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Smart Equipment

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Abstract

Recently, interest in products with embedded intelligence has increased. This thesis presents a survey of objects enhanced with some sort of intelligent behaviour, *Smart Equipment*. I have tried to determine if there are any of these available today, if there will be tomorrow, and what techniques that are used when making the smart equipment smart. I also discuss the importance of a distinction between the terms *intelligent* and *smart*, and give a definition of Smart Equipment.

This thesis corresponds to the effort of 20 full-time working weeks.

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The best way to predict the future is to invent it
— Alan Kay —

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Chapter 1

Introduction

We are at the turn of the millennium and the Internet, the hype of the recent years, is becoming commonplace. It is time to look ahead, time to find out what impact this interconnected way of computing will have on the everyday life. Mark Weiser [1991] has envisioned that the next era of computing is that of *ubiquitous computing*, an era where computers invisibly enhance the world as we know it today.

During my Master of Science education I have been exposed to the 1987 version of Apple's vision of the future [Apple, 1987] in almost every course with the slightest connection to Human–Computer Interaction or Intelligent User Interfaces. Taking into account that the video was produced over ten years ago, one might think that many of the "features of the future" presented therein have been realised today; That is, however, not the case.

As the, quite appealing, vision is not the reality of today, what then is? How far have we come in the quest of the perfect world for so long depicted in Sci-Fi movies and the like?

Thus, I began this Master's project in quest of the holy grail of intelligent environments. Wanting to find out what has been done, what is happening right now, and what we are to expect of the future.

I take a look at not just intelligent houses, but virtually everything and anything claimed to be intelligent. This, maybe foolishly broad view, was, to use the words of Barry Brumitt [1999] (in his reply to my "Call for co-operation", see Appendix B), "a pretty challenging piece of work". However, as I wanted a survey of the field as a whole, the only way to get one was by not restricting myself to look in depth at one particular area.

In my thesis I examine objects enhanced with some sort of intelligent behaviour, *Smart Equipment*. I have tried to determine if there are any of these available today, if there will be tomorrow, and what techniques that are used when making the smart equipment smart.

1.1 Background

1.1.1 Homo Desidiosus—The Lazy Man

What are the key factors of the making of new inventions? The joy of discovery? The curiousness founded deeply in the human nature? Yes, probably. But why are some inventions successful whereas other are merely of interest to the inventor himself?

I believe that a common property of successful inventions is their ability to make life easier. It is the laziness of man that serves as motor of development. A good example of an invention that made life easier and is very successful is the *washing machine*; transforming washing from being one of the hardest domestic duties to now being one of the least burdensome.

Thus, we strive to get away with things as easy as possible. This is why smart things seem so appealing.

1.1.2 Smart Equipment

Recently, there has been an increasing interest in products with embedded intelligence, an interest displayed in a large number of articles in news and media, e.g., [Ruin, 1999], [Odebrant, 1999], [Susac, 1999], [Rohde, 1999], [Talley, 1998], and [Thunqvist, 1999a].

Several companies have embarked upon new business ventures in this area, among them the Swedish companies Ericsson and Electrolux, who have launched a new company (presently unnamed) as a joint venture, combining knowledge from the telecom and domestic appliance businesses.[1]

The Italian company Merloni have shown a similar effort when launching the information appliance Leonardo as part of their Ariston brand. Alongside of Leonardo they have launched a web portal, Ariston Digital, to offer online services. Their vision is an interconnected home with a distributed architecture, and plug and play devices. Their main scenario is influenced by the need for electricity load balancing in the Italian homes, due to low-limit fuses, and depicts how the different appliances negotiate over which one of them should run.[2]

But what is to be considered intelligent or smart? Which are the properties characterising the products that we recognise as smart?

Junestrand [1998] recognises that smart environments or equipment often have the following properties:

- They are interactive, i.e., the user can affect their behaviour.
- One is able to communicate with them.
- They have information technology embedded, often invisible (ubiquitous computing).

[1] See <http://www.e2-home.com/>.
[2] See <http://www.merloni.it/>.

- They have interfaces that differ from the traditional ones (screen, keyboard and mouse).
- They are adaptive, i.e., they adjust to the user.
- They are able to learn, i.e., learn the habits of the user.

Are these the properties to look for when assessing the products? At first they might seem overlapping. How can one interact with an object without communicating with it? Is communication to be regarded as a higher form of interactivity, separated from the mere pushing of buttons? And as for learning, can it not be considered as persistent adaptation? For sure, it is possible to acquire knowledge without adapting to it, but is something learned if not used?

In Chapter 2, I discuss the terms *smart* and *intelligent* and propose a set of attributes to look at when assessing Smart Equipment.

1.1.3 Why is Smart Equipment Interesting?

Smart Equipment will perhaps not by itself change our way of living in a profound way, but it will nevertheless have an impact on daily life. There are several trends in modern society bound to adapt to the new technologies of Smart Equipment at an early stage, simply because it will gain their development and/or success. Among them are:

Medical and Elderly Homecare The problem with an increasing population of elderly is a reality in developed countries all over the world. As people get older they will need more care and medical treatment, a problem in view of the limited resources of health care.

Studies in Japan have examined the use of Smart Equipment in order to reduce the need for actual visits to health care centres. Patients are monitored and examined at a distance, and sometimes an initial diagnosis is made by the equipment in the patient's home [Thunqvist, 1999b].

Mori and Sato [1999] introduce Smart Equipment into the hospital, in the form of their Robotic Room. The concept is that the room itself is proactive and monitors and supports the patient with minor tasks, such as handing objects to the patient.

The possibilities of using Smart Equipment in the context of home care for elderly and people with disabilities were studied as part of an EU research initiative [Horelli, 1994] [Hjælpemiddelinstituttet, 1995].

In their Bachelor's thesis, Fritzsche and Jakobsson [1999] take a look at how intelligent agents can be used in the context of public home care service and show that the personnel would gain from using Smart Equipment.

Stagnated Markets Smart Equipment can be used to vitalise old markets and create new business opportunities. Per Ljunggren [1999], head of R&D of appliance manufacturer Electrolux, sees the development of Smart Equipment as an opportunity to reform the quite rigid appliance market. He foresees a transition from traditional products towards services, made possible by making the appliances smart.

This view is shared by others, e.g., Gustavsson [1999] sees the same trend for utility providers, Negroponte[3] recognises new possibilities for transportation companies, just as Saba [1999] sees opportunities for the packaging industry.

Information Appliances Smart Equipment could provide a foundation for easy access to information. Information appliances, a term coined by Jef Raskin in 1978 [Norman, 1999], should provide access to information *anywhere*, *anytime*, and, as Larry Scadden [1999] pointed out at his seminar in Uppsala, to *anyone*. The latter meaning that the appliance itself should be able to adapt to the channel of communication preferred by the user, e.g., speech recognition or speech synthesis for a blind person.

Automation of Daily Tasks So far, the home automation industry has come up with systems to control and integrate existing devices, such as lighting, ventilation, etc. These systems are becoming more and more sophisticated, but rely on an extensive installation and programming effort in order to get them running. Using Smart Equipment the components of the system will be able to communicate with each other, providing automatic configuration; plug-and-use.

Systems for automated HVAC[4] utilising agent technology have been suggested by, e.g., Ygge et al. [1999] and Lesser et al. [1999a].

Michael Mozer [1999] is taking it all one step further. He and his colleagues recognise that a successful system must be truly unobtrusive. They suggest a system learning from the user's actions—the Adaptive House.

Other areas suited for automation are tedious tasks as vacuum cleaning and lawn mowing, of which, e.g., Electrolux provides a solution for the latter (see Section 3.1.9).

1.1.4 Why Should One Convey a Survey?

A survey part of a Master's thesis, or any research project, is as a way of establishing a ground for the work, and avoiding to do work previously done by others. In my case the major part of my thesis work comprises a survey, followed by further analysis.

[3] Cited in [Törnwall, 1999].

[4] Heating, Ventilation, and Air-Conditioning.

But why did I choose to do a survey as a Master's thesis? The most common thesis project is, among my computer science student colleagues, to implement a part of a program on commission by a company in the field of computer technology. Not only did I choose the somewhat unorthodox task of a survey, but also to conduct it at one of the departments of the Royal Institute of Technology.

I found three main reasons for doing this:

- Making a survey gave me an opportunity to get a good overview of an interesting and evolving field, where things are just about to take off within the next few years.

- Being unattached to any commercial company, I thought that it would be easier to "lure the secrets" from commercial companies. Or rather, they might be less reluctant to co-operate, and give me valuable insights into their work.

- The work was highly needed within the DECIDE research group at the Department of Computer and Systems Sciences (DSV), since new initiatives within the field of Smart Equipment are going to take place. Thus, getting a clear picture of the field was a wish shared between me and my principal. Moreover, an interest has been expressed to use a CD-ROM with material compiled from the survey, see Section 1.3—CD-ROM, in a course in Agent Programming, given at DSV.

1.2 Objectives

The objectives of the thesis were [Eneroth, 1999]:

1. Get an overview of the current market.

2. Describe trends and findings in current research initiatives.

3. Give a definition of the term *Smart Equipment*.

4. Make an assessment of "intelligence" in selected products.

5. Identify possible opportunities for agent technologies in Smart Equipment.

The first two objectives correspond to the goal of getting a survey of Smart Equipment, the main goal of the thesis. The third objective is to make a definition of Smart Equipment, in order to be able to discuss the concept and analyse the products; the fourth objective. Finally, the last objective aims at investigate if, and how, techniques from agent programming and multi-agent systems can be applied in this domain.

1.3 Methodology

Below I describe the main parts of the work involved in the thesis.

Literature Survey An examination of published papers and articles.[5] Information about relevant companies, products, and projects, as well as articles and papers published on the World Wide Web, and other resources available online were searched for using various search engines, e.g., MetaCrawler[6] and AltaVista[7], and databases, e.g., the ACM Digital Library[8] and Cordis database[9].

Call for Co-operation A request in form of an e-mail sent to people and companies selected based on the results of the initial survey, see Appendix B. Out of some 30 e-mails sent, I received about 20 replies, of which 15 led to valuable contacts.

Interviews In five cases the contacts made as a result of the call for co-operation led to personal interviews. These interviews were conducted face-to-face and were quite informal. The concept of Smart Equipment was discussed, as well as views on smartness, design choices made, current products and projects, and future plans.

Analysis When the initial study showed the diversity of the field it became clear to me that I would have to restrict my work; to examine all findings in detail would not be feasible within the limited time of the thesis work. Thus, in my analysis I chose to focus on products available today. However, as the off-the-shelf products are very different in nature it is not easy to make a comparison between them. It would have been more interesting to make an in-depth analysis of similar products, or products within one domain.

In order to have a first look at what people can interpret from and assign to the behaviour of a supposed smart system, I intended to perform a series of user studies on a newly acquired robot—a Cye from Probotics. Unfortunately due to time limitations and problems regarding the facts that the robot relied on soft carpets to work properly—a feature not available on the DSV premises—this study never took place.

