a construction dedicated to learning and training procedures of wrist and finger movement typologies is the one made from a set of Lego pieces (fig.3), to which a set of rotation and tactile sensors is attached to determine the positions and forces developed in the fingers. [4]

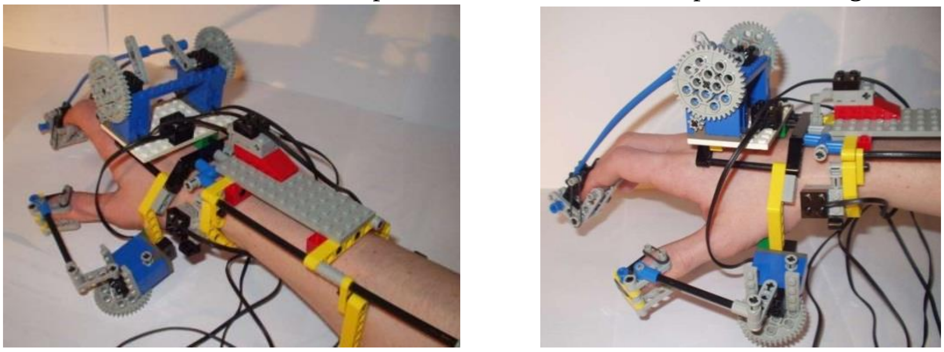

Figure 3. Exoskeleton with Lego pieces from RobotShop [4]

Figure 4. Exoskeleton with Lego pieces and computer interface [5]

The development of the procedure of using Lego floors for the construction of rehabilitation exoskeletons has entered a new phase in which these structures are combined with computer interaction interfaces to generate real-time control sequences and optimise the motor recovery stages of patients with upper limb dysfunctions.
Thus, at the Technical University of Denmark [5] interfaces between the human stroke patient and the computer were designed, and robotics came to the support of patients by creating hybrid, exoskeletal neuroprotection. A prototype upper limb exoskeleton was therefore developed using Lego Technic components (Fig. 4).

As mentioned by its author [5] the exoskeleton prototype is controlled by combining a BrickPi to interface with the Lego motors and a Raspberry Pi to serve as a central control unit and interface with external computers for programming and exporting sensor data.
Lego structures are also used for the construction of robotic arms in order to apply different motion laws which are analysed in terms of positioning accuracy and interactive response (fig.5).

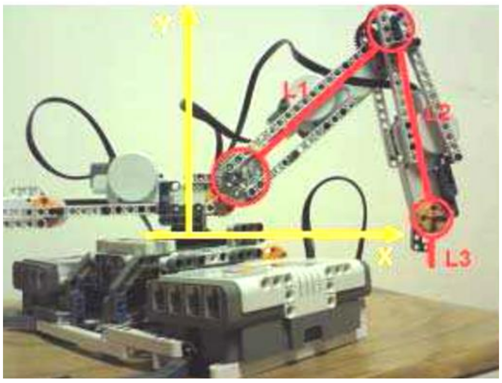

Figure 5. The robotic arm and coordinate systems [6]

One such system using the LEGO-NXT structure has been developed and controlled by a programming library called NXT.Net for controlling NXT Bricks. [6].

As presented by the authors of this research, the software application that was created to control the robot arm built from Lego bricks uses "inverse kinematics that includes the NXT.Net library (NxtNet.DesktopLib.dll), the InverseKinematics library (IKLib.dll) and the host program (nxt.exe). NXT.NET is a .NET library that enables host applications to control the LEGO Mindstorms NXT from managed code via Bluetooth connection". [6]
In the same sense, the combination of Lego pieces and command and control systems has allowed some researchers [7] to highlight the educational and commercial potential of robotic platforms for the development of research and higher education skills (fig.6).

