Chapter 11
Robots in Home Automation and Assistive Environments

By ROBOTNIK, S&C, AVN

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11.1 Introduction

It is expected to be a rapid evolution of robots integrated into home automation and assistive environments in the coming decades. During this evolution process, there are basic issues that need to be addressed in order to ensure that robots are able to maintain sustainable innovation with the confidence of providers, patients, consumers and investors.[1] There are several drivers that move this development but also technological challenges to overcome. However, the integration is desirable only if it provides a set of benefits, such as a higher quality support, lower cost, adaptability to changing needs of the individual user and long-term support.

[1]Simshaw et al. [1].

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11.2 Overview of the Current Situation

With regard to robots in home, there is concern that premature and obtrusive legislation might hamper scientific advancement and prevent potential advantages from happening, burden competitiveness or cause economic or other inefficiencies. At the same time, somehow paradoxically, it is accepted that the lack of a reliable and secure legal environment may equally hinder technological innovation.[2] A transparent regulatory environment is seen as a key element for the development of a robotics and autonomous systems market, where products and services can be incubated and deployed.[3] Currently, there is limited legislation in place that applies to robotics in health care to a greater or lesser extent depending on the type of the robot in question (Table 11.1).

In the absence of specific legislation, the usual point of reference for robots and robotic devices is the International Organization for Standardization and specifically the ISO 13482:2014 standard, which has been developed to specify safety requirements for personal care robots.[4]

The ISO 13482:2014 has been created in recognition of the particular hazards presented by newly emerging robots and robotic devices for new applications in non-industrial environments for providing services rather than manufacturing applications in industrial applications. This international standard focuses on the safety requirements for personal care robots in non-medical applications.

This standard specifies requirements and guidelines for the inherently safe design, protective measures and information for use of personal care robots, in particular, the following three types of personal care robots:

- Mobile servant robot,
- Physical assistant robot and
- Person carrier robot.

11.2.1 Drivers for Robots' Integration in Home Automation and Assistive Environments

- **EU context**

One of the latest trends in Ambient Assisted Living (AAL) technologies receiving active interest from the European research community (e.g. Horizon 2020 research

[2]RoboLaw EU project deliverable, D6.2 Guidelines on Regulating Robotics, published on 22 September 2014.

[3]UK Robotics and Autonomous Systems Special Interest Group (RAS-SIG), 2014:7; cited at ROBOLAW 2014.

[4]Holder et al. [2].

Table 11.1 Related legislation in EU

Regulation	Year	Key points
Health and safety		
Machinery Directive 2006/42/EC	2006	It defines essential health and safety requirements of general application, supplemented by a number of more specific requirements for certain categories of machinery
Defective Product Directive, 85/374/EEC	1985	It establishes the principle that the producer of a product is liable for damages caused by a defect in his product
Data protection and privacy		
Directive 2016/680	2016	It aims to protect natural persons with regard to the processing of personal data by competent authorities for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, and on the free movement of such data, and repealing Council Framework Decision 2008/977/JHA
Directive 2009/136 amends 2002/58/EC	2009	It contains basic standards aimed at ensuring confidence of users in the services and electronic communications technologies. In particular, aims at the prohibition of 'spam', installation of undesired items (cookies) and ensures security policy with respect to the processing of personal data
ePrivacy Directive 2002/58/EC	2002	It concerns the processing of personal data and the protection of privacy in the electronic communications sector
Data Protection Directive 95/46/EC	1995	It aims to protect individuals with regard to the processing of personal data and on the free movement of such data. The Directive applies to data processed by automated means (e.g. a computer database of customers) and data contained in or intended to be part of non-automated filing systems (traditional paper files)

project calls) helps provisioning daily activities, based on monitoring activities of daily living (ADL) and issuing reminders,[5] as well as helping with mobility and automation.[6] Exploiting novel sensor modality such as video processing, audio processing as well as processing approaches such as fuzzy logic and effective modelling offer enhanced monitoring and control capabilities. Finally, such technologies promote sociability amongst users sharing common interest, activities and hobbies or with their family, friends, doctors and caregivers[7,8] highlighting further the interconnection with Internet of Things (IoT) approaches.

[5]Pollack et al. [3].

[6]Spenko et al. [4].

[7]Mynatt et al. [5].

[8]Vetere et al. [6].

