DEVELOPMENT OF A PROTOTYPE OF AN AMBIENT-AWARE TWO-ARM MOBILE SERVICE ROBOT

Branko Karan, Srpska Akademija Nauka i Umetnosti*
Veljko Potkonjak,Elektrotehnički fakultet Univerziteta u Beogradu**
Aleksandar Rodić, Institut „Mihajlo Pupin”
Duško Katić, Institut „Mihajlo Pupin”
Miloš Jovanović, Institut „Mihajlo Pupin”
Branislav Borovac, Fakultet Tehničkih Nauka Univerziteta u Novom Sadu

Abstract: *This paper describes a prototype of an ambient-intelligent advanced service robot of anthropomorphic characteristics that is intended for operation in indoor environment as well as for safe interaction with people. The robot consists of a wheeled mobile platform with a spinal (segmented) torso, bi-manual manipulation system with hands, and a robot head with capabilities to see, hear and speak. It is equipped with a number of advanced sensors, including indoor laser range finder, several ultrasonic probes as distance sensors and obstacle detectors, 3-axis inertial sensors with gyroscope, stereo vision system, 2 wide-range microphones, and 2 speakerphones. Its operation is autonomous but it may be controlled from a host computer through a wireless link. The robot prototype is expected to express advanced cognitive capabilities including spatial understanding, autonomous motion, affective and social behavior. The development of the robot is a joint effort of four Serbian academic institutions and it is expected to have it fully operational in the second half of 2015.*

INTRODUCTION

Development of artificial technological systems that are closely related to humans is recognized for more than one decade as one of important prerequisites for rapid development of modern society. In industry, robotization is moving in the direction of more direct cooperation and contacts between workers and robots. In non-industrial robot applications, which are becoming a growing trend (education, health, public safety, environmental monitoring and other fields), direct interconnections between humans and robots as well as the robot motion in an environment organized for humans are in focus as a starting idea. Robotic scholars and practitioners particularly emphasize human-like movement, human-like intelligence and human-like communication as necessary features of robots [1–3].

Work in the field of humanoid robotics has a long tradition in Serbia. The so-called Belgrade school of robotics is renowned worldwide [4]. However, its most acknowledged results have been achieved in the field of robot motion control, both locomotive and manipulative, and including robot kinematics, dynamics, and a wide range of motion control algorithms.

Recognizing the need to intensify work in human-centric robotics, a group of leading Serbian academic institutions has launched, four years ago, a project of research and development of ambient intelligent service robots. The development of new laboratory prototypes of intelligent service robots, intended for applications in indoor environment, was designated as one of the main objectives of the project. At the same time, the issue was on the variety of software solutions, starting from the modeling and simulation of the motion of service robots to algorithms of multimodal interaction and emotion modeling.

The prototypes are developed with two main objectives in mind: first, to serve as a test-bed for scientific research and second, to provide a basis for possible commercial and noncommercial applications. The intended operation area (closed indoor space) influenced the selection of locomotion structure and navigation sensors. Starting from the decomposition of motion of the service robot into the transport (global) motion by which the robot changes its operating positions (using its legs or wheels) and the local, job-specific manipulation by which the working task is directly performed, a structure consisting of a moving platform with rolling wheels as a means of transport has been adopted as the basis of the prototype. Similarly, the navigation is based on

**Branko Karan, Srpska Akademija Nauka i Umetnosti, Knez Mihailova 35, Beograd, Srbija*
branko.karan@itn.sanu.ac.rs

sensors suitable for operation in closed space, primarily the ultrasonic sensors and low-cost visual depth sensors. In order to bring the manner of carrying out the service tasks as close as possible to human, the task performer was chosen in a form of humanoid torso with a head and hands with anthropomorphic characteristics and the abilities of multimodal (audio, gesticular) communication with human users. The resulting prototype has been assigned the acronym UBMSR (Universal Bi-Manual Service Robot).

The paper is organized as follows. The overview of the prototype as a whole is given in the next section. Especially important subsystems - motion, sensory, and the control system, are elaborated in more detail in three subsequent sections. The closing section contains a short description of the state of the project and further planned steps in finalization of the robot.

