Domestic Robots:- An Emerging Market

D.L.Bisset[1] *iTechnic Ltd*

Introduction

This talk will provide an overview of the emerging field of domestic robotics. It will provide an outline of the main technology issues associated with the construction of complex and successful domestic robots and it will also discuss commercial issues that impact on the potential success of the domestic robot market place.

Defining a Robot

Before proceeding it is important to define what is meant by the term "domestic robot". Using a common definition of the word "robot" such as Websters [1] gives:

> "a device that automatically performs complicated often repetitive tasks"
>
> "a mechanism guided by automatic controls"

Using these definitions a number of domestic appliances would be classed as robots. For example a washing machine that detects the level of dirt in the rinse water and decides to carry out a further rinse cycle is clearly reacting and changing its actions to adapt the particular task it is executing and can thus be said to be a "mechanism guided by automatic controls".

Because of this ambiguity between the definitions of "an appliance" and "a robot" it is important to define what is meant by the term "robot". To do this a distinction will be made between "internal" and "external" systems.

Internal systems are systems that create an internal environment over which they have complete control, they also limit user access to, and user control over, that internal environment.

In contrast "external" systems operate *in* an external environment and do not contain it. They cannot control what happens in the environment, instead they must react to any changes as best they can while achieving their task. No restrictions are placed on the user's interaction with the environment.

From these definitions it is clear that washing machines, dish washers, etc are "internal" systems where as, for example, a robot vacuum cleaner is an "external" system.

It is interesting to note that it is possible to distinguish between the two different classes of system by examining their sensors. Internal systems typically have their sensors pointing inwards, and external systems have their sensors pointing outward.

This definition of robots as "external" systems helps to identify robots as distinct form appliances in a domestic context, and may also be applicable in a more general context.

The Domestic Robot.

Domestic product technology falls into two categories, entertainment technology and functional technology. It is the goal of functional technology to assist the user in completing a task and, ideally, to remove the user from the task altogether. The ultimate goal of functional domestic technology is to completely take over the management of all aspects of the domestic environment.

[1] david@itechnic.co.uk (http://www.itechnic.co.uk)

Although the remainder of this talk will concentrate on functional domestic products many of the points made in it are also applicable to robotic entertainment technology.

What will they do?

There are four basic "work areas" for a functional domestic robot:

- Cleaning.
- Organising. (clearing tables, tidying etc.)
- Maintenance and Repair.
- Security.

Within each of these areas there are a wide range of functions that can be automated. It is possible to classify these functions according to how much cognitive ability is required to achieve them. If a robot is to autonomously carry out a particular task then it must posses the cognitive ability to do so. Alternatively the cognitive ability required for a particular task must be shared between the user and the robot. For example a tele-operated vacuum cleaner requires little or no cognitive ability because the decision making resides with the user not the robot, in contrast a robot capable of autonomously clearing a dining table requires a high level of cognitive ability.

If robots are to fully automate the domestic environment then they will require high levels of cognitive ability.

There are various different ways of assessing this cognitive ability. In a domestic context the term "cognitive ability" can be described as the ability of the robot to correctly identify objects in the environment, to identify the context of their use and to then manipulate them appropriately. A secondary constituent of this cognitive ability is the ability of the robot to interact with the user to interpret commands and to communicate problems, for example to ask for help in the identification of an ambiguous object.

In this context the definition of "object" is very broad and includes both static and dynamic physical objects, e.g. doors, floors, walls, cups, clothes etc.

This assessment of domestic tasks grades them according to the level of manipulative interaction required to complete them, and the level of cognitive complexity exhibited by the objects involved in the task. It captures the idea that objects to not exist in isolation but are characterised by their function in relation to other objects and their cognitive context, this view is closely related to Gibson's notion of "affordances" [2]. For example cleaning the floor primarily involves static objects (walls, furniture etc) and the cognitive interaction is a simple avoidance, whereas clearing the table requires recognition of the individual object on the table, recognition of its state (e.g. clean, full, broken etc), and awareness of the desired end state of each object at the completion of the task (e.g. in the bin, in the dish washer etc).