CD-ROM To be able to report my results to my advisor, in a way as convenient as possible for both parties, I compiled the material found on a CD-ROM. As I collected more and more information I realised the need to summarise the

[5] This is a quite new area of research and development, with little published academic material. There are also difficulties regarding the possibilities of gaining access to results from commercial companies.

[6] See <http://www.metacrawler.com/>.

[7] See <http://www.altavista.com/>.

[8] See <http://www.acm.org/dl/>.

[9] See <http://www.cordis.lu/en/home.html>.

findings. Hence, I made a set of mindmaps (see Appendix C for an example of such a mindmap) which I later found could serve as points of entry to the material on the CD-ROM, by making hyperlinks between the items on the mindmaps and the information on the CD-ROM.

1.4 Structure of the Thesis

Chapter 2 discusses the concept of things being *smart* or *intelligent* and I define the term *Smart Equipment* by proposing a set of properties. Chapter 3 contains a survey of existing, commercially available, Smart Equipment, announced products, and research initiatives. In Chapter 4, I analyse the commercially available products from the survey and discuss some matters of Smart Equipment. Finally, Chapter 5 summarises the thesis and hints on possible research topics.

Chapter 2

Smart, but not Intelligent

This chapter begins with a discussion of why Smart Equipment is in fact a new kind of systems, not just control systems with a brand new look. Then I elaborate on the distinction between the terms *smart* and *intelligent*, and advocate the use of the former. Finally, I define Smart Equipment by proposing a set of essential properties.

2.1 Why it is not a Control System

We have had different kinds of control systems for a long time now—from James Watt's mechanical centrifugal governor to computerised systems with hundreds of sensors and actuators. Systems that have been ingeniously engineered, but without the ability to be smart.

What is it that differentiates an ordinary control system from a "smart" one? Both accomplish tasks for the owner, e.g., regulates the temperature in a room. An ordinary thermostat controlling the temperature in a room does not perform an act of reasoning. A *smart* thermostat might adjust the heating, not only to the temperature in the room, but also to the work performed by other thermostats in other rooms, negotiating a most cost effective way to achieve the temperature goal for the apartment as a whole. Thus, the smart one takes the task one step further, appreciating the working context.

Since we can separate a smart system from a non-smart one, there must be some characteristics to look for. I will get back to this in the following sections.

2.2 Why it is not Intelligence

Apart from the pure semantic difference between the words *intelligent* and *smart*, see Figure 2.1, I think that the use of the latter in the context of things augmented with some kind of, well, intelligent behaviour is just. In this section I will try to argue for this point of view.

The question of what intelligence means has been the cause for a fierce philosophical debate for centuries. Nevertheless, there are systems accepted as intelligent by a vast majority of humans—*humans*. Thus, we always have ourselves as humans, perhaps rightfully, as a measure, although we mean artificial intelligence, i.e., non-human intelligence, when talking about intelligence in the context of computer science.[1]

People who argue against the lure of AI often have the opinion that intelligence is closely connected to the human body, being biological rather than logical [Angell, 1993]. Brooks [1997] sketches a rough outline of the evolution of intelligence where he wants the reader to appreciate the short time in the history of evolution when human "expert" knowledge have been developed; a few hundred years is just a small fraction of the 150,000 years humans, as we know us today, have existed (which in turn is a ridiculously small part of the 4.6 billion years of earth's existence). Brooks' point is that when developing intelligent systems one should work from the bottom up, giving the proper attention to the "primitive" abilities such as vision, motion, and survival related tasks, e.g., avoidance. Once a foundation is made, more and more intelligent behaviour can be added on top of the primitive behaviours. Brooks' subsumption architecture [1989] was formulated around these thoughts.

In Norman's point of view, human intelligence has co-evolved with social interaction, co-operation, rivalry, and communication. He recognises the art of deception as a hallmark of intelligence, and writes "One could argue that computers won't be truly intelligent or social until they, too, are able to deceive" [Norman, 1999 p.141]. Brooks et al. [1998] agree with Norman, but also appreciate the importance of embodiment and physical coupling, and multimodal integration.

Turing suggested that intelligence is a matter of behaviour or behavioural capacity, e.g., whether a system is intelligent or not is determined by what it can and cannot do. He designed his famous test according to this thought. For a system to pass the test, and thereby be deemed intelligent, it is sufficient if an interviewer, in dialogue with the system, cannot separate it from a human [Haugeland, 1997]. So far no system has passed the test.[2]

Rationality (acting so as to optimise your overall goals, given what you know about your current situation) and intentionality (displaying a consistent pattern of rational behaviour) are often mentioned when talking about properties of intelligence. To be intelligent would then be to act "consistently reasonable and sensible, given the situation" as Haugeland [1997 p.18] puts it.

[1] Of course, this view, influenced by work of cognitive scientists, is not shared by everyone in the AI community. Rosenschein and Zlotkin [1994], taking a game theoretic stance, is but one example of an alternative opinion.

[2] Since 1990 an annual contest is held, implementing a modified version of the Turing test. The winner, the computer deemed the most human, is awarded a $2,000 prize. The winner of the 1999 competition received an average human rating of 6.5 (on a scale of 1 (most human) to 10 (least human)). A $100,000 prize awaits the first entry to pass the test, i.e., the first to be rated 1 [Meeden, 1999].

Intelligence Capacity to learn or to understand. In psychology, intelligence is somewhat more narrowly defined as the capacity to acquire knowledge or understanding and to use it in novel situations [Encarta, 2000].

Smart Clever; skilful; having a good quick brain; showing ingenuity [Hornby, 1974].

Figure 2.1: Definitions of *intelligence* and *smart* as found in an encyclopaedia and a dictionary.

Note that although an object is able to display an intelligent behaviour, that is not the same as the object being intelligent. A reactive agent, e.g., can achieve its goal to satisfy its owner by applying responses to perceived stimuli. Is not that agent intelligent in its behaviour? Personally, I would not go so far as to call it intelligent.

An intelligent system is for sure smart, but being smart is *not* a prerequisite for intelligence. I believe that *intelligent* is too strong a characteristic to use when describing the new bread of products. It is not intelligence we experience in these products, although they might display an intelligent behaviour.

2.3 The *Smartness* of Smart Equipment

Is there a set of properties that distinguish smart things from normal, dumb, things?

I believe that people in general have pretty much the same idea of what is to be called smart. When asked, people seem to have a clear opinion if an object presented to them is smart or not. There are for sure individual differences, but I think that a majority share the similar opinions. If this is true, there might exist such a set of properties, properties that would define Smart Equipment in a way acceptable to every one. I do not claim the properties I introduce below to be the "right" ones, but they are essential in my opinion.

However, one should not forget that people tend to grant physical objects more intelligence than intangible ones, e.g., computer programs [Janson, 1999]. Thus, products described as smart stand a good chance of being experienced as more intelligent than they actually are.

When we look at things around us and assess their intelligence, or the intelligence of their behaviour, many of us take ourselves as humans as a measure. Hence, it is natural that a definition of Smart Equipment should be grounded on human traits of intelligence.[3] Brooks et al. [1998] list the following as essences of human intelligence: development, social interaction, multi-modal integration, and

[3] Again, this view is not shared by everyone (Cf. Footnote 1).

If you are a Smart Equipment, then	
Adaptive	Adapt to your users' needs.
Autonomous	Do not depend on your user.
Functional	Act in order to fulfil the goals of your owner.
Learning	Learn from your actions and their consequences over time.
Pro-active	Take initiatives to reach your goals.
Rational	Act in an intelligent, rational way.
Responsive	Interact with the environment.
Social	Interact and collaborate with others.

Figure 2.2: Manifesto of Smart Equipment.

embodiment. Of these I personally believe that the first three are applicable also when talking about Smart Equipment. Embodiment, on the other hand, is not an important attribute. It is simply not of any importance *where* the "intelligence" is located. It could be embodied within the object or acting from the outside via, e.g., a speech and vision system like MIT AI lab's Intelligent Room [Coen, 1998]. It is the performance of the system as a whole that matters.

When I wrote my thesis proposal I suggested that a definition of Smart Equipment should, at least, include three attributes; *Interactive*, *Adaptive*, and *Learning* [Eneroth, 1999]. During the thesis work I have come to the conclusion that five more attributes are needed to capture the essence of Smart Equipment(see Figure 2.2). Below I describe the revised attributes, and motivate why they were chosen.

Adapt to the Users' Needs People talking about the benefits of Smart Equipment in general, and more specifically, information appliances, often point out qualities as *anywhere* and *anytime*. In the case of information appliances, they refer to access to information made available anywhere and at anytime; providing an ever-present resource of knowledge and computing power.

This sounds all good and desirable, one would think. However, one issue is sadly often overlooked, an issue which Smart Equipment is well suited to address—Smart Equipment should not only be accessible all the time and everywhere, but also by *anyone*. They should be smart in a user centric perspective and adapt to the channel of communication preferred by the user, e.g., speech recognition or speech synthesis for a blind person.

Attribute: *Adaptive*

Act Indepently Smart Equipment should not have to rely on human supervision, rather it should be autonomous. Autonomy has the same meaning in this context as described by Jennings et al. [1998 p.8] when talking about agents:

> "[...] the system should be able to act without the direct intervention of humans"

The reason for this is clear—Smart Equipment should relieve us of work, not impose more upon us.

Attribute: *Autonomous*

Go the Owner's Errands The things in the world were not put here by chance (not man-made things anyway). On the contrary, they have a purpose and, more important, an owner.

An owner of things expect the things to work for him, at least that was why they were purchased in the first place. Their purpose may be to entertain, assist, or work for the owner; to add value in some way. It was a conversation with Janson [1999] that made me appreciate that Smart Equipment ought to behave intelligent in this context.

Another aspect is that it is important to remember that Smart Equipment are also set in a commercial context. They are to be bought and sold, just as any other merchandise. Hence, the things should do what they are supposed to and help their owner. No matter how ingeniously designed and advanced technology used, if the product is not working properly, then it is a failure.[4]

Moreover, transfer of control from the owner to the owner's Smart Equipment is a matter of trust. The only way for Smart Equipment to gain a user's confidence, is to function as intended, i.e., be reasonably predictable. However, this does not imply that Smart Equipment never should do unpredictable things. Entertainment robots, for example, would be of little interest if they did not surprise their users.

Attribute: *Functional*

Learn from Interactions, Actions, and Responses Just like it is important that the equipment that surrounds us adapt to our needs in a short, immediate, time perspective, equally important it is that they adapt over time, i.e., that they learn from interactions, actions, and responses and use that knowledge to perform better.

Michael Mozer [1999] has recognised that one of the main obstacles for new "intelligent" environments is their continuous need of a programming effort. Not only when the systems are installed, but also when the lifestyles or preferences of the users change. If people can not even program devices simple as VCRs, then how could they ever be able to control high functionality devices?