SYSTEM OVERVIEW

The UBMSR prototype is designed for applications in indoor space. The robot is designed primarily for research purposes although it has a universal character according to its functionality and, moreover, its modules are of industrial quality. This device can be used in households (as a household appliance or as a socializing or entertainment robot) and in public places (airports, railroad stations, museums, shopping malls, offices, medical institutions etc.) to provide information and user assistance, as a carrier of load and medical waste, as well as in industry, as a mobile flexible robot system easily adaptable to changes in technological process and in production program. Thanks to its soft joints, this robot system may work in cooperation with people without a special need of ensuring safety of the workplace. As a research tool, UBMSR may be used for research, development, and evaluation of algorithms of motion of mobile robots in unstructured environment, artificial intelligence algorithms, sound and shape recognition, development of multimodal command human-robot interfaces, etc.

When designing the system, a care has been taken partly of anthropomorphic proportions as well as the functionalities that should imitate human behavior and activities. For this reason, this device possesses a high level of anthropomorphism although it integrates particular components that are purely industrial realizations, like e.g. lightweight robot arms and hands. In the future, these elements shall be possibly replaced by the corresponding elements that would be bio-inspired by the human body.

The robot consists of several functional modules (Figure 1): (i) the wheel-driven mobile robot platform; (ii) segmented torso; (iii) bi-manual arm system with three-fingered graspers; (iv) movable robot head; (v) sensory-acquisition system; and (vi) control-communication module.

The adopted system structure, as displayed in Figure 1, allows good mobility of the system in the closed space. When determining robot dimensions, human proportions have been partly taken into account, since it has been planned to use the robot in space where people live and work and the robot is expected to cooperate with people on particular tasks. Overall dimensions of the mobile platform, including wheels are L x W x H = 0.70 x 0.70 x 0.72 m. The torso is placed so that the shoulders are on the level of 1.5 m and the span between shoulders is 0.475 m, what corresponds to human proportions [5]. The size of the robot head, from chin to crown is 0.26 m and it is proportional to the width of the torso, whereas the width of the head comes out of proportion due to the need of installing quality microphones at the position of ears. Such defined dimensions of the robot allow its easy passage through the standard door frame (0.80 m) in households and public areas. Drive wheels have a diameter of 0.35 m, whereas the diameter of auxiliary wheels is 0.20 m. These dimensions allow motion of the mobile platform over the flat floor surface as well as the diverse floor cloths. The robot cannot climb stairs but it can roll over small obstacles whose height does not exceed 0.07 m. More details about the mechanical structure of the robot are given in the next section.

*Branko Karan, Srpska Akademija Nauka i Umetnosti, Knez Mihailova 35, Beograd, Srbija
branko.karan@itn.sanu.ac.rs

