An Open-Source Simulator for Cognitive Robotics Research: The Prototype of the iCub Humanoid Robot Simulator

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ABSTRACT

This paper presents the prototype of a new computer simulator for the humanoid robot iCub. The iCub is a new open-source humanoid robot developed as a result of the “RobotCub” project, a collaborative European project aiming at developing a new open-source cognitive robotics platform. The iCub simulator has been developed as part of a joint effort with the European project “ITALK” on the integration and transfer of action and language knowledge in cognitive robots. This is available open-source to all researchers interested in cognitive robotics experiments with the iCub humanoid platform.

Keywords

Open-Source, Simulator, iCub humanoid robot, cognitive robotics.

1. INTRODUCTION

Computer simulations play an important role in robotics research. Despite the fact that the use of a simulation might not provide a full model of the complexity present in the real environment and might not assure a fully reliable transferability of the controller from the simulation environment to the real one, robotic simulations are of great interest for cognitive scientists [18]. There are several advantages of robotics simulations for researchers in cognitive sciences. The first is that simulating robots with realistic physical interactions permit to study the behavior of several types of embodied agents without facing the problem of building in advance, and maintaining, a complex hardware device. The computer simulator can be used as a tool for testing algorithms in order to quickly check for any major problems prior to use of the physical robot. Moreover, simulators also allow researchers to experiment with robots with varying morphological characteristics without the need to necessarily develop the corresponding features in hardware [1]. This advantage, in turn, permits the discovery of properties of the behavior of an agent that emerges from the interaction between the robot’s controller, its body and the environment. Another advantage is that robotic simulations make it possible to apply particular algorithms for creating robots’ controllers, such as evolutionary or reinforcement learning algorithms [12]. The use of robotics simulation permits to drastically reduce the time of the experiments such as in evolutionary robotics. In addition, it makes it possible to explore research topics like the co-evolution of the morphology and the control system [1]. A simulator for the iCub robot magnifies the value a research group can extract from the physical robot, by making it more practical to share a single robot between several researchers. The fact that the simulator is free and open makes it a simple way for people interested in the robot to begin learning about its capabilities and design, with an easy "upgrade" path to the actual robot due to the protocol-level compatibility of the simulator and the physical robot. And for those without the means to purchase or build a humanoid robot, such small laboratories or hobbyists, the simulator at least opens a door to participation in this area of research.

The iCub simulator is currently being used by both the RobotCub and the ITALK project partners for preliminary experiments on the simulator robot, and subsequent testing with the physical robots.

2. ICUB SIMULATOR DEVELOPMENT

The iCub simulator has been designed to reproduce, as accurately as possible, the physics and the dynamics of the robot and its environment. The simulated iCub robot is composed of multiple rigid bodies connected via joint structures. It has been constructed collecting data directly from the robot design specifications in order to achieve an exact replication (e.g. height, mass, Degrees of Freedom) of the first iCub prototype developed at the Italian Institute of Technology in Genoa. The environment parameters on gravity, objects mass, friction and joints are based on known environment conditions.

2.1 Open-Source Approach

The iCub simulator presented here has been created using open source libraries in order to make it possible to distribute the

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simulator freely to any researcher without requesting the purchase of restricted or expensive proprietary licenses.

The very first iCub simulator prototype was developed using the commercial Webots package [10,17], a professional robotic simulator which is widely used in academia and research. The Webots package is primarily designed for industrial simulations but used as a reliable tool for robotic research. Although a powerful software, the main disadvantages of the Webots package are its price, the computational heaviness of the package itself and the fact that, depending on the type of license, there are limitations on the source code available in order to modify some properties of the actual simulator. Therefore the potential open source distribution of such a first prototype was quite limited.

Other open source simulators suitable for robotics research also exist. Amongst others we can find the Player/Gazebo project [6, 7], Simbad [16], Darwin2K [8], EvoRobot [4,12] and the OpenSim [14]. The Simbad, Darwin2K and Evorobot simulators have a strong focus on evolutionary algorithms and they have been mainly developed for scientific educational purposes. They are built to study AI algorithms and machine learning for multi-robot platforms. Gazebo is a powerful and complex multi-robot simulation in a 3D environment. OpenSim is a general multi-robot platform built in a similar way as the Gazebo package. However such systems use the same third party software and libraries.

