Loki, a mobile manipulator for social robotics

P. Bustos, I. García-Varea, J. Martínez-Gómez, J. Mateos, L. Rodríguez-Ruiz, A. Sánchez

***Abstract*—Autonomous mobile manipulators are robots designed to perform a variety of tasks in which the combination of navigation and manipulation plays a key role in achieving more advanced functionalities. These robots have multiple sensors and actuators, and usually an important processing potential aboard combined with a limited energy autonomy. Moreover, when these machines are designed to perform socially, they need to interact with humans in many ways, looking for empathy by showing emotional expressions. In this paper we present the social mobile manipulator Loki in its current state of development. We give an overview of its overall architecture at three levels of organization: mechatronics, software and cognitive architecture. The paper is concluded with a short discussion on the future uses of Loki and on how this costly inversion can pay-off faster by starting collaborative projects.**

***Index Terms*—Mobile manipulator, social robotics, human robot interaction.**

I. INTRODUCTION

Autonomous mobile manipulators (AMMs) are multi-joint robots whose ultimate goal is the execution of complex manipulation tasks in unstructured and dynamic environments. Their large number of sensors and actuators result in very high dimensional state spaces. Also, due to the variety of tasks they have to perform, engineering the entire environment becomes an unpractical task. As a result, these systems have to explicitly address problems arisen because of the uncertainty of sensing and actuation. On top of these challenging requirements, there are additional problems derived from the construction of very large software architectures that control the behavior and intelligence of these robots. Despite the daunting complexity of this landscape, many AMM's have been built during the past twenty five years in a, sometimes pressing, search for general purpose machines. In this paper we present a brief review of some of the most relevant AMM's recently built in the context where they where developed.

Later we describe a new AMM called Loki that has been built as a collaborative process among the University of Castilla-La Mancha, the University of Extremadura, Robotnik S.L.L and IADex S.L. Loki has been designed to perform as a social robot providing services and assistance to humans in their everyday activities. Mechanically, Loki is supported by a differential mobile base and it has two arm, with 7 DOF each, and one Barret hand. It is equipped with high computational capabilities and the energy storage and conversion devices needed to provide full autonomy. As a research robot, it has been designed to provide enough functionality during an extended period of time and, also to be easily updated when new technologies become available. In parallel to the construction of Loki, RoboLab has initiated the preparation of a $70m^2$ living lab where human-robot interaction (HRI) experiments can be performed in real conditions as well as monitored to obtain ground-truth measurements. The final part of this paper includes a brief remark on RoboComp, the robotics framework that Loki runs for providing a rich set of development tools for cooperation, integration and maintenance of the repository of software components that control the robot. Besides, a short description of a cognitive architecture, called RoboCog, that is being built on top of RoboComp is presented, along with some discussion on its high-level cognitive modules that are under active development currently.

J. Mateos is with IADeX.
A. Sánchez and P. Bustos are with the University of Extremadura.
I. García-Varea, J. Martínez-Gómez and L. Rodríguez-Ruiz are with the University of Castilla-La Mancha, Albacete, Spain

II. RELATED WORK

During the last ten years there has been a significant progress in the design and implementation of different types of social AMMs. This section presents recent developments in the field, providing a brief description of the most relevant AMMs found in the literature, specially in the context of social interactive robotics.

- **Cosero (Cognitive Service Robot)**: Cosero has been developed by the Autonomous Intelligent Systems group at University of Bonn (see Fig. 1) for mobile manipulation tasks in domestic environments [1]. The robot is mounted on an omnidirectional base that has four pairs of steerable and powered wheels. Its anthropomorphic upper body has two 7 DOF arms that are equipped with two-finger grippers and a pan-tilt sensor head. The upper body can

Fig. 1: Cosero robot

be moved vertically and twisted to extend the workspace of the arms. Cosero won together with its predecessor Dynamaid the 2011 *RoboCup@Home* competition. The Dynamaid robot can be considered asa a previous version of Cosero which was specifically developed for *RoboCup@Home 2009* competition [2].

- **iCub**: iCub is an open-source, cognitive humanoid robotic platform developed as part of the EU projects RobotCub, ITALK, RoboSKIN and AMARSi, EFAA and CHRIS. It has been adopted by more than 20 laboratories worldwide (see Fig. 2) [3] and, in our opinion, it is the most interesting project in the Cognitive Robotics Calls.

