A Baby Robot Platform for Cognitive Developmental Robotics

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Abstract— **This paper presents a new baby robot platform for cognitive developmental robotics developed by the Socially-Synergistic Intelligence group of JST ERATO Asada Project. We aim at developing a baby-sized humanoid robot with high-performance mobility to tackle research issues which have not been covered by robots developed in our group, for example, motor learning through whole-body motor babbling and motion generation with tactile interaction. For this purpose, powerful and easily controllable actuators as well as a robust structure able to absorb shocks are chosen to allow the development of dynamical motions. Furthermore the robot surface is covered by touch sensors in order to allow studies in physical human-robot interaction. Two research topics that will employ the new platform are presented. The former involves the exploitation of biological fluctuations, a control method inspired from the chemotaxis of bacteria and from gene expressions of growing cells, to learn a crawling motion. The second aims at studying touch as a communication mean to develop robot motions.**

I. Introduction

Cognitive developmental robotics (CDR) [1] has been focused on as a new approach to study mechanisms of human intelligence, cognition, and development with robots and computer simulations. In this approach we usually hypothesize a model of infant development based on existing knowledge in psychology and brain science, implement the model in a humanoid robot which has humanlike kinematics and a perceptual system similar to humans, and verify the hypothesis by comparing phenomena observed in the resultant robot behaviors with the actual infant development. This requires a humanoid robot which can behave in a baby-like manner and naturally interact with persons, and, therefore, a development of humanoid robot platform is also important. In order to cover a wider area of research issues on infant development, it is required that the robot platform has a baby-sized body, a multimodal perception system, and a motor system to enable dynamic whole-body movements. Another important factor in the development of a platform is maintainability, which is necessary for sharing the platform among researchers who work in CDR or have interest in CDR. The growing interest in CDR and the consequent need of new baby robot platforms seems to be confirmed by the recent development of Child robots like CB^2, Child-robot with Biomimetic Body [2], and iCub [3]. CB^2 is a humanoid robot driven by 56 actuators most of which are pneumatic to allow a safe interaction with humans. This robot is equipped with encoders on all the joints, accelerometers and gyroscopes on the three axis, two cameras located in the eyeballs, two microphones mounted in the head and with PVDF (Polyvinylidene Difluoride [4]) film bases tactile sensors distributed over the whole body. Similarly iCub presents a high number of degrees of freedom, precisely 53, which are however powered by electrical motors. This platform is also equipped with encoders, a binocular vision system, gyroscopes and accelerometers, microphones and force/torque sensors. Sensor skin based on a mesh of sensors interconnected is currently under development [5]. Both of these two robots are quite big and heavy, expressly CB^2 is about 130cm high and weights 33Kg while iCub is 94cm tall and weights 22Kg.

In order to decrease the cost, to increase the user safety by diminishing the necessary motor torques and to allow close interactions like hugging we developed a new baby robot platform of reduced size, whose picture is reported in Fig 1.

The developed platform is a completely autonomous, battery powered and servomotor actuated baby robot. The robot weights about 3Kg and is approximately 50 cm tall. As its bigger counterparts it is equipped with two cameras, gyroscopes and accelerometers over the three axes and is covered by a high number of touch sensors.

While pneumatic actuators as the ones employed in CB^2 permit a safe interaction as well as smooth and natural looking movements we decided to employ PID controlled servomotors for the actuation of our compact baby robot. This allowed us both to ease the control, which can be performed without problems using an internal ARM based motor control board, and to remove the necessity of connecting the robot to a compressor or compressed air tank. We based our platform on VisiON 4G, a commercial product manufactured by VStone. The high performances of this robot and its ability to perform whole body dynamic motions could be verified in the Robocup [6] competition, won

