Intelligent Home Appliances

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Abstract. In this paper the use of robots as intelligent appliances is discussed. A number of advertised systems are reviewed and their basic characteristics analyzed. Open issues in terms of navigation, user interfaces, robustness, price are discussed as a basis for issues for future research to enable commercial delivery of such systems.

1 Introduction

Robotics is by now a well established domain for industrial automation. Yet, the major application area to open up is considered to be domestic robots [1]. There are a number of fundamental differences between industrial and domestic robotics, that have to be considered to enable successful deployment of these new robots. Some of the differences include:

Environment The environment is much less constrained that in an industrial setting
Usability The system is to be operated by an untrained operator that might have limited or no computer experience
Energy The run-time for a system should preferably be close to 24 hours a day, in terms of availability, which implies that the system should recharge whenever nothing else is needed. I.e. ad hoc recharging rather than recharging when needed by the batteries
Price To gain widespread acceptance it is crucial that the price becomes low enough to allow acquisition by regular people for everyday tasks, which in general implies a price of less than $1000.

The potential set of applications in a domestic setting involves a large number of tasks. The task domain can be divided into three categories:

1. Entertainment
2. Everyday tasks
3. Assistance to elderly and handicapped

The first category is where the majority of the business is today. The benefit of this category is that the performance metric is forgiving. I.e. the robot is not required to carry out specific tasks that requires accurate navigation and/or path following. As long as the robot does something interesting in terms of behavioural interaction the customers will in general be satisfied. A challenge is here to have an “open-ended” repertoire of behaviours to maintain the interest of the user so that they are not bored after a few hours, days or weeks of use.

The second category is aimed at robot systems for everyday tasks such as vacuum cleaning, fetch-and-carry, ironing, window cleaning, ... These are extremely demanding tasks as the service to be delivered in general has a low monetary value and it has to be carried out in a rather complex setting. The key is here that the performance metric is well defined, while the domain is poorly defined. One wonders why industries want to enter this area.

Finally the area of assistance to elderly and handicapped is motivated by the demographic profile of the western world in general. Over the next few decades the society will have a rapid rise in the number of retired and handicapped people, which is one of the benefits of medical advances in terms of prolonged life-span and new possibilities to save life. Unfortunately to cope with the aging society it is necessary to maintain or increase the current level of productivity to ensure economic growth and in parallel it is necessary to provide assistance to elderly and handicapped so that they will experience an independent style of living [2]. A significant increase of the health sector might in part solve this problem, but it would be better if several of the services delivered to the person are automated so as to have independence. To this end it is also important to notice that tasks such as toilet visits can be assisted by robots without problems while it is less obvious that people are equally comfortable having the same tasks carried out by a human assistance. The performance metric is here a high degree of flexibility and easy instruction while the price potentially might be significant as the alternative would be managed care, which typically a gross price of $100/hour.

Recently a number of robot systems for domestic use have entered the market or been advertised. Many of these new systems are “toy”/entertainment products, but there are also a number of service related products. A key factor for the widespread adaptation of these systems will be price. This is turn requires development of cost efficient methods in a price range that barely has been considered before. In this paper a few example robot systems will be considered and based on this general problems in domestic robotics will be identified as a basis for a discussion of limitations in current robotics research.

2 Example Systems

Two major categories of domestic robotics have been announced over the last three years, they are i) entertainment robots and ii) cleaning robots. A third category might be information management robots, or embodied IT appliances. For now we will, however, restrict our attention to the two initial categories. For these categories it is characteristic that most of the entertainment robots originate from Japan, while the cleaning/service robots all are from Europe. A brief sketch of a number of systems is provided below as a basis for a more details analysis.