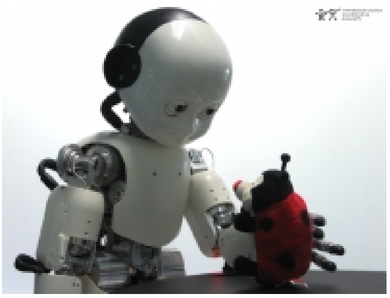


Fig. 2: iCub robot

It has 53 motors that move the head, arms, hands, waist and legs. Currently it can perform some basic behaviors such as sitting, crawling and picking objects. The main research goal of the projects that work with iCUB is to enable it to learn from the environment by watching, listening and touching.

- **Little Helper**: The autonomous industrial mobile manipulator (AIMM) was developed at Aalborg University (see Fig. 3), within the Little Helper project. This project

Fig. 3: Little Helper robot

is an ongoing research and development project at Department of Mechanical and Manufacturing Engineering, Aalborg University, Denmark [4]. This mobile robot acts as a flexible little helper which can be easily and rapidly integrated into several applications in existing production environments. It is able to serve usual production equipment and carry out versatile work related operations - either depending on machine-to-machine (via wireless communications) or man-to-machine (through customized work cycles) communication.

- **ARMAR-III**: The humanoid robot ARMAR-III has been developed whithin the european research project PacoPlus, and it has been designed by the Institute of Product Development of the University of Karlsruhe, Germany (see Fig. 4) [5]. ARMAR-III has 43 DOF: 7 in the head,

Fig. 4: ARMAR-III robot

7 in each arm, 8 in each hand, 3 in the torso and 3 in the mobile base. The head is equipped with two eyes. These eyes have a common tilt and they can pan independently. Each eye has two built-in color cameras, one with a wideangle lens for peripheral vision and the other with a narrow-angle lens for foveal vision. The visual system is mounted on a four DOF neck mechanism (lower pitch, roll, yaw, upper pitch). For acoustic localization, the head is provided with a microphone array consisting of six microphones (two in the ears, and four in the head: two in the front and two in the back). Furthermore, an inertial sensor is installed in the head for stabilization control of the camera images and each arm is equipped with a 6 DOF torque/force sensor and a five-fingered hand with eight DOF. The base of the robot is a four wheel omnidirectional platform with a combination of three laser range finders and optical encoders. The platform hosts the power supply of the robot and the main part of the robot computer.

- **AILA**: The humanoid robot AILA has been designed by the Robotics Innovation Center of the DFKI, Germany (see Fig. 5) [6].
AILA is a mobile dual-arm robot system developed as a research platform for mobile manipulation. It has 32 degrees of freedom, including 7-DOF arms, 4-DOF torso, 2-DOF head, and a mobile base equipped with 6 wheels, each of them with two degrees of freedom. AILA's arms

Fig. 5: AILA robot

can lift 8kg and weight 5.5kg, thus achieving a payload-to-weight ratio of 1.45.

- **HERB**: HERB is the Home Exploring Robot Butler at Intel Labs, Pittsburgh (see Fig. 6) [7]. This robot

Fig. 6: HERB robot

can efficiently map, search and navigate through indoor environments, recognize and localize several common household objects, and perform complex manipulation tasks. HERB is the union of several onboard and offboard components. Onboard components include a Segway RMP200 mobile base, a Barrett WAM arm, several sensors and a pair of low-power computers, both powered by a custom-built power supply. Onboard components communicate over a wireless network with offboard off-the-shelf PCs [7].
- **Meka M1 Mobile Manipulator**: M1 was inspired by the successful design of the Georgia Tech robot named Cody. It features compliant force control throughout its body, a customizable sensor in the head, durable and strong grippers, and a small footprint omnidirectional base (see Fig. 7) [8].

Fig. 7: Meka robot

The main features of the standard version of Meka M1 comprise: a S3 Sensor Head with Kinect compatible interface and 5MP Ethernet camera, two compliant manipulators with 6 axis force-torque sensors at the wrist and its corresponding grippers, and an omni directional base with prismatic lift and a computation backpack.
- **UMan**: The University of Massachusetts Mobile Manipulator UMan, has been devised to support research in algorithms and control for autonomous mobile manipulation. Due to the focus on dexterous manipulation, UMan's ability to perform physical work in its environment was of particular importance during the design process. (see Fig. 8) [9]. The uMan robot is composed of a mobile base