EU identified and highlighted the needs of the increasing ageing European population and they have to be addressed, namely, issues regarding risk of cognitive impairment, frailty and social exclusion with considerable negative consequences for their independence, quality of life, including that of those who care for them and for the sustainability of health and care systems. Special emphasis is given by the EU on the development of robotic services applied in the context of AAL and particularly for supporting ageing population. The key concepts that need to be addressed regard modularity, cost-effectiveness, reliability, flexibility, applicability to realistic settings and acceptability by the end users.

Over the last years, research projects in robotics for ageing well have been funded under the ICT strand of the seventh research framework programme (FP7) and under the AAL Programme, with a total budget of 50 M€. In addition, since 2015, a batch of care robotics projects have been launched under the Horizon 2020 Programme, with a total funding amount of 185 M€.

- **Cloud Technologies**

Cloud computing has become a necessary tool during the last years. The principal functionality is to provide remote computational resources as services invoked through a network.[9] This gives the possibility to provide low-resource devices with access to a massive amount of data and computation power, including distributed and parallel processing. Cloud computing is expanding in several domains and improving in provided services. It offers ease of data exchange, scalability of solutions and flexibility in configuration among others. The robot's connection to the cloud provides the possibility of introducing dynamic machine learning algorithms, collective robot learning offering enhanced capabilities regarding aspects such as speech recognition, emotion recognition and localization.[10]

- **Smart Assistants**

Only a few years ago, the concept of artificial presence (as the one of robots) was considered high risk, as the anticipated acceptance by humans was unknown. Therefore, AAL and smart home architectures focused on the 'de-personalization' of the installation, hiding the interface to the smart infrastructure (and the cloud-based services) under screen-based GUIs. The RADIO project insisted at that time on bringing a partner (the robot) in the scene, taking that risk.

Since then, smart assistants like Apple Siri and Amazon Alexa have entered the market with unprecedented acceptance; rapidly shifting the interface paradigm. Future systems, based on robot-centric access to the smart home and assisted living problems, will leverage from this and add smart assistant interfaces enabling the user to literally talk and interact to his/her robot.

[9] Pinta et al. [7].

[10] Pinta et al. [7].

11.2.2 Technological Challenges for the Integration of Robots in Home Automation and Assistive Environments

- **Interoperability**

One of the major challenges for wide adoption of robotics in home automation and assisted living is that of interoperability of various devices. Various sensors, smart appliances, network interfaces, actuators, location devices and the robots need to connect seamlessly at various levels concurrently:

- Network layer—at this level, all nodes should be able to exchange data, either directly or through some bridge or gateway. This can be achieved either by having a single-network installation where all nodes use the same protocols or by ensuring that the multiple networks can connect at the bridge points. Single-network systems are feasible today but they are not growing because (a) the initial setup cost is big and (b) the risk of following a non-future-proof protocol is still high. Industry trends do not show any real convergence; on the contrary, many standardisation initiatives are competing with no clear winner foreseen.
- Semantic layer—at this level (and assuming data transfer is achieved at the network layer), the way this data is constructed and processed has to enable interoperability. Having data semantics defined will allow multiple applications to run in a heterogeneous system, allowing upgrade of the system or provider selection without having to reinstall or reconfigure the infrastructure. Interoperability at this level is not possible today and there is no industry-driven approach to achieve it.

The above points show that achieving an open, configurable and expandable system, which ensures interoperability of devices and applications from various vendors is a major challenge. A challenge, however, has to be confronted by any attempt to develop and deploy a smart home for assisted living. The RADIO consortium tackled interoperability at the network level, by supporting multiple wireless standards.

- **Security**

An important aspect in recent home automation scenarios is the security of the entire system, especially of wireless connections. Therefore, methods have been developed that take this into consideration and are able to face these challenges.

At the wireless infrastructure layers, this is accomplished by employment of the latest security updates in Z-Wave and Bluetooth Low Energy (BLE) standards. At the embedded SW and HW level, all current measures have been taken and any future security updates can be updated on the field. By using reconfigurable architectures, the maintenance of programmable hardware is enabled in so far, as updated security standards can easily be implemented. The RADIO approach is based on the Xilinx Zynq SoC, providing an all programmable approach for both software and hardware. The software part is hereby realised by a modern ARM multi-core processor, while FPGA hardware resembles the programmable and reconfigurable hardware.