On the assumption that cognitive ability will improve progressively over time, then by categorising the work area tasks against cognitive ability, the incremental steps in the product life cycle of a particular class of domestic robot can be identified. In other words there is a one to one relationship between improvements in cognitive ability and functional improvements in domestic robot products.

From this it follows that at any particular future time there will be an upper limit on the achievable cognitive ability. This implies that work area tasks that require more cognition than this upper level are unlikely to be autonomously achieved with an acceptable level of competence for the user. This is because the robot will fail to interpret the cognitive context of an object correctly and thus will fail to manipulate it. By shifting the cognitive competence onto the user it may be possible to carry out the task however this will be at the expense of a more complex user interaction and a consequent loss of benefit to the user.

Being able to identify the progression of robotic tasks by assessing the required cognitive ability is clearly an important factor in deciding, at any point in time, which tasks are amenable to robotic implementation.

This view point has specific impacts on the domestic robot market:

- Major functional increments in domestic robots will be driven by developing higher levels of cognitive ability.
- In the early stages of the robot market there will be a limited number of exploitable applications. As the cognitive ability of robots increases additional work areas will open up allowing new market opportunities.
- Setting the balance of cognitive ability between the user and the robot will be an important design parameter.

Taking the security work area as an example the following incremental steps demonstrate how increasing cognitive ability matches to increased functional performance and thus product increment:

a) The robot can roam around a flat pre defined space (controlled by a guide wire) and monitor incidents by using an array of sensors. It can report incidents and sound an alarm.

b) The robot can roam freely over flat surfaces and can extinguish fires. It follows a path that covers the area to be patrolled. It can continue to operate in a changing environment.

c) The robot can be commanded to go to a specific location and can then autonomously patrol the area. It can challenge an intruder verbally.

d) The robot can follow an intruder and record their activity. It can challenge them and attempt to force them to leave the area. It can assess the level of damage to property and call assistance as necessary.

It is also clear that there is progressively less user interaction at each of these stages.

From the above example it is possible to see a progression that may be generally applicable to all domestic robots.

- Detect the presence of objects.
- Identify objects that have specific context to the task (possibly using dedicated sensors).
- Identify object location in a global frame.
- Identify significant object properties.
- Identify the state of specific objects.
- Identify specific objects in the environment.

In parallel to this will be a set of abilities related to the grasping and manipulation of objects, and the ability to interact with the user.

Market Development

Currently the domestic robot market is dominated by single function machines, and this is likely to continue for some time. As the level of cognitive ability improves the opportunity will arise to design robots that can carry out tasks across different work areas. So for example the security robot may double up as a house painter or garden maintenance robot during the day.

This will have cost benefits for the user, although there may be significant IP barriers to this type of cross area development. (See “Who will build domestic robots?”).

One alternative is to develop general purpose robot platforms which accept add-on modules to execute particular functions. It is possible that with sufficient standardisation these add-on modules could be provided by third party manufacturers thus avoiding the IP limitations.

Provided the problems of cross work area product development can be solved then in addition to product increments based on cognitive improvement, products will move progressively from single function robots towards multi-function robots, however the dream of a general purpose robotic “Jeeves” is many decades away.

Product Generations

It is possible to categorise this progression of domestic robot products into a series of generations.

Existing first generation products can be characterised as carrying out a single work action over a 2D surface.

Second generation machines will be capable of carrying out work actions on selected areas of a 2D surface. This is likely to result in a number of subsequent progressions from this basic definition:

- Carry out different work action on selected areas of 2D surfaces.
- Carry out work actions at different orientations or at short distances from the robot base.

Third generation machines will be able to use manipulators to grasp and manipulate objects in the environment and will be 3D machines.

