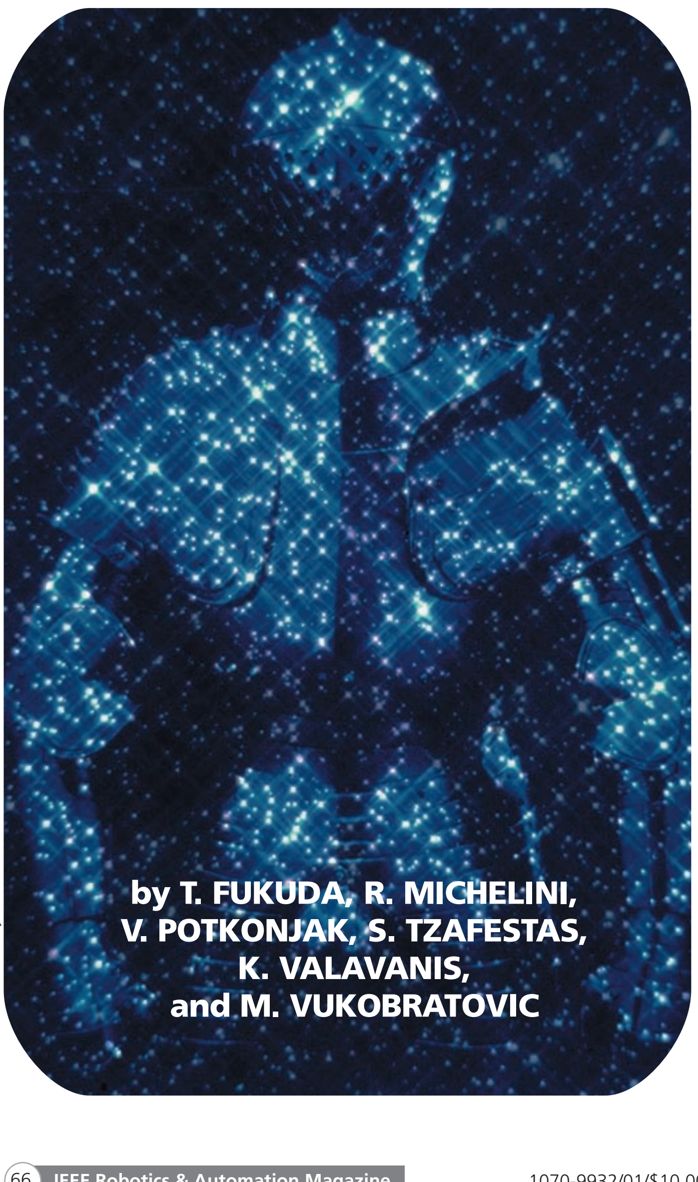
How Far Away Is "Artificial Man"?

Are We Ready to Take the First Step Toward Realizing "Personal" Robots with Human-Like Motion, Intelligence, and Communication?



by T. FUKUDA, R. MICHELINI, V. POTKONJAK, S. TZAFESTAS, K. VALAVANIS, and M. VUKOBRATOVIC

All through craft history and technological progress, several attempts have been made to build a "device" that looks and behaves as humans do. In modern times, it was Karel Capek's imagination that first captured the idea of a true artificial man, a robot (the very root of "robot" derived from the Czech word "robota" addresses incumbent work), with the desire to create duty-driven devices capable of executing human tasks. Since then, and in particular since the 1950s, after three robot design generations, robotics has evolved to the point that different branches, such as industrial robots, mobile robots, legged transportation systems, medical prosthesis and orthosis, micro-robotics as well as autonomous (mobile) vehicles, have reached a remarkable level of maturity as evidenced by immense results and a variety of applications.

However, a careful examination of robotics science and technology from its origins in the 1950s to its current status reveals that such progress, albeit very important, profitable, and with a strong impact on society, was basically the "side activities" to the ever-existing and continuous desire of mankind to build and realize humanoid robots, artificial men equipped with proper intelligence capable of operating autonomously, thus replacing trained individuals for dexterous jobs. Although that desire was not previously so visible, it is currently a real fact!