- **Heterogeneity of solutions**

The RADIO ecosystem consists of several processing elements, ranging from microcontrollers over processors to FPGAs. The sensors are connected to gateways which are running on an ARM processor. These sensors establish a connection via a microcontroller within the dedicated dongles for either BLE or Z-Wave communication. The RADIO robot consists of two main processing platforms naming the Intel NUC, which is a processor system, and the PicoZed, which is a low-power development board containing the Xilinx Zynq SoC. By using the proposed all programmable hardware, a heterogeneous approach is featured. This applies therefore not only to the diversity of used gateways but also to the processing elements itself. One heterogeneous challenge for the RADIO robot is to incorporate both processing systems to work cooperatively on dedicated robot tasks.

- **Localization**

In order for the robot to be a useful addition in home automation and assistive environments, the robot needs to be autonomous. This is the necessary condition for further technological improvements. Figure 11.1 shows the tasks of the autonomous robot control loop. It consists of localization, cognition, motion control and perception. Each task depends on the prior tasks, and thus all tasks have to be executed continuously. The cognition task requires the data from the location task, i.e. the robot's position in a known environment. From a higher control level, the cognition task receives a goal it needs to achieve. This can be a target position for the robot or an optimal path planning for grabbing an object. The cognition task provides the motion control task with the desired movements to execute in the real-world environment. The motion control task is the only task that interacts with the environment. One problem that needs to be tackled in this task is solving the

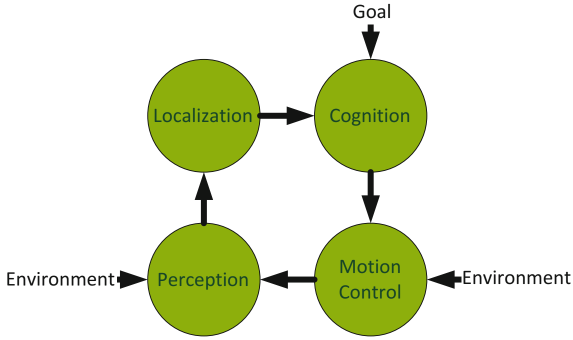

Fig. 11.1 The four task phases of an autonomous robot

inverse kinematics problem. This is especially important for grabbing objects. The final state of the robot is then sent to the perception task where all sensor data is accumulated and analysed so that the localization task can process this information.

- **High obsolescence rates**

A challenging factor in the field is the product's short life cycle. Robotic technology and ICT products are characterised by high obsolescence rates. For instance, hardware become obsolete in only a few years and are replaced by new ones, while software gets updates at times and it also becomes obsolete and users switch to new ones. In this dynamic context, most of the revenues are generated in the very short run, while there is an increased need for new products and services.

Robots currently are developed and provided by firms that have been used to such short life cycles, originating from the personal computer/laptop or from the—even shorter—software marketplaces. For robots to be successful, their life cycle model should resemble that of white appliances or even cars, ensuring that the individual's investment is justified in terms of return.

- **Energy consumption**

The proposed hardware architectures enable the low-power operation of the robot. Therefore, a camera is connected to the PicoZed which analyses the scenery and wakes up the power-hungry components of the robot, such as the Intel NUC and the processing core of the PicoZed itself. The BLE technology used within the RADIO approach allows the low-power operation by design, thus allowing long operation times and availability of the RADIO ecosystem. As the RADIO ecosystem also includes Z-Wave devices, which are not as power-hungry as Ethernet-based components, further steps towards energy-efficient homes have been taken within the RADIO projects.

11.2.3 Initial Roadmap for the Integration of Robots in Home Automation and Assistive Environments

The main technological advancement of RADIO is the combination of cutting-edge technologies that enable high-quality systems that meet human-centric requirements by being adaptive, interactive and contextual. This high-level concept is translated into specific technological challenges that need to be addressed.

- **Communication systems**

These systems are composed of a number of different devices that require a fast interaction between them in order to share information. Robust communication systems are required to enable interactive solutions. For example, the robot requires proper WiFi connection to navigate inside a house in order to be continuously connected to the global controllers. Robotic platform is expected to support two communication interfaces. On the one hand, it is required to support a communication with the sensors gathering environmental information (laser, RGBD cameras, microphones, etc.), while on the other hand the robot must be able to interact with the RADIO home controller in order to access services external to the RADIO home. Physical connection between the mobile robot and smart home devices and the RADIO home controller must be achieved through WiFi connection to the ADSL router that also provides Internet connectivity. An off-the-shelf WiFi sub-dongle will suffice for such connectivity requirement.