ROBOT MECHANICS AND ACTUATORS

A. Mobile robot platform

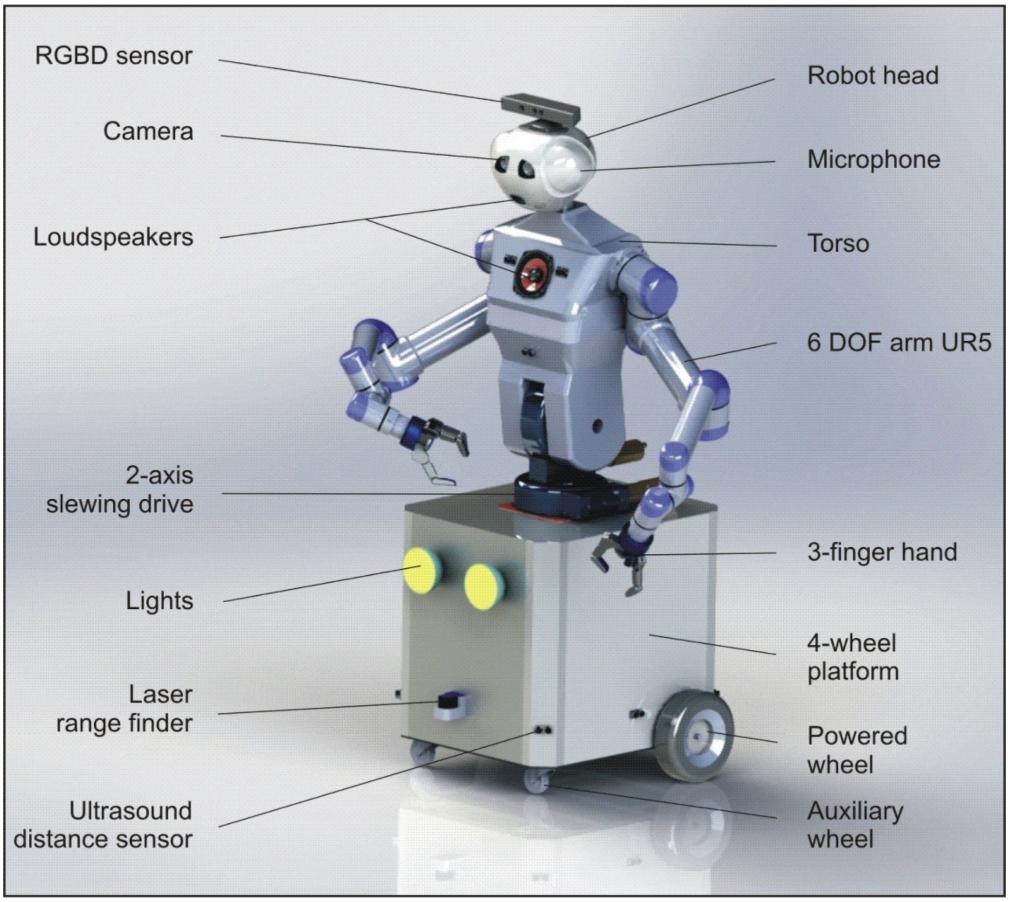

Figure 1: The UBMSR robot

The mobile robot platform is a motorized cart with two driving, microprocessor controlled wheels and two auxiliary wheels ensuring stability and maintenance of direction of motion. The platform is designed to house a cabinet with two horizontally divided compartments. On the lower level, two 12V 120Ah batteries are placed together with a 12V 230V AC DC adapter/charger, electrical fuses, etc., whereas the upper level houses the control and communication electronics - the brain of the device. To unload the actuators of the torso and achieve the optimal distribution of masses, i.e. to get the center of mass placed as low as possible, a care has been taken to seat all electronic boards inside the cabinet and not in the head or torso of the robot. The system is designed to ensure safety against overturning even in the position of maximally extended robot hands and with maximum load.

B. Segmented torso

The torso of the robot consists of a lower and upper part. The upper part carries the robot head and two 6 DOF robot arms with hands. The lower part is a central support pillar ending with a two-axis rotation drive with a slewing transmission, allowing the bending (change in elevation) of the upper part of the torso around the horizontal axis in the range [-30, +60] degrees, and turning (rotation about the vertical axis) in the range [-180, +180] degrees. These redundant degrees of freedom significantly expand the operation space of the robot (reachability of its hands).

C. Bi-manual manipulation system

The bi-manual manipulation system consists of two 6 DOF 5 kg payload universal robot arms UR5 [6] of industrial quality. Each arm is equipped with a three-fingered Barrett-type hand grasper [7].

*Branko Karan, Srpska Akademija Nauka i Umetnosti, Knez Mihailova 35, Beograd, Srbija
branko.karan@itn.sanu.ac.rs

The two-arm manipulation system, combined with the ability of bending the torso, provides good manipulation properties of the overall system. The universal robot hands UR5 possess compliant joints facilitating the interaction with the man without the risk of injury. The hands have their own industrial controllers that are integrated in the UBMSR control structure.

D. Movable robot head

The robot head (Figure 2) contains (i) the kinematic mechanism with 3 DOF, actuated by three DC electric motors with slewing transmission, (ii) two industrial-grade cameras for robot vision, (iii) two wide-band professional-grade microphones with increased sensitivity, and (iv) the optional visual depth sensor placed on the crown of the head. The head has good kinematic abilities of rotation about three axes: vertical, frontal, and sagittal. Thanks to visual and audio capabilities of the robot, the head can be rotated in the direction of the source of the light or sound. The robot is also equipped with the appropriate LED illumination facilitating its functioning in the conditions of reduced ambient light.