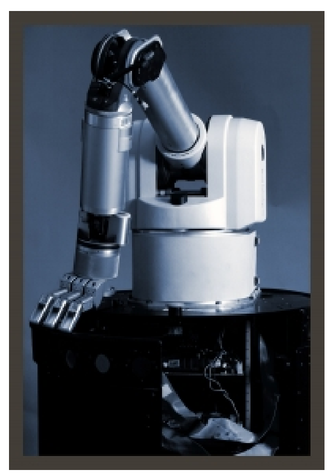


Fig. 8: uMan robot with a Barrett WAM

(a modified XR4000) with a Barrett WAM arm mounted on top of the base.
- **KATE 1.0**: The Kids Avatar Teacher and Entertainer is a humanoid robot developed by FutureBots Humanoid Lab (see Fig. 9) [10]. Kate has sensors to see, hear, smell, talk and express emotions. It has a 22 DOF for the body as well as a fully articulated mouth that can show emotions such as happiness or sadness. It has a nose that detects elements like carbon dioxide, carbon monoxide, natural gas, humidity and smoke from a fire

Fig. 9: Kate robot

to keep people safe. It relies on the Microsoft Kinect sensor for motion detection and image depth processing and have sonar sensors for distance measurements. The robot track system is very powerful and can move on all surfaces as well as on steep inclines. It also has two completely articulated hands and arms, as well as a GPS sensor.

- **Care-O-Bot 3**: The Care-O-Bot 3 robot has been developed for more than ten years by the Fraunhofer IPA (see Fig. 10) [11], [12]. Care-O-bot 3 has an

Fig. 10: Care-O-Bot robot

omnidirectional platform, with four steered and driven wheels which enable the robot to move in any desired direction and therefore, to safely pass through narrow passages. It is also able to autonomously plan and follow an optimal, collision free path to a given target. Dynamic obstacles such as human beings are detected by the sensors and avoided automatically. Care-O-bot 3 is equipped with a highly flexible, commercial arm with seven degrees of freedom as well as with a three-finger hand. This makes it capable of gripping and operating a large number of common objects and, thanks to its tactile sensors in the fingers, it is able to adjust the grasping force. A multiplicity of sensors (ranging from stereo vision color cameras and laser scanners to a 3D depth-image camera) enables the robot to detect the environment in which it is operating.
- **PR2**: PR2 is a robotic platform designed and built by Willow Garage for use in robotic development and research. Willow Garage aims at having the PR2 used as the *go to* robot for exploring the potential of personal robotics (see Fig. 11) [13]. PR2 combines the mobility to

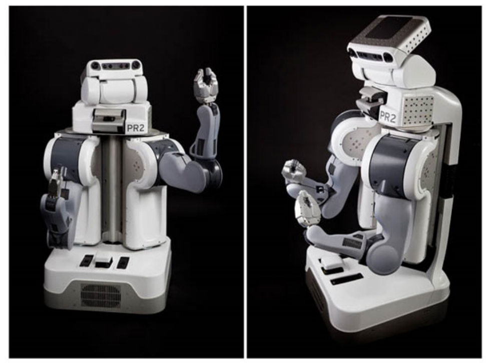


Fig. 11: PR2 robot

navigate human environments and the dexterity to grasp and manipulate objects in such environments. The robot runs under ROS open source software with high processing power, two articulated arms and a sophisticated system of sensors. The whole robot maneuvers around on a rolling base, swiveling to turn quickly. The arms of PR2 are back-driveable and current controlled so that PR2 can manipulate in unstructured environments, and have a passive spring counterbalance system to get the arms floating even when the power is off. The Wrist of PR2 has two continuous degrees of freedom and enough torque in order to PR2 to manipulate everyday objects like doors or frying pans. The PR2's grippers can grasp different objects such as towels, tea cups, brooms and cans.

In view of these developments, it can be observed that AMMs projects share several characteristics while they differ in specific details. Concretely, most of them use an omnidirectional base fitted with wheels and a wide range of sensors: visual cameras, the Microsoft Kinect device, laser scanners, microphones and inertial sensors. On the other hand, there are some aspects in the design of autonomous mobile manipulators where proposals differ notoriously. These aspects are the shape and number of end-manipulators and the design of the human-like head.

In relation with the design on the head, we can identify three alternatives: lack of head (HERB, uMan, Care-O-bot and Little Helper), unrealistic human-like head (Cosero, ARMAR-III, Meka, Kate and PR2) and realistic human-like head (iClub and AILA). In Loki, we have opted for a mobile base fitted with wheels, two arms and an unrealistic human-like head.

