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# Designing a sensor toolbox for reactive environments and smart objects

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# Designing a sensor toolbox for reactive environments and smart objects


## Abstract

This thesis describes the design and development of a sensor toolbox to be used for building small prototype microcontroller units. In this context, a toolbox is a kit of sensors along with other building blocks useful for rapid prototyping. The building blocks are sensors, communication equipment, software modules and standard electronic components. A user of the toolbox should be able to rapidly assemble a microcontroller unit e.g. to measure temperature and air humidity and then transmit that data via radio to another unit.

The emphasis during the design process of the toolbox has been on flexibility and usability. New sensors and electronic components can easily be appended and existing parts of the toolbox can be rearranged to customise it for new applications. Since people without deeper knowledge in microcontrollers and electronics should be able to use the toolbox, there has also been a focus on simplicity and modularity. To a big extent, software and sensor building blocks can be used without any knowledge of their internal functions.

It has been established that this sensor toolbox could be very useful for rapid prototyping. In addition new interesting suggestions of continuation and extensions of the toolbox have been discovered. However, some difficulties have also been stepped upon. There is a trade-off between performance and easiness to use the toolbox. For non-experienced users to be able to assemble systems all building-blocks must be high-level i.e. no great knowledge of electronics and programming should be required. This implicates limitations in the sensor toolbox performance.

# Utveckling av en verktygslåda för att bygga intelligenta ting och miljöer


## Sammanfattning

I detta examensarbete redogör jag för hur jag skapat en verktygslåda som skall användas för att bygga små mikrodatorstyrda prototyper. Denna verktygslåda innehåller sensorer, kommunikationsenheter, mjukvarumoduler och elektiska standardkomponenter. Med hjälp av verktygslådan kan man snabbt bygga en mikrodatorstyrd enhet för att exempelvis mäta temperatur och luftfuktighet och skicka dessa data till en annan enhet.

Det har lagts en stor tonvikt vid flexibilitet och användbarhet. Verktygslådan kan utökas med nya sensorer och komponenter; dessutom kan redan ingående delar ändras för att passa nya tillämpningar. Eftersom även personer utan djupare kunskap inom mikrodatorteknik och elektronik skall kunna använda verktygslådan har också enkelhet och modularitet prioriterats. Man kan i tor utsträckning använda verkstygslådan utan att känna till den inre funktionen hos delarna.

Det har visat sig att denna verktygslåda är användbar för att snabbt bygga prototyper. Dessutom har många förslag till vidareutveckling upptäckts under arbetets gång. Dock har även vissa problem upptäckts. Det blir alltid en avvägning mellan verktygslådans kapacitet och lättheten att använda den. För att ovana användare skall kunna bygga system måste samtliga ingående delar vara på en hög nivå dvs användaren skall inte behöva ha stora kunskaper inom elektronik och programmering. Detta innebär en begräsning i verktygslådans möjligheter.

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Stockholm 9 January 1998

Jon Persson

# 1. Objective

The objective of this project was to design a sensor toolbox as well as describing the underlying needs and fields of applications. A sensor toolbox is a utility with electronic components for building microcontroller units that can sense and react to their environment. It should contain a disperse variety of sensors as well as communication facilities. A sensor is an electronic device that senses a physical entity and transforms it into an electrical signal. The main purpose of a sensor toolbox is to speed up and to simplify the building of prototypes of so called smart things and reactive environments. The definition of smart objects in this context is everyday objects with integrated computers. An environment can be considered reactive if it collects and responds to changes in its surroundings.

The toolbox should enable people without a deeper knowledge in sensor technology and computer science to build small microcontroller units for data acquisition or simple control applications. This also requires software modules and examples to simplify writing software for the microcontroller.

One practical example, using the sensor toolbox, should also be built as a proof of the concept.

# 2. Introduction

In chapters 3 through 5 three research areas, CSCW, Ubiquitous computing and Affective computing are described. They all share the need for sensor technology and communication features in reactive environments and for smart objects. Typically the sensor toolbox will be used to build prototypes for different projects within these research areas. Hopefully the reader will gain a greater understanding of the possible applications of the sensor toolbox when reading these chapters.