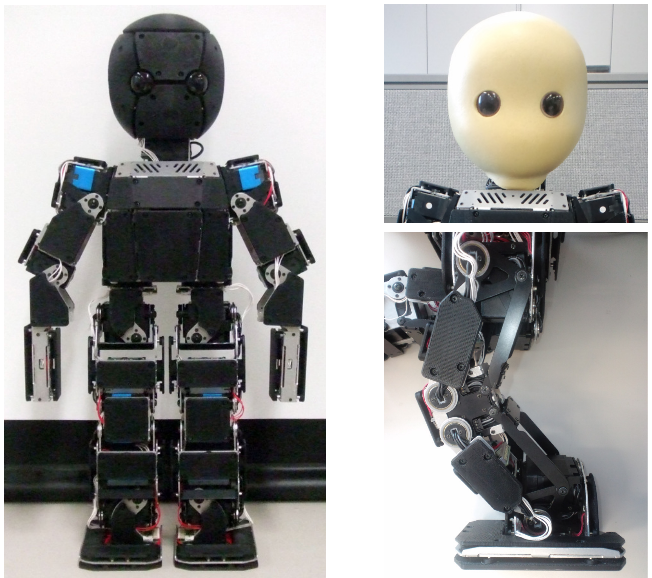

Fig. 1. Photo of the developed baby robot (left), head covered with urethane foam (right top) and detail leg parallel link mechanism (right bottom).

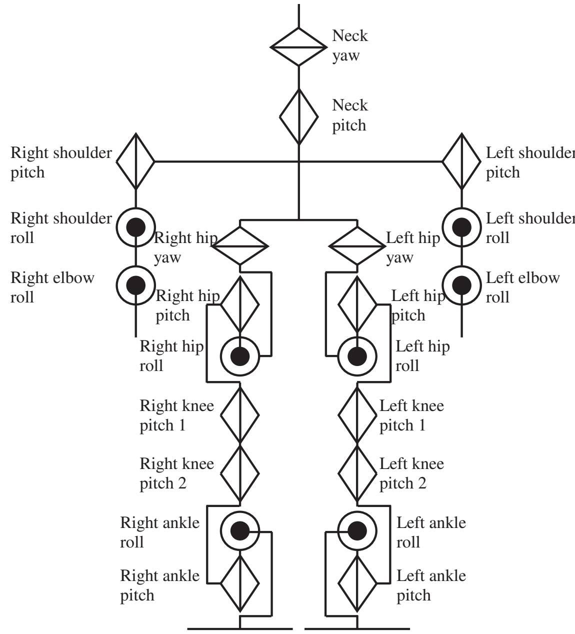

Fig. 2. Degrees of freedom of the developed baby robot.

by Team Osaka using VisioON 4G for two consecutive years. The robot, developed to resist to the impacts with opponents during the Robocup games, reveals to be very robust. The touch sensors covering the robot surface of our research platform were designed aiming at maintaining this robustness, and in fact the presence of elastic elements in their structure even improves the robot absorption of shocks. We plan to make the sensor option commercially available in a near future. We in fact expect our research platform to be an interesting trade off between cost and richness of available sensory information.

Section II illustrates the robot features and in particular subsection II-B provides a description of the touch sensor available on our platform. In section III we describe two research themes that will be pursued using the presented platform. We conclude in section IV by summarizing the content of the paper.

II. Robot Description

A. Servomotors and control boards

As stated in the introduction the developed research platform is based on the robot employed by Team Osaka, VisiON 4G, which is a commercial product manufactured by VStone[1]. The robot has 22 degrees of freedom (DOFs) powered by metal gear PID controlled servomotors. Employing servomotors allows an easy position control, without the strong nonlinearity problems presented by artificial muscle as the pneumatic actuators used in CB^2. More precisely VisiON 4G presents 7 DOFs for each leg, 3 for each arm and 2 DOFs, expressly pan and tilt, for the head, as shown in Fig. 2. The legs present a parallel link structure, as visible in Fig. 1, to increase the leg robustness. As can be seen in the photos the