The Domestic Robot Customer

The primary problem to be overcome when designing a domestic robot is how to provide a low cost solution in a robust and reliable package that the consumer can understand and use.

Not only does this present a significant engineering challenge in terms of the development of core technologies but it also presents a unique product design challenge to identify product types and the associated sets of essential features that will open up and sustain the emerging market.

The domestic robot market cannot survive on high cost minimal function robots that will sell a few thousand world wide. They do not create a sustainable market and indeed may damage the market by presenting domestic robots as high cost non-functional gimmicks.

An essential part of the product design process is therefore identifying the potential market for domestic products, and the resulting customer requirements.

Robot based products present particular problems in this respect because the average consumer has either no expectation or an over optimistic expectation of what they will be able to do. This means that product options must be researched very carefully in order to succeed.

Despite not being able to suggest in advance what might be a useful feature or a good design, when faced with a real product consumers quickly grasp the essential features. Customers will pay a premium for *significant* added function provided that the benefits justify the cost.

In general the realistic expectations of a typical customer are one or more of the following:

- That the robot will perform better than an existing appliance.
- That the robot will perform better than a human performing the same task.
- That the robot will perform the task sufficiently well to take over from the user.

Here the qualitative term "better" refers to either the time taken to achieve the task or the quality of the end result.

It is generally perceived that the main benefit of robotic appliances is time saved. The net time saved will be enhanced by

- High quality performance. Thus reducing the need to occasionally do the task manually.
- Ease of use. The robot will be used more often if it is easy to use.

Key to satisfying these customer expectations is creating appropriate technology.

Technology Challenge

In each of the work areas there will be specific technical challenges, but in addition to these there are several core technical challenges for the design of domestic mobile robots, these are

- The robot needs to intuitively interact with the user to receive instructions and to communicate problems.

- The robot must be able to precisely locate itself in a dynamic environment which can change during the task.
- The robot must fully sense a complex environment containing everyday objects as well as handle hazards such as stairs, fires, pets and babies each of which must be reacted to safely.
- The robot must be able to identify and manipulate objects in the domestic environment.

These challenges translate into technical challenges for user interface design, localisation, object sensing and manipulation respectively.

User Interface

In order for the robot market place to become self sustaining robots must become an integrated part of domestic life, and not just a short term gimmick.

Ultimately they will blend into the fabric of our living spaces and tasks that once were everyday chores will be done quietly and efficiently without us noticing.

Before domestic robots reach that level of ability we will need to interact with them to specify tasks and resolve problems. Above all we will need to build confidence in their ability to carry out the tasks we have assigned.

The user interface is the key component in building the confidence required to become easy and familiar with interacting and commanding the robot. It is also the key component in maximising the benefit gained from the robot. For example a poor user interface will reduce the likelihood of the user employing a particular feature that could have provided a useful benefit.

High technology products do not have a good track record in providing comfortable user interfaces. Domestic robots with low cognitive ability do not need much user interaction but as the cognitive ability of robots increases the user will require a similar increase in its ability to communicate in order to be able to precisely command the robot and thus maximise its benefit. Improved communication between the robot and the user will be an important factor in convincing the user that the robot is a trustworthy and capable machine.

In particular the user interface must be intuitive to use for *all* consumers. The market for domestic robots will be significantly narrowed if only the technically competent can operate them.

One solution is to design the robot such that few choices are left to the user about how to operate the device. Instead the machine is designed to be able to make those choices on behalf of the user by picking between different operational strategies depending on the conditions it encounters. This is likely to require enhanced sensing and will therefore result in a higher end cost. This solution is equivalent to shifting cognitive ability from the user into the robot.

Choosing the interaction technology for the robot will be a key design parameter. Fundamentally there are three choices a voice based interface a graphical interface, and a physical interface (e.g. buttons and lights).

With current levels of voice recognition technology a voice based interface is likely to be too complex to set up. Assuming that we will feel comfortable talking to the vacuum cleaner and provided improvements in voice recognition technology and natural language understanding are sufficient to parse commands such as "Go to the cupboard by my desk and clean the coffee spill" then this may become the easiest way of commanding a robot.