An environment is considered reactive when it detects activity and senses physical entities e.g. in a room. Sensors can detect movement, locations of objects and humans, temperature, air humidity etc. This acquisition of data is then leading to some type of response or reaction. Smart objects are basically objects with integrated computers. They can either be ordinary objects into which computing power has been added or objects designed especially considering that computers can enable new properties.

In chapter 3 CSCW is described and the emphasis is on one of the most interesting areas in this field of study, media spaces. A media space is an "electronic media, like video communication, that has the property of altering and augmenting physical space" [Tollmar et al.. 1997]. The VideoCafé at CID is a media space using cameras and monitors to obtain a link between CID and Ericsson. When designing a media space there is a need for a reactive environment. Chairs and sofas should know if someone is sitting there to enable the camera to zoom in on persons in the room. The floor and the walls need sensors to measure air pressure, light, noise level, temperature and also where in the room people are standing and if there is anyone in the room at all. It is also described how the use of sensors can help to find solutions to many of the problems within CSCW.

In chapter 4 ubiquitous computing is explained. Since it aims to make many computers available throughout the physical environment, but making them effectively invisible to the user, sensors will act as input devices to the computers. A computer that constantly requires human input can never be made invisible. Hence it is wanted that the computer is intelligent enough to gather wanted information on its own e.g. using sensors.

Affective computing is described in chapter 5. This field of study differs a bit from the examples of CSCW and Ubiquitous computing because it requires sensors to measure human states such as blood pressure, sweat, body temperature and heart rate. The problem is not to measure those entities but to make intelligent conclusions from the readings; how should a computer react when a person sweats a lot, breaths heavily, has an increased body temperature and an abnormal heart rate? It could mean that he has caught a cold, that he just came back from a jog or maybe that he hit the jackpot on the lottery. And there are even more complex problems where data acquisition is facile but interpreting is very difficult indeed. One such example is brainwaves. They are straightforward to measure but they look like white noise when monitored. Mathematical models and Fourier transforms are needed to interpret the waves.
The descriptions of these fields of study will give the reader an understanding of the possible needs and applications involving sensors and embedded microcontroller systems and also serve as an extended background of this thesis.

In chapter 6 some smart materials are described. They will play an increasingly important role in the technological designs of the future. Sometimes a smart material itself can be used as a sensor or as an actuator. In the two following chapters the toolbox is described and explained. These are of course the main chapters of this thesis. And finally, in chapter 9, it is described how a prototype, to be used for research, is designed using different components in the toolbox such as microcontrollers, A/D-converters, sensors and other electronic components.

# 3. Computer Supported Cooperative Work – CSCW

### *3.1 Introduction*

CSCW is a relatively new research area, which involves people from diverse disciplines such as computer and social sciences. The first worldwide conference was held back in 1988. CSCW can be defined as computer-assisted coordinated activity carried out by groups of collaborating individuals [Baecker et al.. 1995]. Examples include communication and co-working documents and drawings. To enable this type of working situation new software is required. It is called groupware. With the rather loose and wide spanning definition of CSCW many computer applications such as e-mail may be defined as groupware even though many researchers in this discipline exclude them from the groupware domain.

One of the problems of working with new ideas and visions in CSCW is making a prototype [Grudin 1994]. There is a need to reach the critical mass of users because all users have different ways and techniques to approach new products or software. This has shown to be a problem difficult to solve since many test users mean high costs and long test time.

### *3.2 Groupware*

Groupware can be considered a paradigm shift in computer use. Because unlike other software, groupware accentuates multiple users and is focused on communication between humans instead of computer-human interaction. It involves communication between people at different places as well as people at the same place. An example of the latter is public computer displays and electronic meeting rooms.

There are two different approaches when developing new groupware. Collaboration transparency is basically a single user application that is used together with some special system software to make it groupware. The alternative approach, collaboration-aware system, requires more effort. The application in mind has to be significantly modified or even completely rewritten. The implementation of groupware in a network can be difficult since the network has to maintain a real-time consistent view of for instance a digital workspace [Greenberg & Marwood 1994]. Issues that have to be dealt with include synchronisation and concurrency control.