[4] In some cases it might be applicable to go one step further and take all the different aspects of the purchase into account, e.g., *support*, or *quality of service*.

Smart Equipment should relieve us from the burden of programming and take that responsibility on themselves. They might do this by observing the actions of the users and learning to anticipate and accommodate their needs. Mozer and colleagues have implemented these ideas in the Adaptive House.

Attribute: *Learning*

Take Initiatives Smart Equipment should not just respond to events in the environment (see description for *Responsive* below). Instead it should be active and take initiatives to achieve its, or rather the owner's, goals.

Attribute: *Pro-active*

Act Intelligent When looking at a system it is important to keep a holistic stance and not get lost among the individual parts. Where the intelligence is located is not important. It is the performance of the system that matters, or in the words of Brooks [1997 p.419]:

> "It is not feasible to identify the seat of intelligence within any system, since intelligence is produced by the interactions of many components. Intelligence can only be determined by the total behaviour of the system and how that behaviour appears in relation to the environment."

Then how should the system as a whole behave? The short answer is that it should act *rationally*. Russell and Norvig [1995 p.7] define rational actions as:

> "Acting rationally means acting so as to achieve one's goals, given one's beliefs."

That is, to make the best possible choices knowing what you know, which in turn implies that performance may improve if mistakes previously made are avoided and motivates learning (above), and also that some kind of means for decision and reasoning must be present.

Attribute: *Rational*

Interact with the Environment If objects are to act in, and affect, the world in which they are situated they must also be aware of it, i.e., must be sensitive to changes in their domain and react to those changes accordingly. Thus, smart systems ought to act intelligently "in" the world. In order to do that they must be able to interact with their environment.

Attribute: *Responsive*

Interact with Others If a Smart Equipment is to be of any use to its owner, the owner should be able to *interact* with it. One could argue that one should

not have to control the objects, they should manage themselves—are they not smart? True. But, as I mentioned above, transfer of control is a matter of trust. People should not hesitate to trust their appliances to do their jobs. One should always be able to take control and override the actions manually, if necessary.

Co-operation is another of the social abilities Smart Equipment should have. Imagine what would happen if a team of soccer players would try to score as many goals as possible, individually. The team performance would not gain from team-mates stealing the ball from each other in their strive to score. In successful teams the players have made an agreement to maximise the team's performance, rather than the individual's.

The same is true for Smart Equipment. Gustavsson [1999b] gives an example of this when describing the HomeBots project:

> "[...] when each equipment agent would carry out time-of-use shifts to cheap hours in a completely individualistic fashion, a sub-optimal situation would result [...]. Hence, HomeBot equipment agents must communicate and collaborate in order to achieve the desired overall optimum load situation. Equipment only becomes smart through co-operation."

Another aspect of co-operation is *emergence*. Birds in a flock or ants in an anthill seem to work together towards a common goal and thereby give rise to a more complex and seemingly more intelligent behaviour that emerges from the group interaction. Smart Equipment can in the same way utilise co-operation to produce a complex behaviour from many simple distributed units.

Co-operation depends on *communication* and *collaboration*, and Gustavsson's example hints on yet another important social ability, *negotiation*, as a means to achieve a global optimum.

Attribute: *Social*

Figure 2.2 summarises the properties of Smart Equipment, as I recognise them. I call it a *Manifesto of Smart Equipment* in order to make it clear that it is not **THE** definition of Smart Equipment, but rather my view of the concept.

2.4 How to Assess Smartness?

Different instances of Smart Equipment will of course display variations in the attributes listed in Figure 2.2. Thus, to be able to talk about Smart Equipment, and compare different objects and grade their "smartness", a measurement-system is needed. It is too blunt to merely investigate if the attributes exist in a product.

Some of the attributes are examined with ease, e.g., pro-activity, but not at all easy to grade or compare among different products.

However, the multidimensional nature of a measure originating from a set of eight attributes is seldom easy to interpret. Thus, it is necessary to combine the different attributes. It is my belief that it would take a separate Master's Thesis project to examine a suitable measurement-system. Hence, I will leave this question open.

Chapter 3

A Survey of Smart Equipment

This chapter comprises the main part of the thesis—a survey of *Smart Equipment*. The survey was made in order to get a good overview of the current field of Smart Equipment, both existing off-the-shelf products as well as products to be released within the next few years. Much of the information this chapter is founded on originates from web pages and documents available from the World Wide Web. In Appendix A these resources are listed.

Two of the sections are devoted to research initiatives; one of them taking aim on initiatives taken within the frames of the European Union, EU. I choose to make this distinction due to the fact that one does not often think of the EU as an originator of research (at least I know that I did not). Hence, I grant these initiatives a section of their own, to emphasise this source of knowledge.

The reader may find the alternating use of both *smart* and *intelligent* in this section to be conflicting with the distinction I made between the two terms in Chapter 2. However, I chose to use them both, to reflect the wording used in the original sources.

As a survey is but a perishable snapshot of its topic, the following subsections will not give a *complete* description of the field of Smart Equipment. However, I believe that they will give the reader a good view of the current activity.

3.1 Existing Products

This section describes some of the off-the-shelf products available today. The products have one thing in common—they are marketed as being "intelligent" in some way.

3.1.1 Aibo

Aibo is a robotic toy dog made by Sony, see Figure 3.1. Although quite expensive for a toy, sold at $2,500 each, it was sold out in very short time when released to the

Figure 3.1: Aibo, Sony's robotic dog.

Japanese and US markets; 3,000 were sold in Japan within one hour and another 2,000 were sold within two weeks in the US [Robot, 1999].

Sony did not expect the toy, or entertainment robot—Sony's preferred label, to be that big a success, hence the limited edition. In an attempt to satisfy this enormous customer demand, Sony released a new limited second edition of 10,000 robots in the late fall of 1999. The new edition have some minor external features that differentiates it from the original edition, such as colours, as well as some new internal ones, as new behaviours and sounds. The new version was released to some countries in Europe as well as Japan and the US.

A performer kit is sold separately, with which you can alter some of the motion behaviours of the dog, as well as create completely new behaviours. It is also possible to associate patterns of motion with sounds. Aibo is autonomous, but can be remotely controlled.

Aibo's behaviours evolve during its life cycle as the robot learns from interacting with the user and the world. The user can foster Aibo by stimulating the robots various sensors, e.g., pet or scold it. Aibo also features six different emotional states which it expresses using body language and sound, thus providing feedback to the user on its internal state.

A special, not commercially available, version of the robot participated at RoboCup'99 in a league of its own. The event was a great success and gained a lot of media coverage [Coradeschi and Karlsson, 1999] [RoboCup'99, 1999]. The participating teams did not make use of the robot's means of communication to establish communication between the robots, and thus did not explore benefits of co-operation within the multi-agent system of the team [Guttmann, 1999], but such advances are expected for RoboCup2000.

Figure 3.2: CareBot from Gecko—a new PC peripheral.

3.1.2 CareBot

CareBot from Gecko Systems is a "Personal Computer Robot", to use Gecko Systems' description of this new PC peripheral (see Figure 3.2). It is about one meter high and semi autonomous—it is controlled via a radio link by a program running on a PC. It relies on a forward-looking sonar range-finder for detection of obstacles.

The behaviours of the robot are modelled in layers, inspired by Brooks' subsumption architecture, allowing the owner to add new behaviours on top of the provided basics. The bundled software takes care of house exploration, mapping, avoidance, and other basics, as well as the main feature of the robot—vacuuming.

Gecko Systems point out that their robot is easily expandable by mounting third-party hard- and/or software. Thus, it can be seen as a platform for further development.

CareBot is currently only available with vacuum cleaning accessories, but future versions will accomplish tasks such as Care for Elderly Relatives, Wheelchair Augmentation, Remote Child and Elder Monitoring, Errand Running, Home Automation Control, etc.

3.1.3 Cye

Cye is a domestic robot from Probotics, see Figure 3.3. Like CareBot, see Section 3.1.2, it is controlled by a PC via a radio link. The robot's only external sensor is a microphone used to detect and react to the owner's hand claps. To detect obstacles it monitors increasing resistance in its wheels. As the environment is explored, a task done with a little help from the user, a map is generated. The map is then used as a basis for path-planning, using a "better safe than sorry" policy avoiding unexplored areas if possible. Navigation is thus done by detecting obstacles and

Figure 3.3: Probotics' Cye. Here shown without the vacuum cleaning add-on.

counting the number of turns of each wheel—dead reckoning. A good precision in navigation is obtained thanks to Cye's patented wheels, whose tips dig deep into the carpet, avoiding slips. But the ability to dig into carpets is not only roses, at least not if you try to use the robot in Sweden, where soft carpets are rare.

To communicate with the robot one is constrained to use brute force, nudging the robot, hand claps, as mentioned earlier, which are reserved to send Cye to predefined locations, or using the graphical user interface on the computer. The robot itself provides feedback by using whistles and chirps much like R2-D2 from Star Wars.

Probotics are working on a voice-controlled version.

3.1.4 Furby

Furby, developed by Tiger Electronics (now part of toy giant Hasbro), is a little furry toy, taking the role of an alien visiting the human community (see Figure 3.4) [Kirsner, 1998]. Its native "tongue" is Furbish, but during its life it "learns" to use some English words.

The creature goes through four stages of development in which new behavioural patterns appear. It is not able to learn any new patterns or words, but simulates learning by cleverly revealing an increasing subset of its capabilities [Lund et al., 1999] [Furby Autopsy, 1998]. New behaviours might be displayed based on time (as the Furby "matures"), interaction patterns, or Furby-to-Furby communication; the latter simulating the sharing of knowledge between two Furbys.

Furby-to-Furby communication is established via an infrared interface, one of Furby's sensors; front and back tactile sensors, speaker, microphone, light sensor, spatial acceleration (to detect tilting or lifting the Furby).

The user can trigger the Furby's behaviours by performing sequences of inter-

Figure 3.4: Furry Furby from Tiger Electronics.

action acts. For example, to play the game "Furby Says" with your Furby, do the following (from [Tiger Electronics, 1998], where "my" is your Furby):

1. Tickle my tummy
2. Pet my back
3. Clap your hands
4. Cover my eyes

The pattern in the example causes the Furby to respond by saying its name and "listen me", to confirm that the pattern was recognised, and then it begins to play the game.[1]

However, Furbys are capable of some simple reinforcement learning. The owner is able to stimulate a favoured behaviour by rewarding the Furby—by petting it on the back two times—after displaying the wanted behaviour.

3.1.5 Koby

Interactive toys are here to stay. After the success with Tiger Electronics' Furby, see Section 3.1.4, a new generation of interactive toys is established by MGA Entertainment's *Koby* the Interactive Bear, see Figure 3.5.

[1] "Furby Says" is an adaption of the game "Simon says", and the user is to repeat a sequence of actions he is told by the Furby.