Although the proposed iCub simulator is not the only open source robotics platform, it is one of the few that attempts to create a 3D dynamic robot environment capable of recreating complex worlds and fully based on non-proprietary open source libraries.

2.2 Physics Engine

The iCub simulator uses ODE [13] (Open Dynamic Engine) for simulating rigid bodies and the collision detection algorithms to compute the physical interaction with objects. The same physics library was used for the Gazebo project and the Webots commercial package. ODE is a widely used physics engine in the open source community, whether for research, authoring tools, gaming etc. It consists of a high performance library for simulating rigid body dynamics using a simple C/C++ API. ODE was selected as the preferred open source library for the iCub simulator because of the availability of many advanced joint types, rigid bodies (with many parameters such as mass, friction, sensors...), terrains and meshes for complex object creation.

2.3 Rendering Engine

Although ODE is a good and reliable physics engine, computing all the physical interaction of a complex system can take a good deal of processing power. Since ODE uses a simple rendering engine based on OpenGL, it has limitations for the rendering of complex environments comprising many objects and bodies. This can significantly affect the simulation speed of complex robotic simulation experiments. It was therefore decided to use OpenGL directly combined with SDL [15], an open source cross platform multimedia library. This makes it possible to render the scene with much more ease and to carry out computationally-efficient simulation experiments.

2.4 YARP Protocol

As the aim was to create an exact replica of the physical iCub robot, the same software infrastructure and inter-process communication will have to be used as those used to control the physical robot. iCub uses YARP [5, 9] (Yet Another Robot Platform) as its software architecture. YARP is an open-source software tool for applications that are real-time, computation-intensive, and involve interfacing with diverse and changing hardware. The simulator and the actual robot have the same interface either when viewed via the device API or across network and are interchangeable from a user perspective. The simulator, like the real robot, can be controlled directly via sockets and a simple text-mode protocol; use of the YARP library is not a requirement. This can provide a starting point for integrating the simulator with existing controllers in esoteric languages or complicated environments.

2.5 Architecture

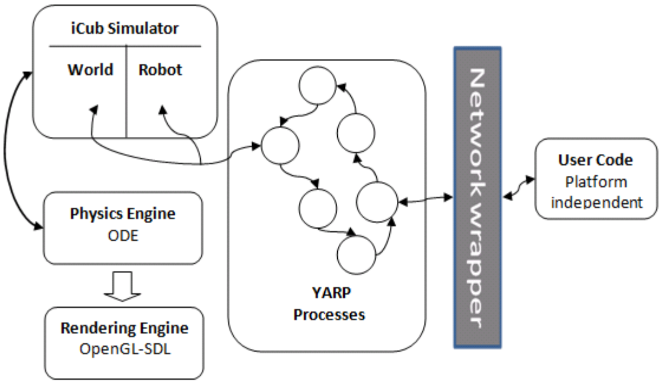
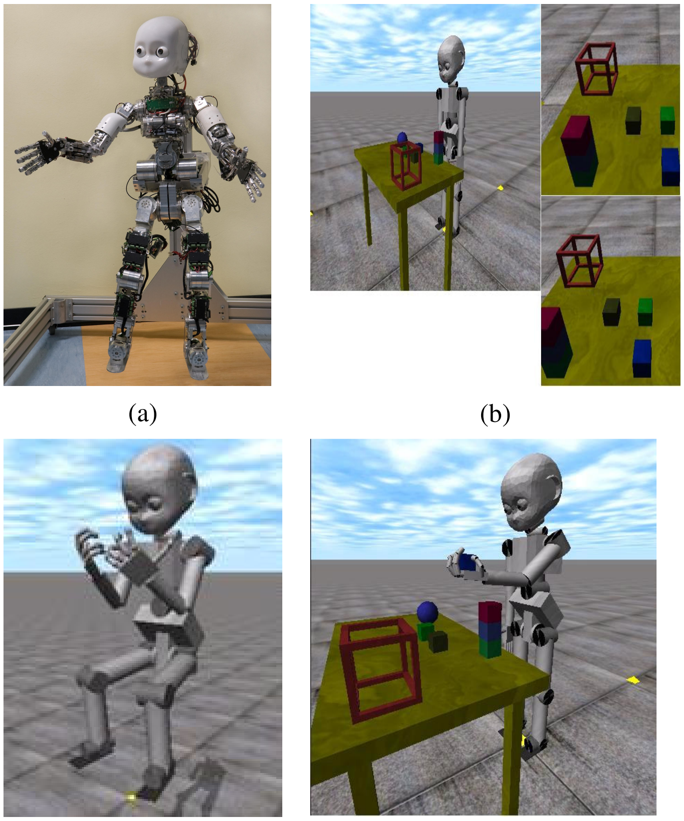