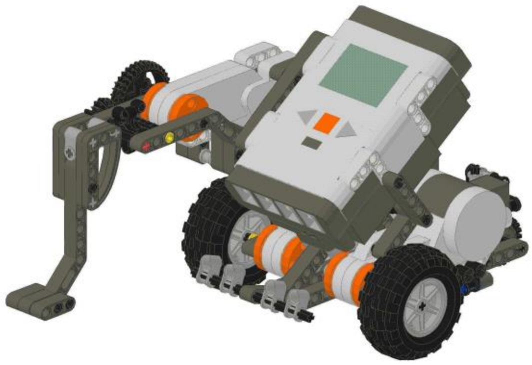

Figure 6. LEGO mobile robot platform [7]

Studies based on this type of platform are particularly aimed at students in higher education who are emphasising research and creative skills.
These features are, as mentioned by the authors, achieved through the development and implementation of algorithms "for navigating mobile robots based on the NTX platform. The discussion includes an introduction to NXT features and to the ROBOTC© programming learning which in turn is used to implement trajectory control and position control on the mobile robot"[7].
All these variants presented and many other studies carried out in the last period highlight the usefulness and the need to develop interactive and flexible platforms, accessible and easy to navigate based on the structures of Lego pieces, robotic command and control systems, along with modulated sensory systems.
These structures are developed in such a way that young people of all ages, together with educational tutors, can access, compile, build and improve them, thus achieving the most important goal of access to technique and technology and increasing creativity in different areas of general interest.

3. Development of the experimental demonstration model

The experimental demonstration model built on Lego pieces includes, in the final phase, three modular subsets that constitute the structure of the hand with its wrist, the forearm with the elbow joint and the arm (fig.7). The microelectronics elements used include servo-motors for actuating the arm-forearm from the elbow joint, bending sensors for evaluating finger movements and command and control systems based on Arduino Uno technology for achieving variability in the movements of the exoskeleton.
The assembly of such a demonstration model followed the use of as many Lego pieces as possible, easy to handle and to assemble by going through all the steps for each sub-assembly (fig.8).

3.1. Theoretical foundation of upper limb movements created from Lego pieces based on the classical Denavit-Hartenberg convention with fixed coordinates

Most of the time in research on the kinematics of robot arm movements the Denavit-Hartenberg (DH) convention is applied in order to construct the most accurate rotation or translation matrix (where applicable).
The DH parameters are the most suitable and easy to apply technique for kinematic structures having parallel or orthogonal axes.
There is however an important problem with DH parameters (fig.9), so that between two general positions (respecting the rule of right hands following the coordinate system) there is an uncertainty whether the transformation matrix $J_{i-1,i}$ - passing from position (i-1) to position (i)- can be realized following the typical procedure, as multiplication of a rotation matrix with angle θ_i around the z_{i-1} axis, with the translation matrix of displacement d_i along the z_{i-1} axis, then with the translation matrix of displacement a_i along the x_i axis and with the rotation matrix with angle α_i around the x_i axis, respectively, as shown in the following equations [8]

$$Rot(z_{i-1}, \theta_i) = \begin{vmatrix} cos\theta & -sin\theta & 0 & 0 \\ sin\theta & cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \quad \text{and} \quad Rot(x_i, \alpha_i) = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\alpha & -sin\alpha & 0 \\ 0 & sin\alpha & cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \quad (1)$$