In this article, an attempt is made to look at such a humanoid robot through the realistic tasks/jobs it will most probably do. It is postulated that this humanoid robot be considered as a personal helper to be called a *home robot* or *personal robot*. Given the present level of technology, the question is posed: are we ready to move towards personal robotics, and what might be the first step? A possible answer to this question is given through a discussion of the human-like characteristics a personal robot must have; namely, human-like motion, human-like intelligence, and human-like communication.

Attempting to Create "Artificial Man": Origins and Evolution

Looking back at history, one may observe that the idea of building an artificial man has its origins in ancient Greek civilization. Greek mythology refers to the giant

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Talus, made of brass, who guarded Crete against intruders. Much later, depending on manufacturing knowledge and technology, craftsmen or engineers have attempted to design devices that look like a human and imitate a human's movement and behavior in general. Although these devices might be considered as toys or decoration and were properly referred to as *automata*, rather than (duty-driven) *robots*, their true role was to demonstrate their creators' skill as applied to a specific design-example. Such well-known creations include: the figure of a girl playing a lute (1540, Gianello della Tore, Kunsthistorisches Musseum, Vienna), two mechanical dolls called the scribe and the musician playing a piano (1770 and 1773, Henri-Louis Jaquet-Droz, Musee d'Art et d'Historie, Neuchatel), the talking machine (1778, Wolfgang von Kempelen), the Philadelphia doll [another writing mechanism built before 1812 (Les Maillardet, Franklin Institute, Philadelphia)], the steam man [walker powered by a gas-fired boiler, 1893 (George Moore)], and the automatic electromagnetic chess-playing machine [the first decision-making machine, 1912 (Leonardo Tores Quevedo)]. Jasia Reichardt presents a review of such devices in her book *Robots: Fact, Fiction and Prediction (*Thames & Hudson Ltd., 1978).

In modern times, Karel Capek's imagination first captured the idea of a true artificial man, a robot (Capek's play *Rossum's Universal Robots* (*R.U.R.*) had its first performance in Prague in 1921 and in New York in 1922). Capek described robots as being "mechanically perfect" and "highly intelligent." He not only coined the term *robot*, derived from the transferred ability of replacing skillful workers, but he also tried to explain the ever-existing human desire to create an artificial man. The main character in Capek's play was inspired by a foolish and obstinate wish to prove God to be unnecessary and absurd. After Capek, several science fiction book authors and science fiction film producers centered their books/films around specific robot characters, making science fiction writers rather successful in their predictions of robotics science and technology developments. A leading authority among writers of robots and science fiction is Isaac Asimov. His *Three Laws of Robotics* can now be found in almost all robotics books, from popular to highly professional editions (his story "Runaround" appeared in the March 1942 issue of *Astounding Science Fiction*).

Since the late 1950s, there has been a revolution in robotics and industrial automation, from the design of robots with no computing or sensory capabilities (first generation), to the design of robots with limited computational power and feedback capabilities (second generation), and the most recent design of what may be considered as intelligent robots that possess diverse sensing capabilities (third generation). Indeed, after three robot design generations, robotics has evolved to the point that different branches have reached a remarkable level of maturity, as evidenced by immense results and a variety of applications. Despite all this progress, while aiming at accomplishing work-tasks originally charged only to humans, robotic science has perhaps quite naturally turned into the attempt to create artificial men.

In particular, research [1, 2] done in the 1960s and early 1970s provided the theoretical background for a biped-walking machine (well-known concept of "zero-moment point"). Research in multi-body dynamics [3,4] gave the solution to robotic arms dynamics, thus providing the theoretical foundation and background to the growing field of industrial robotics. The first major application of industrial robots was aimed at specific manufacturing sectors (for example, the automotive industry), but industrial robots changed essentially the entire manufacturing industry. Because of their success, new challenges to develop applicable and profitable robotic devices for other, nontraditional, branches of scientific robotics were launched. One such challenge is the field of medical robotics, which has resulted in the development of highly sophisticated prosthetic and orthotic devices for hands and legs. Since the 1980s, there has also been tremendous progress in mobile robotics (with immediate applications in hospital environments), autonomous (mobile) vehicles, legged transportation systems, and very recently in microrobotics, to name a few.