TABLE I
VS-SV410 characteristics

size	40.5 × 21.0 × 32.9mm
weight	62g
torque	41Kgf cm (at 16.8V)
speed	0.14s/60°
range	180°
power supply	min 10V max 18V

robot is completely realized in aluminum, ensuring robustness over other low cost hobbyist robots that include plastic parts as, for instance, the very diffused Kondo HRV series[2]. The servomotors, unlike conventional PWM servomotors, present a serial input that allows chaining them over a serial bus, strongly reducing the required wiring. Table I provides a detailed specification of their characteristics. Having a serial bus allows a rich protocol that permits to runtime set target positions as well as the PID parameters like the gain, and to read the temperature, position and voltage. The servomotor and in particular their high gear ratio allows very fast and whole-body dynamic motions, as visible in figures 3 and 4.

The robot is powered by two Nickel-metal hydride battery packs lodged in the robot's torso that provide 14.8V and 1400mAh. The main body also contains a CPU board, a microcontroller based motor control board, a board with two gyroscopes and three accelerometers (VStone VS-IX001) and two speakers. Two CMOS USB cameras and two microphones installed in the head, allows for binocular vision and detection of external sounds despite the very compact dimensions of the robot. The CPU board consists of a Pinon[3] PNM-SG3 500MHz that thanks to its x86 compatible Geode LX800/CS5536 processor and its 512Mb of DDR400 RAM

[1] http://www.vstone.co.jp

[2] http://www.kondo-robot.com/

[3] http://www.pinon-pc.co.jp/

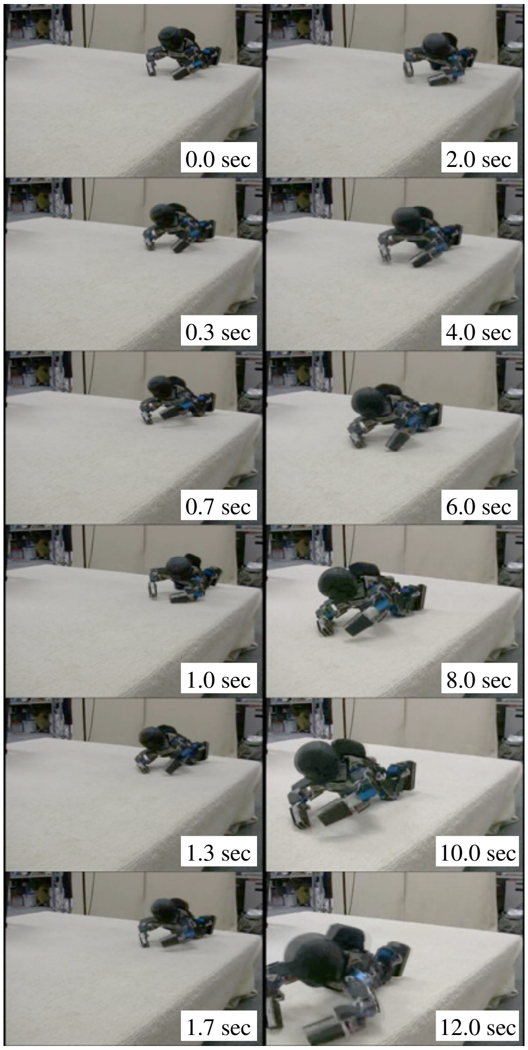

Fig. 3. Crawling motion executed by the developed platform.