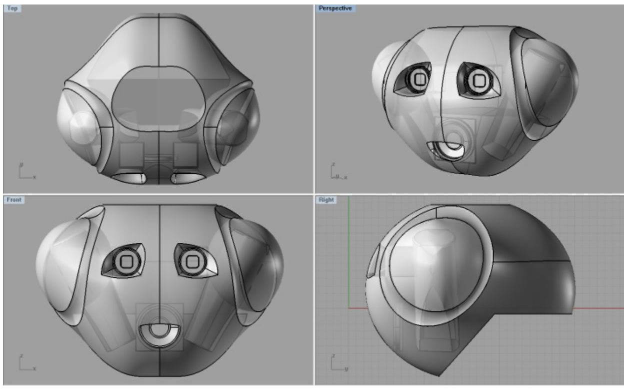

Figure 2: CAD model of the UBMSR head with audio and vision systems

SENSORY SYSTEM

The sensory and data acquisition system of the robot is heterogeneous and it serves to provide the robot a perception of physical and social environment. Sensors are embedded almost throughout the whole mechanical structure of the system. The robot has joint position (optical encoders) and velocity sensors (tachogenerators) as well as the external distance sensors (laser range-finder and ultrasonic probes), inertial sensors such as 3-axis gyroscope and 3-axis accelerometer, and optional special-purpose sensors (humidity and temperature sensor, smoke detector etc.). The universal robot hands possess joint encoders, torque sensors in arm and wrist joints, and force/torque sensors in hand graspers. A tilt sensor is placed on the platform to detect a collision with surrounding objects.

Two fast industrial grade CMOS color cameras [8] and audio equipment - microphones [9] and speakers [10, 11] are embedded within the robot head. It is also possible to place the optional RGBD sensor (the combined color and depth camera) on the crown of the head that can be used for human gesture recognition and identification of moving obstacles within the range of 1–4m around the robot. The actual version of the employed RGBD sensor is Kinect XBOX 360, operating as a structured light sensor [12], but it is planned to replace it with a more advanced Kinect for Windows v2 time-of-flight sensor [13].

It is possible to set the visual system to operate in different configurations yielding different performances of vision-based navigation. The basic configuration is a bifocal stereo vision consisting of two CMOS cameras (monocular system is also feasible, but its depth derivation is possible only when the robot is in motion). The system can be used both in open-air and indoor conditions, but its effectiveness significantly depends on the texture of surrounding objects. Furthermore, it is possible to improve the robustness and speed of the system by adding the third camera, obtaining in this manner a trifocal sensor. Alternatively, the CMOS cameras can be completely replaced by the RGBD sensor, which is limited for use in indoor environment only and is slower compared to industrial grade CMOS cameras, but which provides better resolution of

*Branko Karan, Srpska Akademija Nauka i Umetnosti, Knez Mihailova 35, Beograd, Srbija
branko.karan@itn.sanu.ac.rs

depth maps. Further combinations of RGBD and ordinary cameras are also possible, and they can be tuned to inherit good features of both sensors.

CONTROL ARCHITECTURE

E. Control and communication module

The control module has a hierarchical and distributed structure that best suits the individual tasks that are set before the service robot. This implies that there is a controller at the highest hierarchical level, which coordinates all tasks, data acquisition, and communication traffic, and which have subordinated particular low level controllers such as (i) mobile platform controller, responsible for motion planning, navigation, and path following with obstacle avoidance, and which takes into account different characteristics of the friction between the wheels and the ground; (ii) controller of the manipulation system (totally 12 DOF) including the torso (2 DOF) and the robot head (3 DOF), which also integrates two separate industrial controllers for UR5 hands; (iii) image and sound processing, interpretation of voice commands, etc.

The communication block provides networking of the robot in LAN using a Wi-Fi modem (the case of information-structured environment), and connecting the robot to the Internet. Also, it is planned to remotely command the robot from a smartphone running an Android application. This assumes a GSM modem on the robot which brings an additional functionality of remote communication with authorized access and ability to monitor system parameters or remote transmission of image and sound.

F. Cognitive interface

Since the UBMSR is intended for service tasks with interaction with people, a special cognitive interface, the so-called EI (Emotional Intelligence) controller is designed, allowing the robot a better integration and social acceptance by humans. The EI controller should provide the robot the ability of perception/acquisition of people emotions (affective state), understanding the emotions, and control of its own affective and social behavior and interaction with people - interpersonal interaction. These capabilities shall be developed on the basis of embodied attributes of the artificial emotional intelligence in robots using the human personality profile models that assume the type of personality, temperament and character of personality. The basis for this is research from humanities, and especially psychology [14].

