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Wireless Robotics: A Highly Promising Case for Standardization

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Abstract Mobile robots are an area of active research with enormous, untapped potential for the future—for household use, for applications in industry and production, for elderly care, in hospitals as well as in a host of other fields. In order to realise the possibilities that future robots hold, there are a number of obstacles to be overcome before mass markets can evolve in these individual segments. This paper discusses the main challenges related to the adoption of wireless robotics and gives a comprehensive overview of the suitability of existing wireless technologies, while arguing the need for standardization in this rapidly advancing area.

Keywords Wireless robotics · Standardization · Wireless personal cooperative robot

1 Introduction

Wireless is overtaking wired as the primary mode of connectivity to the Internet; nowadays there are 500 million Internet connected servers/PCs versus two billion cellular phones (of which 400 million are Internet capable). Concerning sensors, their deployment is just beginning and around 10 billion of them are expected to be active in 2020 [1]. WWRF predicts that in 2017 seven trillion wireless devices will be serving the 7 billion earth inhabitants, which means 1,000 wireless devices per person will be active [2]. These devices will belong not only to traditional mobile telephony, but also to health and medical, smart homes, intelligent cars and Radio Frequency Identification (RFID) applications. Besides the spectrum efficiency, this poses challenges for the network architecture as well. The main challenge is to do the proper networking of potentially trillion wireless devices within a few GHz bandwidth [3,4].

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This scenario is related with the so-called self-organizing networks (SONs), which are characterized by self-configuration, self-service, self-knowledge, self-awareness and self-maintenance capabilities. Examples of networks with self-organization capabilities include: ad-hoc networks, wireless sensor networks (WSNs), and mesh wireless access networks. SONs are decentralized and this implies a limited amount of information available compared to centralized networks. One key issue is to quantify and minimize the information required to be exchanged by the nodes of a SON such that still performance will be acceptable.

Mobile robots are an area of active research with enormous, untapped potential for the future—for household use, for applications in industry and production, for elderly care, in hospitals as well as in a host of other fields. In order to realise the possibilities that future robots hold, there are a number of obstacles to be overcome before mass markets can evolve in these individual segments. One of the biggest hurdles is the fact that currently there are no wireless communication technologies available that fit the specific needs of robot systems. Before defining those needs in more detail, we note that robots can be considered highly complex cases of general sensor-actuator systems. Standards developed for this field may, therefore, find applications in other areas as well, e.g., from the closed-loop control of drives and machines in industry by way of simple household appliances with a motor component to the fails-safe communication of an electric car with its charging station.

Robots—in particular household robots—are mass products that can be very price-sensitive. Therefore, such products can hugely benefit from cheap, reliable and transparent communication technology.

This paper discusses the main challenges related to the adoption of wireless robotics and gives an overview of the suitability of existing wireless technologies, while arguing the need for standardization in this rapidly advancing area. The paper is further organized as follows. Section 2 lists the communication types for wireless robotics. Section 3 proposes the concept of the Super Intelligent Wireless Personal Robot (SIWPR). Section 4 concludes the paper.

2 Communication Types for Wireless Robotics

In principle, it is necessary to standardize three basic types of communication in the field of robotics:

(i) Communication between a (mobile) robot and a fixed base station: for example, for remote control of the robot under real-time conditions, for enabling the robot to obtain access to the Internet, or for contacting the robot from the Internet, etc. This would include a “broadcast mode”, e.g., for distributing environment information to a number of receiving robots.

(ii) Communication between robots, without a base station. Robots should be able to communicate directly with one or a (potentially large) number of peers, when they get into transmission reach. This is mandatory whenever tasks are to be performed jointly, e.g., jointly carrying a load, but also joint sensory tasks, such as distributed exploration of the environment and map building. This will involve operating modes for self-organizing, ad-hoc and WSNs.

(iii) Communication between the individual components of the robot itself. The internal wiring of robots can become very clumsy, even messy and unmanageable—ultimately it may impair the robot’s mobility. This is particularly important in the case of humanoid robots with many degrees of freedom and actuators that need to be controlled with timely and highly synchronized commands.

For case (i), wireless links based on currently available technology, i.e. IEEE 802.X, are in routine use for simple tasks. However, the results in terms of transmission quality, latency and in particular, robustness, are less than satisfactory at this point. For case (ii) one could imagine networks of a mixture of access points for multi-point links, but this is also not satisfactory. Finally, for (iii) body-area network types could become a basis for standardization, provided the communication parameter requirements needed for this application can be successfully met.