2.1 Sony AIBO

The Sony Inc. AIBO dog pet has been released in two generations. Both are quadruped dog type toys with a camera build into the nose, a microphone for sound analysis and a loudspeaker for "simple" feedback. The system comes with predefined behaviours for basic motion etc. In addition the commercial model has a build in learning method for "adaptation" to user preferences. The robot is battery powered and uses a MIPS M4000 300 MHz processor with 32MB memory. The robot is programmed using the Open-R proprietary operating system from Sony. Limited information has been made available on the system layout, but it is evident that is uses a behaviour based method of programming [3]. A special version of the AIBO has been released for use with the RoboCup competition. A programming kit using a "finite-state automata" model is available as an add-on. Programmes can be uploaded to the dog through a memory-stick. Various version of more advanced programming kits have appeared on the internet, these programmes have, however, been retracted after Sony has indicated copyright issues and threatened to take legal actions.

2.2 Sony SDR-3X

Recently Sony Inc. advertised (Nov. 21, 2000) the SDR-3X robot as the "robotic partners". This is a small humanoid style robot (biped) that has 21 degree of freedom with the ability to walk and "dance". The robot has a height of 50cm, and a cross ratio of 22 x 14 cm. It has a weight of 5 kg, and a walking speed of 15 m / min (25cm/s). The robot has build in monocular vision system for motion based recognition, and microphone and loudspeaker for speech interactions. In addition the system has a built in 802.11 network connection. The robot is controlled using a "remote-brain" approach [4], where motion initially is planned/programmed in a PC based simulation system and subsequently downloaded to the Open-R system that resides on the SDR-3X system. At present it is not known in detail what type of programming interface that will be offered.

2.3 NEC M100

The NEC M100 robot is a small tricycle robot construction that is driven by a pair of differentially controlled wheels. The robot navigates using a set of ultra-sonic sonars. The robot has also a built in camera system that is connected to a face recognition system. Finally the system has a microphone and loudspeaker for speech recognition and replay. The robot is in principle a rovering answering machine that automatically recognises the occupants in a house and replays messages to them upon encounter. It is not evident that robot can be programmes to carry out specific actions.

2.4 IRobot

The company iRobot has announced the iRobot platform for domestic and office use. The robot is basically a web-cam on wheels. The robot has a video dome with a build-in web cam sitting on a neck that can be raised and lowered. The head has a $\pm 45°$ motion capability of the camera. The head is mounted on a a set of 8 wheels that are mounted on an articulated body (1 DOF) so as to enable traversal of “simple” staircases and minor obstacles. In addition to the earlier mentioned camera the robot has microphone and stereo speakers for tele-conferencing. The robot is supposed to run Linux for basic control and a tele-conferencing system for remote control. The idea is to allow home owners to navigate around their home while away, and to use the robot as an embodied character for professionals that have to attend video conferences. So far (Spring 2002) the company has taken orders but not yet delivered any systems.

2.5 Dyson – DC06

The Dyson DC06 robotics vacuum cleaner was announced by summer 1999. The idea is to have a fully autonomous vacuum cleaner for home environment. The robot has a differential drive system and 2 caster wheels that are suspended. The robot is controlled by 3 computers (type 68xxx). In addition the system is equipped with 50 different sensors (a mixture of sonars, encoders and accelerometers) to allow structured traversal of a specific region. The robot is battery powered and it is not apparent if it comes with a recharging unit. The robot is supposed to have a running time of about 1 hour. It is not expected that it will be possible to programme the system.

2.6 Kärcher – RoboClean

The Kärcher RoboClean vehicle is a differential drive system for random traversal of rooms [5]. The robot has a weight of 1.4 kg. The robot has bumpers for detection of collisions but not other methods for mapping of the environment. The robot comes with a pollution sensor that allows control of suction power and speed in proportion to the amount of dirt picked up from the floor. The robot covers a particular region using a random motion pattern. The run-time between recharging is 20-30 minutes. The robot comes with a structured method for automatic docking with the recharge station (phase based sound direction estimation). The performance is $\sim 15m^2/h$.