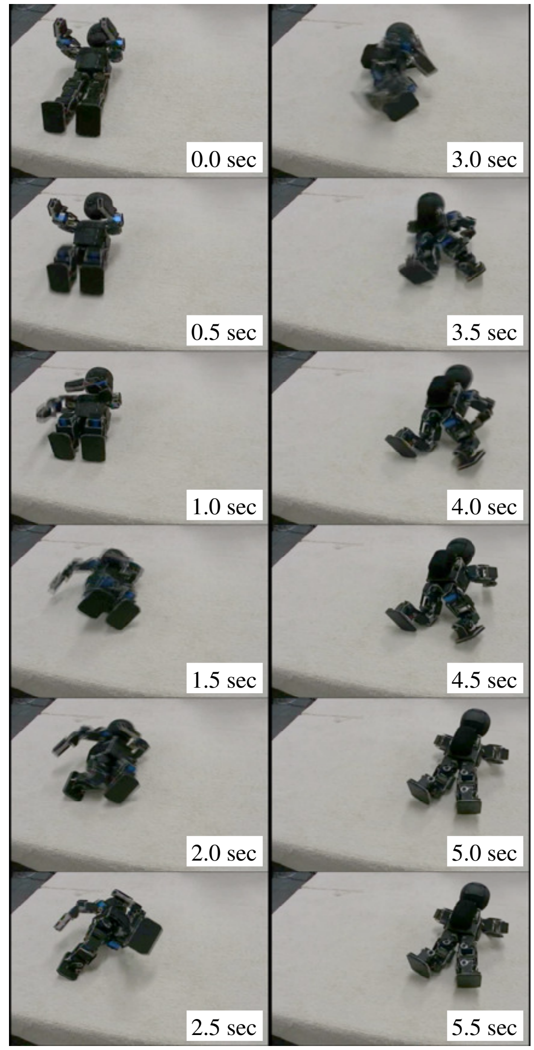

Fig. 4. Turn over motion executed by the developed platform.

allows running conventional operating systems like Windows XP or Linux on the robot while keeping the power consumption very low (only 5W). As a conventional computer a VGA output (resolution 1920x1440, 32bit color depth), a USB bus and two serials are provided. Storage is provided by a compact flash disk, and a supplementary compact flash slot allows plugging in a network card for connection to conventional IEEE 802.11b and 802.11g wireless LANs. In order to allow real time motor control without using CPU resources the robot includes a 60MHz ARM7 microcontroller based motor board (VStone VS-RC003) that can communicate to the main CPU board through a serial connection. The motor control board presents also a USB mini B connector for direct communication with an external PC. The USB communication protocol is managed by VStone SDK that allows development of motions and acquisition of gyroscope and accelerometer information by a set of high level API. These API are fully integrated with the Robovie Maker development environment released by VStone and it is possible, for instance, to create robot motions by a classical slider based interface and to execute it by few lines of code. Simple signals can be sent to the ARM board also by a wireless bluetooth Playstation 3 controller (SCPH-98040, trademarked ”SIXAXIS”), permitting, for instance, real time execution of different sets of motions.

B. Touch sensors

As reported in the previous section the developed platform is an extension of a commercial product called VisiON 4G. However the presence of a high number of touch sensors despite its reduced size distinguishes it from its commercial counterpart and in general from small humanoid robots available on the market. Figure 7 indicates the location of the 90 pressure sensors placed over the whole robot.

The structure and working principle of each of the touch sensors is schematized in Figure 6. A small (12x4 mm) board equipped photo interrupter is attached to robot aluminum frame (see Fig. 5). A plastic plate, visible in figure 5, is fixed to the frame by a screw tightened over a spacer and is usually kept at a fixed distance from the frame by an elastic material that functions as a spring. A white disc attached to

Fig. 5. Photo of the photo interrupter board attached to the robot's aluminum frame and plastic plate

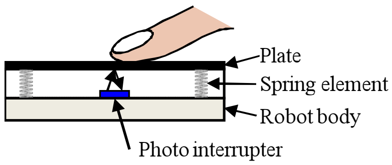

Fig. 6. Schema of our touch sensor.

