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# A Mechatronic Platform for Behavioral Studies on Infants

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*Abstract*— **In this article the design and fabrication of a new mechatronic platform (called "Mechatronic Board") for behavioral analysis of children are presented and discussed. The platform is the result of a multidisciplinary design approach which merges input coming from neuroscientists, psychologists, roboticians and bioengineers, with the main goal of studying learning mechanisms driven by intrinsic motivations and curiosity. A detailed analysis of the main features of the mechatronic board is provided, focusing on the key aspects which allow studying intrinsically motivated learning in children. Finally preliminary results on curiosity-driven learning, coming from a pilot study on children are reported**

## I. INTRODUCTION

The acquisition of new skills and know-how is one of the most astonishing behavior which could be observed in humans and animal models. The driving force that shapes this process is unknown. Children seem to acquire new skills and know-how in a continuous and open-ended manner [1]. Before developing tool-use ability, for example, children show typical exploratory behaviors based on trial and error which could be considered as a self generated opportunities for perceptual learning [2]. Most important, this process is not goal directed but it seems to be completely spontaneous and not related to the context. According to [3], this process follows a well defined path strictly linked to the development of cognitive and morphological structures, which are related to the new acquired skills (e.g. tool use). How children learn to use these skills in a different context to reach a specific goal is unknown. To study which is the driving force that shape exploratory behaviors underling learning processes in humans, we design a new mechatronic tool for behavioral analysis (called "mechatronic board"). The new platform should allow to test if exploratory actions, which are not instrumental to achieve any specific goal, improve participants capacity in solving a subsequent goal-directed task, which requires the proficiency acquired during free exploration. This study is part of the European Project Intrinsically Motivated Cumulative Learning Versatile Robots (IM-CLeVeR). The main goal of this project is to study learning strategies based on curiosity and novelty detection in children and animal models, modeling such strategies, and replicate them on a humanoid robot (the iCub system developed at IIT as part of the EU project RobotCub see www.iCub.org) which has the anthropometric measures of a 3 years old child.

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## II. THE MECHATRONIC PLATFORM

### A. Functional Specification

The mechatronic board is an innovative device specifically designed for research on intrinsically motivated cumulative learning in children. This platform has been designed to be modular and easily reconfigurable, allowing to customize the experimental setup according to different protocols devised for children. A similar platform has been also developed for comparative studies on animal models [4]. The board should promote both intrinsically and extrinsically motivated actions that is, respectively, curiosity driven and rewarded actions. It should embed non-intrusive ecological technologies small and light enough to fit the objects that will be manipulated. To allow different possibility of interactions, the board should be equipped by instrumented interchangeable objects stimulating different kinds of manipulative behaviours and allowing to record several kinds of actions (e.g. rotations, pushing, pulling, repetitive hand movements, button pressing, etc). It should be also provided of a system for multimodal stimuli generation and a system for reward delivering when a set of reprogrammable actions is performed. Finally it should be made of materials, mechanism, and electronic components robust and safe enough for children.

### B. First Prototype

The first prototype of the mechatronic platform is composed of *(i)* a planar base ( 650x500x450 mm) provided of three slots (180x180 mm) where push-buttons or different mechatronic modules can be easily plugged in; *(ii)* a reward releasing unit (650x120x400 mm) mounted on the back area of the planar base and containing the reward boxes where rewards are placed by the experimenter. The boxes are made by transparent material, so that the partecipants can always see what is inside; *(iii)* a system for stimuli and reward generation: the whole platform is provided by a set of different stimuli (acoustic and visual) to provide various sensory feedbacks associated to the manipulation of mechatronic objects (see Fig. 1).

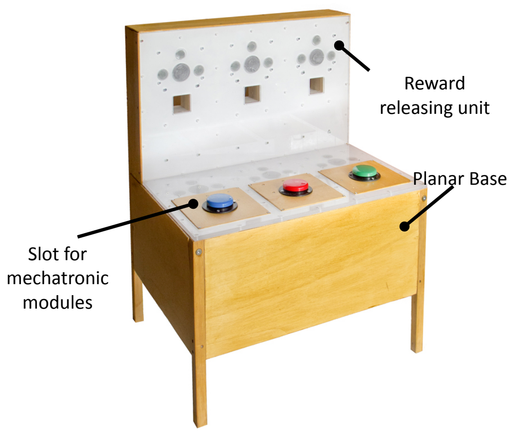



Fig. 1. First prototype of mechatronic board for children.