As the cognitive ability of robots increases and the level of interaction increases as a consequence of this, the use of a physical interface will become too limiting to be useful. This leaves graphical interaction as the only viable alternative to voice.

With both voice interaction and graphical interaction there is a particular challenge in matching the users naming of physical spaces and objects to the robot's internal representation of spaces and objects in any environment.

It will be argued in the next section that global maps cannot easily be given in a pre-defined form to a domestic robot. This means that part of the interaction with the robot will involve labelling its internal object store so that specific locations can be identified by either graphical or vocal tags. This allows those locations to be subsequently recalled during an interaction.

The design of user interfaces for robots raises many questions that will need further research before workable solutions emerge.

Localisation

Many domestic tasks require precise localisation in space not only of the robot but also of manipulators and end effectors.

All but the simplest tasks will require the robot to remember the location of objects. Object memory can be based on different frames of reference and operate over different time scales. Typically object memories are referred to as "maps" however this should not be taken to necessarily imply a Cartesian representation.

Robots often have two different types of map, global maps and local maps. Global maps are defined as having a long life and being represented on a world centric reference frame, and local maps are defined as having a short life and being represented in a robot centric frame of reference. Local maps are typically formed directly from sensor readings whereas global maps are accumulated over a longer time scale and may use external data sources as well as sensor readings. In some applications global maps may be preserved over many operating cycles. Not all robots will necessarily have both types of map.

Local maps are typically used for fusing information from the robot's array of sensors into a single data structure from which the robot's control systems can extract information to decide on courses of action.

Global maps are typically used for planning task execution and for monitoring the overall progress of the task. The global map may well contain information about the location of a base station or the location of significant objects such as doors etc or a record of space visited or acted upon.

The domestic environment places a number of constraints on the global map generation process.

Firstly it is undesirable to make the user enter parametric information about the working environment into the robot, for example by entering architectural plans of the room layout. There are two reasons for this:

- Firstly providing a user interface through which this information can be provided and maintained by the average consumer presents a significant challenge in its own right.
- Secondly it significantly increases the difficulty of moving the robot between homes, and of hiring out robots because of the extended setup time.

These constraints mean that the robot must be able to construct its own global maps and to make use of them when planning a task, but that the absence of a map should do no worse than reduce efficiency.

To achieve expected performance levels at higher levels of cognitive ability most domestic tasks will require at least centimetre positioning accuracy and repeatability. For example a vacuum cleaner must be able to position itself against a previously cleaned area with enough accuracy not to leave an uncleaned strip. Similarly manipulators will need to position themselves accurately enough that compliance in the actuators can absorb any inaccuracy.

This level of positional accuracy cannot be obtained from external global positioning systems such as GPS even if they worked reliably inside buildings. The robot must therefore fall back on self-localisation schemes of which there are three distinct categories:

- Dead reckoning systems.
- Sensor based systems
- Beacon based systems.

Each of these schemes has particular problems and it is likely that any successful domestic robot capable of centimetre position accuracy will employ a combination of these different sources of position information.

Dead Reckoning systems

Dead reckoning systems are based on the direct sensing of motion by different sensors. [3]

- Odometers for linear motion on a surface.
- Gyroscopes for rotational motion.
- Accelerometers for planar motion.

They all suffer from long term drift as the robot moves through space resulting in significant errors after only a few meters of motion. Each type of sensor suffers from different sources of error:

- Odometers suffer different levels of drift on different floor surfaces and impulse errors when transitioning over edges. These transitions show up as rotations and discontinuities in the direction of motion.
- Gyros suffer long term drift, as well as thermal drift and can also be difficult to calibrate. Software may also need to take into account the earth's rotation if the robot is to be used over a long period.
- Accelerometers only provide linear outputs over small ranges of acceleration.