- **Navigation, localisation**

There are many handicaps that robots find when navigating in unstructured home environments, like pushing away obstacles, using stairs or elevators, sidestepping humans, pets, other robots, etc. They all require 3D perception and the use of cameras (cameras are cheaper and can be richer in information than many LIDAR sensors). RGBD sensors are great for indoors; they are cheap and we can use them to map with different approaches (i.e. real-time SLAM software for RGBD sensors) with many functions such as multi-session mapping, appearance-based closure detection, map optimization to new constraints, 2D projected map, etc.[11] The house needs to have a clear path for the navigation of the robot: the robotic platform must be always able to locate a path to move. It is important not to drop obstacles that might cause difficulty in robot movement.

- **Human–Machine Interaction (HMI)**

The integration of robots in home automation and assistive environments require some improvements in the design of elderly HMI. Effective end user involvement in all stages of the system development is highly desired. Creative design activities and evaluation methods that suit the elderly need to keep improving. User interfaces through television, touchscreen, avatars or speech have shown significant acceptability for the elderly. Television allows displaying avatars that they are used to show exercise or reminder messages. Also, the usage of television as the main interaction device is possible using arrow buttons of the remote control for navigation.

- **Robotics technology**

The healthcare community requires low-cost robotic aid that provides input–output capabilities to the user interface, control, safety and autonomy procedures. For example, once the robot detects that its battery is low, it goes directly to the recharging station, in a similar way as the vacuum cleaner robots. User's acceptability depends on physical structure of the mobile robot, interaction, mobility systems, system of sensors such as cameras, infrared, shared control, etc.

[11] In order to cope with the navigation and localization problem, RADIO makes use of ROS since it provides powerful and well-tested software to deal with navigation issues. Gmapping and hector slam are the most used ROS packages by the community for SLAM (both based in MCL).

- **Artificial Intelligence**

With the emergence of sensors that keep getting better, smaller and more capable of measuring almost anything, context awareness will be a key factor for most applications in home automatization and assistive environments. The availability of many types of sensors in smartphones and the IoT are providing enormous volumes of contextual data available. This has serious implications for Artificial Intelligence (AI). First, it is expected that systems are self-aware and understand the context through reasoning process. The systems are trained for specific contexts and then use contextual reasoning and specific learning techniques to efficiently and effectively solve problems. Context reasoning is as important as learning for deriving models. The next AI advances should find a way to balance contextual reasoning and machine learning that enable systems to be dynamic enough to adapt and improve with experience. Second, AI plays a relevant role in acquiring contextual awareness through the use of speech understanding mechanisms and emotion recognition by face and voice detection.

- **Security, Privacy and Data Protection**

Security, privacy and data protection are critical issues in the IoT domain when this involves users who store and exchange their medical data. The aforementioned legislation provides guidelines regarding the use of personal data retrieved from ICT technologies (ePrivacy Directive) in order to avoid misuse. A safe approach suggests the use of data encryption and digital certificate infrastructure for ensuring confidentiality and integrity of the medical data collected from wearables, sensors.[12] A secure transmission to the cloud and access to official and unofficial caregivers is also important.

- **Technology Standards and Specifications**

Technology standards and specifications provide the basis to achieve interoperability, integration and scalability through standardised protocols and data models. The standards should apply to all technologies, robotic, wireless sensor networks, health monitoring devices, smart home systems, etc.

11.3 Market Opportunities Arisen from RADIO Robot

The RADIO outcomes that can generate market opportunities are the next:

- Audiovisual Activities of Daily Living (ADL) detection methods: Methods that detect ADL from audio and visual signal.

[12] Doukas [8].