A distinction can be made between synchronous and asynchronous groupware. Synchronous groupware assists people that are working together as a group, all at the same time while asynchronous means that the work is being done at different times.

Typical examples of synchronous groupware include desktop conferencing systems, electronic meeting rooms etc. One of the milestones is Xerox Parc’s Colab project [Stefik et al.. 1987] in which a variety of multi-user interfaces were featured. All participating persons had interlinked workstations with tools for collaborative brainstorming, sketching etc. The Colab was intended for use of 2 to 6 persons. This environment proved to be very useful in enhancing the quality and efficiency of face-to-face meetings and workgroups. Since Colab was introduced in the late eighties there has been a tremendous increase of desktop conferencing systems and this is now one of the most important areas in CSCW.

One possible way of achieving collaborative real-time software is screen sharing. All users can make input to the software and they all have the same workspace that of course has to be consistent. According to the distinction made above this would hence be a collaboration transparency approach. A model that might be better in some work groups is to use window sharing where users have a common visible-to-all window but also a private workspace. This enables the user to work with own thoughts and ideas (and also handling private matters) without using the common workspace.

Another example in which synchronous groupware is used is media spaces. At KTH, CID, have in cooperation with the Ericsson Medialab designed a media space called the VideoCafé [CID]. The aim of all media spaces is to overcome the obstacles of physical separation. The Video Café has a permanent Internet ATM connection between CID and Ericsson that communicates real time sound and video. This system aims to make meetings and collaborative work more efficient and the physical distance easier to bridge.
In picture 1 the VideoCafé at CID is shown. The Ericsson Medialab can be seen on the monitor.

**Picture 1: The VideoCafé at CID, KTH**

*Source: Konrad Tollmar*

The other groupware domain is asynchronous communication. Applications include asynchronous conferencing (bulletin boards), email and organisational memory. It is clear that the most successful and widespread asynchronous groupware is electronic mail. Coming email protocols will support graphics, sound and even video [Borenstein 1993]. Since email can be multicasted i.e. sent to several people it is a very useful groupware. However problems arise today when receiving to many emails or when searching in databases where information is too abundant and poorly organised. These problems are likely to increase as more and more people get access to the Internet and other data communication systems. The need for systems to organise and categorise email and other incoming information is constantly growing.

### *3.3 CSCW problems to solve*

CSCW has lead to new studies of human interaction and communication but there are still many problems with this technology; the communication is not rich enough, using the technology implies more unwanted work and there is also a problem with user availability. The first of these three main problems can be minimised by an abundant use of sensors [Grudin 1988]. In the VideoCafé project it has been suggested that two different locations can melt into one, sharing the same humidity, temperature and light. The problem is however too complex to solve simply by coordinating the physical aspects of the environments.

The second problem, with CSCW creating new work and new tasks that the user has to fulfil, can also be helped with the use of sensors [Ishii & Ullmer 1997]. Many configurations and other settings can be automated to avoid that too much extra work has to be performed by the user. If users have to focus on the technology instead of on communication, the benefits of the technology will be partially or completely lost.

Finally, the problem with user availability cannot be solved only by using sensors. But within the possible solution there might be sensors included in ubiquitous objects giving users a better access to other users and hence increasing the availability of the carrier of the object. These objects might be cellular phones or smart badges.

### *3.4 Discussion*

Many, but not all, CSCW applications require sensors. Very often there is a need for high level sensors such as video or audio sensors. These applications require much computational power and can hence not be built using small embedded microcontroller systems.

To gain a greater understanding for the need of different sensor types within CSCW project, a mediaspace like the VideoCafé can be considered. In its optimal appearance a mediaspace like the VideoCafé has no other user interface than an on/off-button. Instead the environment should be reactive and intelligent and sensors should register the movements and locations of people in the room. Piezo sensors in the floor can detect where people are standing, stretch sensors or pressure sensors can detect where people are sitting etc. One could also imagine that the three interconnected rooms should have the same temperature, air humidity and lightness. This requires sensors as well as computer-controlled ventilation and lights.

# 4. Ubiquitous computing

In the preceding chapter a short introduction of CSCW was given. Ubiquitous computing applications differ from many CSCW applications in the sense that they need to be smaller and the focus is more on the human-technology interaction than on human to human interaction.