Figure 1. This figure shows the architecture of the simulator with YARP support. The User code can send and receive information to both the simulated robot itself (motors/sensors/cameras) and the world (manipulate the world). Network wrappers allow device remotization. The Network Wrapper exports the YARP interface so that it can be accessed remotely by another machine.

2.6 iCub Body Model

The iCub simulator has been created using the data from the physical robot in order to have an exact replica of it. As for the physical iCub, the total height is around 105cm, weighs approximately 20.3kg and has a total of 53 degrees of freedom (DoF). These include 12 controlled DoFs for the legs, 3 controlled DoFs for the torso, 32 for the arms and six for the head.

The robot body model consists of multiple rigid bodies attached through a number of different joints. All the sensors were implemented in the simulation on the actual body, such as touch sensors and force/torque sensors. As many factors impact on the torque values during manipulations, the simulator might not guarantee to be perfectly correct. However the simulated robot torque parameters and their verification in static or motion are a good basis and can be proven to be reliable [11].



(a) (b)

(c) (d)

Figure 2. Photo of real iCub (a), of simulated iCub and the binocular view (b) The simulated iCub moving all four limbs as part of a demo (c) and the simulated iCub looking at and manipulating an object in its environment.(d)

All the commands sent to and from the robot are based on YARP instructions. For the vision we use cameras located at the eyes of the robot which in turn can be sent to any workstation using YARP in order to do develop vision analysis algorithms.

The system has full interaction with the world/environment. The objects within this world can be dynamically created, modified and queried by simple instruction resembling those that YARP uses in order to control the robot.

3. ICUB SIMULATOR AND COGNITIVE ROBOTICS RESEARCH PROJECTS

This section presents a research initiative on embodied cognition and developmental cognitive robotics based on the two EU projects RobotCub (robotcub.org) and ITALK (italkproject.org). Various robotics experiments in these two projects will rely on the use of the iCub simulator.

The RobotCub project aims at the development of an open humanoid robotic platform (iCub) and simultaneously the advancement of our understanding of cognitive systems by exploiting this platform in the study of the development of cognitive capabilities in humanoid robots. The idea is that, by creating a common platform, this will enable many laboratories to join this effort without having to invest themselves in developing yet another robotic platform. The second aim of RobotCub is to investigate the development of these cognitive skills in natural and artificial cognitive systems. The project will carry out a plan of empirical research including neuroscience, developmental psychology, and robotics. This plan is centered on manipulation behavior, ranging from the direct aspects of reaching and grasping for objects to the use of gestures for communication. Aspects that will be touched along the way are—for instance—looking and overt attention, reaching, the detection and discovery of affordances, learning through imitation, and interaction. The emergent approach naturally encompasses the study of ontogenic development and, in fact, a comparatively large effort will be devoted to its study. The RobotCub project roadmap for this investigation includes the study of the starting point in terms of core abilities, the motivation of the system to explore and gather data, and new studies on a few research areas such as looking, reaching and manipulation, posture, locomotion, and social interaction. For each of these areas, issues of prospective use of information, motivation, and the mechanisms of exploration have to be experimentally investigated. The RobotCub agenda aims at covering—through targeted empirical investigation—most if not all of these issues.

The ITALK project intends to develop cognitive robotic agents, based among others on the iCub humanoid platform, that learn to handle and manipulate objects and tools autonomously, to cooperate and communicate with other robots and humans, and to adapt their abilities to changing internal, environmental, and social conditions. The main theoretical hypothesis behind the project is that the parallel development of action, conceptualisation and social interaction permits the bootstrapping of language capabilities, which on their part enhance cognitive development. This is possible through the integration and transfer of knowledge and cognitive processes involved in sensorimotor learning and the construction of action categories, imitation and other forms of social learning, the acquisition of grounded conceptual representations and the development of the grammatical structure of language.