In addition to the above, there has always existed a continuous research effort on problems of anthropomorphic robots, now called *humanoid robots,* that need special attention and need to be mentioned separately. Major research was conducted at Waseda University that has resulted in building the famous WABOT and WABIAN humanoids [5], while there was also a successful demonstration of the HONDA humanoid [6, 7], after which, the principal role of humanoid robotics became more evident. Several other researchers in Japan are trying to formulate landmark projects in this field, and their idea of a soccer match that would take place in 50 years (from now) between a team of humanoid robots and the actual world champion is an astonishing one, albeit realizable at some point in the future [8].

It is true that artificial men or humanoid robots open certainly very broad prospects; with restriction on the task-bent abilities, a convenient and very realistic way to look at them is through the jobs they will probably do in the future. This "robot" may be viewed as a personal helper, and it will be called a *home-robot*, or *personal robot*. Surprisingly enough, the idea of a home robot is not a new one. In 1964, Professor M.W. Thring predicted that domestic robots, robots for operations like scrubbing floors or baths, washing clothes, dusting, or making beds, would be available up to 1984 ("A Robot About the House," in Nigel Calder (ed.), *The World in 1984*, vol. 2, New Scientist: London, 1964; and Penguin Books: London 1965). It didn't happen!

Now, at the beginning of a new millennium, and given the current level of technology, it is realistic and at the same unavoidable to pose the question: *are we ready to move towards personal robotics, and what might be the first step*? It is believed that the first step in a coordinated effort toward *home robots* should be an *assessment project* that evaluates the idea and promotes technological initiatives in specific aspects of humanoid robots and man-machine analogy. The rest of this article provides a viewpoint on how this may be started.

The Target

The objective is to initiate a long-term, multidisciplinary research activity with the final goal of looking at and possibly designing function-oriented "devices" equipped with proper "on-board" intelligence capable of autonomously performing common human work, with knowledge of the surroundings and the workspace environment, such "devices" will be interacting with. Namely, the ultimate objective is that of creating a *robot that resembles human behavior* regarding *motion*, *intelligence*, and *communication*. As a practical result, a *truly personal robot* is envisioned.

Such a challenging target requires coordinated and integrated research efforts that span a wide range of disciplines such as system theory, control theory, artificial intelligence, communications, materials science, mechanics, and even biomechanics and neuroscience, with each discipline having reached independently a different level of maturity. Thus, the research is risky, but the target is challenging and promising and the (potential) impact of personal robots on people's everyday life will be comparable with the impact personal computers have had in the last two decades.

Why an Assessment Project?

The proposed topic deals with a rather new direction of *integrated research*. As already stated, the fields of system theory, control theory, artificial intelligence, communications, materials science, mechanics, biomechanics, and neuroscience have been explored—mainly independently—for years at different levels of depth and breadth. Even on this individual basis, the current level of technology advancement in each field may be insufficient for achieving the final goal, and thus, further progress may be required. In addition, new target-oriented efforts need to be imposed in order to reach the expected integral outcome.

Therefore, the assessment project should focus on gathering relevant information about the state-of-the-art in each field, its readiness for the foreseen integrated application, and the efforts that should be made toward accomplishing the common goal. Then, after evaluating the current status, individual and joint research priorities should be defined and revealed along with relations to other research topics. Some proper experiments must be made to preliminarily check the feasibility of the idea.

A successful assessment project will provide the set of topics that need to be researched, a timetable, and a set of minor and major milestones that collectively lead to a *combined technological initiative* involving several smaller-scale research projects. The combined success will depend on the degree of reaching the set targets and milestones, as well as the set of intermediate selected goals.

What Might Be the Benefits?

A successful and detailed assessment project also lays the foundation for the expected long-term and short-term benefits, which include benefits of and after the final outcome (primary benefits), as well as benefits resulting from reaching intermediate goals and milestones (secondary benefits). The two sets of benefits are not exclusive, but they are equally important, particularly in a multidisciplinary field like robotics in which "side results" might become applicable in practice well before the final target is reached, resulting in a potential economic impact that may overcome the impact of the final outcome.

It is generally true that if a new initiative is launched, the final target must always be attractive even though there may not be a direct impact to industry, society, or people's everyday life. It is the intermediate technological breakthroughs achieved before the end result is reached that make the new initiative profitable and worthy of support. The humanoid robots soccer match and the American man-on-the-moon space program are examples of initiatives with attractive final but not clearly defined practical targets (as yet) and no direct impact on people's everyday life (at least as of now). But the American space program was and still is successful because it was seen as the ultimate answer to the Soviet Union technological challenge, and it has opened new horizons in robotics (e.g., Pathfinder).