The stimuli come both from the mechatronic objects (object stimuli) and from the reward releasing boxes (box stimuli). The acoustic stimuli are managed by a low-level sound module (Somo- 14D manufactured by 4D Systems) that can playback a set of pre-stored audio files; the files used during the experiments were chosen among a bigger database of natural and artificial sounds. The visual stimuli consist of a set of 21 independent multicoloured lights. The actions on the mechatronic objects produce the activation of the audio-visual stimuli and/or the opening of the reward boxes, as defined by the experimental protocol. The reward system is conceived so that the subject can retrieve the reward only when he/she performs the correct action on the mechatronic modules. The reward releasing mechanism (see Fig. 2) was designed to be not backdriveable (so that the subject cannot force the opening). A Parallax Continuous Rotation Servo motor (maximal torque: 0.33 Nm) has been used to drive the mechanism. The motor is coupled to the sliding door by a worm-wheel low efficiency mechanism $(\eta_{tot}) = 0.3$). The low torque of the motor and the low efficiency of the transmission makes the mechanism not harmful if the partecipants hand is caught in the sliding door. The action-outcome association is managed by the high-level control system and it is fully programmable according to the experiments requirements.

To easily reconfigure the experimental setup responding to the requirements detailed above, a hierarchical *three-level control architecture* was chosen (see Fig.3). The *physical level*, is made by the interfaces partecipants can directly interact with: modules and rewarding mechanisms. This level is mechanically and electronically decoupled by the other higher levels allowing, on one hand, an easy change of mechatronic modules, on the other hand, an improvement of the robustness of the apparatus. The microcontroller-based *middleware level control* manages low level communication

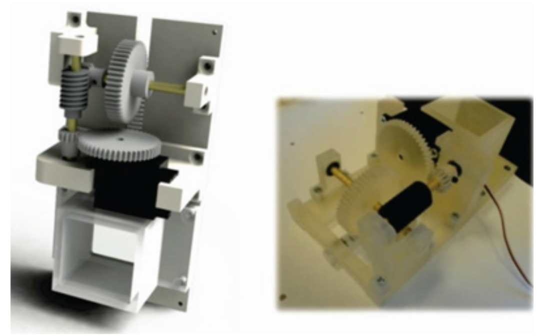


Fig. 2. Reward/releasing mechanism: on the left rendering of the mechanism; on the right, the developed mechanism.

with mechatronic modules, reward mechanisms, and audio-visual stimuli while the *high level control* is a control program running on a remote laptop which allows supervising the acquisition and programming the arbitrary association between action and outcome.

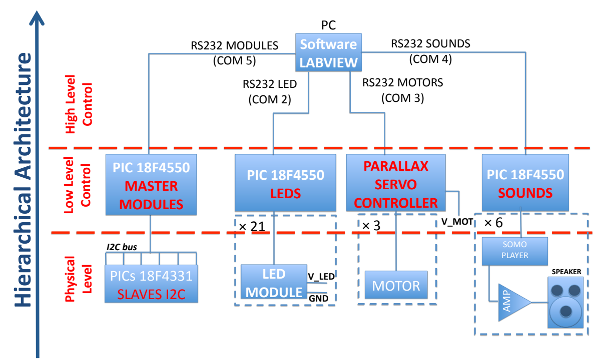



Fig. 3. Hierarchical architecture of the board: physical level made by the interfaces with subject; local low-level control microcontroller-based; high level control running on a remote laptop.

All the electronics of the microcontroller-based middleware levelx has been integrated in a single motherboard, which could be easily embedded into the planar base, and connected to the Audio/video stimuli boards and to the mechatronic modules using 10-way flat cables.