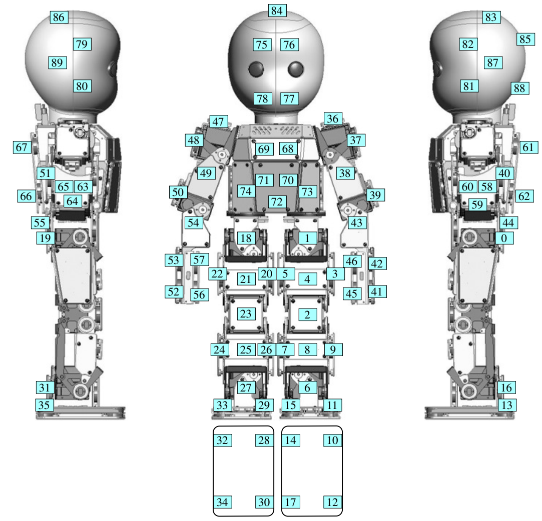

Fig. 7. Arrangement of the touch sensors on the robot body.

the plate reflects the light coming from the photo emitter to the phototransistor of the photo interrupter. The amount of reflected light changes depending on the distance between the photo interrupter and the white disc, i.e. depending on the pressure applied to the plate, allowing detection of forces applied to the plate.

Although the relationship between the applied force and the reflected light measured by the phototransistor is strictly monotonically increasing, it is non-linear and the small differences in the elasticity of the materials make calibration necessary for each of the sensors. In particular, the range of the values read by each of the photointerrupters is different. In human-robot interaction studies, where categorizing the touch in two or three classes (no pressure, soft pressure, strong pressure) often suffices a simple calibration that determines the offset value and the range of each sensor can be sufficient.

Groups of up to 8 photodiodes are connected to 19x35mm boards that manage the A/D conversion of the signals. Nineteen of such boards, placed over the whole robot, are chained by a serial bus that can be used to read the data coming from all sensors with a simple polling protocol similar to the servomotor one.

III. Applications

In this section we introduce two of the research topics that will employ the baby platform presented in the previous sections. Expressly subsection III-A will describe a biologically inspired approach able to learn parameters suitable to make a robot crawl and subsection III-B will briefly illustrate the idea of employing touch to teach motions to a humanoid robot.

A. *Biological fluctuations for crawling learning*

Often simple living beings like bacteria present a highly adaptive and robust behavior despite their structural simplicity. For instance bacteria are able to sense changes in the concentration of nutrients and direct their movements toward the food molecules while escaping from poisoning substances without any complex planning strategy.

Among the various alternatives for the microorganism movement toward or away from the chemical stimuli, a process usually termed as chemotaxis, the behavior of Escherichia Coli (in the following referred as E. Coli) has been deeply studied [7]. These organisms utilize a biased random walk for their movement. In particular, these bacteria have only two way of moving, rotating clockwise or counter-clockwise. When they rotate counter-clockwise the rotation aligns their flagella into a single rotating bundle and they swim in a straight line. Conversely clockwise rotations break the flagella bundle apart and the bacteria tumble in place. The bacteria cannot therefore choose the direction of their movement, but just keep alternating clockwise and counter-clockwise rotations. In absence of chemical gradients the length of the straight line paths (counter-clockwise rotations) is independent of the direction, and the bacteria essentially perform a random walk. In case of an increasing gradient of attractants (like food) the bacteria instead reduce the number of tumbles, i.e. proceed in the same direction for a longer time and the overall movement is directed toward increasing concentrations of the attractant. This kind of behavior, which is more and more deterministic the better the conditions are and conversely more and more stochastic the worse the state is can be formalized under the very general framework of biological fluctuations [8], [9]. Expressly assuming to have a continuous time system the model of biological fluctuations is given by the equation

$$\dot{x} = Af(x) + \eta. \tag{1}$$

where $x \in \mathbb{R}^m$ is the control signal or represents the value of some parameter that determine the behavior (of the animal, or, in our case, of the robot), $f : \mathbb{R}^m \rightarrow \mathbb{R}^m$ is a deterministic function of the current value of x, η is a random variable and $A : \mathbb{R}^n \rightarrow \mathbb{R}$ is a function, called "activity", that indicates the fitness, or "quality" of a particular state of the living being/robot. Intuitively when the state is getting better the value of A increases and the control actions becomes mainly deterministic, while when the conditions worsen the control becomes more and more stochastic. This mechanism can simply search high-fitness states while utilizing internal and external constraints. We are investigating a possibility that this mechanism underlies human motion generation, such as motion emergence from motor babbling in infant development.