The *personal-robot technological initiative* is challenging and broadly appealing to scientists, researchers, industry, as well as citizens (taxpayers), and it also has a practical outcome. If supported by federal, state, and private funds, it may advance tremendously technological progress in many other related fields of science and engineering. In this particular case, not only the final goal is an attractive one, but also the technological breakthroughs that may be achieved during the research efforts make the overall project profitable. If the necessary funding is secured during the various stages of the project, the accomplishment of the intermediate goals will generate multiple revenues, thus making the overall project more appealing. In Europe, the significance of service and anthropomorphic robots has already been recognized [EARLR (European Association for Research in Legged Robots), http://www.earlr.gr/].

The practical outcome will have a potentially high impact on people's everyday life. The final goal to create a truly personal robot opens a huge new market for robot manufacturers and for the producers of application software in the fields of artificial intelligence and man-machine communication. The foreseen result may be cast in a more general class of robots, called *service robotics,* consisting of more autonomous and more intelligent robots working at home, working as medical assistants, used for building security, as well as for other services.

Personal robots and service robotics may be a viable alternative offering new application fields to the evident saturation of robots performing "classical" industrial jobs [9]. The problem of sustained growth of industrial robotics is directly related to the robots' ability to cope with new jobs that require higher levels of skill. Intelligence and skill, being indispensable properties of personal robots, would eventually lead to a new generation of industrial robots in addition to the fact that personal robots and service robotics open a new, long-term, and very profitable field of robotics.

State-of-the-Art and Principles of the Proposed Approach to Personal Robots

The current state-of-the-art in service robotics may be considered from two points of view: the first viewpoint concerns the devices that may be classified as "service robots," while the second viewpoint considers the present status of research in directly linked and associated technologies. A brief overview of the state-of-the-art in both is given, followed by the authors' conclusion on the features of personal robots.

Existing service robots include mobile robotic platforms (automated vehicles) with some additional accessories that define their purpose [10] with applications from hospital environments (carrying medication to the nurse station on each hospital floor) [11-13] to military/antiterrorist services [14-16].[Besides the review paper [10] there have been specific sessions for mobile robotics in the Proceedings of international conferences (e.g., sessions on Mobile Robots, Mobile Robotics, and Mobile Vehicle Mechanics at IEEE ICRA 2000), as well as associations, annual meetings and exhibitions related to this matter (Association of Unmanned Vehicle Systems: Annual Symposia and Exhibitions)]. Mobile systems equipped with manipulator arms for service jobs are reported in [17, 18] while there is a growing interest in humanoid robots [5-8, 20-23] and bio-robotics [20-21, 24-25]. Besides the provided reference list, there were also special sessions at IEEE ICRA 2000 dealing with different aspects of anthropomorphic robots (Humanoids, Dynamic Simulation of Humanoid Motion, Biped Robots, Bipedal and Climbing Robots, and Legged Locomotion) and meetings regarding this topic (1st Workshop on Humanoid and Friendly Robots—IARP'98, Japan, and *HUMANOIDS 2000*, the First IEEE-RAS International Conference on Humanoid Robots, MIT, 2000). A list of special issues in scientific journals dedicated to humanoid robots and human-friendly robots is provided in the references.]

Within the class of service robots, perhaps the most promising are home robots or personal robots. Under the concept of personal robots, there are often included hobby robots or other automated home devices (like a vacuum cleaner) and highly sophisticated robotic toys [19]. The founded relation between neuroscience and robotics supports the expectations that future personal robots will have an anthropomorphic structure (humanoids or semi-humanoids) and will follow the biological analogy [26].

The authors view personal robots as devices properly defined in terms of their ability to replace a human being in a number of everyday file jobs (domestic chores or rescue missions, nursing and disable care, or dairy food district dispatching, etc.). Such personal robots will "live" among humans, having the ability to maneuver in human-oriented environments, and are expected to have substantial autonomy in performing the required tasks in such complex environments. Further, it is anticipated that while waiting for the new generation of home devices (washing machines, cookers, etc.) they should be able to handle existing types of home equipment. Appropriate communication between the human and the personal robot is essential and goes beyond traditional man-machine interfaces. The co-existence and living of the human being and the personal robot in the same environment requires consideration of the *human's psychological sense about his robotized "butler"* and a solution on how the home robot will adapt to ordinary human feelings in order to avoid any human discomfort. Avoiding any additional discussion on other psychological, ethical, and perhaps moral issues, a first conclusion regarding personal robots is drawn:

Personal robots should feature human-like characteristics in their behavior, regarding motion, intelligence, and communication.