The undergoing research falls into five main research themes: (i) action development, (ii) conceptualisation, (iii) social interaction, (iv) language emergence, and (v) integration and bootstrapping of cognition.

The study of the development of complex action manipulation capabilities will –in contrast to existing approaches– be based on synchronous development of motor, social and linguistic skills. For this it is fundamental to identify the characteristics of action development that are compatible with this scenario and reject those that are mere engineering solutions. Two core properties of biological motor control systems will be considered: compositionality, the construction of hierarchically ordered gesturing and manipulation, and generalization. We will study how action development can be guided by individual exploration by the robot and by imitating humans.

A fundamental skill of any cognitive system is the ability to produce a variety of behaviours and to display the behaviour that is appropriate to the current individual, social, cultural and environmental circumstances. This will require agents (1) to reason about past, present and future events, (2) to mediate their motor actions based on this reasoning process and (3) to communicate using a communication system that shares properties with natural language. For this agents will need to develop and maintain internal categorical states, i.e. ways to store and classify sensory information. We term such internal states *embodied concepts* and we understand them as representations grounded in sensory-motor experiences that identify crucial aspects of the environment and/or of the agent/environmental interaction.

Another essential component of the ITALK research project is to look at the role of social learning and social interaction to support the development of a shared linguistic communication system. In particular, new research will consider (i) the role of imitation and human-robot interaction for the acquisition of shared communication systems based on deixis, gestures and reference, (ii) the role of users' expectation in human-robot interaction and (iii) the emulation of actions and gestures in the learning of multimodal task-oriented behavior. Such research will be based on a series of human-robot interaction (HRI) experiments and on observational studies on parent-child dyads which will inform robot-robot and human-robot experiments. We expect to extend the expertise and methodologies in dialog systems for HRI studies to new studies on social interaction and communication where the robot's linguistic communication system develops through interaction with its environment and other robots and humans.

The ITALK project will follow a cognitive linguistics approach. As it is centred on the interaction between action and language development, it provides the ideal testbed to investigate the emergence of linguistic constructions in close interaction with the development of action, social and grounded conceptual capabilities. We will focus on the emergence of linguistic structure. Among the research issues include (i) generalisation as the basis of the emergence of symbolic systems, (ii) the role of speech and "acoustic packaging": speech or sound signals which serve as a cue to aid the learning of action sequences, (iii) the role of constructional grounding: the acquisition of linguistic construction and how one construction become favoured over another, (iv) the ontogenetic emergence of compositional lexicons, and (v) evolutionary studies on language emergence.

In the coming years the ITALK project aims to achieve a series of scientific and technological objectives such as providing new scientific explanations of the integration of action, social and linguistic skills and in particular on the hypothesis that action, social and linguistic knowledge co-develop and further bootstrap cognitive development. Another main aim deals with developing sets of methods for analyzing the interaction of language, action and cognition in humans and artificial cognitive agents using robot learning experiments, computer simulations, cognitive linguistic analysis, and experimental investigations from developmental linguistics, the neuroscience of language and action, and human-robot interaction experiments. Furthermore the project will develop innovative and cognitively plausible engineering principles, techniques and approaches for the design of communicative and linguistic capabilities in cognitive robots able to interact with their physical and social world and to manipulate entities, artefacts and other agents including humans.

All of the above aims would be demonstrated through the use of robotic experiments on the acquisition of object manipulation, social skills and linguistic capabilities in simulated and physical cognitive robots. In particular, robotic agents will be able to (a) acquire complex object manipulation capabilities through social interaction; (b) develop an ability to create and use embodied concepts; (c) develop social skills that allow flexible interaction with other agents or people; (d) develop linguistic abilities to communicate about their interaction with the world.

4. CONCLUSION

The current version of the iCub simulator has been used for preliminary testing by partners in the RobotCub and ITALK projects. In addition to being used for experiments on the development of controllers for the iCub robot, some groups have used the simulator to create a mental model [2] used by the robot to represent the current state of the environment.

Future plans on the simulator development will mostly involve the design of functionalities to model and interact with the physical environment. For example, this will allow the users to modify the objects in the world where the iCub resides, in order to allow different types of experiments. Finally, further work will focus on the systematic testing and replication of simulation studies with the physical robot.

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