- ROS/IoT middleware integration: Integration of Robot OS components with IoT middleware and web services and with human–robot interaction components for integrated automation/mobile robot environments.
- Privacy-preserving Data Mining: Data management components for privacy-preserving data mining.
- WSN gateway design and development: Enhanced WSN gateway supporting heterogeneous communication technologies both concerning the WSN network and the back-end communication. Additionally, respective design offers advanced functional features and resilience characteristics incorporating internal databases and intelligence.
- BLE communication technologies: Enhance BLE enabling extended coverage area, mobility support, dynamic topology support and more efficient traffic/data management.
- Design and develop an end-to-end versatile communication platform: The proposed platform (ATLAS) is able to be easily extended and expanded concerning various critical aspects. Particular focus has been devoted to offering flexible interfaces, allowing the easy integration of future communication technologies. Additionally, support of all prominent database types is offered, delivering advanced performance characteristics. Finally, the development of application is significantly facilitated following the microservice paradigm, allowing the easy plugging and unplugging of specific application components. In the context of RADIO, it is used for various functionalities intended for the technical personnel.
- ADL detection methods through smart home sensors: Data mining and machine learning techniques will be developed to detect ADLs through the energy consumption in homes. Each activity is associated with measurable features such as the time of day, users' movement patterns through the space and the on/off status of various electrical appliances.
- Advance TurtleBot2 platform to support RADIO services: Adapting the generic platform of TurtleBot2 to carry hardware equipment that supports RADIO services.
- Hardware acceleration for intensive audio and visual processing: To achieve increased autonomy of the robot, power-efficient solutions are developed by the development of dedicated and highly parameterised IPs implemented in hardware that enable processing of audio and video at lower power and higher speeds.
- Hardware acceleration architecture (Based on the Xilinx tool flow): The image processing algorithms that need to be accelerated require a specific architecture in order for them to be integrated into the ROS environment of the robot.
- APIs for the connection between controller, robot and smart home: The controller module will be in charge of getting information from the different platforms, robot and smart home, combining and analysing data to create the proper ADLs. This requires a direct connection between the controller and smart home and controller and robot through APIs.

- RADIO complete architecture and services: From an elder care facility, RADIO complete architecture will provide new opportunities to hospitalisation. It will also offer to caregivers and nurses remote patient monitoring and after a surgical intervention, it will offer rehabilitation before going back to their homes.

11.4 Conclusion

As we have seen throughout this chapter, the usage of robots integrated into home automation and assistive environments is not 100% solved from some perspectives:

- Although integration is technically feasible with the existing and emerging technologies, there are still some technological difficulties and challenges that must be solved (as interoperability, security and heterogeneity of solutions or energy consumption).
- There is still work needed for enhancing standardisation options and elaborate suitable legislation in order to adapt to the changing needs and technology advancements.
- User's acceptability will be the key aspect of the commercialization and therefore these technologies have to cover real needs and offer the appropriate return on investment.

Finally, we can summarise the next steps as the key points to commercialise the RADIO solution:

- Establish a robust communication system to enable interactive solutions.
- The robot should have a localization and navigation system.
- Address user's need for continuously improving systems for human–machine interaction.
- Ensure user's acceptability of robot's design, data collection, behaviour and functionalities.
- AI to provide a dynamic service adapting and improving with experience.
- Provide security, privacy and data protection.
- Comply with technology standards and specifications.

References

1. Simshaw, D., Terry, N., Hauser, K., & Cummings, M. (2016). Regulating healthcare robots: maximizing opportunities while minimizing risks. *Richmond Journal of Law and Technology, 22*(3). https://hal.pratt.duke.edu/sites/hal.pratt.duke.edu/files/u13/REGULATING%20HEALTHCARE%20ROBOTS.pdf.

2. Holder, C., Khurana, V., Harrison, F., & Jacobs, L. (2016). Robotics and law: Key legal and regulatory implications of the robotics age (Part I of II). *Computer Law & Security Review, 32*, 383–402.
3. Pollack, M. E., Brown, L., Colbry, D., McCarthy, C. E., Orosz, C., Peintner, B., et al. (2003). Autominder: An intelligent cognitive orthotic system for people with memory impairment. In *Proceedings of Robotic Autonomous Systems*.
4. Spenko, M., et al. (2006). Pamm—A robotic aid to the elderly for mobility assistance and monitorng for the elderly. *Transactions on Neural System Rehabilitation*.
5. Mynatt, E. D., Rowan, J., Jacobs, A., & Craighill, S. (2001). Digital family portraits: Supporting peace of mind for extended family members. In *Proceedings of SIGCHI Conference on Human Factors in Computing Systems*.
6. Vetere, F., Davis, H., Gibbs, M., & Howard, S. (2009). The magic box and collage: Responding to the challenge of distributed intergenerational play. *Journal of Human-Computer Studies*.
7. Pinta, D. L. P. J., Maestre Torreblanca, J. M., Jurado, I., & Reyes De Cozar, S. (2017). Off the shelf cloud robotics for the smart home: Empowering a wireless robot through cloud computing. *Sensors, 17,* 525. https://doi.org/10.3390/s17030525.
8. Doukas, C. (2012). Enabling data protection through PKI encryption in IoT M-Health devices. In *Proceedings of the 12th International Conference on Bioinformatics and Bioengineering (BIBE), Larnaca, Cyprus* (pp. 25–29), November 11–13, 2012.