Figure 3.5: Koby—MGA Entertainment's interactive bear.

Koby features an embedded speech recognition chip using artificial neural networks, developed by Sensory Inc.[2], providing the toy with speaker independent voice recognition. Koby recognises dozens of words and phrases, and speaks over 200 words. This is used to teach children, e.g., ABCs, multiplication tables, or square roots.

A Koby bear is able to communicate with other Koby bears.

3.1.6 Margherita2000.com

Margherita2000.com, released in Italy in mid December 1999, is a new washing machine, fitted with a GSM modem for connection to telephone networks, and the Internet. The machine can be controlled and monitored remotely, via a WWW interface, or SMS messages. It is also by possible to download and install wash-cycle software upgrades.

See Section 3.2.4 to learn about products announced by Merloni.

3.1.7 Mindstorms

A LEGO *Mindstorms* standard kit comprises a box with a controller unit, different sensors and actuators, and lots of ordinary LEGO blocks. Software is also included, co-developed with the Massachusetts Institute of Technology, providing a simple visual programming environment. The available expansion sets offer additional sensors and actuators, visual enhancements, and special purpose software.

Mindstorms makes it possible to add functions and behaviours to physical creations made by ordinary LEGO bricks. The controller unit can not only be programmed using the bundled software, but also by using an ActiveX control to pro-

[2] See `<http://www.sensoryinc.com/>`.

Figure 3.6: Husqvarna's automatic lawnmower.

vide integration to common programming languages, e.g., Visual Basic, and C++, making it possible to create more advanced programs [LEGO, 1998].

At the LEGO lab, University of Aarhus, Denmark, Lund and colleagues have used the Mindstorms set, combined with custom made sensors and actuators, to successfully build robots. See Section 3.3.7 for more details.

3.1.8 SmartOne

SmartOne is a home automation product line from Smart Corporation. It features CEBus[3] technology via existing power lines, thus avoiding the need of rewiring. The products are built upon a distributed architecture and they do not need a central control unit. Thus, they are more robust than a system depending on an ever up-and-running central. The units are programmable via a PC, or a special control panel.

The SmartOne products comply with the Home Plug & Play specification, defining how products automatically become part of a home network and achieve interoperability with other products. Once connected, these products form a home network, allowing them to communicate and work together.

SmartOne comprises a variety of products, e.g., sensors for temperature and light level, switches, an audio/video controller, load controllers, and a control panel.

3.1.9 SolarMower and AutoMower

SolarMower and *AutoMower*, see Figure 3.6, are two autonomous lawnmowers from Husqvarna (a subsidiary of Electrolux). They differ in the means of power charging: SolarMower relies on onboard solar panels while AutoMower needs to return to a base station for recharging. Navigation to the base station is accomplished by searching for, and then following, a burrowed lead-in wire. When recharged mowing is resumed.

[3]Customer Electronics Bus, CEBus is a digital-communications-network protocol over a diversity of media, standardised by the Electronics Industries Alliance, EIA, (EIA-600).

Figure 3.7: Bandai's Tamagotchi.

They mow in an area defined by an electrical fence, a burrowed wire. Within the bounds of the fence, they move, and mow, in a random pattern, changing direction randomly whenever an obstacle, or the wire, is encountered. If an area need more thorough cutting, e.g., if the grass is particularly dense, the lawnmower switches to a more systematic cutting mode; it mows in a square-pattern to cover that area. Resistance in the rotating knife is monitored to inform the robot of the status of the lawn.

Just like Swedes on holiday, the SolarMower has a preference for sunlight. In order to keep its batteries charged it tries to stay in the sun as much as possible, moving to shady areas only when the sunlit ones are properly cut.

3.1.10 Tamagotchi

Tamagotchi were the first instances of electronic pets. Tamagotchi is a combination of the Japanese words tamago (egg) and watchi (watch) [Stutz, 1997]; a Tamagotchi is a virtual creature living inside a small plastic box (see Figure 3.7). Since they were introduced in 1997, manufacturer Bandai have sold several millions of Tamagotchi, in Japan alone [Brown, 1997].

The Tamagotchi resides on a small LCD screen and develops from a small egg to a full grown creature under the caring supervision of its owner. If not given the proper attention it will get sick and eventually "die". You give it food, play with it, etc., by pressing one of the buttons.

Its displayed behaviours are predefined and are triggered by timers, or the user's actions. During its "growth" it goes through some pre-defined states—baby, slightly older, one of two young adult shapes, or one of the six final shapes [Rae, 1997].

Figure 3.8: Electrolux's automatic vacuum cleaner.

3.2 Announced Products

This section depicts the future of Smart Equipment as it gives an account for products announced to be released within a few years time. As commercial companies, for obvious reasons, are reluctant to reveal their plans for the future, much of the information originates from press releases, articles, and interviews. Thus, the products described may be quite different when, or if, they are released.

Unlike the previous section, arranged by individual product, this section is arranged by company, since each company often has announced more than one product.

3.2.1 Electrolux

ScreenFridge, an intelligent refrigerator, will help you to keep track of what you have in your fridge, as long as you let it know what you put in and take out by scanning the packages' bar codes with the built-in scanner. Featuring a touch-screen and a video camera, ScreenFridge can act as a message centre for the family, providing video and voice mail to complement the ubiquitous messages and papers usually posted on the refrigerator door.

The product will be one of the first in a line of products and services offered by a new company, a joint venture between appliance manufacturer Electrolux and telecom company Ericsson. The new company, yet unnamed, was formed to establish a new niche of the domestic appliance market, in an attempt to find new business opportunities in the new market of smart and interconnected equipment.

This is a step towards a new role as a provider of services and not only phys-

Figure 3.9: Matsushita's pet of tomorrow: Tama.

ical objects. The refrigerator will use Ericsson's E-box[4] as a residential gateway. Ljunggren [1999] sees an "always on" Internet connection as necessary for the new service offerings to be successful.

Another product announced by Electrolux is an *automatic robot vacuum cleaner* (see Figure 3.8). It cleans the floor in a random fashion, starting off by locating the closest wall and then circulates the room by moving along the wall. When the robot has made an outline of the room, it continues with the interior, changing direction in a random fashion when encountering an obstacle. The change in direction looks a bit like reflection (angle in equals angle out).

If the robot gets trapped, e.g., between the legs of chairs around a table, it disables the cleaning, i.e., shuts off the fan, in order to preserve energy, while entering a more structured search mode. When free from obstacles the cleaning continues.

The robot uses a sonar system, an acoustic radar, for navigation and avoidance, as well as a bumper sensor to make it stop if it runs into an object the sonar did not detect. When closing in on fixed objects it slows down.

3.2.2 Matsushita

Tama is an intelligent toy cat, see Figure 3.9, designed to aid senior citizens. Kuniichi Ozawa, General Manager of Matsushita Electric's Health and Medical Business Promotion Office, says in an interview that the idea behind Tama is that of animal therapy, i.e., using pets as stimuli to keep patients in a good mood, which in turn make the healing process easier [Drexler, 1999].

[4]Ericsson's E-box serves as a connection point between external networks and services, and internal networks of the home. See `<http://www.ericsson.se/>` to learn more about the E-box.

Equipped with built-in tactile sensors and a microphone, the robotic pet is able to respond to both contact and "his master's voice" with either motion or speech. Tama can stimulate daily conversation as it recognises five common phrases, e.g., greetings, and is able to utter about 50 standard phrases. It can also supply news and other messages transmitted from a remote centre.

Tama stores data on the interaction with its user. This information can then be accessed remotely by the user's physician, or influence new actions and behaviours.

3.2.3 mediaCenter Forschungsgesellschaft

The researchers at mediaCenter, a research subsidiary of German company IQENA, have a vision of connected appliances that are able to communicate with each other and can be remotely accessed, via the Internet. Their first prototype is an *intelligent fridge*, which is aware of its contents, able to compile shopping lists and suggest recipes.

To achieve awareness a different approach than the bar code scanner used by, e.g., Electrolux's ScreenFridge (see Section 3.2.1) has been chosen—radio tags. The advantage is that the user never needs to think about keeping the fridge up-to-date since it scans the interior continuously. The drawback is, of course, that the user needs to attach the radio labels to the goods, since this is not a kind of label found in the stores, and also enter information about what kind of product that is labelled, date of purchase, etc.

The refrigerator features speech synthesis and a LCD display for user feedback.

Other products in the pipeline are, e.g., a toilet which tests urine for internal disorders, such as diabetes or renal calculus[5], and a wash-basin which checks saliva for caries, and then displays the results in the bathroom mirror, or send a message to your dentist or physician, via the Internet.

3.2.4 Merloni Elettrodomestici

Ariston digital is a new generation of household appliances of Merloni Elettrodomestici's Ariston brand. Common for these products is the use of Merloni's Web Ready Appliance Protocol (WRAP) to establish communication among the appliances themselves, via the power line, as well as with remote services, via the telephone network or the Internet.

The Ariston Digital line of products features plug&play installation—just plug in the electricity cord to enable inter-appliance communication—as well as distributed intelligence—no central computer is necessary. Merloni also introduces the information appliance Leonardo, see Figure 3.10, to manage the other appliances in a convenient way.

By transmitting their current status, regarding power consumption, all appliances are aware of the total amount of power being consumed (at least by the Ariston Digital appliances) and actions can be taken to balance the load, e.g., by

[5] Stones in the kidneys.

Figure 3.10: A kitchen appliance of a new kind: Leonardo.

giving some appliances a higher priority, in order to avoid the risk of a black-out[6], or running high consuming appliances during off-peak hours, taking advantage of cheaper rates.

Another appliance in this series is the *Ariston digital oven* featuring cooking cycles for almost every type of dish. As it will be connected to the Internet, new cooking cycles can easily be accessed at Merloni's *Ariston Digital* web portal.

3.2.5 NCR Financial Services Knowledge Lab

London based NCR Financial Services Knowledge Lab have announced several intelligent products as part of their *Personal and Home Networks* initiative, of which two are described below.

Microwave Bank is a microwave oven, fitted with a touch-screen LCD display and voice recognition. Connected to the Internet it will provide easy access to banking services, as well as other online services.

Using a built-in bar code reader the oven can be used to make up shopping lists—just swipe, e.g., an empty beverage can across the reader to add it to the list—and then send it to a store with online order-taking services.

The *Intelligent Trashcan* appreciate that things thrown away should be replaced. Hence, it scans items thrown away as they enter the bin and, trying to maintain a preferred stock of goods in your home, re-orders them from an online store. This could lead to a nightmare scenario, as pointed out by the Jeeves group [1999, adapted]:

> Imagine how you keep on trying to get rid of a product you do

[6]This seems to be a common problem in Italian homes due to low-limit fuses.

Figure 3.11: R100, NEC's mobile robot.

not like by putting it in the bin, only to find it again in the next day's delivery!