2.7 Electrolux – Trilobite

The Electrolux vacuum cleaner is another differential drive robot system. It has a weight of about 2 kg, a diameter of ~ 40 cm, and a height of ~ 12 cm. It features a number of casters in addition to the drive wheels. The robot has a 180° sonar sensor for mapping of the environment. In addition the robot has a shock absorbing bumper for handling of small objects [5]. The robot has a run time of about an hour between recharging. The robot uses a semi-structured approach to traversal of rooms. Initially the robot will drive around the boundary of the room and upon completion of the cycle it will move at random through the rest of the room [5]. The robot comes with a recharging circuit that allows extended operation for hours at a time. It is not evident that it will be possible to programme this system. It is further not obvious if the system will have a traditional user interface.

2.8 Siemens/Hefter – ST81 VarioTech

In a collaboration between Siemens AG and Hefter Cleantech a robotics floor scrubber has been developed as a example of a new brand of floor cleaning systems. This is not really a domestic system, but more clearly aimed at the professional market. The robot is a differential drive system with 4 additional caster wheels. The robot has a weight of about 800 kg and a run time of a few hours. The robot is about 80 cm high and covers a ground area of 1.5×0.7 meters. The robot features 24 ultra-sonic sonars and a SICK laser scanner for mapping and navigation. The robot can move at a speed up to 0.5 m/s. The user interface is through a single line LCD. In addition the programming of the robot is through specification of an area, that is to be covered using a Zamboni pattern.

2.9 Analysis

A quick review of some of the most dominant/credible systems about to enter our houses reveals several things. For the purpose of a more in-depth analysis the major characteristics of the system are summarised in table 1.

The table (1) reveals a number of issues. First of all the price for a home robot is still beyond $1000 for the majority of the units, which implies that the true mass market is still beyond reach. In addition most of the systems have very limited facilities for navigation (most of them have either no facilities for absolute navigation or is based on ultra-sonic sonar systems). Finally the user interfaces are either of the entertainment variety (lot of activity/relative low information contents) or a “primitive” LCD display with minimal feedback. Further it is noticeable that the run-time for most of these systems is very limited and a most on the order of an hour. The weight/run-time ratio is still too high for many applications.

Manuf.	Name	Run-Time	Navigation	User-If	Cost (est.)
SONY	AIBO ERS	∼ 30 min-1 h	Prog. Walk	Audio, Behaviour	∼ $1500
SONY	SDR-3X	1 hour	Prog. Walk	Audio, Behaviour	∼ $5000
IRobot	IRobot	2 hours	Tele. Oper	Video/Audio	∼ $2500
NEC	M100	3-4 hours	Track/Sonar	Audio, Face Rec.	Unknown
Kärcher	RoboClean	20-30 min	Bumper	None	∼ $1000
Electrolux	Trilobite	1 hour	Sonar/Bumper	LCD	∼ $1200
DYSON	DC-06	45 min	Sonar/INS	None	∼ $4000
Siemens/Hefter	VarioTech	2 hours	Sonar/Laser	LCD	∼ $10000

Table 1. Summary of robot system characteristics

3 Analysis/Synthesis

3.1 Localisation and Mapping

To make truly useful robots it will be necessary to equip them with facilities for versatile navigation in rich environments such as a regular house, that has obstacles such as door thresholds, clothing on the floor, furniture, ... To be useful in such environments the robots must be able to perform automatic mapping and localisation in these environments, which requires methods such for “Simultaneous Localisation and mapping” [6–11]. A problems with most of these approaches is unfortunately a relatively high computational cost that is close to prohibitive for domestic systems. There is here a need for inexpensive methods that can run on a standard DSP type processor with limited need for high dimensional linear algebra or similar. Simply optimization is not considered adequate for construction of such systems. Thus, while there might exist algorithms to perform SLAM in specific setting the problem is by no measure solved.