Some of these problems can be alleviated by combining different sources of motion detection. In particular combining odometers with a gyroscope has proved particularly effective [4].

Typically these sensors are only useful in defining short term motion. However they do provide detailed instantaneous information about the local motion of the robot which is difficult to obtain by other means, for example the inclination of the robot. Useful state information can also be extracted from these direct motion sensors for example detecting that the robot has become wedged under a table and is not actually moving or is being pushed or picked up. Detecting these states has a significant impact on the robot's ability to failsafe.

Coupled with object sensing dead reckoning sensors make it is possible to construct good short term local maps but they are not sufficient for the construction of world centric large scale maps without additional localisation information to calibrate the placement of the short term motions.

Sensor based localisation

Sensor based localisation is a much discussed area of robotics and there is little point in reviewing all of the material in this area. Key to the design of successful domestic mobile robots will be the design of cost effective sensing and localisation strategies.

Vision based localisation [5] provides a powerful tool in that our domestic environments are already designed to be visually distinctive. Panoramic cameras may well prove to be a very cost effective tool for visual based localisation [6].

Beacon Based Localisation

With one particular exception the use of beacons in the domestic environment is typically unacceptable. There are a number of reasons for this:

- Visual intrusion, this is comparable to the annoyance of having several burglar alarm sensors in every room.
- Supplying power. Combining the beacon with mains outlets seems at first glance to be a good idea but how often will they be unplugged or turned off when needed?
- Being able to find suitable locations.
- Cost and long term maintenance issues. If beacons have to be fitted into each room then this will be both expensive and disruptive. The ability to trace failures in the robot to a poorly placed beacon or a failed beacon will result in high field service costs.

The only exception to these objections is the use of a base station to provide a fixed reference for the robot. A base station, such as that used on the Karcher vacuum cleaning robot, may serve multiple functions including providing recharging for batteries, a depository for resources or waste as well as a reference point for localisation.

There is also a major commercial disadvantage to using beacons in that it ties the robot to a particular house this precludes sharing your robot with your friends or even moving it between houses. It also precludes robot hire schemes.

Sensing

The domestic environment is full of unexpected objects. They are of various shapes and sizes and many are delicate. Robot owners will expect the robot to recognize valuable or significant objects and react to them as they would do, for example to recognise a Lego brick or item of jewellery on the floor and not vacuum it up.

Part of the trust that will be built up between the robot and the user is about how the robot reacts to the objects in the users environment. The user will expect:

- That the robot will avoid all obstacles in the room.
- That the robot will not mark any of the things it encounters.
- The robot will not get stuck.

If the robot uses a manipulator then the user will expect:

- That the robot will not damage any item as a result of reaching for an object.
- That the robot will not damage the object by grasping it.
- That the robot will not cause any indirect damage by grasping and moving the object. E.g. it will not topple other objects on a table while reaching.

These six expectations may turn into fundamental prerequisites of domestic robots rather like Azimov's more general laws of robotics. [7]

The ability of a robot to achieve these expectations will depend exclusively on the quality of its object sensing and recognition.

Sensing Technologies

For tasks that require a low level of cognitive ability, for example those that only require the detection of the presence of an object, simple point based ultrasonic or infrared based sensors will be sufficient. If the shape of the robot is complex or large even these sensors may not be able to provide a cost effective solution because of the large quantity required to cover the space into which the robot needs to move and the relatively high cost of each sensor.

As the required cognitive ability rises, for example when object recognition or orientation is required, then vision based sensing will become the only sensing technology able to provide the richness of data capable of supporting high levels of cognitive ability. Providing vision based object sensing represents a significant design challenge and until this is achieved in a cost effective way successful domestic robots will have to find novel and ingenious ways of using more limited sensing technologies to achieve higher levels of cognitive ability.

One alternative is to use scanning laser range finders (LADAR) however these are not yet cost effective in the domestic environment.

The lack of good object sensing has a particular impact on the "organising" work area since this area largely depends on being able to identify and manipulate objects appropriately.