3.2.6 NEC Corporation

NEC's mobile personal robot *R100*, see Figure 3.11, will assist you in operating appliances, send and deliver messages, and guard your home.

The robot locates a speaker, using three microphones, and then uses two cameras, also used for navigation, to identify him. It will be able to recognise the faces of about ten persons, and respond to some 300 vocal commands. Synthesised speech is used to give feedback and deliver voice messages. You can leave a message with the robot for it to playback on a nearby television for the intended person, or send it via the Internet as a voice or video mail.

The robot can be instructed from remote locations via e-mail, for example to get a report on the state of the home via video mail.

3.2.7 Reima-Tutta

Finnish clothing manufacturer Reima-Tutta's *Smart Clothing* project aims at creating a prototype of Smart Clothing, which will assist the wearer, e.g., if an accident occurs. The prototype will be presented in June 2000, at the Finnish Pavilion at the Expo2000 in Hannover.

The Reima suit features heart rate, acceleration, temperature and humidity monitoring. Thus, the garment will be able to monitor the health-status of the

wearer. If a possible accident occurs, indicated by abnormal health-status readings, the suit alerts the wearer with audio and light signals. If the alert is not acknowledged, the suit autonomously call for help by sending position, obtained from a GPS receiver, and health-status of the wearer to the rescue service.

An electronic compass is used to complement the GPS receiver making the garment a navigational aid.

3.3 Research Initiatives

This section describes research initiatives investigating different aspects of Smart Equipment and is arranged by research institute, much in the same way as the previous section is arranged by company.

3.3.1 AI Lab, Massachusetts Institute of Technology

Michael Coen [1999] describes the utility of the way of computing as we know it today with the following words:

> "The value of a computer decreases with the square of your distance from its monitor."

He and his colleagues at the Artificial Intelligence Laboratory, Massachusetts Institute of Technology, want to free computational power from the traditional "altar" of desktop PCs and put it into intelligent environments. To make environments intelligent is to bring computation into the world of humans, and it may be more valuable to make *people interfaces* for computers, than computer interfaces for people. The computer should help the user in his activities, being unobtrusive, or transparent, doing so.

Ubiquitous computing is often mentioned in the context if intelligent environments, but Coen [1998] states that it is not necessary to have computation taking place everywhere, in every object taking part in interactions. What is of importance is the behaviour of the system as a whole. By using vision systems to recognise objects and associate them with different actions, minimal hardware modifications are necessary and potentially more information is available, than in a system relying on sensors.

To make it all work, enabling communication and co-operation between the different parts of the intelligent environment, Coen [1997] proposed to use distributed collections of simple agents designed in a layered architecture; *Scatterbrain*. The layered architecture is inspired by Brooks' [1989] subsumption architecture for robots.

Recently *Metaglue* was developed by Coen et al. [1999] in order to provide a high-level programming language for agents supporting resource management.

Two rooms have been built to serve as test-beds; the *Intelligent Room* and *Hal*, the second generation intelligent room.

3.3.2 Centre for Autonomous Systems, Royal Institute of Technology

The Centre for Autonomous Systems (CAS), Royal Institute of Technology, is Sweden's main academic centre of robotics. Their main research project is in the domain of *intelligent service robots*.

The work done at CAS can be characterised by two keywords: *integration* and *robustness*. Integration, meaning that the group take a systems view of the problem, trying to integrate all aspects necessary for the robot to function in a human environment, instead of looking at each aspect separately. Robustness is important since a robot must function in any kind of domestic, or office, environment; not just an artificially created one or one altered to fit the robot's, for example, navigation system. To give the robots a "natural" environment, the group have furnished a room with IKEA furniture.

In order to identify problems and, hopefully, their solutions, robots are set to perform different tasks, of varying complexity. Most of the tasks that are carried out are fetch-and-carry tasks. Tasks such as these, as simple as they might seem, give rise to a number of research topics, e.g., navigation among obstacles, object recognition, multi-agent systems, and human-robot interaction.

3.3.3 Centre for the Study of Language and Information, Stanford Univ.

The *Archimedes Project* at the Centre for the Study of Language and Information, Stanford University, studies smart houses as part of a larger topic of *Human Centred Interfaces to Ubiquitous Computers*. The goal of the project is to ensure that everyone has access to information regardless of individual needs, abilities and preferences. Part of the work is to enable each and every person to select an interface that matches his individual requirements [Scott et al., 1998].

Smart houses can support people with disabilities, as well as people with other functional limitations, e.g., aging and busy people. Necessities for disabled and aging people become conveniences for everyone else.

Scott et al. advocate the use of "ageless components"—an infrastructure where old and new appliances, tools, and interfaces can be mixed in any manner, and can be easily added or removed at any time. This supports an incremental way of building intelligent environments, where new components can be added when needed, or afforded. To avoid that the environments become obsolete, interfaces should be separated from the infrastructure; not "hard-wired" into it. A clear separation is necessary, between the infrastructure, which must be long-lived, and the parts that interact with the users and the environment. Occupants must be able to choose appliances and interfaces that best match their individual needs, abilities, and preferences. These needs will change over time as the inhabitants get older, moves, or pets come and go.

3.3.4 Centre for User Oriented IT Design, Royal Institute of Technology & The Interactive Institute

The *Smart Things & Environments for Art and Daily Life* studio is a joint research program between the Centre for User Oriented IT Design, Royal Institute of Technology, and the Interactive Institute. Within the frames of this program several projects are taking place, for example:

Digital Breakfast The Digital Breakfast project aims at making everyday meals more interesting by letting the breakfast and kitchen products talk to you, e.g., about how they were produced and their means of usage, by connecting them to online information via, e.g., a bar code reader.[7]

comeHOME In co-operation with telecom company Telia an apartment has been equipped to serve as a test-bed for development of domestic services. Fredrik Petersson is currently doing a Master's Thesis's project in the apartment, establishing person localisation and awareness.

One part of the comeHOME project is to investigate the use of public and private zones, comZONES, as a means to establish communication. A scenario is depicted where the user can affect what the receiving party sees and hears by moving in and out of a virtual public zone [Junestrand, 1998] [Junestrand and Tollmar, 1998].

At a recent workshop, Junestrand [1999] described an initiative to use the comZONES to aid video mediated communication for people with intellectual disabilities.

Common for the projects is a wish to "activate the world", to make everyday technology accessible and usable for a wider range of people. The things should be smart, from the perspective of the user [Sjöberg, 1999].

3.3.5 Computing Science Dept., Uppsala Univ.

Jeeves is the name of a 15 credits senior undergraduate project at the Computing Science Department, Uppsala University. The aim of the project is to develop two prototypes, demonstrators, for utility side load balancing. That is, enable an energy distributor to smooth out peaks in the energy load by regulating equipment inside the customers' homes. The project was initiated by the EnerSearch research consortium.[8]

Thus, this project is different in that equipment, as appliances and electric heaters, are to be regulated externally. However, when an infrastructure for communication between equipment is established, the utility is able to offer services other than energy to the consumers—making a transition towards services (cf. Section 3.3.11).

[7] Cf. ConnectThings, a service providing a connection between the bar code on a product and a corresponding online web page. See `<http://www.connectthings.com/>`.

[8] See `<http://www.enersearch.se/>`.

3.3.6 Dept. of Architecture, Carnegie Mellon Univ.

On top of the roof of Margaret Morrison Carnegie Hall, on the Carnegie Mellon campus, the *Intelligent Workplace* is being built on initiative of the Advanced Building Systems Integration Consortium (an industry-government-university consortium) and the Centre for Building Performance and Diagnostics.

The 650 square meters big "laboratory" will serve as an inhabited test-bed and demonstration centre for new ideas in the field of office environments, e.g., from new building materials to automatic customised heating and lighting.

3.3.7 Dept. of Computer Science, Univ. of Aarhus

The LEGO lab at the Department of Computer Science, University of Aarhus, is, as one might guess by the name of the lab, a collaboration between the department and toy manufacturer LEGO. The collaboration is visible in the use of LEGO Mindstorms (see Section 3.1.7), with custom made sensors and actuators, as a platform for robots—the main focus area of the lab.

Their view is that robots should resemble humans, rather than machines, in interactions with the environment and strategies for evolution. Internal "moods" should be visualised in a way natural for humans, e.g., using facial expressions [Lund et al., 1999].

Neural networks are used to evolve behaviours and to train the robot to associate them to spoken words.

One goal of the work is to investigate new playing concepts for children in a world of ubiquitous computing. During the RoboCup Jr activity, at RoboCup'99 in Stockholm, the LEGO lab arranged open sessions for children to design robot soccer players to compete with in a daily tournament. Lund [1999] describes how pre-built LEGO Mindstorms robots were programmed to play "soccer" by children in 30–60 minutes, using a specially developed user-guided behaviour-based software.

3.3.8 Dept. of Computer Science, Univ. of Colorado

According to Michael Mozer [1999] at the Department of Computer Science, University of Colorado, the reason why automated homes are not commonplace is that they require a significant programming effort. Not only when installed in, and adjusted to, a particular home, but also when updated as the family's lifestyle changes. As people have a hard time programming their VCRs, this is far beyond the capabilities and interest of typical home inhabitants.

In an attempt to tackle this problem, they have equipped a house to serve as a living laboratory; the *Adaptive House*. Controlled by a system called *ACHE*, Adaptive Control of Home Environments, the Adaptive House learns to manage energy resources in order to anticipate the needs of the inhabitants and, in addition, conserve energy. The control systems are based on neural network reinforcement learning and prediction techniques. By inferring occupancy and usage patterns in

the home, the system can make life more comfortable and conserve energy at the same time.

The Adaptive House should be transparent to the inhabitants and no special interactions should be forced upon them. Hence, no touch-screens, or the like, are used to control the system. Instead, light switches, thermostats, etc., are monitored by the system, serving as training signals, instructing the house how to behave.

Using about 75 sensors the system attempts to infer patterns in the environment to predict the inhabitants actions, and if reliably anticipated, the system performs these actions automatically, freeing the occupants from manual control of the home.

Mozer gives some examples of what the Adaptive House will be able to do: predict when the occupants will return home and adjust the heating of the house to reach a comfortable temperature at that time; infer where the occupant is and what she is doing, and adjust the lighting patterns and intensities accordingly.

Michael Mozer is also involved in Sensory Inc., who developed the speech recognition chip used in MGA Entertainment's Koby (see Section 3.1.5).

3.3.9 Dept. of Computer Science, Univ. of Massachusetts

The Multi-Agent Systems Laboratory at the Department of Computer Science, University of Massachusetts at Amherst, study multi-agent co-ordination in the domain of intelligent environments in a project called the *Intelligent Home (IHome)*. The main goal of the project is to investigate methods for sharing of limited resources, and co-ordination of activities depending on these.

Lesser et al. [1999 a,b] describe how they use a simulated home environment, consisting of a four room apartment, populated with intelligent home-control agents to manage appliances and a robot (simulated, that is). One agent is associated with every major appliance and interact directly with each other to negotiate over shared resources; electricity, hot water, noise[9], and room temperature.