3.2 User interfaces

It is further characteristic that systems are designed either for no interaction with the user or very limited feedback. It is not yet obvious how a user is supposed to give “unconstrained” commands to a mobile platform. There has been significant research on human-computer interaction and often speech and/or gestures are used. Unfortunately there are few if any speech systems available that can manage large vocabularies and provide enough robustness to facilitate a true dialogue with an (inexperienced) user. First of all it is essential to be able to generate feedback to the user beyond simple line style LCD displays. In addition it is essential to recognize that the user might not be standing next to or in front of the robot all the time, which implies a need for flexible user interfaces [12,13]. In addition the addition of methods for gesture recognition is complex, non-robust and expensive [14,15]. Thus there have to be strong arguments for considering how and if there is a need for direct interaction. It might here be possible to build systems with well defined vocabularies, which are used in “word spotting” mode to allow for fairly general interaction. In addition it might be useful (for some types of robots) to have pattern matching methods for face recognition for identification of different types of users, but here only if the functionality can be provided at a very limited cost.

3.3 Everyday use of robots

Almost all of the research systems that are reported in the literature worked on the course of a few hours or a few days. Most of them never ran more than a couple of hours continuously. This is in part due to battery problems. Today it is possible to provide “intelligent” recharging systems that allow one to operate a robot for days or months [16]. Once a system is to operate over extended time periods it is essential to consider automatic map adaptation, handling of memory, recovery from (minor) failures, ... These are problems that often are neglected in research systems and several commercial system can only operate for very limited periods or within narrow operational bounds. To gain widespread acceptance it will be necessary to setup and run *long*-term experiments. To this end it might be useful to have standard benchmarks for comparison of performance and evaluation of algorithms and/or integrated systems. This is a field that only is about to emerge.

3.4 Mobile Manipulation

Few if any of the systems available today or in the short term have facilities for mobile manipulation. I.e. all system have facilities for navigation. To perform mobile manipulation there are two options: i) to engineer the object so that it is easy to locate and pickup, or ii) to provide the robot with facilities for recognition of objects. The latter option is a truly hard problem in computational vision. Some progress has recently been reported for systems that utilize statistical learning theory [17], it remains however to be demonstrated that these methods will generalize to large collections of objects that are placed in general environments where there are variations in illumination, shadows, clutter, viewing angle, ... Finally there is a need for flexible grippers that will allow pick-up and manipulation of a significant number of different objects. The grippers available today are either extremely expensive or lack adequate sensor or actuation facilities for use with several domestic objects.

3.5 Mobility

Traditionally mobile robotics has been designed as wheeled systems. Yet, there are few standard wheeled platforms around as commercial products. Recently the locomotion problem has also been extended to legged systems in particular in relation to R&D in Japan. Walking is, however, much harder than wheeled locomotion and it introduces additional complexity in terms of balancing, gait selection, etc. It is, however, important to consider that small domestic robots, such as the previously mentioned vacuuming robots, will have difficulties handling many everyday objects such as staircases, clothing, and toys. Relatively to the size of the robot these are large objects that have to be attended to. In particular staircases poses an interesting challenge as it might be fatal to a robot to interact with a staircase. Thus wheeled locomotion might still be the easiest solution to implement, but there is a need for additional methods to ensure robust handling of both obstacles and lack of ground support.

3.6 Intelligent Environments

Today's robots are largely built for autonomy, i.e. under the assumption that it will use its own set of sensors, its own computational resources. A notable exception is the work by Inoue et al using the "remote brain" approach [4]. In parallel to the introduction of robots there is also a constant diffusion of other appliances and aids to the domestic market. This includes burglary alarms (ir-detectors and cameras), web servers, personal computers, PDAs, etc. With the introduction of inexpensive means of communications it is not obvious that all methods have to be integrated on the robot. It might be beneficial to exploit existing infra-structure for the operation of the robot to reduce price, optimize energy consumption, etc. Recently a number of new electronic components have appeared with ...

4 Summary

A number of service robot applications have been advertised and there are great expectations as to the use of such systems. So far few have managed to deliver systems for operation in regular houses. The only widely available systems are the SONY AIBO and the Electrolux Trilobite.

It is evident that a number of fundamental problems will have to be addressed to allow delivery of *robust* systems that can be used by regular people at a reasonable cost.

In this paper a number of the advertised systems have been analyzed and major issues to be resolved for wide spread use of robots have been identified. The UN World Robotics [1] predicts that the market for service robots will grow by an order of magnitude over the next five years, yet it is not obvious that the technology is mature enough to meet such a demand.

