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Robot Companions for Citizens

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Abstract

This paper describes the scientific vision and objectives of the FET Flagship candidate initiative Robot Companions for Citizens. Robot Companions will be a new generation of machines that will primarily help and assist elderly people in activities of daily living in their workplace, home and in society. They will be the ICT solution for a new sustainable welfare.

Keywords: Robotics; nanotechnologies; material science; tissue engineering; biomaerials; neuroscience; social neuroscience; human and social sciences; ethical and legal issues

1. Introduction

Humans have moved beyond their evolutionary inheritance by progressively mastering nature through the use of tools and the development of culture. Our current industrialized societies are far removed from the environments in which early human hunter-gatherers existed. However, the welfare that has been generated in the developed world by

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the evolution of human society has brought new challenges and its sustainability is questionable. Among others, one of the most critical challenges is the *ageing of the population*. In fact, in 40 years from now, nearly 35 per cent of the European population is projected to be 60 years old or over, hence the urgency to provide solutions enabling an ageing society to remain active, creative, productive, and – above all - independent [1,2].

2. The vision

In order to solve problems in the real-world one has to act in the real-world. We envisage that in order to maintain the current quality of life of the population, we require a new class of machines and linked technologies that will fulfil a variety of assistive roles, namely the Robot Companions for Citizens. The Robot Companions (RCs) will be a new generation of machines that will primarily help and assist elderly people in daily activities at home, in their workplace and in other environments. RCs will be able to perform a multitude of roles thanks to their capabilities to act and interact physically, emotionally, socially and safely with humans, providing for an improved quality of life. RCs are a key enabling technology for the foundation of a new affordable welfare for all citizens. RCs will be ubiquitous and user-friendly, preserving and augmenting human capabilities and experience, extending the active, independent life of citizens. In other terms, RCs will be the affordable, sustainable, fully recyclable and dependable ICT solution to the challenges associated with the ageing of the population.

Robot Companions will be:

- *strong machines*: RCs act; they will be able to lift objects and assemble artefacts. We should imagine the robot companions being able to help an old bricklayer who is still productive and willing to work, to build a stone wall or fabricate a concrete block, perform house work, such as cleaning and cooking, or retrieve and transport objects;
- *graceful* and *soft machines*: RCs structure, motion and behaviour will be graceful, smooth and quite; they will not be rigid; their bodies (i.e. joints, actuators, skin, etc.) will be compliant, and capable of expressing practically zero-lag responses to external perturbations thanks to their embodied control systems;
- *sentient machines*: sentience is the integration of perception, cognition, communication, feeling, action, awareness of self, others and environment. Robot Companions will not execute their tasks in a stereotyped and predefined way, they will be cognizant of the scenario in which they operate and of its human elements; they will be able to "understand" humans, other animals, physical systems and each other and act accordingly; they will communicate with humans through a multi-modal human-machine interface; by virtue of being sentient they will be dependable machines we can trust.

3. More than mechatronics

In order to develop this new generation of machines, we need a new generation of components to develop both a new bodyware and a new mindware. Today's robots are mechatronic or bio-mechatronic systems: robots are the result of the integration of many components each having a peculiar and well-specified function. Hence, if we want robots with a more adaptive and complex behaviour, we usually need to increase the number of degrees of freedom, the number of sensors, the computational load, the energy consumption and the baud rate of the human machine interface. This approach, although extremely successful in the design of a wide range of industrial products in the last decades, may exhibit some limitations, resulting in machines that are bulkier, more complicated to control, less energy efficient, less adaptive, and (importantly) less dependable. Starting from well-established as well as innovative mechatronic design solutions and components, RCs will gradually move towards a close integration of micro-/nano-fabricated smart materials, each having multiple functions such as sensing, actuation, information processing and communication, energy supplying and mechanical support. In this case a more adaptive and more complex behaviour is obtained, not by increasing the number of components, but by integrating smarter functional materials, guaranteeing a quantum leap to overcome the profound limitation in current approaches to creating robotic artefacts. In analogy with the known metaphor of "more than Moore" in microelectronics, Robot Companions are definitively "more than mechatronics". They will be characterized by: less components, higher robustness, lower computational load, higher energy efficiency, higher adaptability and higher dependability. The design and engineering of RCs will be grounded in an integrated view on the natural principles underlying the power of the integrated body-brain systems that nature has evolved.

Let's consider two concrete examples: actuators and computation. Nowadays, new actuators are mostly a smart integration of traditional components such as motors, spring, cables [3]. We envision that the actuators of the future Robot Companions will be based on nano-fabricated smart materials and bio-artificial components. Mental skills are memory intensive. Nowadays, the "memory" (or any other mental skill) of a robot is mostly implemented by means of an algorithm running on Von Neumann architecture hardware. In contrast, RCs will literally have a true electronic brain. For example, memristors represent a feasible approach towards a new artificial brain architecture, offering attractive features to develop biologically based processing units and connections, or neurons and synapses [4]. They are nanofabricated and packable to form dense memories, and are compatible with CMOS processes. This technology will implement the new brain-like processing architectures the FET Flagship will investigate and develop, with higher bandwidth, less power dissipation and capable of both computing and information storage. In this way, we can both power the RCs and provide validation platform for our developing concepts and theories on mind, brain, behaviour and sentience.