Combining Object Sensing and Localisation

It is possible that vision or scanning laser systems will be the sensors of choice on domestic mobile robots simply because they are able to provide information for localization and about surrounding objects.

Combining object detection and localization will make for smaller and cheaper domestic robots because one set of sensors will fulfil both functions.

Object Manipulation

Almost all domestic tasks beyond a certain level of function require the ability to grasp and manipulate objects in the environment. Designing cost and energy efficient manipulation methods represents another significant design challenge to the developers of domestic robots.

Safe and compliant manipulation of objects without damage to either the surrounding environment or the object being manipulated is an important development. It is highly likely that the technology to achieve these functions will be developed by specialized third party suppliers able to integrate object sensing and manipulation into a usable package that can be adapted to different work area tasks.

Why is the domestic robot late?

Why has it taken so long for robot vacuum cleaners to appear?

Taking as an example the most successful domestic robot to date, the product complexity of the iRobot Corp. Roomba vacuum cleaner is less than that of a car engine management system, and roughly equivalent to that of a washing machine. Why then has it taken so long for the robot vacuum cleaner to come to market?

It has not been delayed as a result of unresolved research issues, it would have been possible to design and put into mass production a robot like Roomba at any time in the last 5 years.

The question can only be answered by examining the nature of the domestic appliance market and its relationship to technological innovation.

Who will build domestic robots?

One of the most interesting questions in domestic robotics is: Who will build and design domestic robots? There are three potential candidates for this role:

- New companies with innovative ideas and/or existing robot technology.
- Domestic appliance manufacturers.
- Existing global technology suppliers.

Interestingly to date only the first two have been players in the market.

On the surface it seems that the most likely organisations to develop domestic robotics are the domestic appliance manufactures.

The large domestic appliance manufactures have had very mixed responses to the exploitation of new technology in their products. This has created niches such as that exploited by Dyson's dual cyclone technology .

Secondly they do not have the high technology research and development infrastructure into which they can easily transplant existing robotics research and bring it to product.

As a result the large domestic appliance manufactures have followed the lead set by Electrolux and concentrated almost exclusively on robot vacuum cleaners ignoring other areas of the market and have largely failed to produce cost effective products.

For example Electrolux launched their Trilobite robot in every major country starting in the UK in December 1997 before finally putting it on sale in Scandinavia in 2001 and the UK in 2003.

In the process Electrolux accumulated significant publicity and initially seemed to have little motivation for bringing the product to market. Although Electrolux started this pattern most other major appliance manufacturers worldwide have now followed with various levels of publicity about research projects or collaborations but with no actual products appearing.

Of the main appliance manufactures to date only Electrolux, (including Husqvana which is owned by Electrolux) and Karcher (in Australia) have made domestic robot products available for sale.

All the other robot products to reach the market have come from new robot companies (iRobot, Friendly Machines, Probotics (Cye)).

In the longer term these new companies may find themselves in a difficult position once the large domestic manufacturers start to create products. In particular IP ownership will become a significant issue.

IP ownership

Creating optimally efficient domestic robots will require two different types of technology, robot technology and appliance technology. This means that two different sources of IP must be joined in order to make a product. The IP required to make robots and the IP required to make domestic appliances.

Any new company trying to create a domestic robot, that has common functions with an existing appliance, will run into difficulty with respect to the IP held by the existing domestic manufacturers.

So for example a new company trying to build a robot lawn mower may be forced to use an inefficient cutting blade because an appliance manufacturer owns a patent that covers the most efficient design.

In order to avoid this conflict new companies will be faced with a set of choices:

- Find niche application areas where no prior IP exists.
- License their technology to the appliance manufacturers.
- License the appliance technology from the appliance manufacturers.
- Rely on technical superiority to produce desirable products.
- Sell out to the highest bidder.

In order to secure their position in the market new companies will need to create significant IP.