This chapter will also show that many ubiquitous objects are nothing but wearable microcontroller systems with as well sensors as communication features. Hence, the sensor toolbox can be used for building different types of prototypes of mobile and ubiquitous objects.

## *4.1 Background*

The first step in the development of computers was mainframes – many people used one computer. As computers became cheaper, more widespread and more user friendly the second phase began where one person used one computer (often a PC). This phase is still peaking. The next generation, Ubiquitous computing, is now coming strongly.

Ubiquitous computing is the method of enhancing computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user[7]. The interaction with the computers is transparent and well integrated in our everyday lives. It's based on the idea that humans should use computers without reflecting over it. Today, people still use computers to solve a certain task. But in the future there will probably be many computers in our environment that work independent and without the users attention.

The term "Ubiquitous computing" or UbiComp was invented by one of the pioneers in this field of study, Mark Weiser at MIT [Weiser 1997a]. Ubiquitous computing involves microelectronics, computer sciences, sensor technology, social sciences and human factors. Mark Weisers vision of the future is an environment soaked with computers. They will be integrated in everyday objects and environments e.g. pens, clothes, kitchens (to an even bigger extent than today) and even worn in watches, necklaces and shoes. These are called wearable computers where "wearable" symbolises more than just smallness and lightness. Wearable computers have to fulfil a certain need or purpose for the user.

The initial incarnation of ubiquitous computing was in the form of "tabs", "pads", and "boards" built at Xerox PARC, 1988-1994. These were fully functional prototypes, in everyday use by PARC experimenters.

The Pad was a prototype pen computer [Weiser 1997b]. It had a 4-hour battery life, and weighed 2.5kg. It used a Motorola processor with 4 MB ram running a unique real-time OS. The Pad featured an electronic pen designed at Xerox with a built-in microphone, a 640x480 display, keyboard and serial ports. The Pad could communicate through an infrared transceiver at 19.2kbs, through a near field radio at 240kbs, and through a 1Mbs wire which also supplied external power for operation and recharging. A complete Pad system also had a radio base station that served as a recharging station and Ethernet gateway for the Pads.

The Tab was a prototype handheld computer [Weiser 1997c]. It had an ability to sense its position within a building. It was palm-sized and had a 2 week battery life on rechargeable batteries, and weighed 300g. It used a Phillips 8051 processor with 128k RAM. It featured an external $I^2C$ external bus, a custom resistive touch screen, and a 128x64 mono display. A complete Tab system included an infrared base station in the ceiling for LAN connectivity. The Tab project is considered by many to be the most significant of the three prototyping efforts. It's a good example of ubiquitous computing – the system is designed under the assumption that the tab will be worn at all times. It doesn't have an on/off switch. Instead it simply turns on when someone starts interacting with it.

**Picture 2:**
**The XeroxPARC Tab**
*Source: http://www.ubiq.com/parctab/*

### *4.2 Hardware requirements*

The designers of processors have always let the need for high speeds dominate the need for low power consumption [Weiser 1993]. This is something that has to be changed to enable autonomous computers. The power consumption in a chip falls off as the square of the applied voltage. Hence, processor manufacturers are now manufacturing processors with 3,3V instead of 5V. This could mean that there is a need to lower the clock frequency and to make the processor bigger due to more parallelism and pipelining to compensate the lower frequency.

Since computers are destined to be everywhere they must also be cheap and small. Since that is already achieved and still continuously improved this is no longer a problem. On the other hand many people still think that a PC is the only needed computer in a regular home. Mark Weiser uses the parallel of the vanishing of electric engines [Weiser 1991]. In the beginning of the century a single machine powered the entire factory through a complex system of shafts and pulleys. Today an ordinary car has small and cheap electric motors integrated everywhere.

Another problem that has to be addressed when objects are made intelligent and communicating is networking. All such objects will send and receive data from other objects as well as from humans. Probably many of them will also be mobile. This requires a combination of wired and wireless networks that can support hundreds of mobile communication objects in each room.