## III. PRELIMINARY TRIALS

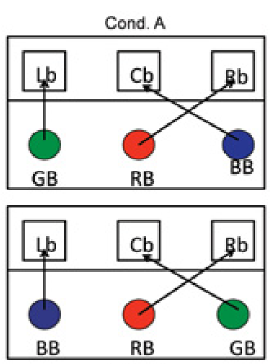
Here, we provide an example of in-field use of the above mechatronic board equipped with pushbuttons. Pilots experiments were carried out at the day-care centre La Primavera del Campus, (Universita' Campus Bio-Medico, Rome, Italy), on children aged between 23 and 68 months

### A. Experimental Protocols

The experiments are performed by placing the board in an empty room where the child is introduced by his/her teacher. The teacher invites the child to explore the board by saying "*Look at this new toy. What is this? What can it do?*", without say anything about what the board actually does. The experimental protocol is divided in two phases: a training phase and a test phase. The main goal of the protocol is to assess whether a child can use a motor skill that he/she has acquired during the training phase (push a button in a way that opens a box) to retrieve a reward in the test phase.

During the training phase the child discovers 'by chance' that he/she can open the boxes. In the training phase the child can freely explore the board and its functionalities. The board is programmed to react to each single press of the buttons with both visual and audio stimuli, and to open the reward boxes when a button is hold pressed for more than one second (rewarded action). The single press makes the lights close to the button to turn on and causes a single xylophone note to sound (three different notes are set for the three buttons). On the other hand the rewarded action produces the opening of one box (which is always empty in the Learning Phase), the lighting of the box lights and the light inside the box, and at the same time generates a sound of an animal cry (one for each button: a rooster, a frog and a cat).

To test if a preference in pushing behavior is related to colors or it is an effect of the position of pushbuttons, the board is presented to children in two conditions: in Cond. A the blue pushbutton is on the right and green pushbutton on the left; in Cond. B the above positions are inverted (see Fig. 4 ). We decided to change the position of green and blue pushbuttons because the ability to distinguish these colors is related to the rode and cone cells which develops during the first three years of age.




outcome matrix

| | EXP | CTRL |
|---|---|---|
| **Simple push** | –Turning on proximal lights<br>– Play a xylophone notes | –Turning on proximal lights<br>– Play a xylophone notes |
| **Extended push (>1s)** | –Turning on frontal lights<br>–Play a xylophone notes<br>–Play an animal sound<br>–Open a box | –Turning on frontal lights<br>–Play a xylophone notes<br>–Play an animal sound |

Fig. 4. (*Left*), Schematic representation of the arrangement of buttons and their association with boxes from the perspective of the user. (*left*) Outcome matrix for Training phase (*right*). During Test phase the box opening is allowed both for CTRL and EXP subjects

The Learning phase lasts about 10 minutes and is followed by the second phase (hereafter called Test Phase). In the Test Phase the reward (a sticker) is shown to the child and then randomly placed in one of the three closed boxes, where it is clearly visible to the subject. The child is only asked to retrieve the sticker, without adding any other suggestion on what action is associated to box opening. As in the Training Phase, the reward can be reached by pushing and holding the associated button for more than one seconds. The other stimuli are set as in phase 1. Once the subject opens the box and reaches the reward, it is given to the child as a prize for his/her success. If he/she does not retrieve the sticker after 2 minutes, the sticker is moved to the next box. The Test Phase ends after 9 successful openings (three for each box) or after 18 minutes. The partecipants are divided in two groups: the Experimental Group and the Control Group. The protocols for the two groups differ only in the Training Phase: while in the Experimental Group the rewarded action causes the opening of the associated box also in the training phase phase, in the Control group the boxes do not open in the training phase. All the other audio-visual stimuli are set in the same way in both groups.

Fig. 5. Typical experimental scenario: child is sit on the knees of the teacher interacting with the board

## B. Preliminary results

Twelve children aged between 24 and 68 months were involved in the experiment with pushbuttons (see Table I). All children were identified as right-handed by their teachers. This study is supposed to serve has the basis of a neuro-inspired control of the humanoid robot iCub which has the anthropometric measures of a 3 years old child. For this reason a threshold of 36 months was used to distinguish younger children from oldest ones.

