Physical Human-like Interaction with the Acroban and Poppy Humanoid Platforms.

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***Abstract*— In this paper we will present two humanoid platforms (Acroban and Poppy) developed in our lab to study biped locomotion and physical interaction. We will present how their morphologies (compliance, vertebral column, and soft materials) produce human-like movements and natural responses to external perturbations. We will illustrate this behavior with the example of the socially guided biped locomotion. We will also discuss the very positive emotional reactions aroused when presenting Acroban to the general public. We will hypothesize that this behavior could be explained by the contrast between its crude visual appearance and its smooth and compliant movements which increases the impression of like-likeliness.**

I. Introduction

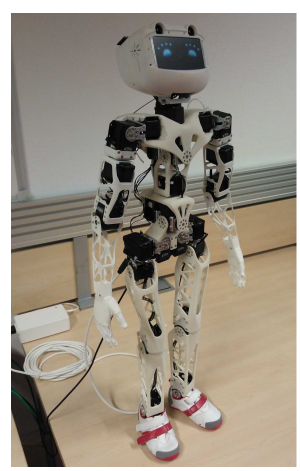
Humanoid robots draw more and more attention as they are predicted to play a key role in domain such as personal robotics, cognitive or social assistance and even entertainment. As they are brought from controlled environment such as factories or scientific laboratories to our everyday homes, robots and their users will have to operate in close proximity. Among the many challenges raised by sharing a common environment, it will necessarily lead to physical human-robot interaction. While those interactions could be intentional (e.g. taking the arm of a robot to show it how to perform a task) or unexpected (e.g. bumping into the robot while it was walking), they are known to significantly impact the user's perception of the interaction (e.g. trust, acceptability) and to be a really powerful way to intuitively transmit information both from the human to the robot [1] and from the robot to the human [2].

Yet, most existing robots do not permit, or permit very limited and unsatisfying, physical interaction. This is particularly the case for humanoid robots (e.g. Honda's ASIMO [3], HRP [4]) whose physical properties make them heavy, fragile and powerful. In this context, physical contacts likely risk to harm the human and/or the robot. Their rigidity (e.g. Nao [5], Darwin-OP [6]) make them not very robust to unknown external perturbations such as an expected physical contact and lead to rough, unpleasant and oversimplified physical interaction.

Several lines of research have flourished around physical human-robot interaction [7]. Researchers have investigated how accidental and/or unwanted contact with robots could be made intrinsically safe [8]. They have also explored the potentiality of physical contacts for communication such as communicative touches to teach a robot correct posture [9] or intuitively guiding a nursing assistant robot [10]. Learning by demonstration has also largely been used to demonstrate complex motion trough intuitive and simple interactions [11][12]. While physical interaction is known to have a strong impact on the user's perception, very few researches have been made in this direction. Cramer et al. showed that touch and proactive behavior seems to have a linked effect on the perception of the interaction [13]. The Paro robot has been developed to further investigate the touch aspect of emotional communication and their effect on hospitalized persons [14].

In the rest of this abstract, we will first quickly describe two humanoid platforms developed in our lab (see section II). Those robots have notably been designed to allow for safe and full-body compliant physical interaction. Their conception follows the morphological computation principle, where the use of soft materials, springs and compliant motors allows for direct body reaction through the mechanics. Such an approach as been shown to produce human-like movements [15]. We will illustrate in section III how the combination of the robot's morphology and its compliance allows non-expert humans to intuitively guide it physically by the hand, producing a very human-like walking gait. Finally, we will describe qualitative observations made from public exhibitions of Acroban, where the difference between its crude visual appearance and its smooth and compliant motions seems to increase its life-likeliness (see section IV).

(a) Acroban



(b) Poppy

Fig. 1: The two developed humanoid platforms.

*This research was partially funded by ERC Starting Grant EXPLORER 240007.

[1] INRIA Flowers Team, Bordeaux, France `pierre.rouanet, matthieu.lapeyre, pierre-yves.oudeyer at inria.fr`

II. Humanoids Platform for the physical interaction

We developed two robotic platforms to explore compliant humanoid dynamics. First with the Acroban prototype [16] in 2009, which was the first robot with a 5 degree of freedom trunk. Combined with compliant actuators and elastic materials Acroban showed highly interested physical interaction behavior and empathic emotion from non-expert user. As the robot appeared weak and clumsy, people were more willing to physically interact with Acroban to help it. This human-Acroban interaction lead to an emergent behavior to help the robot walks [17].

A second humanoid robot was developed in 2012, Poppy [18]. This robot integrates some of Acroban's main features such as the articulated vertebral column and the full-body compliance. The legs were re-designed from scratch to study the challenge of producing a human-like biped locomotion. The head was changed to permit the expression of emotions trough a LCD screen. As this platform is the most advanced one, we will present an overview of its morphology:

Anatomical proportions are bio-inspired: Poppy's limbs respect the proportion of the human being [19].

Large sensorimotor-space: Poppy has a large sensorimotor space composed of 25 Robotis Dynamixel[1] servo-motors (23 MX-28 and 2 AX-12). These servo-motors give access to a large number of internal sensors and allow the dynamical tuning of their compliance. The sensors space is extended by the addition of 8 force sensors under each foot, an inertial measurement unit located in the head, and two wide-angle HD cameras. The total sensorimotor space is composed by more than 150 dimensions giving access to several kinds of data (e.g. position, speed, load, temperature, acceleration, foot pressure).

Articulated spine: Poppy has 5 motors in the trunk allowing the reproduction of the main DOFs of the human spine [20] (see Fig. 2). These DOFs enable more natural and fluid motions while improving the user experience during physical interaction [21]. In addition, the spine plays a fundamental role in bipedal walking and postural balance by actively participating in the balancing of the robot.