A similar conclusion may be drawn for the next generation of industrial robots. Despite their rather long history, their usage still requires a well-structured working environment, where the physical presence of humans is not allowed. Considering the major advances in computer hardware and software, in sensor technology, and recent improvement of robot intelligence (machine intelligence [35]), it seems reasonable to expect that a direct cooperation between the human worker and the robot will be possible in the near future. Mutual safety is a basic prerequisite of direct cooperation inside a common working space, including appropriate communication between them. Comfortable working conditions for the human and the robot are essential since they may have a significant impact on productivity.

Therefore, regardless of whether one refers to a home environment or the job floor environment, in future cooperation of the human with the personal home robot or the new intelligent industrial robot, the human's feeling of comfort will depend not only on the specific nature of the working task, which means a specific operation procedure and working dynamics, but also on the human's *psychological sense about the robotized associate*. This is another way of concluding that the achievement of human behavior of robots (in terms of motion, intelligence, and communication) is essential.

Elaboration on State-of-the-Art Technologies

Human-Like Motion

At the very beginning, this topic requires choosing between biped robots and wheeled configurations [27], as well as analyzing existing and desired actuator units. However, regardless of choice, the following holds true.

The objective of high maneuvering abilities may be naturally achieved by designing robots to imitate humans both morphologically, to some extent, and in the way humans execute motions. Research in this field is related to the so-called *bio-robotic* approach. From the mechanical point of view, a robot resembling a human should be kinematically redundant; i.e., its mechanism should feature a higher degree of mobility than required for a given motion task defined in the operational space. Redundancy means that the same end-effector's trajectory can be realized with different configuration motions. Kinematic redundancy contributes to robot dexterity and flexible coping with unpredictable changes in its neighborhood. It avoids mechanical limits in robot joints, enables obstacle avoidance, singularity avoidance, fault tolerant operation, and robot dynamics optimization. However, redundancy increases the mathematical complexity of the robot control problem with implications that are particularly emphasized when solving the inverse-kinematics problem. Conventional solutions to this problem adopt some additional engineering performance criterion, for example energy consumption. This, in turn, leads to a "too mechanical" motion according to human impression.

Research related to how to control a robot in order to improve the human psychological evaluation of its motion may be found in [28, 29]. A promising approach of redundant robot motion is based on human motion synergy, resolving the inverse kinematics by resembling the behavior of a human performing the same task as discussed in [22, 23, 30-32].

Human-Like Intelligence

Human-like intelligence is an absolute prerequisite to designing personal and service robots. Situations faced by such robots are ambiguous and uncertain, and robots have to be able to create and evaluate different possible courses of action. In a varying, complex, dynamic, and uncertain environment such robots should have self-organized capabilities, should be able to learn and adapt, and then use their on-board reasoning/problem solving capabilities to interact with the environment and perform tasks efficiently and safely.

Key elements of any intelligent robot include cognition, perception, planning, control, sensing, and actuation [33-40]. Current results in research and development in robot-embedded human-like intelligence are encouraging but additional work is still needed to achieve high levels of robotic competence that approaches human competence in real-life home, domestic, and service tasks. Areas that have been extensively studied thus far are path planning and navigation among fixed or moving obstacles [37, 38]. The use of neural networks and fuzzy logic promises to offer more adaptive and more competent obstacle avoiding schemes in real situations, especially event-based or agent-based schemes [37, 41-43].

Personal and service robots must also be equipped with cooperating robotic arms/hands, and therefore the problems of planning, navigation, and control become more difficult and more challenging. In this area, only limited practical results have been reported so far [44-51].