Loki, has been designed and build taking into account the major characteristics of the above presented AMMs. In the next section a detailed description of the mechatronics of Loki is presented.

III. Loki mechatronics

Loki is an autonomous mobile robot built as a collaboration among the University of Castilla-La Mancha, the University of Extremadura, Robotnik S.L.L and IADex S.L. It is composed of a mobile base, a rigid back spine, a torso with two arms and a head. The base is an evolution of the former Robex series of mobile robots [14] adapted to support 200 Kg. It has been resized to accommodate two 36Ah/24V batteries, power supplies, a battery charger, a DC/AC 2 KW inverter, two lasers and a dual-socket, 12-core, liquid-cooled Xeon board. This configuration provides enough autonomy and processing power to host several layers of control software. The system is designed to be extended when needed with an additional Xeon board or GPUs (See Fig. 12).

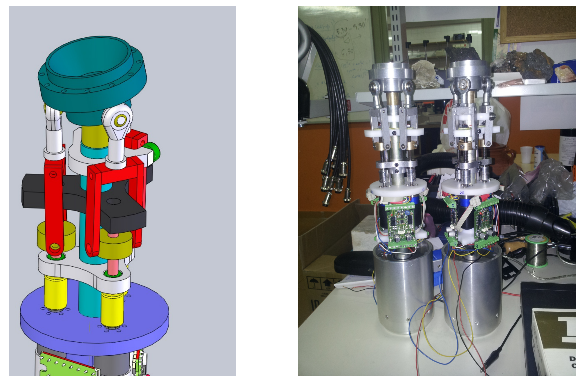
(a) Loki, initial design (b) Loki with on board computation

Fig. 12: One-armed version of Loki

Initially, version each arm had six DOF in anthropomorphic configuration, with a 3 DOF shoulder, an elbow and a 3 DOF wrist. Fig. 13 shows the initial version of Loki's arm. It is a complete solution provided by the company Robotnik S.L.L. including servo-motors supplied by the German company Schunk and with a maximum payload of 9 Kgs. Attached to the wrist, the arm holds a six DOF torque-force sensor and a three fingered 4 DOF BH8 Barret hand. All power and control wiring passes through a duct inside the servos.

Fig. 13: Loki's initial arm with a Barret hand

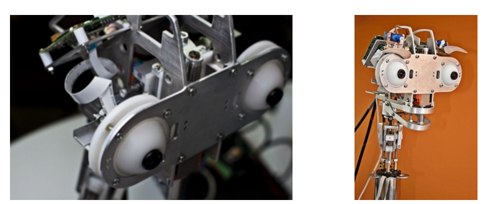
By the end of 2011, we started a major re-design of this arm to add a third DOF in the shoulder (along the upper arm bone) and to substitute for the three motors of the wrist by a new forearm created from a collaboration of RoboLab with the mechatronics company IADex S.L. This piece is a cylindric element that holds inside 4 motors from Faulhaber along with power circuits, control electronics and a CAN bus connection. One motor provides a turn along the forearm axis. The other three are arranged in a parallel kinematic configuration and provide the two additional DOF in the wrist. The force/torque sensor is attached to the wrist and the Barret hand to it, as in the previous arm design (see Fig. 14). The design of this new arm element allowed us to incorporate a second arm to Loki, thereby reducing the overall footprint and improving the aesthetics and the functionality.



(a) Schematics (b) Final design

Fig. 14: Loki's 3 DOF forearm

On top of the torso Loki exhibits the expressive head Muecas. This head is a design developed in parallel to Loki and also in collaboration with IADex SL. It has a 4 DOF neck built employing a similar technology used for the forearms. It also features a binocular visual system composed of two PointGrey Flea2 1Mp cameras with 6mm focal lenses. The cameras are housed inside two hollow spheres made in Teflon. These eye-balls can pan independently and have a common tilt. The eyes are moved by means of three linear motors from Faulhaber that provide enough force to avoid the need of gear trains and to reach maximum angular speeds close to 600 deg/sec. Muecas also has an articulated yaw driven by a micro-servo and 2 DOF eyebrows, controlled by 4 servos as well.



(a) Eyes (b) Head

Fig. 15: Muecas head

Currently we are working on expression synthesis and recognition using Muecas (see Fig. 15). The techniques involved include TTS analysis in experiments involving groups of humans [15], expression recognition using Bayes models

[16] and synthesis of expressions to imitate and recognize human emotions.