In [10] we showed by simulation results that a crawling motion can be achieved by a robot using this simple technique. Expressly we simply controlled each robot joint by a sinusoidal function and set x as the space of the phases of these sinusoids. We then defined $f(x)$ as the negative gradient of a surface given by the sum of 20 randomly placed Gaussian shaped holes, and A as a function of the velocity in the forward direction (i.e. in the direction defined by vector going from the robot's torso to its head center).

B. Teaching by Touching

Tactile interaction is a fundamental aspect of interaction between babies and their mothers [11]. We aim at studying the mechanism of the development of intention interpretation through what we termed "Teaching by touching" in [12]. Briefly, touch is an intuitive method of communication employed in human-human as well as in human-machine interaction [13]. For instance touch is frequently used by sports coaches or dance instructors [14] to correct a learner's posture or motion. Tactile interaction therefore appears particularly appealing as an intuitive method for humans to teach robots. Our goal is to validate the idea of employing touch as a way for inexperienced users to program robot motions intuitively.

The systems available on the market requires the users to think at the motion in terms of keyframes and for each of this key-postures the angles of each robot joint must be specified by a moving slider. This process is not straightforward, since, for instance, the user must identify which is the joint that moves the robot parts in the desired direction. Conversely, we can imagine that for novice users directly touching the robot parts whose movement should be modified would be quite intuitive, as in general with kinesthetic demonstration [15]. Essentially the teachers' touching is a method of transmitting their internal image of what the robot postures should be. To make communication successful, the robot must then interpret these touches in terms of adjusted body postures. However, for the robot this reconstruction process is not straightforward since similar touches could have different meanings depending on the context. For example if the robot is standing, touching the upper part of one leg could mean that the leg should bend further backwards. However if the robot is squatting, the same touch could mean that the robot should move lower to the ground by bending its knees (see Fig. 8).

Furthermore, the style and method of touching could be in part or totally user-dependent. Defining a fixed protocol and forcing the user to employ it would allow solving these

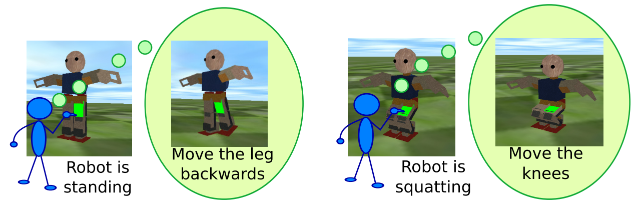

Fig. 8. An example of the context dependence of the touch meaning. The user presses the same sensor, but due to the different robot posture the desired posture modifications (bend the leg and bend the knees, respectively) differs.

ambiguity problems. However, we believe that by making the robot's instruction interpretation adaptive users will be able to touch the robot more naturally and therefore develop motions with a very low mental effort. Figure 9 summarizes graphically our model for the emergence of touch instructions. According to our model users have an intended joint modification and, depending on some of the features of the physical context that they unconsciously perceive, they provide a tactile instruction. In [12], we presented an interface that uses the K-Nearest Neighbor algorithm with a specifically designed weighting to construct the inverse mapping from touch instruction and physical context to intended joint modification.