Bio-inspired bended thigh: The shape of the thigh is inspired of the human thigh. It is bended by angle of 6^o, increasing the stability of the robot.

Lightweight: Poppy weights only 3.5kg allowing the use of less powerful motor which ensure that physical interaction with the robot is safe for humans.

Small feet with compliant toes: To produce an efficient and human-like walking gait, Poppy's feet design takes some functional inspiration from the actual human foot such as the proportion (i.e. small compared to conventional humanoids), compliance and toes which are key features concerning both the human walking [22] and biped robots with a human-like gait [23].

[1] http://www.robotis.com/xe/dynamixel_en

Fig. 2: These figures illustrate some morphological features of the Poppy humanoid Robot: Poppy has an articulated trunk of 5 DoFs which allows more natural and fluid motions while improving the user experience during physical interaction and actively participating to the balance of the robot.

III. Socially guided walking example: lead me by the hands

An original and initially unplanned feature of Acroban appeared during a public demonstration of the robot in Napoli's Science Museum in Italy in November 2009, where children (around 150) could interact personally and physically with the robot. While showing that Acroban could be pushed or pulled at various places of its body (head, torso, legs, arms...) without falling and keeping natural smooth compliant movements, some children began to take the hands of Acroban, like parents take the hands of their children, and tried to have Acroban follow them. And, to our surprise, Acroban followed. As we afterwards robustly and easily reproduced ourselves, they could lead Acroban by the hand in any direction, have it turn on itself, and this even by applying extremely gentle forces on one or both hands. Yet, no force sensors were used to measure such external perturbations and not a single line of code in Acroban was written to produce such a behavior.

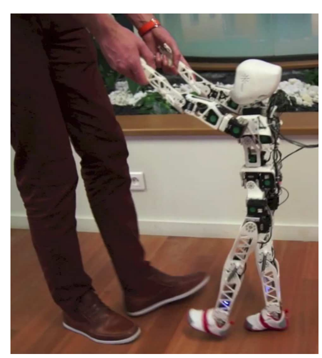


Fig. 3: Users can physically help Poppy to learn how to walk by leading it by the hands and thus providing both balance and control of mass transfer. This social guidance is also a way to make sure that Poppy will learn a human-like gait.

On Poppy, we reuse this kind of social guidance where people lead the robot by the hands while it is walking to assist its gait. This allows an intuitive, playful and safe way to teach the robot how to walk (see Fig. 3). In the video[2], the experiment consists in playing an open-loop walking primitive while the robot is guided through the physical interaction of a human. The users role is to provide both balance and control of mass transfer. By producing small lateral motion on the upper-body they can help the robot to move its center of gravity from one foot to another. This approach seems really interesting to us as it could also be a way to circumvent the problem of defining what makes a gait human-like. By having users directly providing "good" examples of what they think correspond to human-like steps we could make sure that the robot will produce motions which appear to users as human-like.

IV. Emotions in Physical Human-Robot Interaction with Acroban

While demonstrating Acroban during public exhibitions such as Futuro Remoto (Napoli 2009) or Siggraph (Los Angeles 2010), we have discovered that it provokes spontaneous highly positive emotional reactions. Yet, as opposed to many other robots, its morphology is neither roundish nor cute. Even if we have not yet conduct thorough studies, we have formulate hypotheses to try to explain those reactions.

Fig. 4: Demonstration of Acroban during the Futuro Remoto exhibition in Napoli 2009. Children physically interacted with the robot provoking human-like mechanical responses of Acroban.

As one can see on the figure 4, its visual appearance creates low expectation of intelligence and life-likeness. He has no big eyes and no funny color. He has only three raw motors in place of the head. He is just made of metal, and its appearance shows it explicitly. But when it starts to move with smooth and compliant movements or when one physically perturbed it causing human-like mechanical responses, it triggers a high contrast and a positive surprise: life unexpectedly appeared. We can compare this effect to what happens in Pixar's Luxo Jr animated cartoon where a neutral desk lamp provokes a positive surprise when animated like a life form [24]. While most recent robots tend to advocate the use of morphologies/shape/colors which should trigger positive expectations before the interaction starts (e.g. by taking baby-like features without falling into the uncanny valley effect [25]), Acroban's design tends to minimize expectations and thus maximize the effect of positive surprise due to its actual behavior. The user discovers that the robots is actually "more" that it seemed at first sight.

Acroban and Poppy also follows principles of animated cartoons to trigger the illusion of life: in particular, their high-compliance and passive dynamics allow observers to directly see/feel the weight and inertia of the robot, much like Disney's explanations on the "importance of weight" for animating walking creatures [26] (see also [27] for a related study).

As stated above we have not yet investigated thoroughly this effect. Systematic and quantitative HRI experiments should be conducted to verify and precise our hypothesis. Many parameters could be involved: e.g. the crudeness of the appearance, the lack of visible human-like sensors, the smoothness of motion. As one can see on the figures, while Poppy has been conceived after Acroban, its conception followed more traditional design guidelines (big head, roundish shape). Yet, as it has been made from 3D printed parts [18], it can be a really interesting tool to perform such comparative studies. One could imagine having different versions of Poppy - e.g. with a big head with visible eyes, without a head, with a rigid and closed trunk hiding the inertia of the robot, with square section limbs... - simply by 3D printing a new limb. The possibility of modifying and/or replacing parts of its design permits to easily separate and thus identify the possible underlying factors. To go further in this direction the Poppy platform will soon been opened (both the hardware and software) to the academic community.

[2] `http://vimeo.com/poppyproject/firstwalk`

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