Fig. 16: Render of the final version of Loki

Fig. 16 shows a render of the final aspect that Loki would exhibit (including an external covering made of fiber-glass) when the current design is finished. It is the first Spanish platform with these characteristics and one of the most advanced in the European circuit. Several layers of control software run in Loki provide a basic set of functionalities for navigation, visual attention, SLAM and HRI. This software has been developed using the RoboComp framework, which is briefly described in the next section.

IV. The RoboComp framework

RoboComp is an open-source, component-oriented framework designed to facilitate the rapid development of large-scale robotics sofware. Since detailed descriptions can be found in the literature [17], [18], we will only describe the latest improvements. RoboComp is based on three main elements: a component model, a set of model-based tools and reference implementations of available communications middlewares such as Ice [19] and Nerve [20]. In its current version, RoboComp follows a Model-Driven approach to maximize the scalability and adaptability of the repository [21]. The most

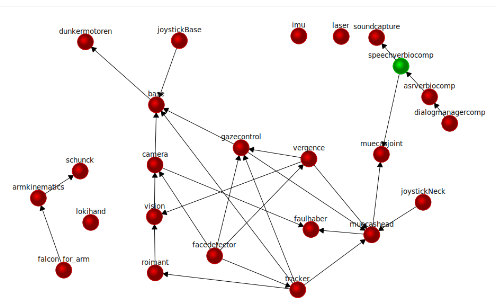


Fig. 17: An example of Robocomp components for the HAL of Loki

important elements of the component's development cycle are defined with Domain Specific Languages (DSL). This new level of abstraction allows for the automatic generation of task-independent source code and facilitates the integration of third party software [18]. Fig. 17 shows some of the RoboComp components that constitutes the Hardware Abstraction Layer of the (one-armed) Loki. There are now several research groups working with RoboComp in Loki and in other robots to create a new cognitive architecture that is sketched briefly below.

V. Cognitive architecture

A *cognitive architecture* has been recently defined as a hypothesis about the underlying infrastructure for an intelligent system, including those aspects of the cognitive agent that are constant overt time and across application domains [22]. These aspects cover: a) short-term and long-term memories that store content about the agent's beliefs, goals and knowledge; b) the representation of elements that are in these memories and their organization in large-scale mental structures; and c) the functional processes that operate on these structures [23]. It is still surprising that a quick search of the word *robot* through the 36 pages of Langley's review only throws 4 matches. Most of the architectures presented take for granted a crisp, internal representation of the agent, its beliefs, goals, operators and the effect of applying an operator on the represented world. When robots are involved from the beginning and real world interaction is at stake, current large-scale, cognitive architectures, such as CRAM (and its related modules ORO, SPARK and DIALOGS) [24] put much more emphasis on the way the internal representations are created, updated and related to the reasoning processes. An interesting proposal by Domingos [25] that might be relevant in this context suggests the use of Markov Logic as the interface between AI foundations and its applications.

Loki has been designed to be a social robot that will be interacting with humans safely in their daily activities. It should be of help to people while keeping a safe interaction policy. Loki's initial goal is to understand simple human requests and to realize them, such as "Please, bring me the blue mug on the table over there" or "Please, help me to get up". To achieve this performance we are building an architecture called RoboCog that is based on the idea of two concurrent cognitive loops, one relating the outer world with its internal representation, and a second one unfolding this representation into a predicted or imagined future. Both loops intersect at what we call InnerSim, an internal modeling and simulation system.

RoboCog is initially designed as a constellation of modules (components) with different functionalities that interact among them and with the InnerSim itself. These functionalities include a hardware abstraction layer that gives access to all the hardware in the robot, and abilities such as local navigation, SLAM, path and task planning, object detection and recognition, human detection and tracking, and an attention mechanism. The novelty in RoboCog is the inclusion of an internal simulator with which all these modules interchange information. InnerSim is an internal representation of the robot itself, the environment and the objects and agents in it. There are many open issues about how this models represent the past, the predicted present [26], the future and the alternative courses of action (counterfactuals). All of them, though, may play a crucial role in generating intelligent robot behavior [27] [28] [29] [30]. Unlike blackboard architectures, InnerSim is an active process that can itself request information from perceptive modules and knowledge repositories to compute the immediate future or the outcome of planned sequences. One of the most important drawbacks of centralized modeling systems is the, so called, *representational bottleneck* that limits the amount of detail a model can maintain, if real-time, responsive behavior is to be achieved. To avoid this situation, InnerSim builds representations as minimal renderable models. Only when detailed information is required, the represented object is rendered down to the needed resolution or decomposed in its constituent parts.