Our system allows the users to switch between two modalities. In the "motion-development" phase the users press touch sensors and the robots moves according to its interpretation of the touch pattern. When users feel that the robot interpretation does not reflect their intention, they just switch to the "touch-meaning-teaching" phase and provide, by other means (direct robot manipulation or classical, slider based interface) the posture modification they intended by the applied touch. In this way the (supervised learning) algorithm for touch interpretation can be refined more and more online, i.e. during motion development. This approach presents an interesting secondary advantage: the collected training examples, consisting of a touch pattern and the corresponding desired joint modification, can be studied afterwards to help improve our understanding of how humans communicate via touch.

Preliminary results were obtained using simulated touch sensors. Expressly we used a simulator, depicted in Fig. 10, and asked the users to develop motions by clicking on the simulated touch sensors. The experiments show that simple linear models failed to capture the structure of the mapping between touch instructions and desired joint modification. Conversely, our algorithm revealed to perform well (at least in comparison to ridge regression) on unseen validation data and pilot experiments suggest that the employed system can reduce the motion development time with respect to classical slider based interfaces. The presence of a strong user dependency of the touch protocol was identified using a limited number of users and in detail we got insights on the fact that different users employ different levels of abstraction in their instructions:

- a nearly fixed mapping from a small set of sensors to

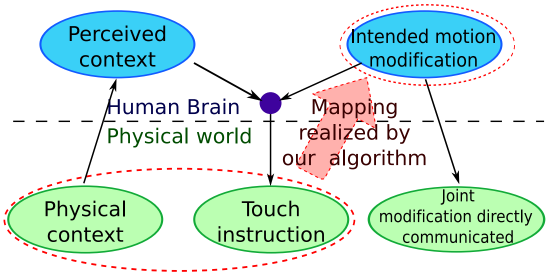

Fig. 9. Conceptual schema of the generation of touch instructions.

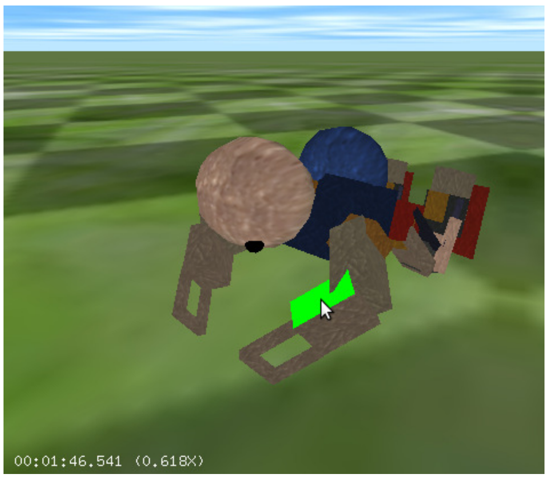

Fig. 10. Screenshot of the simulator used in our experiments. A mouse click on a simulated touch sensor on the robot arm makes the sensor color change for clarity.

the joints on which the context has little or no influence

- a mapping based on physical considerations; in this case, the context, for instance the position of the ground, becomes crucial
- a very high level representation of the motion, where for instance just the limb that should be moved is indicated by touching; at this level of abstraction a single touch corresponds to a motion primitive.

The developed platform, equipped with touch sensors on the whole body, will permit direct interaction with the real robot, without the need of simulated touch sensors and will allow us to study tactile interaction in a more natural setting.

IV. Conclusions

In this paper we introduced a newly developed baby robot. Thanks to its compact size this platform allows a safe and easy interaction while providing most of the sensory information given by bigger size and more complex child robots spreading in developmental robotics. We briefly illustrated its onboard components, and in detail the CPU and motor control board that makes it completely autonomous. We then described the touch sensors that cover its whole body and that make it unique in the small humanoid robot field. Two examples of researches that will be pursued on the platform had then been presented. Firstly we outlined how learning of a crawling motion can be achieved by a simple, biologically inspired approach. Successively, we presented an application that will make full use of the touch sensors available on the robot to develop robot motions and, more importantly, to study the way humans employ touch to convey information. Short term future works will clearly involve the actual implementation of the presented experiments, currently conducted only in simulation, on the real robot.

V. Acknowledgments

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