4. Scientific challenges

The starting point of the vision of Robot Companions comes from a deep knowledge and full awareness of the current state-of-the-art of worldwide robotics research. Robotics research in Japan, USA, China, Korea, India, Australia and Europe (and many other countries) has reached a very advanced level [3,5]. Robots are accurate, fast and dexterous in structured environments. They can perform many tasks such as effectively producing goods [6,7], performing surgery [8,9], exploring Mars, and serving humans as prostheses [10]. Nevertheless, robots are only modestly able to meaningfully and safely interact with humans, to autonomously realize tasks at any level of complexity, or to experience and explore unknown environments, let alone to blend seamlessly into the complex, everyday social world of humans [11–13]. On the other hand, living organisms, from human beings to so-called "lower animal species", can perform complex tasks, such as simultaneously executing and coordinating multiple motions, effectively exploring their external environment, adapting to novel situations, expressing advanced individual and collective cognitive capabilities, adapting to external and internal changes (e.g. ageing) and surviving injuries through self-repair. They are able to accomplish these tasks despite the nervous system's relatively long delays in transmitting and processing information (as compared to silicon-based computational systems), the stringent physical constraints and the energy rationing.

The logical consequence of this analysis is that the development of the Robot Companions for Citizens are definitely not just a technological challenge. Indeed, our ambition and confidence is to go far beyond what robotics research has accomplished and presumably will accomplish pursuing an incremental approach. Rather than relying on the progressive advancement of current ICT technologies, RCs ask for new scientific avenues and findings onto which this new generation of real-world artefacts can be based. Indeed, RCs will move substantially beyond current and future robotic technologies developed by leading countries like Japan [14], US and Korea.

At the core of the vision there is the belief that the development of RCs must be grounded in our understanding of the most advanced machines we know—animals. This will range from highly effective and specialized solutions to specific tasks found in insects to the general purpose adaptive and predictive capabilities of perception, cognition, communication and action found in humans. The fundamental point is that the identification of the key design principles underlying biological sentient machines will allow us to engineer a wide range of synthetic ones that might be biomorphic, anthropomorphic or express fully novel body-brain configurations. The engineering of these systems will not be a blind copy of biological solutions but will advance our understanding of the general design principles which evolution has generated to build bodies and brains and will exploit this understanding to build a new generation of robots. RCs will force both the pace of the realization of these new technologies and of the basic science programme on which they are based. The detailed investigation of natural psychological and social systems will also lead to a better understanding of the key features that can make a machine a companion that is really effective in assisting, helping and extending humans, and displaying advanced collaborative and cooperative skills within the real world. "Robot Companions for Citizens" is an integrated science- and engineering-driven initiative, whose scientific mission is complex, multidisciplinary and broad.

The above formulation leaves open the key question "which features of living beings do robot companions need?", and, more specifically, "which features of living beings would we like to see in our robot companions?" Further, we can ask "which features would we like to see in our robots that living beings do not have?". Thus, central to the present vision, is the identification of the kind of scientific knowledge we will need to gather and jointly develop to answer

these questions, which disciplines we will need to bring together, and which new challenges will need to be overcome to provide the best opportunity to solve these formidable problems.

By answering the above questions and forging a new roadmap, the "Robot Companions for Citizens" initiative will address the following grand scientific challenge: to unveil the secrets of the embodied perception, cognition, and emotion of natural sentient systems that make them capable of acting, interacting and adapting effectively to their physical and social environment and of being cognizant and sentient of this relationship to the world.

The grand scientific challenge of the "Robot Companions for Citizens" initiative requires an advanced understanding of the principles underpinning the mind-body (or structure-function) relationship, (or in other terms the role of "matter" in building the mind), the principles of neuroscience, and the principles that make living beings cognizant and sentient. By promoting the investigation of this "mind-body relationship", "neuroscience" and "sentience", "Robot Companions for Citizens" will pave the way for a new "science of sentient robot companions". At societal level, this new science will also seek to understand emerging social processes in networks of embodied cognitive systems (natural and artificial).

5. A multidisciplinary vision

The vision of "Robot Companions for Citizens" is strongly multidisciplinary. This vision relies on the idea that, for the first time, robotics becomes an active technology provider rather than a passive technology user, and is based on the systematic and federated contribution and continuous involvement of many different disciplines and communities, such as: robotics and the morphology-behaviour relationship in living systems; nanotechnologies, material science and tissue engineering for a new bodyware; biomaterials, and micro- and macro-scale cell biology, for developing biological-artificial hybrid systems (i.e. bio-hybrid and bio-artificial actuators and sensors, e.g. artificial muscles); nano-fabrication technologies for energy storage, production and harvesting; neuroscience and the organizing principles of the sensory-motor system at any scale (i.e. cell-scale, tissue-scale, system-scale); systems neuroscience with the goal of understanding the generic design principles of brains and the processes that allow their evolution, development, adaptation and maintenance in the real world; social neuroscience, cognition and principles of human-human, human-robot and robot-robot interaction; principles of knowledge accumulation and expression; human and social sciences to favour the social acceptability of the Robot Companions and facilitate their co-existence with humans; ethical and legal issues.

6. Embodiments and transformative impact of Robot Companions

We imagine that the RCs that will be generated in the 10-year framework of the FET Flagship will likely have a shape compatible with that of humans. However, it is clear that the new bodyware and mindware technology that will be developed during the FET Flagship (whose most significant breakthrough will be at the level of new components) will have a huge transformative impact. In fact, at a later stage (reasonably after the 10-year framework of the FET Flagship), the same new bodyware and mindware technology will be transferred and applied to the development of several new other Robot Companions embodiments, such as a powered suit, advanced prostheses or a legged vehicle for environment exploration and rescue, which will specifically target other emergent societal challenges, such as the sustainability of urban services, environmental care and monitoring, natural disasters, and the general safety of the population. We expect to see research platforms with these morphologies developed during the 10 years of the flagship transforming into a second wave of sentient machines that will serve society.

Supplementary material related to this article found, in the online version, at doi:10.1016/j.procs.2011.12.017.

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