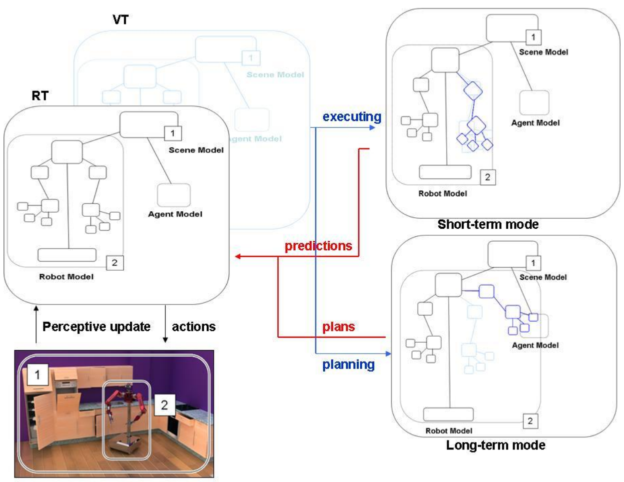


Fig. 18: Loki's deployment graph

InnerSim has been built using, as starting point, the RCIS robotics simulator that is part of the RoboComp suite. RCIS is built as a native RoboComp component, which means that it can easily expose its internal functionality through IDL public interfaces. The same robot and scene description language that is used to set up the simulated world in RCIS, is used by InnerSim to dynamically model the robot and its environment. Updates come from a set perceptuo-motor components whose activation is mediated by an attention system [31]. Moreover, the rendering capabilities already in RCIS that simulate the response of the robot's sensors to changes in the environment are used in InnerSim as a forward model to predict the response of the robot itself to the outcome of its actions.

As mentioned before, InnerSim is at the intersection of two main cognitive loops, a world-model loop and a planner-model loop. Each loop requires the model to unfold, usually setting the first loop as the initial condition for the second (i.e. that plan starts from where the robot is right know). To allow for this double internal behavior, the RCIS simulator is being modified to keep two instances, one modeling the predicted present and one representing the planned future. Fig. 18 shows this idea.

The InnerSim module as well as an opportunistic planning module and a symbolic knowledge management module are now under active development. The combination of these elements will make RoboCog and it will be tested on simulation, using RCIS as an external simulator and with the robot Loki. As part of these research RoboLab is building a living lab at the University of Extremadura. Fig. 19 shows a 3D drawing of the facility.

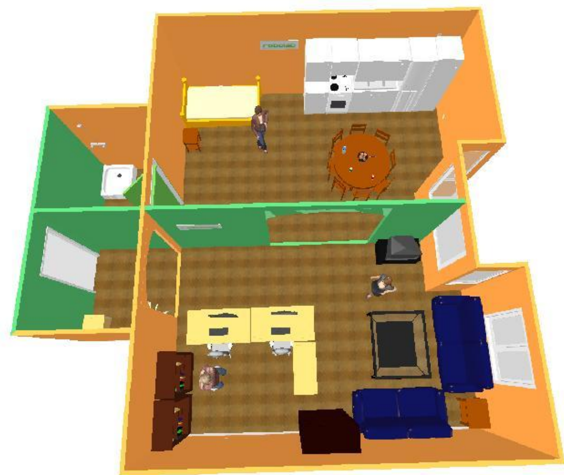


Fig. 19: RoboLab's RoboHome

VI. Conclussions

In this paper we have reviewed some of the most advanced AMMs that are currently in development by worldwide robotics research laboratories. Following this discussion we have presented a new AMM called Loki in which our research groups have been working during the last months. Although it is now possible to acquire advanced AMMs for research purposes, the availability of local know-how in building these machines provides a much higher level of technological independence and the possibility of modifying and adapting the initial design to forthcoming needs. We believe that Loki will be a very productive and robust research platform for social robotics and autonomous manipulation. The existing development tools, such as the RCIS simulator, and the new collaborative projects that are being launched around Loki, aim at bringing together a larger community of researchers that can put together their efforts and share the costly resources needed to meet the challenging goals of social robotics.

Acknowledgements

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