Human-Like Communication

The type of human-robot interaction and communication influences strongly the effectiveness of any semiautonomous or autonomous intelligent robotic system. A personal human-friendly robot must have easy to use natural, human-like, communication interfaces. People usually communicate via language, facial gestures, handwriting, and expressions [52, 53]. From that perspective, principal functions of the human-robot interface should include: input handling, perception and action, dialogue handling, tracking interaction, explanation, and output generation [54]. The use of speech/voice communication in human-robot interaction has become very popular and has reached an advanced level of maturity as opposed to vision-based human-robot communication that only recently has started to attract researchers and practitioners' interest. An example is the visual face tracking system proposed in [55].

Natural language interfaces (NLI) have been considered and used in many systems [56-58]. However, in order to decide whether to use an NLI for human and robot speech communication, one has to consider several factors such as cost, ease of learning, conciseness, precision, semantic complexity, need for pictures, etc. The NLI used in the ROMAN service robot [58] is based on a dialogue involving voice command inputs, visual-screen-based monitoring, tactile control during mobile handling, and voice output during task operation. The voice command generator performs the following functions: translation, consistency check, completeness check, data expansion, and macro separation. The command's generator output is the corresponding robot command.

Visual interfaces (VI) must enable the robot to recognize facial gestures such as "yes" or "no" and to determine the user's gaze point; i.e., where the person is looking. For a personal (human-friendly) robot the ability to recognize a person's gaze point is of paramount importance. For example, a personal robot serving as an assistant for a disabled person may need to pick up objects that attract the person's gaze. The type of equations needed in such a face-tracking system is best illustrated by the system described in [59, 60]. This system uses a monocular camera and a hardware vision system to track the different facial features (eyes, eyebrows, ears, mouth, etc.) and on the basis of this information it determines the 3-D pose and orientation of the head. A total of 19 facial features can be tracked simultaneously.

Graphical human-robot interfaces (GHRIs) can be used for task analysis, on-line monitoring, and direct control. GHRIs are frequently combined with animation and virtual reality (VR) tools. Examples of this combined type of GHRI have been reported in [61-62]. On a GHRI, the user can define a series of movements and actions by clicking or dragging a mouse on the screen. The geometric and task planners can then determine a sequence of motions and actions that implement the desired task, avoiding possible collisions with obstacles, robots, and other objects.

It may be concluded from the short elaboration given here that there are still limited results on human-like motion, while the field of human-like communication has produced several viable alternatives. On the contrary, human-like intelligence is the main obstacle to be overcome due to its complexity and multidimensionality; it is also responsible for coordination of the entire personal robot behavior.

Work to be Done at the Assessment Level

Having reviewed current relevant technologies, and after an initial evaluation of the idea of personal robots, the next steps consist of examining the levels of mutual relation of the related fields, their readiness for integration towards the new outcome, and what needs be done in terms of new theoretical and applied research and development, as well as preliminary experimentation that will lead closer to the final target, the true personal robot.

Human-Like Motion

A study of the state-of-the-art in modeling and control of human-like motion of robots must be done. The evaluation of different approaches should provide the guidelines for future research. For example, modeling and control of biped gait rely on certain experience [1, 2, 5-7], as does the grasping task [63, 64]. However, problems related to human-like motion of the arms have not been adequately explored. Original and innovative techniques that lead to new results should be achieved and then tested in typical human motion tasks to prove feasibility. Such tasks should include human-like distribution of operational motion to a redundant number of robot joints, imitation of fatigued and nonfatigued motion of human arms [65], and coordination of arm motion and grasping. Issues of bilateral manipulation should also be investigated. Those desired functions of the personal robot should be put under new concepts of robot mechanical design and construction and control schemes inspired by biomechanics and neuroscience.

Human-Like Intelligence

A state-of-the art investigation should be carried out to compare and evaluate existing approaches, methods, and techniques from the diverse disciplines of science engineering and mathematics (AI, computer science, system theory) related to solving human-like intelligence problems in present-generation robots. There currently exist several paradigms of intelligent robotic systems with human-like intelligence executing a rather restricted repertoire of tasks. These systems usually employ the principle of increasing precision with decreasing intelligence (IPDI) [35, 65-66] or follow the nested hierarchical structure architecture [67,68]. However the implementations presented thus far differ from each other; they also concentrate on "machine intelligence" rather than artificial intelligence [35]. Much work is still needed to unify the details of imitation of human intelligence and to develop modular hardware and software architectures implementing human-like intelligence for practical human-friendly personal and service robots [35, 37, 39, 40, 69-70]. It is envisioned that potential candidate architectures will combine event-based, agent-based, and behavior-based components arranged with a hybrid configuration (hierarchical and heterarchical) [42, 71-72].