Acknowledgments This research has been carried out within the Centre for Autonomous Systems, that is a facility sponsored by the Swedish Foundation for Strategic Research. The support is gratefully acknowledged. A number of the issues presented in this paper has arisen out of discussions with the PhD students and post-doctoral researchers affiliated with the centre. The support and encouragement of the involved researchers is much appreciated.

References

1. J. Karlsson, *World Robotics 2001.* UNECE/IFR, Geneve, CH: United Nations Press/International Federation of Robotics, October 2001.
2. P. Wallace, *AgeQuake: Riding the Demographic Rollercoaster Shaking Business, Finance and Our World*. London, UK: Nicholas Brealey Publishing Ltd., 1999. ISBN 1–85788–192–3.
3. R. C. Arkin, *Behaviour Based Robotics.* Intelligent Robots and Autonomous Agents, Boston, MA: MIT Press, 1998. ISBN 0-262-01165-4.
4. M. Inaba, S. Kagami, F. Kanehiro, Y. Hoshino, and H. Inoue, "A platform for robotics research based on the remote-brained robot approach," *International Journal of Robotics Research*, vol. 19, pp. 933–954, October 2000.
5. E. Prassler, A. Ritter, C. Schaeffer, and P. Fiorini, "A short history of cleaning robots," *Autonomous Robots*, vol. 9, pp. 211–226, December 2000.
6. H. Feder, J. Leonard, and C. Smith, "Adaptive concurrent mapping and localization using sonar," in *ICRA-98*, vol. 2, (Leuven), pp. 892–898, 1998.
7. J. J. Leonard and H. J. S. Feder, "A computationally efficient method for large-scale concurrent mapping and localization," in *Robotics Research* (J. J. Hollerbach and D. Kodichek, eds.), Berlin: Springer Verlag, March 2000.
8. J. A. Castellanos, J. M. M. Montiel, J. Neira, and J. D. Tardos, "The spmap: A probabilistic framework for simultaneous localization and map building," *IEEE Trans on Robotics and Automation*, vol. 15, pp. 948–952, October 1999.
9. M. G. Dissanayaka, P. Newman, S. Clark, H. Durrant-Whyte, and M. Csorba, "A solution to the simultaneous localisation and map building problem," *IEEE Trans. on Robotics and Automation*, vol. 17, pp. 229–241, June 2001.
10. D. Austin and P. Jensfelt, "Using multiple gaussian hypotheses to represent probability distributions for mobile robot localization," in *Proc. of the IEEE International Conference on Robotics and Automation (ICRA'00)*, vol. 2, (San Francisco, CA, USA), pp. 1036–1041, May 2000.
11. S. Thrun, D. Fox, W. Burgard, and F. Dellaert, "Robust monte carlo localisation for mobile robots," *Artificial Intelligence*, vol. 128, pp. 99–142, May 2001.
12. H. Christensen, H. Hüttenrauch, and K. Severinsson-Eklundh, "Human-robot interaction for service robots," in *Robotik-2000*, (Berlin, Germany), pp. 315–324, VDI, June 2000. (Keynote).
13. S. Thrun, "Interaction with mobile robotics in public places," *IEEE Intelligent Systems*, 2000.
14. S. Waldherr, R. Momero, and S. Thrun, "A gesture based interface for human-robot interaction," *Autonomous Robots*, vol. 9, no. 2, pp. 151–174, 2000.
15. H. I. Christensen, D. Kragic, and F. Sandberg, "Vision for robot interaction," in *M2VIP* (S. Chen, ed.), (HongKong City University), IEEE, August 2001.

16. I. Nourbaksh, "Sage." http://www.cs.cmu.edu/ illah/SAGE, 1998.
17. D. Roobaert, *Pedagogical Support Vector Learning: A Pure Learning Approach to Object Recognition.* PhD thesis, Electrical Engineering and Computer Science, Royal Institute of Technology, NADA/CVAP, SE-100 44 Stockholm, sweden, May 2001.