2.1 Communication Parameters for Wireless Robotics

Depending on the application and the communication type, the requirements for the network links will vary considerably. However, it will be possible to identify limits for minimum service quality including bandwidth, latency times, acceptable compression losses, parameters relevant to overall network safety and minimum end-to-end reliability/availability. These can be grouped according to robot types (e.g., mobile, fixed, combined), to use cases (e.g., actuator control, encrypted low or high-bandwidth sensor data communication, closed loop control across remote devices), to applications (multimodal human-interfacing, video transmission for data streams that need to be processed by machine vision algorithms), etc. Such grouping will necessitate a careful study of complete robot systems, existing now and extrapolated into the future.

Both for system pricing and for time needed for producing first standards, it would be highly desirable to re-use already existing building blocks, both in terms of protocols and standards, but also in terms of system reference architectures, hardware blocks and software layers. However, such a migration option should not become a handicap in the development process on the way to optimal standards for wireless robotics.

2.2 Scenarios for Test and Deployment

Sets of wireless robots are, in essence, complex spatially distributed sensor-actuator networks with a high variability in bandwidth and service types moving about in dynamically changing environments in ever-changing network structures and topologies. Moreover, these systems are used in environments that are characterized by potentially massive electromagnetic disturbances. The propagation characteristics of radio signals vary dramatically when the robots themselves, massive products or machines are moving. This might affect preconfigured datapaths and result in the necessity of rerouting. Furthermore, also frequency changes might be necessary along with a continuous adaptation of modulation types, etc. This necessitates the development of smart and flexible techniques, e.g. SONs, techniques for flexible spectrum usage (cognitive radio) and automatic link adaptation, e.g. intelligent power control, multiple antenna and multipath techniques, adaptive modulation and coding.

Since the applications are safety-critical, the network must guarantee a minimum quality of service (QoS). One way of guaranteeing such safety features could be the support of both uni- and multicast communication. During normal operation, unicast communication can save bandwidth and guarantee the overall quality. In the case of an emergency, the data might instead be flooded into the network to guarantee a timely reception at the sink (multiple or single sinks).

Obviously, a quick adaptation towards current communication requirements vs. changing environmental conditions in real-time is a must. This could be achieved by a reconfigurable network stack, which can also be the foundation for new modeling and programming paradigms to achieve an optimal communication for highly complex sensor-actuator networks in such dynamic and adverse environments.

The ability to adapt to such changes, the interoperability between components and network stacks, the quality of the communication and examples of the resulting applications can ideally be demonstrated in test scenarios and interoperability test centres, which should be set up as part of the standards development.

2.3 Networking Perspective

In the beginning of the technological development, multiple robots with communication functions were considered a client-server type communication prototype between robots and an access point. Now, as one evolves toward teams of robots supported by wireless ad-hoc networks, the main motivation for connecting the robots is to achieve a common mission of the robots in a distributed and parallel manner.

In many practical applications, this approach is more efficient and economical than the approach with a single intelligent robot. However, effective communication among robots is a difficult issue in the coordination of group behavior. Group of robots combine a large degree of autonomy with complex collaborative behavior to accomplish common tasks. Enabling such awareness brings into question many currently existing fundamental communication paradigms. In turn, this opens the way to novel applications of telecommunication systems, which can be seen as ICT-based applications. Real-time wireless communication can help dynamic resource management and self-organization for a team of cooperative robots. The multiple robots communicate with each other, sharing the same mission. In this respect wireless communication is an excellent candidate for inter-robot information exchange [5].

As a result of this development, and maybe more importantly, machine to machine communications (M2M) will quickly become as important a communication mode as machine-to-human, human-to-machine or human-to-human information exchange. With this paradigm shift, the average distance between communication pairs will continuously decrease. This shortened distance will shape the radio network to be far more interference-limited. The randomness of the network will be expanded in terms of node mobility, interference, and energy consumption. The answers to the above-mentioned challenges lay in smart, intelligent and self-organized wireless communications designs.

3 Super-Intelligent Wireless Personal Cooperative Robot (SIWPR)

One of the main goals of the Super-Intelligent Wireless Personal Cooperative Robot (SI-WPR) is reducing the need for human presence in scenarios where it implies a high risk for human beings, e.g., disposal of toxic waste, operations in nuclear plants, fire-fighting or rescue missions. The key concept for implementing SIWPR is the Wireless Cooperative Robots Network, making use of whatever consumer electronics are available in a home/indoor scenarios to build intelligent SONs.

The nodes of such networks can be any device, e.g. mobile phones, TV, domotic appliances, robots etc. The key problem here is to build wireless networks which can build, optimize and maintain themselves in a smart, flexible and self-organizing manner.

To meet the technical requirements in terms of safety, security, QoS, latency is going to be challenging in such unstructured environments, where lack of centralized coordination has to be assumed, as opposed to traditional outdoor cellular networks. Indeed, in a large system with many mobile robots, it becomes difficult for all of the robots to exchange information at a time because of their limited communication capabilities; in this case, an ad-hoc robot networking scheme is more promising [6].