During training phase the exploration of the board was quantified in terms of total number of pushes and number of

TABLE I

SUBJECTS INVOLVED IN THE PRELIMINARY TESTS

| Subject | Age[Mo] | Group |
|---|---|---|
| CBM06 | 23.3 | CTRL |
| CBM05 | 23.4 | EXP |
| CBM08 | 23.6 | EXP |
| CBM04 | 23.8 | CTRL |
| CBM11 | 32.4 | EXP |
| CBM09 | 31.2 | CTRL |
| CBM14 | 38.8 | CTRL |
| CBM17 | 47.2 | EXP |
| CBM16 | 49.1 | CTRL |
| CBM19 | 49.8 | CTRL |
| CBM20 | 57.5 | EXP |
| CBM22 | 68.3 | EXP |

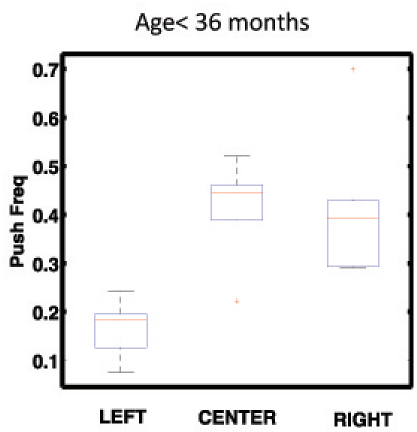



Fig. 6. Box Plot of Push frequency: the left pushbutton is less pushed than the others

extended pushes. A preference in the exploration of central and right pushbuttons (see Fig. 5) was observed in younger children (age<36 mo). A one-way ANOVA was used to test for push frequency differences among the three different positions in the two age groups. Frequency push differs significantly across the three positions, ($F(2,17) = 10.02$, $p = .0017$) in the younger children group (age<36 mo). No preference related to color were observed ($F(2,17) = 10.02$, $p = .0017$).

Performance of the two groups were compared during Test Phase in terms of number of retrieved reward, time necessary to children to retrieve the reward, and Spatial Relationship Index (SRI) defined as:

$$SRI = \frac{Number\ of\ correct\ pushes}{number\ of\ total\ pushes\ per\ trial} \quad (1)$$

A two samples t-test was conducted to compare performance of the EXP and CTRL group: There was significant trend toward higher number of retrieved rewards for EXP (M=7, SD=2.4495) in comparison to CTRL group (M=3.67, SD=2.325); t(10)=2.2250 p=0.0503 There was a significant difference in the time taken by children in the EXP (M=50.32 SD=47.14) and CTRL (M=88.76 SD=46.21) group to complete the trial (including timeouts = 120 s) t(106)=-4.2794 p= 4.1219e-05. A two samples t-test was conducted to study if partecipants of the experimental and control group have learnt the spatial relationship between buttons and boxes: There is a significant difference of the SRI between the EXP (M=0.53 SD=0.39) and CTRL (M=0.36 SD=0.29); t(106)=2.5215, p = 0.013 Considering separately the two cases of simple (direct) and crossed relations: There is a significant difference of the SRI between the EXP(M=0.66 SD=0.3170) and CTRL(M=0.32 SD=0.3245) group in case of direct relation (t(34)=3.1608, p=0.0033) whereas there is not a significant difference for crossed relation (t(70)=1.1912, p=0.2376).

These preliminary results seems suggest that workspace play a crucial role in the strategies of explorations of infants, which seem to explore more frequently objects in central and right position. Children who were given the chance of discover a new skill are more likely to use this skill later, however neither the EXP nor the CTRL group did learn more complex spatial relationships.

## IV. CONCLUSIONS

In this work we presented a new mechatronic platform for studying intrinsically motivated learning in children. A discussion on main features of the platform has been reported as well as a detailed description of the its first prototype for children. An example of its in-field use with children is provided. The board was tested with 12 children aged between 24-68 months. Preliminary data seems suggesting that this platform can be effectively used for behavioral studies on children. Despite the preliminary experiments were carried out using the platform equipped only with pushbuttons, more challenging mechatronic objects with different possibility of interaction and affordances have beed designed and and will be used.

## V. ACKNOWLEDGMENTS

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