If an agent is responsible for producing a shared resource, e.g., hot water, then that agent also manage that resource, i.e., distributes it among other agents in need of that resource. Decentralised resources, e.g., electricity, are negotiated over in an unmoderated fashion, directly between the consuming agents.

3.3.10 Dept. of Food Science, Rutgers Univ.

At the Department of Food Science at Cook College, Rutgers University, an initiative is taken aiming at providing greater product value to the role of packaging in new era of information. This initiative, named *Intelligent Product-Delivery Systems* describes a shift in the traditional paradigm for packaging—in which packaging becomes a more valuable information link. The package can serve as an intelligent messenger throughout the entire chain of product-delivery.

[9]Noise made by appliances in a room is not allowed to exceed some predefined level.

> "When the system is able to share vital information among its components for decision making and optimisation, the 'intelligence' of the system can be developed." [Saba, 1999]

To prove their point, they have, in co-operation with Samsung, developed an *Intelligent Microwave oven*. The oven is equipped with a bar code scanner, enabling it to recognise the food being processed—prepared food that is, in packages with a bar code—and optimising the cooking parameters to fit that particular dish.

Standard package bar codes do not contain any information about the food or size of the package, but acts as an identification tag. Cooking data can then be looked-up, either in a data base contained in the oven or on the Internet by accessing the manufacturer's web site. The latter is of course a better alternative, since the number of dishes the oven can handle then is practically infinite.

In this example the package is the carrier of information. Wilks, mediaCenter (see Section 3.2.3), foresees the use of radio tags instead of bar codes to enhance the role of the package as an intelligent component.

Gustavsson, University of Karlskrona/Ronneby (see Section 3.3.11), shares the view of new business opportunities for old markets.

3.3.11 Dept. of Software Eng. and Computer Science, Univ. of Karlskrona/Ronneby

The Societies of Computation research group at the Department of Software Engineering and Computer Science, University of Karlskrona/Ronneby, is investigating the use of multi-agent systems to control intelligent buildings.

Villa Wega, a three-story research laboratory, has been equipped with power-line communication technology to serve as a test-bed for energy load management. Agents, named *HomeBots*, acting on behalf of the consuming equipment, negotiate over power by participating in auctions on a computational market. Other participants in the auctions are intermediate Service agents, representing collections of HomeBots, and the Utility agent of the electric utility [Gustavsson, 1999a].

Gustavsson [1999b] describes how the deregulation of the energy market will force utilities to change into service providers, and recognises that the same is true for other competitive markets with low profits:

> "From kWh to services [or] From refrigerators to selling freezing services"

Villa Wega has also been used to investigate a multi-agent approach to tackle the often conflicting goals of energy saving and inhabitant satisfaction. Using active badges to identify persons, Personal Comfort agents negotiate with Room agents over room temperature and light intensity; Personal Comfort agents trying to maximise adaptation to each persons preferences while Room agents try to save as much energy as possible. Centralised decision making is used, where pronouncers make decisions on behalf of the simple agents [Boman et al., 1998].

Boman et al. [1999] states that simulations indicate that significant energy savings, as far as up to 40 per cent, are possible when using the multi-agent system.

3.3.12 Georgia Institute of Technology

The Future Computing Environments (FCE) Group is a inter-institutional group at the Georgia Institute of Technology, investigating computing environments that they believe will be commonplace in 10–15 years. Many of the projects are connected to ubiquitous computing and how to support daily tasks in an unobtrusive way.

The *Classroom 2000* project explores how ubiquitous computing will affect, and be able to support, education. A full size classroom has been equipped with electronic whiteboards and audio and video recording, allowing complete lectures to be captured and saved for later reviewing. Thus, the need for ordinary note-taking is reduced and the students can be more engaged in discussions during the lecture.

The electronic annotations, audio, video, and even Web browser activity, are all recorded and time-stamped. Afterwards a set of standard HTML Web pages is automatically generated, including a timeline of the lecture, providing an index to the video, slides, and visited Web pages. By clicking on one of the lecturers annotations, for example, the video and audio recorded as the annotation was made are replayed, making the context, in which the annotation was written, clear [Abowd, 1999] [Classroom 2000, 1999].

Beth Mynatt [1999] describes the work within the *Everyday Computing* project in a white paper, recognising that ubiquitous computing should support us in our day-to-day activities; unlike the most software of today which support our tasks. Activities tend to be more loosely defined, in time and focus.

In the *Domisilica* project Mankoff et al. [1998] explore how ubiquitous computing can serve as a link between physical and virtual worlds, exemplified in *CyberFridge*, a refrigerator augmented with a display mounted on the door, some sensors and a network connection. They choose to use a refrigerator as they recognised it as a central place for communication and information, a place where notes and messages are collected. In CyberFridge a bar code scanner was used to identify packaged groceries, together with a vision recognition system to identify fruit, allowing the refrigerator to be aware of its contents. Using this knowledge, a shopping list of supplementary ingredients could be generated once a recipe is chosen.

One of the most interesting projects within the FCE group is the building of the *Aware Home*. When in operation, it is currently under construction on the campus area, the Aware Home will serve as a living, inhabited, laboratory for ubiquitous computing in support of home life. Kidd et al. [1999] describes how they want to create an environment that is capable of knowing information about itself and the whereabouts and activities of its inhabitants. They are moving away from the office and focusing on how computing can support us in our everyday lives. Essa [1999] sees the house as a test-bed for implementing and trying out various technologies

of ubiquitous sensing, to enable environments to be aware of the activities that goes on.

A major goal of the work is to make the Aware Home an assisted living facility for the elderly, by supporting social connections between elder parents and their adult children, as well as "everyday cognition"—augmenting those aspects of memory that decline with age, and sensing and identification of potential crisis situations in order to alert outside services as needed.

3.3.13 Media Lab, Massachusetts Institute of Technology

Kitchen Sync is a project at the Media Laboratory, Massachusetts Institute of Technology, investigating of how the kitchen of the future may look, and act. They got interested in the kitchen as a place to investigate intelligent environments, when realising that the kitchen is intrinsically dynamic. Thus, kitchen comprise a more natural part of homes to first be introduced, or promoted, to intelligent environments than, e.g., living rooms (in focus of studies at, e.g., MIT AI Lab or Microsoft Research, see Sections 3.3.1 and 3.3.14).

As Joseph Kaye [1998] puts is in a white paper of the project:

> "Raw materials enter, are processed and leave. The user of the kitchen invariably contributes to that processing, whether it be putting a pre-frozen lasagne in the microwave or meticulously leafing through The Joy of Cooking for a four-course dinner. As the two-way conversation of the Internet is to the one-sided oratory of television, Kitchen Sync is to the Living Room of the Future."

Kitchen Sync is a digitally connected, self-aware kitchen which has knowledge and memory of its activities, built around *connected* intelligent objects.

Development of the prototypes of smart appliances goes through three stages of devices, in which self awareness and communication gradually increases, and adding memory capabilities at the final stage.

Kaye et al. [1999] describe the prototypes, e.g., *Mr Java*—a coffee machine that recognises your cup, and makes the coffee as you like it; *Counter Intelligence*—a prototype intelligent counter acting as an interface between you, the recipe, and the food being prepared.

3.3.14 Microsoft Research

Microsoft Research are investigating ubiquitous computing in a project called *EasyLiving*. They have a vision of how to make the use of computers easier to use and more versatile than traditional desktop PCs. Computing, not the computer, should be as natural a part of a room as lighting.

Shafer et al. [1998] point at three characteristics as necessary for intelligent environments to be successful; self-awareness, casual access, and extensibility. That

is, a room should know its own geometry and capabilities, be aware of its occupants and respond to voice and gesture commands, and allow new components to be added with a minimum of effort.

Self-awareness is elaborated in Brumitt et al. [1999], concluding that it is important to model the location of *things* as well as persons. In order to automatically redirect, e.g., a video stream to a monitor close to a person, it is not sufficient to know the position of that person—you must know where the monitors are, and what is between the monitor and the person, since the closest one might be on the other side of a wall. Moreover, knowing the location of the socket to which the monitor is connected is not enough—the monitor might be placed around the corner in a different room, pointed in an unpredictable location.

3.3.15 Telia Research

Telia Research in Nynäshamn, a research subsidiary of Swedish telecom service provider Telia, study how to provide an infrastructure for intelligent homes in a project called *Communication of the Home*. As part of this work they take an active part in the Open Services Gateway Initiative (OSGi), working on international standards on how to connect external services to internal clients.[10]

At the 8th World Telecommunication Exhibition, Telecom 99, in Geneva, Telia Research participated with a Jini demonstrator, referred to by SUN, showing the plug-and-use of a Jini enabled camera, file server and printer [Alm, 1999].

A new project will look at *Things That Think and Communicate*, initially in the domains of toys and kitchens. Thus, Telia Research is following a trend of domestic activation, just like, e.g., MIT Media Lab and mediaCenter (see Sections 3.3.13 and 3.2.3).

3.4 Initiatives Taken by the European Union

This section describes a few of the research projects initiated and funded as part of the European Union's Research and Technological Development programs. A major part of the information about these projects was found in the Cordis database web site, `<http://www.cordis.lu/en/home.html>`, and on the Prosoma web site, `<http://www.prosoma.lu/>`. These sources can be consulted to learn about more EU funded research projects.

3.4.1 Autonomous Cleaning Robot (ACRO)/Test Environments for Autonomous Cleaning Machines (TEAM)

The ACRO project resulted in a demonstrator of an autonomous cleaning robot, Acromatic. The TEAM project aims to further develop the robot towards an industrial product.

[10] See `<http://www.osgi.org/>` for more information.

Tests are performed in real settings and two different types of navigation systems are examined, in order to establish an appropriate trade-off in flexibility and ease of operation. In addition careful attention is being paid to public acceptability of using an “electronic bumper” as protection.

3.4.2 Consumer Home Applications Based on Low-cost Intelligent Sockets (CHABLIS)

The CHABLIS project focuses on the development of one of the most fundamental low-cost consumer home appliances—the intelligent socket. A industrial objective of CHABLIS is to allow the development of cost effective intelligent power line sockets based on the European Home Systems (EHS) power line communication technology.

Two types of appliances will be investigated: receiving only, and transmitting/receiving appliances. Several applications for demonstrational purposes will be developed in co-operation with commercial companies.

3.4.3 Control ELECTric (CELECT)

CELECT is a control system designed to minimise the cost of energy through demand side management. It was initially designed to control electric space and water heating, but can be applied to any process where the supply of power can be deferred at times of high cost, e.g., air conditioning; that is, inert systems. Comfort is assured by the use of advanced thermal management techniques that learn the characteristics of the room being heated.