In the same way that the mobile phone manufacturers have had to turn to third party software suppliers to take advantage of operating systems and user interfaces. So it is likely that domestic appliance manufactures will have to turn to independent third party suppliers for the technology to exploit the domestic robotics market.

The final unknown is whether or not the high technology companies (Microsoft, HP, Intel etc) will see the domestic robot market place as being an appropriate new market, either for the development of component technologies or as a direct revenue stream. They may uniquely have the financial weight to negotiate licensing and collaboration deals with existing domestic appliance manufacturers as well as the research and development capability that the domestic appliance manufacturers lack.

Ultimately it is likely that all three players with an interest in the domestic robot market place will end up being involved. Given the technical complexity of a robot at both a hardware and software level it is likely that the existing domestic appliance suppliers will continue to be reluctant to invest in technology development outside of their main stream. Instead they will either collaborate with or buy in the necessary technology, integrating sub systems into domestic robotic products. They will do this simply in order to retain market share. The “robot companies” will gain through licensing IP and through providing the domain expertise to develop new products in collaboration with the domestic suppliers. (Much as Psion has moved from a niche PDA supplier to a major third party software supplier in the handheld and phone market).

As in all areas of technology these collaborations and third party alliances will require a level of standardisation in order to reduce costs.

Standardisation

Product standardisation will be far less of an issue in domestic robotics than in many other areas of domestic technology. This is because most customers will not expect to be able to move parts of a robot between robots manufactured by different organisations. Some consumer level standardisation will be needed in the communications and user interfaces to allow remote access to domestic robots and to allow third party tools to trigger actions say via phone or internet access.

The majority of standardisation will be internal and will relate to the ability of third party suppliers to design sensors, manipulators and other sub-systems in the knowledge that they can be integrated together to create robots. These standards will not necessarily be confined to the domestic robotics market but are more likely to emerge as standards for the whole robotics industry.

One area of essential standardisation for the consumer will be product performance testing. Standard tests will allow a consumer to directly compare products from different manufacturers and will limit customer confusion about rival performance claims.

Summary

In many senses the age of the robot is late. The technology required to produce simple but effective single function robots has been available for a number of years but has largely remained unexploited.

The main reason for this is the inertia of the domestic appliance manufactures and their lack of technology expertise.

In terms of sales volume new companies have dominated the market to date although there are still only a very small number of products in the market.

To produce the second and third generations of domestic products, that are more able to interact, will require further research and development. In particular the market will depend both on the development of higher levels of cognitive ability and on the cost effective implementation of sensing and localisation mechanisms. In particular third generation products will require a significant step up in cognitive ability to become viable.

Domestic robotics is in its infancy. The potential size of the market means that it will become a global business attracting global players.

The issue of IP ownership is likely to become a driving force in the market place and may ultimately determine the shape of the industry.

From the consumers point of view robots will have an increasing impact on our domestic lives as their cognitive ability improves. The main result of this will be more spare time and a reshaping of how we interact with our domestic environment. Robots will become an essential part of our daily lives.

References

[1] Websters online dictionary. http://www.m-w.com/home.htm

[2] "The Ecological Approach to Visual Perception" J.J.Gibson 1986 Lawrence Erlbaum Associates ISBN 0-89859-959-8.

[3] "Navigating Mobile Robots: Sensors and Techniques" J.Borenstein, H.R.Everett, L.Feng 1996 A.K.Peters Ltd.

[4] "Gyrodometry: A new method for combining data from gyros and odometry in mobile robots" J. Borenstein, L.Feng Proc IEEE Int. Conf. Robotics and Automation 1996 pp 423-428.

[5] "Real-Time Simultaneous Localisation and Mapping with a Single Camera", A.J.Davison ICCV 2003

[6] Links to various omni-directional vision projects http://www.cis.upenn.edu/~kostas/omni.html

[7] "I, Robot", I.Asimov 1950 Gnome Press.

[8] "Against the Odds" J.Dyson ISBN-0-75280-981-4