At this stage, it appears that the available theoretical foundation, methodologies, application case studies, and experimental results may be sufficient to carry out the human-like intelligence aspect. However, what is lacking is a systematic and synergetic blending and integration of the existing approaches as directly applied to model and evaluate human-like intelligence functions of a personal robot.

Human-Like Communication

The more autonomous a robot is, the more sophisticated is the structure of supervisory control required [73], which in turn calls for increased quality of communication and cooperation between the human and the robot [74]. A unifying consideration of human-machine communication in robotic systems can be found in [54] and a comprehensive presentation of presently available human-computer interaction (HCI) models, methods, tools, and applications is provided in [75]. These and other references show that a high level of maturity in HCI has already been achieved. Many HCI techniques and tools can be used and embedded in robotic systems to make them user-friendly and capable of communicating with the human in several human-like modes [58, 76].

The proposed assessment project should evaluate the integration of more types of HCIs under new conditions and combinations in an effort to duplicate as much as possible the competence of human-to-human communication. In such intelligent communication schemes, three task levels of user-model support are needed: human error evaluation, plan recognition, and procedural support. In home robots, tactile/touch interactive communication (feedback) is also required. Currently, a variety of tactile/touch/haptic feedback robotic devices exist, but in general they are complex and expensive [77]. New ideas and new work are required to integrate and put in production efficient and cheap human-like human-robot communication systems for home and service robots. An important type of personal robot is the autonomous wheelchair with robotic manipulator(s) mounted on it to serve the handicapped [37, 78-81]. In the SENARIO intelligent wheelchair [78], the M3S (Multiple Master-Multiple Slave] bus was used to increase the capability of the handicapped to control the wheelchair via easy-to-use input devices.

Integration Experiment

In summary, a simplified robotic system integrating all three aspects should be developed and tested.

Conclusion

This article posed the question about whether current research and technology in robotics and other linked fields are adequate and allow one to proceed with the design of personal robots. The authors have argued for the need of an organized effort in this direction and for the launch of a new coordinated technological initiative. As a first step, an assessment project has been proposed. The proposed initiative can draw attention and be recognized as promising by all players involved: researchers, companies, and citizens. Being aware of the fact that the relevant technologies need further advances in order to meet the requirements, the authors have provided a brief overview of the state-of-the-art and have highlighted a series of next steps that need to be accomplished before such an initiative becomes applicable.

The scope of "humanoid robots" is properly restricted to the domain of "personal robots," stressing task-bent functions and analyzing the requisites to make available friendly (artificial) servants, replacing humans for most of our necessary but tedious or hazardous work. The considered approach is confined to factual assessments: thus, the artificial man concept is addressed to figure out actual scientific and technical problems. The issues might not be the best as far as task accomplishment effectiveness; they are most likely more appropriate for personal robots, granting smooth friendliness by emulating the behavior when interacting in everyday-life contexts.

The authors feel that now is the time for an organized and well-coordinated action by all interested parties (engineers, scientists, and researchers in fields such as materials, actuators, controls, information technologies). After all, it is not difficult to imagine that it may not be long before biologists construct a "perfect personal robot"—a real human, cloned and genetically engineered with all attributes of a perfect "battler" (a worker, a soldier?) despite all ethical, moral, and sociological problems that may exist.

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T. Fukuda is with Nagoya University, Japan (e-mail: fukuda@mein.nagoya-u.ac.jp). **R. Michelini** is with the University of Genova, Italy (e-mail: michelini@dimec.unige.it). **V. Potkonjak** is with the University of Belgrade, Yugoslavia (e-mail: potkonjak@www.yu). **S. Tzafestas** is with the National Technical University of Athens (NTUA), Greece (e-mail: tzafesta@softlab.ece.ntua.gr). **K. Valavanis** is with the Technical University of Crete (TUC), Greece (e-mail: kimonv@dpem.tuc.gr). **M. Vukobratovic** is with the Mihailo Pupin Institute-Beograd, Yugoslavia (e-mail: vuk@robot.imp.bg.ac.yu).