### *4.3 Applications*

There is no doubt that as computers become smaller and at the same time cheaper, new computer applications will be invented. Who would have thought only ten years ago that there would be portable computers the size of a wallet and with the functions of a PC, mobile phone and fax integrated?

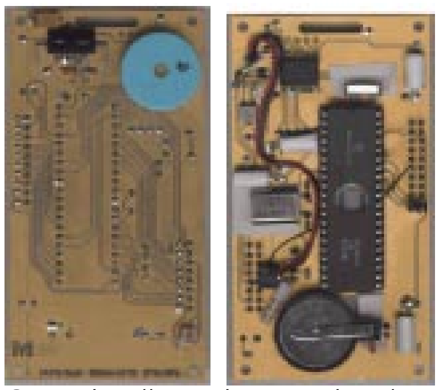
Tomorrow's world will most certainly, literally speaking, have computers everywhere. There will be computers in our shoes and clothes, in ceilings and floors and maybe even inside our bodies. Since computer memory constantly becomes cheaper there might soon be a possibility to wear a tiny digital video camera in spectacle frames. This camera could then register everything that is observed and store that information in a memory. This means that a person using this equipment will at any time be able to replay a previous part of his life. Tests have been performed at Sony by Katashi Nagao and Jun Rekimoto where the environment is experienced through a wearable computer. This computer is equipped with a camera and the users watch a LCD instead of reality. This allows the user to ask the computer questions about objects on the LCD. An interesting topic, which is outside the scope of this thesis, is whether people will accept this new technology and its effect on human perception. According to [Thad Starner et al.. 1997] at MIT, the first researchers to try camera-based reality, this technology has applications in repair, maintenance, medicine etc.

## Active badges

The Active Badges originate from Olivetti Research Laboratory (ORL). An Active Badge is a personal badge that mainly is used to track the wearer within a building. The ORL badge transmitted its identity using an IR data link. Sensors that were distributed inside a building detected the presence of badges and communicated the information to a main system. Today new versions of the Active Badge are worn at many places around the world, mainly research labs and universities. Since these badges are personal they cannot protect integrity and privacy because anyone can record the identity of someone's badge and then use that information to locate that person or claim to be that person.

**Picture 3: The Smart Badge**

***Front view*** ***Back view***



*Source:http://www.elec.uow.edu.au/people/staff/beadle/badge/wearable2/wearable2.html*

G. Q. Maguire Jr, H. W. Peter Beadle and M. T. Smith Gerald are involved in the design process of another type of badge, the Smart Badge [Maguire et al.. 1997]. This badge has multiple sensors, infrared communication link and some other features. Security and privacy have been well considered (even though the designers' ambition has not been to design a foolproof system) and the Smart Badge data is encrypted. As mentioned previously the problem with badges bursting their identity is that someone might record that infrared signal and then send messages to the system claiming to be that badge. Maguire, Beadle and Gerald have come up with a solution to that problem. When the badge is turned on it has a default encryption key and identity. Then the system sends a message to the badge containing a new, randomly chosen, encryption key. This key can then be altered regularly to prevent snifters from using the badge's identity.

### *4.4 Discussion*

One of the most important features of ubiquitous objects is their communication feature. Humans will most certainly in the future carry communication devices that enable a permanent connection to the Internet. There are already much research on how to design wearable computers, where to wear them and how to wear them.

The Active Badge and other similar devices might one day be a widespread ubiquitous object that many people will use. It is of course very neat if all electronic equipment carried could be integrated into one unit. Many people carry mobile phones today and they could in the future contain an active badge making many other devices obsolete e.g. keys, credit cards and driver's license.

The drawback of many ubiquitous computers and objects is their lack of security. To be useful they must have some identification, which means that they can be monitored and often located for instance within a building. If the computer is also gathering and storing information there is a great danger of losing integrity.

# 5. Affective computing

## *5.1 Introduction*

R.W. Picard at the MIT Medialab, defines affective computing as “computing that relates to, arises from, or deliberately influences emotions” [Picard 1995, Picard 1997]. The reason why affective computing is so important is that neurological studies have shown that emotions play an important role in human intelligence and interaction. Emotions are not separate from other human factors such as perception, conception and interaction. Endless possibilities would be the result of a better understanding of human emotions.