3.1 SIWPR and Personal Area Networks

Quite a lot of achievements have been obtained in the field of Personal Area Networks (PAN) and these could be reused in order to develop wireless personal robot communications. In this respect, a prominent role was played by the EU-funded projects MAGNET and MAGNET-Beyond, which aimed to provide a competitive technological edge for Europe in this critical area, aiming to fulfil the European citizen's expectations for a global platform for PN systems, ensuring scalable, decentralized and cost-effective communication [7].

The timeliness of PAN is confirmed by the trend that more and more of the wireless communication traffic is going to be indoor, keeping to the outdoor cellular networks mainly to provide a support service in case e.g. of emergency calls. An important business case for PAN are recreationally and educationally-oriented entertainment, where robots and other domestic appliances could be communicating and commanded e.g. by voice giving rise to end-less opportunities of entertainment in-house.

3.2 SIWPR for Safety, Security and Rescue

Disasters occur in short time periods and are usually unexpected, leaving in their wake large numbers of casualties and severe infrastructure damage. These disasters can be due to natural causes (earthquakes, fires, floods, hurricanes, epidemics or combinations of thereof) or manmade (industrial accidents, terrorism and war).

Coordinated relief to the affected areas needs to be given as soon as possible, so to minimize further nefarious effects. In such scenarios is vital that communications between interested parties, i.e. relief and security groups, are established as quickly and as easily as possible, ideally in a plug & play or zero configuration fashion. The fact that infrastructure-based networks in such deployment areas may be destroyed raises the need for new alternatives and communication paradigms, ideally infrastructure-less, and for decentralized wireless technologies. Wireless ad-hoc networks of robots could be efficiently employed in disaster areas e.g. to help immobilized civilians.

Safety, security and rescue robotics is an important application field that can be viewed as a prototypical example of a domain where networked mobile robots are used for the exploitation of unstructured environments that are inaccessible or dangerous for humans. Tele-operation for Safety, Security, and Rescue Robotics (SSRR) must move up to the behavior and mission levels where a single operator triggers short-time, autonomous behaviors, respectively, and supervises a whole team of autonomously operating robots. Consequently, a significant amount of heterogeneous data—video, maps, goal points, victim data, etc.—must be transmitted [8].

In the last decade, WSNs have been successfully deployed to perform numerous automation tasks such as environmental monitoring, surveillance and inventory tracking. By introducing actuation capabilities (in particular controlled-mobility), robots have the potential to improve the capabilities of existing WSNs significantly. Recent advances in robotics as well as the availability of inexpensive robotics platforms have made it feasible to develop hybrid networks in which multiple mobile robots interact with each other and other static sensors to perform complex tasks. On the other hand, design and implementation of such hybrid systems bring forth new algorithmic and systems challenges related to coordination, planning, and resource management.

4 Conclusions

Wireless robotics is a rapidly growing area with the potential to significantly affect current mobile telecommunication networks and to advance application areas such as disaster and rescue management; remote healthcare; quality of life and so forth. Standardization is a key means to ensure the commercial value of this very promising research area. It is through proper standardization process that the impact of, and how to deal with, the demands of a wide variety of wireless robotic devices, can be assessed. The communication needs of wireless robotics range widely: from a few bytes at long intervals to on demand full motion video and audio. Standardization should also look at how to deal with smart wireless robotic devices.

It is now the right time to commence the standardization process. Already, standardization bodies are addressing the needs of areas such M2M. Wireless robotics is closely related to M2M and deserves an equally focused attention.

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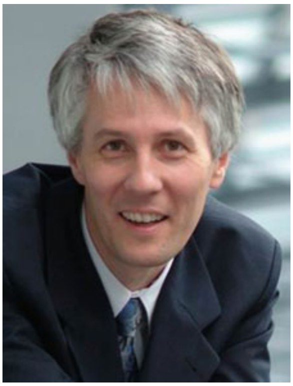
Author Biographies



Alois Knoll received the diploma (M.Sc.) degree in Electrical/Communications Engineering from the University of Stuttgart, Germany, in 1985 and his Ph.D. in Computer Science from the Technical University of Berlin, Germany, in 1988. He became a full professor in Computer Science at Bielefeld University in 1993. Between 2001 and 2004 he was a member of the board of directors of Fraunhofer-Institute for Autonomous Intelligent Systems. Since 2001 he has been a professor of Computer Science at Technical University Munich. Between April 2004 and March 2006 he was Executive Director of the Institute of Computer Science at TUM. He is the director of the Graduate School of Information Science in Health at TUM. Since 2009 he has been a director of fortiss GmbH, an independent research institute specialising in cyber-physical systems. His research interests include cognitive, medical and sensor-based robotics, multi-agent systems, data fusion, adaptive and real-time systems.

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