The power utility transmits relative cost information to the customer once a day as a set of 48 half hour Cost Reflective Messages (CRMs). Costs are minimised by optimising the use of thermal storage and direct heating based on the relative costs of electricity throughout the day. Running costs is said to be reduced by 15–20 per cent (for the same comfort temperature) using CELECT.

The CELECT system has a fully distributed architecture. Each heater (appliance) performs its own optimisation based on the data received, so each room can be controlled independently.

3.4.4 Navigation of Autonomous Robots via Active Environmental Perception (Narval)

The goal of the Narval project is to develop mobile robots, able to operate without any a priori knowledge about the regions in which they operate. The robot must be able to operate without special purpose landmarks being added to its environment. Hence, the robot must be able to select natural landmarks, and to navigate with respect to them.

This require the robot to be able to infer its position from learned natural landmarks of the environment using its perception system, and to use the changes of its

perception of the environment over time to correct position estimates obtained by dead-reckoning.

3.5 Similar Work

I have not found any previous survey trying to describe the field of Smart Equipment. However, there are collections of resources available that covers parts of the field. A good example of this is the Smart House Web Survey (see Appendix A), made by the Future Computing Environments group at the Georgia Institute of Technology, listing resources available on the Internet concerning Smart House technology. This is, however, a mere collection of links and no further analysis seems to have been done.

Chapter 4

Analysis and Discussion

During the initial work of the survey, I realised that it would not be feasible to analyse every existing product and project in detail; the domain of Smart Equipment is too diverse. In my analysis I have chosen to focus on products available today. Announced products, which may change in major ways before they are released, and research initiatives, often focusing on a few key issues, are discussed later in this chapter.

4.1 Analysis of Existing Products

In this section off-the-self products from Section 3.1 are analysed, or rather assessed, to what extent they comply with the definition of Smart Equipment (see Section 2.3). A proper analysis of AI techniques used, e.g., strategies for machine learning or decision making, has not been possible, since I, unfortunately, have not had access to detailed descriptions of implementations and design choices of the various products, nor have I had an opportunity to try out all of the products myself.[1] Hence, the assessment relies on available information, and my interpretation of that information.

The section is arranged by attribute, and I give some examples of products who either comply with each attribute, or fail to do so.

4.1.1 Adaptive

Smart Equipment should be smart in a user centric perspective, and be able to adapt to a channel of communication preferred by the current user. Of course, it may not be feasible, at least not for cost-driven commercial products, to offer a multitude of interfaces, but at least an effort should be made to provide some alternatives. However, none of the products in the survey was able to comply with this.

[1] Still, if I had had access to that kind of information, then the commercial setting of the products would have imposed non-disclosure agreements upon me, restricting me to more vague statements of the kind I now make.

Some of the products, e.g., Cye and CareBot, are controlled via software running on a separate computer, software that could be adapted to provide alternative ways of interaction, e.g., speech recognition.

4.1.2 Autonomous

Almost all of the products are autonomous. CareBot, for example, is able to perform house exploration and obstacle avoidance on its own. Aibo is also autonomous, but one could argue that the robot often demands the user's attention, and that it depend on interaction with its user to develop its behaviours. However, Aibo, as well as other toys, should activate the user—it is part of its entertainment function.

Tamagotchi, on the other hand, is not autonomous. Like Aibo it is a toy, and the user *should* be engaged in playing with it, but unlike Aibo it demands constant attention to "survive".

4.1.3 Functional

Husqvarna's autonomous lawnmowers are good examples of products whose functionality is easily verified; it suffice to inspect the lawn and see if the grass has been properly cut. Other products are not as easily verified. The function of toys like, e.g., Aibo and Furby, is to entertain the user. Whether the user is entertained or not is quite subjective, and varies from user to user. Thus, as it is hard to impose demands on the quality of the entertainment, products in this domain can get away with much.

CareBot is above all sold as a platform for further development, and as such it has special demands for functionality, but even the off-the-self version is able to perform simple task, e.g., deliveries.

When I tried out Cye I found out that the robot depends on soft carpets; when used on hard floors it slipped and failed to navigate properly. This is of course a severe drawback and affect functionality in a negative way.

4.1.4 Learning

When the two domestic robots, Cye and CareBot, explore their surroundings they both generate a map, i.e., they learn how the rooms are laid out. The map is later used for navigation and path planning.

Aibo's movements and behaviours evolve during its life cycle as the robot interact with the world and the user. This is of course a much more advanced kind of learning than Furby's ability to learn to favour one of its pre-designed behaviour.

4.1.5 Pro-active

Several products display a pro-active behaviour. For example, Cye tries to, when disoriented, return to its home base in order to calibrate its location on the map

with the reality. A simpler kind of pro-activeness is shown by Furby when it takes initiatives to play with the user by, e.g., demanding to be fed; initiatives initiated by internal timers.

4.1.6 Rational

An action is said to be rational if the actor who performs it act on what is known to him when trying to achieve his goals. Hence, Cye's better-safe-than-sorry strategy, trying to avoid unexplored areas when planning paths, is clearly rational.

4.1.7 Responsive

All products are responsive in that they are all affected by external events. Examples of this is CareBot's ability to avoid collisions when autonomously exploring the environment; Furby's reactions triggered by light, sounds, touches, etc.; and Tamagotchi's responses to buttons being pressed.

4.1.8 Social

Social ability is one of the most interesting and important attributes in the definition of Smart Equipment, comprising many different aspects of communication and collaboration.

The products in the survey are all able to interact *with* the user, although some of them, Husqvarna's lawnmowers, only provide a feedback channel and lack the ability to receive instructions *from* the user.

Furbys are able to communicate with each other, an ability enabling them to collaborate on the task of entertaining their users, e.g., by dancing together.

4.2 Reflections on Existing Products

Some observations can be made from the analysis of the off-the-shelf products in the survey:

- *None* of the off-the-shelf products could meet the definition of Smart Equipment. They all lacked one or more of the necessary properties.
- *None* of them was adaptive, i.e, no one could adapt its interaction to a channel preferred by the user.
- *All* were responsive.
- *All* were, more or less, functional. The commercial setting imposes demands on the functionality of the products, demands which they ought to obey if their manufacturing company is going to be successful.
- Their social skills are poor; mere communication instead of collaboration.

Two categories of products are discernible, *entertainment* and *service*, with very different demands on, e.g., functionality. It is easy to claim that a toy successfully entertains its users. Thus, if one is to be able to make statements and comparisons about products from different domains, then a proper measurement-system is needed.

Moreover, a measurement-system is also needed when comparing products in the same domain. Aibo, for example, is not far from meeting with my definition of Smart Equipment, a property it shares with Furby, who too comply with many of the requested attributes. But, as discussed above, although they both are capable of learning, their capabilities are totally different.

4.3 Comments on the Announced Products

Two major areas of interest can be recognised:

Information Appliances Domestic appliances are turned into information centres, providing access to the Internet and online services. They are also intended to serve as interfaces for other Smart Equipment.

Domestic Robots Companies are announcing domestic robots that will perform tedious tasks as vacuum-cleaning, assist elderly, or act as more natural interfaces to other products.

Several of the announced products are information appliances, and as such they are able to serve as control panels for an interconnected home. But what if you do not have a control panel? Merloni state that their products will start to collaborate the moment they are plugged in, and negotiate over shared resources, e.g., power consumption. But how are the priorities set? Which are the appliances that should have priority over the others? Moreover, how are appliances located in different apartments distinguished? Signals tend to wander when sent on power lines. Surely, you do not want your neighbour's dinner plans stop you from taking a hot shower!

4.4 Trends of Research

Although they are addressing Smart Equipment in many different ways, some trends and similarities can be found among the current research initiatives:

Intelligent Environments Several projects are investigating how intelligent environments can be used to support elderly and people with mental disabilities. Other projects focus on how to make environments appreciate the preferences of their inhabitants.

Transition of Old Markets One trend of the current research initiatives is to use Smart Equipment as a means to enable actors on old markets, e.g., power utilities, to make a transition towards more service oriented products.

Kitchen Appliances It seems as if the kitchen has become a popular place for research. It is recognised as a good place for introducing domestic Smart Equipment. Several projects focus on kitchen appliances (especially refrigerators), making them self-aware.

Robots Smart Equipment projects concerned with robotics focus on domestic robots for entertainment and service.

4.5 The Future of Smart Equipment

In the near future is is likely that existing products are augmented with intelligent behaviour, in order to make way for completely new products. I believe that people are less reluctant to choose a smart version of a product they are already familiar with, e.g., when buying a new washing machine, than they are to new phenomena like, e.g., domestic robots.

Toys is one domain in which we are to expect things to take an early start, a domain in which techniques for Smart Equipment will be tried out. The reason for this is that people do not have as high demands on the functionality of smart toys as they have on the functionality of, e.g., smart houses, since it is not that big a problem if a toy malfunctions, than it is if your house needs a restart.

However, in the end we do not want Smart Equipment. Rather, it is a step towards the goal of *unobtrusive* and *ubiquitous computing*.

4.6 Opportunities for Agents and Multi-Agent Systems

I believe that agents and multi-agent systems are bound to make their way into the domain of Smart Equipment. In fact, as described in Section 3.3, several research initiatives *are* using these techniques today. So far, many products have been stand-alone systems, but there is a trend of making interconnected, collaborating equipment of various kinds, and multi-agent systems are well suited to deal with issues that will appear, e.g., distributed decision making, social norms, and the need for a common language.

4.7 Collaboration in Research

Smart Equipment provides a domain for interdisciplinary research, and should attract researchers form many different fields, e.g., robotics, agents and multi-agent systems, computer vision, and human factors. Unfortunately interdisciplinary research initiatives are not as common as they ought to be; often due to unspoken rivalry between institutions, or difficulties to get funds. Hence, an effort should be made to promote such initiatives, as they fecundate all parties involved.

Chapter 5

Conclusions

5.1 Summary

This thesis has presented a survey of Smart Equipment, providing an overview of products available today, products announced to be available in a few years from now, and research initiatives and activities with connection to this area going on in the academic community.

None of the products available today is able to meet my definition of Smart Equipment, i.e., not one of the products has all the necessary properties. A property all the products were lacking was *Adaptive*, i.e., they could not adapt their channel of communication to one preferred by the user. Nor do any of the announced products address this in any satisfactory way.

Is the definition too hard? Maybe the definition is too hard to meet for any of the commercial product available today, but I believe that the properties included in the definition are essential ones, and they should be given proper attention when developing Smart Equipment for tomorrow.

5.1.1 Objectives Revisited

Four objectives of the thesis were fulfilled, whereas the fourth objective was only achieved in part:

- √ Get an overview of the current market.
- √ Describe trends and findings in current research initiatives.
- √ Give a definition of the term *Smart Equipment*.
- Make an assessment of “intelligence” in selected products.
- √ Identify possible opportunities for agent technologies in Smart Equipment.