Almost all other interfaces would become obsolete if the brain and the human body could talk to computers simply by using thoughts. This is indeed a fascinating perspective and it would also give a new dimension to wearable computers, which could then interact solely by sensing and interpreting thoughts and physical entities of its bearer.

## *5.2 Applications*

Of the different types of computing systems, computer-supported communication, and other research areas described in this thesis, affective computing is the one with the most mind-thrilling possibilities. Imagine computers integrated into clothes and walls whos reactions are based on the mood or emotional state of the person wearing the clothes or being in the room.

The most known and used affective computing system is the lie detector. Physical states such as heart rate and hand sweat are measured. But as with many affective computing systems, the accuracy is poor partially due to the difficulties of interpreting the accumulated data.

Affective environments could change or enhance different moods. A virtual disc jockey could suggest different music styles depending on the listener’s emotional state. Lights, temperature and sound could be adjusted to suit different moods.

Measuring sentic responses would also be useful for companies when researching their public image. They could measure people’s reactions when exposed to the companies’ logotype or when walking into their office. This is so effective because a well working affective computing system can never be fooled. Hence there is also a big risk in this technology, matters of individual integrity must always be considered.

## *5.3 Body sensors*

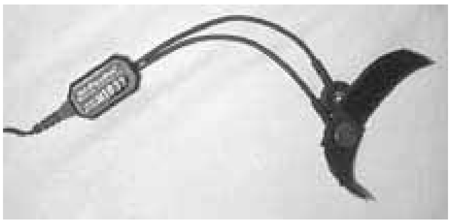
A few common sensors that could measure the physical state of their wearer will be described in this section. They have been tested by researchers at MIT [MIT]. The sensors are pretty straightforward but since body signals often are very low in power, sometimes amplifiers and filters are used before processing the signals.

**Respiration sensor**

This sensor can either be worn around the chest or over the diaphragm. The stretch of the belt is transformed into a voltage. Since this is not a binary sensor it reveals more than just the rate of respiration; it also measures the depth of the breath.

**Galvanic skin response sensor**

Skin conductance is considered to be a function of the sweat gland activity and the skin's pore size. Hence by applying a very small voltage and measuring the current the conductance can be computed. When a person experiences anxiety the skin conductance increases rapidly. However there is a big need of calibration because skin conductance varies with gender, diet and skin type.



**Picture 4:**
**Galvanic skin response sensor**
*Source: http://www-white.media.mit.edu/*

**Heart rate sensor**

The Blood Volume pulse sensor uses photoplethysmography to detect the blood pressure and hence the heart rate. Photoplethysmography is a process of applying light and measuring the light reflected by the skin. At each contraction of the heart, blood is pumped through the peripheral vessels, producing engorgement of the vessels under the light source and thereby changing the amount of light on the photo sensor. Blood pressure measurement can in addition to sensing heart rate also display changes in sympathetic arousal. High blood pressure indicates decreased sympathetic arousal.

## *5.4 Discussion*

There are not many problems in acquiring data from the human body. Entities such as blood pressure, heart rate, sweating, body temperature and brain waves are easily measured. So the problem lies within interpreting and in some cases processing the data.

Imagine that we measure some physiological states on a human body. The signals that require processing such as brain waves and other complex measurement results from the neurological system, are processed and analysed. That would give many physiological aspects of that person but that does not solve the problem. Because the really difficult part is analysing and interpreting the data. For instance, what conclusions can be drawn from the fact that the test person uses a small patch in the back part of his right brain half whilst the blood pressure is high and the sweating is low?

Hence the problems are, as one might expect, mainly of medical and psychological character. And understanding emotions is crucial to design affective computing systems which is why different scientific disciplines must work together. Other issues, outside the scope of this thesis, must also be considered. There is obviously a great danger in computers sensing and interpreting human emotions.

# 6. Smart materials

### *6.1 Introduction*

In this chapter some smart materials will be described. As constructions are getting more and more complex the choice of materials has to be more rigorously considered. Smart materials can play a fundamental part in a design. Instead of just being used as a passive piece of material, they can be the functional base of an object.