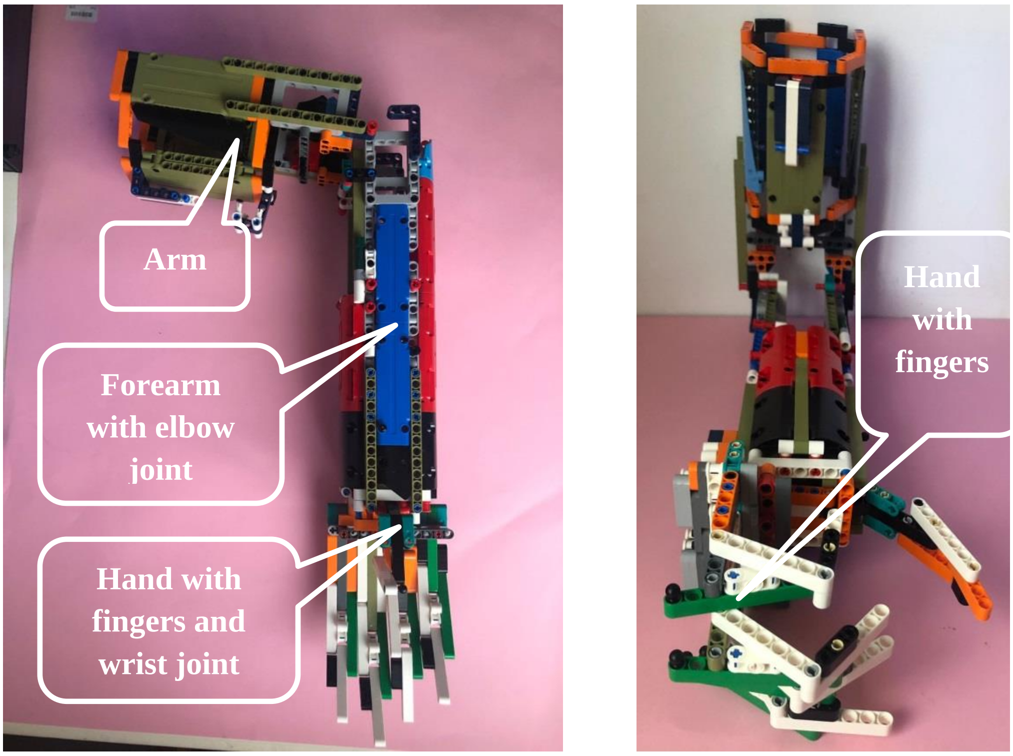

Figure 7. Exoskeleton for upper limb- experimental demonstration Lego model.

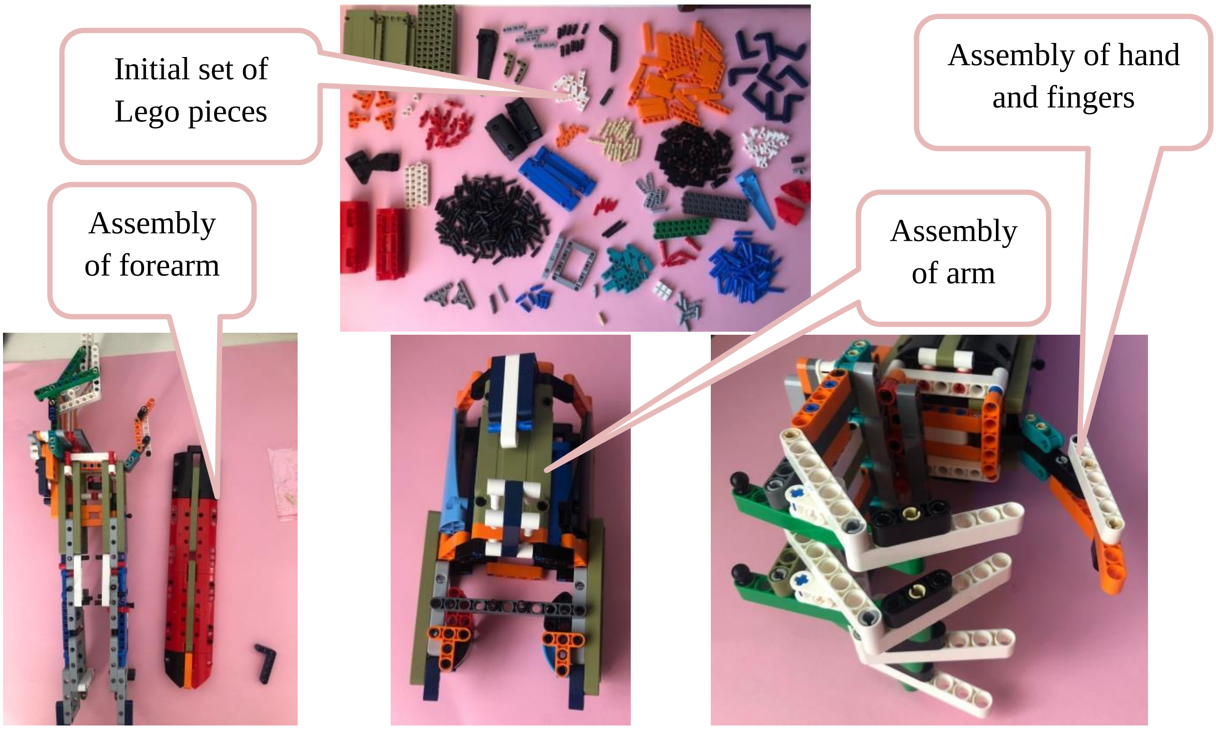

Figure 8. The initial set of Lego pieces and sub-assemblies for the forearm, arm and hand with fingers.