Although I have analysed products available off-the-shelf, in Section 4.1, and made statements on their “intelligence” and whether they should be described as

Smart Equipment, my goals were set higher. I was hoping to gain an insight into AI-techniques used in the Smart Equipment, but I soon came to realise that that was not feasible when investigating commercial products. Thus, the fourth objective was only achieved in part.

I believe that it would have been possible to conduct the analysis as intended if I had restricted it to include only a few products from the same domain, as I then could have collaborated with the companies behind those products. However, as I wanted to get an overview of the field as a whole I chose to be independent of any commercial company, as I thought it would benefit the survey. Thus, the first objective was in conflict with the fourth.

5.2 Future Research

This thesis has shown that there are many current initiatives in the field of Smart Equipment, and that there is still a lot to be done. This section elucidate some topics for further research in this domain.

5.2.1 A Survey of Smart Equipment

The presented survey does not give a *complete* description of products and research in this domain. Nor can any survey do, as new products are announced and new research projects are started all the time. Hence, it will be necessary to make a new survey in a year.

5.2.2 A Measurement-System for Smart Equipment

As I wrote in Section 2.4, it would be useful to have a measurement-system for Smart Equipment in order to be able to compare the intelligent behaviour of the products, or grade their "smartness". The elaboration of such a measurement-system might be suitable for a Master's thesis project. During the elaboration the properties I proposed in Section 2.3 should be examined and verified (or rejected).

5.2.3 Experienced Intelligence

It would have been interesting to investigate my assumption that people in general *are* regarding the same things as smart or intelligent. Intelligence of an object is a rather subjective property, experienced in the eye of an observer, as he interpret the objects behaviour.

For example, it would have been interesting to investigate Electrolux's way of choosing a less complex random route instead of a highly planned one when designing their automatic vacuum cleaning robot (see Section 3.2.1). The random motion was chosen because user tests showed that it offered a more interesting

motion pattern, in the eyes of the observer—a pattern interpreted as more intelligent than the carefully planned one.[1]

5.2.4 Smart Education

MGA Entertainment's Koby (see Section 3.1.5) and the Classroom 2000 project at Georgia Tech (see Section 3.3.12) are two examples of Smart Equipment used in an educational domain.

It would be interesting to investigate how these kinds of tools affect learning, e.g., how interactive toys could be used in pre-school education to stimulate learning, or how the automatic capture of complete lectures could assist persons with mental disabilities.

5.2.5 Collaboration

There are a number of issues that need to be addressed if collaboration among Smart Equipment is to take place, issues also found in multi-agent systems, e.g., the need of common language (cf. KQML[2] for agents); social norms, like veracity and benevolence; and how to solve conflicts, e.g., when negotiating over limited resources. Thus, much can be learned from previous research.

However, it would be interesting to investigate if there are special demands imposed upon Smart Equipment as physical objects. An initiative in this direction is currently taking place at Microsoft Research, see Section 3.3.14.

[1] Another reason was that a domestic robot can do much of its planning in vain, due to the complex environment of a furnished home.

[2] Knowledge Query and Manipulation Language.

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Appendix A

Resources Available on the Internet

Similar Work

Smart House Web Survey made by the Future Computing Environments group, Georgia Institute of Technology:
<http://www.cc.gatech.edu/fce/seminar/fa98-info/smart_homes.html>

Existing Products

Aibo <http://www.sony.com/>

CareBot <http://www.geckosystems.com/>

Cye <http://www.personalrobots.com/home.html>

Furby <http://www.furby.com/>

Koby <http://www.mgae.com/>

Margherita2000.com <http://www.margherita2000.com/>

Mindstorms <http://www.legomindstorms.com/>

SmartOne <http://www.smartcorporation.com/>

SolarMower and AutoMower <http://www.international.husqvarna.com/products/robotic/index.html>

Companies Announcing Products

Electrolux <http://www.electrolux.com/>

Ericsson <http://www.ericsson.com/>

Electrolux/Ericsson joint venture <http://www.e2-home.com/>

Matsushita <http://www.mew.co.jp/e-index.html>

mediaCenter Forschungsgesellschaft <http://www.mediacenter.de/>

Merloni Elettrodomestici <http://www.merloni.it/>

NCR Knowledge lab <http://www.knowledgelab.com/>

NEC <http://www.nec.co.jp/english/>

Reima-Tutta <http://www.reima.fi/>

Research Initiatives

AI Lab, MIT <http://www.ai.mit.edu/>

Centre for Autonomous Systems, KTH
<http://www.nada.kth.se/cas/>

Centre for the Study of Language and Information, Stanford Univ. Archimedes Project: <http://hypatia.stanford.edu/arch/>

Centre for User Oriented IT Design, KTH & The Interactive Institute Smart Things and Environments studio:
<http://www.nada.kth.se/cid/smart/content.htm>

CS Dept., Uppsala Univ. <http://www.csd.uu.se/>

Dept. of Architecture, CMU The Intelligent Workplace:
<http://www.arc.cmu.edu/cbpd/iw_press.html>

Dept. of CS, Univ. of Aarhus LegoLab:
<http://legolab.daimi.aau.dk/>

Dept. of CS, Univ. of Colorado The Adaptive House:
<http://www.cs.colorado.edu/~mozer/nnh/index.htm>

Dept. of CS, Univ. of Massachusetts Intelligent Home:
<http://mas.cs.umass.edu/research/IHome/project.html>

Dept. of Food Science, Rutgers Univ. Intelligent Product-Delivery Systems: <http://foodsci.rutgers.edu/ipds/index.htm>

Dept. of Software Eng. and CS, Univ. of Karlskrona/Ronneby
<http://www.ipd.hk-r.se/>

Georgia Tech Future Computing Environments Group:
<http://www.cc.gatech.edu/fce/>

Media Lab, MIT <http://www.media.mit.edu/>

Microsoft Research EasyLiving:
<http://www.research.microsoft.com/>

Initiatives Taken by the European Union

Cordis database <http://www.cordis.lu/en/home.html>

Prosoma web site <http://www.prosoma.lu/>

Appendix B

Call for Co-operation

Master's Thesis on Smart Equipment

Dear Sir/Madam,
I write to you with a call for co-operation.

As a senior undergraduate at the School of Electrical Engineering and Information Technology, the Royal Institute of Technology, Sweden, I have recently started my Master's Thesis work. In my thesis I will make a survey of commercially available smart equipment, spanning from toys to house automation products, in order to get an overview of the current market and see if there are any truly smart products out there, or if it is just a marketing gimmick. I also hope to be able to gain insights from the cutting-edge work done by researchers around the world.

One of the main goals with the survey, apart from getting an overview, is to analyse the products in regard to machine learning strategies and to what extent agent technology is used, or could be used, to achieve the intelligent behaviour.

My advisor for the thesis work is associate professor Magnus Boman, of the Department of Computer and Systems Sciences, University of Stockholm, Sweden.

I believe that the work you and your colleagues/company are doing in this field would be very interesting to incorporate in the survey. Hence, I would truly appreciate if you could help me by letting me into your recent results.

If you would benefit by a survey like this, it would be my pleasure to keep you updated on the progress of the thesis.

Best regards,
Göran Eneroth
- - - - - - - - - - - - - - - - - - - -

[Contact information]

Appendix C

CD-ROM and Mindmaps

An important part of the thesis work is transfer of knowledge. Both between me as author and readers of the thesis, and between me and my advisor, in order to keep him updated on my work. To be able to report my results to my advisor, in a way as convenient as possible for both parties, I compiled the found material on a CD-ROM.

Layout of CD-ROM

The CD-ROM is divided into eight categories; Articles, Companies, EU, Links, Mindmaps, Misc, Research, and Thesis. Each category consists of up to 30 subsections, which in turn contains web pages, papers, and other kinds of electronically published material.

Mindmaps

I found it hard to maintain a good overview of the substantial amount of material I collected in the survey, and realised the need to summarise the findings. Hence, I made a set of mindmaps.

Later I discovered that the mindmaps could serve as excellent points of entry to the material on the CD-ROM, by making hyperlinks between the symbols on the mindmaps and the information on the CD-ROM.

Figure C.1 shows an example of one of the eleven mindmaps used; one of three mindmaps depicting research initiatives. As the mindmaps were saved in html-format, they could be viewed, and used to access the material, with any web browser currently available.

The mindmaps were made with Visio Technical.

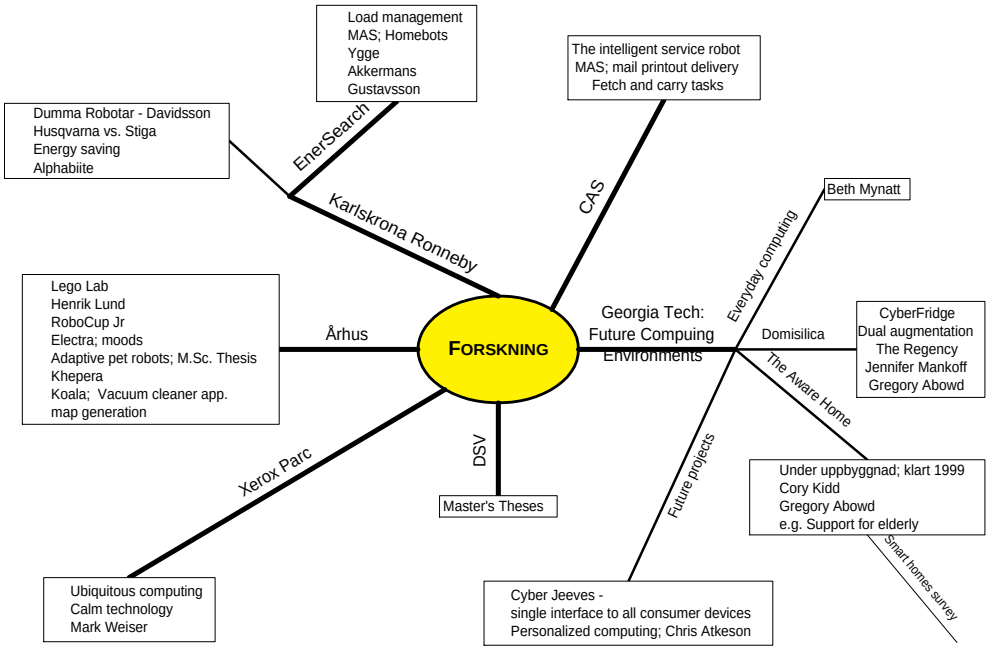

Figure C.1: Example of a mindmap. This is one of three mindmaps depicting research initiatives.

Appendix D

BibTEX reference

```
\usepackage{url}
```

```
@MastersThesis{eneroth2000:MScThesis,
  author =       {Göran Eneroth},
  title =        {Smart Equipment},
  school =       {School of Electrical Engineering and Information
                  Technology, Royal Institute of Technology},
  year =         2000,
  type =         {Master's Thesis},
  month =        {February},
  note =         {Available from World Wide Web:
                  \url{<http://www.d.kth.se/~d95-gen/thesis/>}}
}
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