STATE OF DEVELOPMENT

The paper has described the elements of the laboratory prototype of an autonomous robot system that can be applied as a personal or service robot. The development of such a system is an important step towards the integration of “smart” home technology of the future with social robots for personal purposes.

During the work done so far, many individual modules have been developed and/or separately tested. Provided that would be no further delays in acquisition of components, as previously proved to be a significant problem, it is expected to achieve the integration of the prototype within the course of the next year. The laboratory prototype will be tested and evaluated in typical household tasks, which should open up the possibilities for its commercial applications. Besides, using the indicators collected during the development of the prototype, it is planned to conduct a detailed techno-economic analysis of the possibilities of serial production and placement of the robot on domestic and foreign markets.

ACKNOWLEDGMENT

The work presented in this paper was supported by the Serbian Ministry of Education, Science and Technology Development under grant TR-35003.

*Branko Karan, Srpska Akademija Nauka i Umetnosti, Knez Mihailova 35, Beograd, Srbija
branko.karan@itn.sanu.ac.rs

REFERENCES

1. R.A. Brooks, C. Breazeal, R. Irie, C.C. Kemp, M. Marjanović, B. Scassellati, and M.M. Williamson, “Alternative essences of intelligence,” in: Proc. AAAI'98/IAAI'98, American Association for Artificial Intelligence, Menlo Park, CA, USA, pp. 961–968, 1998.
2. T. Fukuda, R. Michelini, V. Potkonjak, S. Tzafestas, K. Valavanis, and M. Vukobratović, “How far away is ‘artificial man,’” in: IEEE Robotics and Automation Magazine, Vol. 8, No. 1, pp. 66–73, 2001.
3. B.R. Duffy, “Anthropomorphism and the social robot,” in: Robotics and Autonomous Systems, Vol. 42, Issues 3–4, pp. 177–190, 2003.
4. M. Vukobratović, Belgrade school of robotics, Institute Mihailo Pupin, Belgrade, 2002.
5. HPC - Human Proportion Calculator (ideal), online at: http://hpc.anatomy4sculptors.com (accessed 16.11.2014)
6. Universal Robots A/S, Universal robot UR5, online at: http://www.universal-robots.com/GB/Products/Downloads.aspx (accessed 16.11.2014)
7. Barrett Technology Inc., Barrett hand, online at: http://www.barrett.com/robot/products-hand.htm (accessed 16.11.2014)
8. Point Grey Research Inc., Flea3 1.3MP color USB 3.0 camera (e2v EV76C560), online at: http://www.ptgrey.com/flea3-13-mp-color-usb3-vision-e2v-ev76c560-camera (accessed 16.11.2014)
9. Sennheiser Electronic GmbH, Sennheiser MK 4 - condenser microphone for professional studio recordings, online at: http://en-de.sennheiser.com/condenser-microphone-studio-recordings-professional-mk-4 (accessed 16.11.2014)
10. ProElectronic, Piezo visokotonski zvučnik KHS106 (Piezo tweeter KHS106), online at: http://www.proelectronic.rs/PIEZO-VISOKOTONAC-KHS106-KHS106-4367.htm (accessed 16.11.2014)
11. ProElectronic, Mini zvučnik 45021 (Mini speaker 45021), online at: http://www.-proelectronic.rs/MINI-ZVUCNIK-45021-MINI-ZVUCn17-13181.htm (accessed 16.11.2014)
12. Microsoft Corporation, Microsoft XBOX Kinect, online at: http://www.microsoft.com/education/ww/products/Pages/kinect.aspx (accessed 16.11.2014)
13. Kinect for Windows team, Revealing Kinect for Windows v2 hardware, online at: http://blogs.msdn.com/b/kinectforwindows/archive/2014/03/27/revealing-kinect-for-windows-v2-hardware.aspx (accessed 16.11.2014)
14. A. Rodić, M. Jovanović, “How to make robots feel and social as humans,” in: Proc. 6th IARIA International Conference on Advanced Cognitive Technologies and Applications (COGNITIVE 2014), Venice, Italy, May 25th-29th, 2014, pp. 133–13

**Branko Karan, Srpska Akademija Nauka i Umetnosti, Knez Mihailova 35, Beograd, Srbija*
branko.karan@itn.sanu.ac.rs