$$Trans(z_{i-1}, d_i) = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{vmatrix} \quad \text{and} \quad Trans(x_i, a_i) = \begin{vmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \qquad (2)$$

$$J_{i-1,i} = Rot(z_{i-1}, \theta_i) Trans(z_{i-1}, d_i)\, Trans(x_i, a_i) Rot(x_i, \alpha_i) \qquad (3)$$

This convention commonly used for selecting reference frames in robotic applications was introduced by Jacques Denavit and Richard S Hartenberg in 1955, becoming a classical method that allows the coordinate system to establish a fixed position on the axis direction.

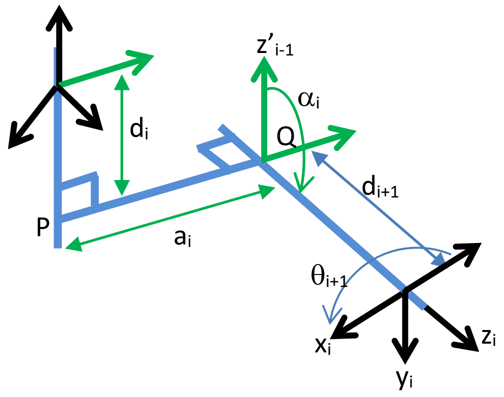

Figure 9. Principle of obtaining DH parameters [8]

But in this way a number of problems are obtained such as inapplicability for all forms of joint modelling and ambiguous local analysis of joint position. In order to obtain an intuitive and accurate modelling method, the coordinate system fixed on the initial DH convention system, i.e. CFDH (DH convention with fixed coordinates) is much more useful in developing the modelling basis. The CFDH convention is formulated by simplifying the joint structure and fixing a coordinate system on each link arm. In this way the multi-articulated system can be kinematically described using the four parameters for each link arm: length and twist angle describe the link bar itself; axis distance and joint rotation describe the connection of the link bar to a neighbouring link bar. In the usual case of a revolute joint, θ_i is called the joint variable, and the other three tie-bar parameters are fixed. For prismatic joints, d_i is the joint variable and the other three tie-bar parameters are fixed.

Table no.1. Mass of body segments as % of total body mass [9, 10]

Segment of the body	**% of total body mass**
Upper arms	5.31
Forearms	3.64
Hands	1.41

Table no.2 Mechanical specifications of an exoskeleton for the upper body (feminine subject) [9]

Segment	**Length [mm]**
Hip-shoulder	687.5
Wrist - load	25
Shoulder – elbow (L1)	240.3
Elbow – wrist (L2)	245.7
Range of the elbow (q2)	10^0 - 165^0

3.2. Estimation of exoskeleton characteristics in relation to the human body

The range of motion (ROM) that this exoskeleton assembled from Lego pieces can achieve is limited by the size and configuration of the joints, but it can be useful in exemplifying elbow joint and wrist movements along with finger movements. These generally estimated size values for an adult (female gender) are shown in Table 1 and Table 2.

This model of exoskeleton made of Lego pieces and operated with microelectronics is used to analyse the movements of the arm assembly by varying the kinematic parameters (velocities, accelerations) but also by changing the angles between the modules in the starting position.

The variation of the actuation speeds by the servomotors equipping the system allows an analysis of the training and training possibilities of a patient with motor dysfunction at the level of the upper limb so that he can train and train progressively, constantly and controlled with a professional equipment that performs these movements.

4. Results and conclusions

The model thus designed and built from Lego pieces proves to be useful in analysing and explaining the movements of the three component modules (arm, forearm and hand) for a patient with motor dysfunction. Also the system being built from pieces that can be changed and assembled in a different way from the dimensions and movement limits of the upper limbs (left, right) is versatile in terms of use. The possibility to change the actuation speeds, the sizes of the assembled modules and the usefulness in the training process by exemplifying the operation, make this experimental demonstration model an assembly with multiple uses (development of assembly skills, software application design or development of recovery/rehabilitation procedures).

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