When using a traditional approach to product design one of the first steps is to decide a suitable material. Considerations will include price, strength, toughness, fatigue resistance, weight etc. But when using smart materials new possibilities are made available. These new types of materials can be considered an integral component of the product. They can be used to enhance functions without adding any new electronics or mechanics.

Many materials can be considered smart. But what is it that makes a material a *smart material*? Well, a transistor is made of silicon doped with small amounts of materials like Aluminium, Gallium or Arsenic. But even though this piece of doped semiconducting silicon is very similar to intrinsic silicon that is an element, a transistor is not what we think of as a smart material. A possible definition of a smart material might be a material that replaces a previously used passive and non-smart material thus enhancing the function of the object.

### *6.2 Examples of smart materials*

Since only an informal discussion of the definition of smart materials is given in the introduction some examples will in this section illustrate what smart materials are and what they can be used for.

**Piezo electric crystals**

One of the most common smart materials is the piezo crystal. It has the property that when exposed to vibrations it generates a voltage but it does also generate vibrations when a voltage is applied across it. These properties are extremely useful in many applications because the very same crystal can be used both as an actuator and as a sensor. Power consuming products that are worn need some sort of power supply. Usually this means that batteries have to be added to the product, making it heavy, bigger and in need of recharging. In these kinds of applications piezo crystals could be used to accumulate electric energy from the movements of the body. This is in fact already reality. Some manufacturers of watches use this technique to power their watches without batteries. There are some problems however using this technology. The voltage that is induced by the crystal as a reaction to deformation is sometimes spike shaped and there is hence a need of filtering the voltage pulses.

The properties of the piezo crystal enable a way to both sense and affect the surroundings with the same sensor. A crystal used to sense vibrations can also be used to generate vibrations i.e. a possibility to effect and sense the environment using the same object. When used together piezo crystals can be used to obtain a thin sensing layer e.g. like skin on a robot hand. Since the piezo crystals are very fast and reliable this layer can be sensitive enough to read Braille [UT-Arlington].

**Shape Memory Alloys**

Shape Memory Alloys or Muscle wires is today in use in many different applications. One of the most common memory alloys is Nitinol developed at the Naval Surface Warfare Centre. It uses the changes in crystal structure of the alloy. The name memory comes from the fact that these metals can be deformed when warm but they will still return to their original shape when cooled off. The memory is hence a structural or shape memory.

Metals consist of atoms arranged in crystals. Depending on temperature these crystal structures can be arranged in different manners. Most of the time this is a problem e.g. when you pour cold water into a hot frying pan it might change crystal structure and loose its flatness. But this property of metals can also be useful. An alloy of almost equal shares of Nickel and Titanium has a face-centred cubic crystal structure, FCC. FCC is the most compact metal structure, 74% of the volume are solid spheres (atoms)  [Callister 1993]. When this material reaches about 70°C a change in the unit cell angles[*] of the material result in a shortening of about 7%. Even though slower in transition than piezo crystals, muscle wires are much more powerful.

When this alloy is shaped in to thin wires these can be used as muscle fibres. When the temperature reaches 70°C the wire contracts like a muscle. NASA uses muscle wires on some of their satellites. When the sun heats the wires they contract and fold up antennas and other equipment without the use of motors or electricity.

When used in electric applications the best way to shorten the wires is to run a current through them. Since they have a small radius and aren't as good conductors as for instance copper, they heat up very quickly with a contraction as a result.

**Optical polymers and plastics**

When constructing new products the strength, toughness and fatigue resistance are problems that have to be addressed. Traditional methods such

[*] A unit cell is the smallest building block of a crystalline structure. It can be a cube with atoms in each corner or some other atom arrangement deciding density and shear strength properties of the material.

as finite element methods can be used generate computer modules of the stresses and strains in a construction but sometimes these tools are both too time consuming and too difficult to pursue. Hence there is a need for easier and cheaper test methods. One of the methods that has proven to be very useful, is to cast a model of the product in special polymeric materials. These polymers have the properties that they change colour when exposed to stress. This means that a model can be cast and then used to see in what parts the stress is biggest - a method that saves many hours of work at the same time as being cheap and reliable.

**Transparent displays**

There are many applications in which a transparent display would be useful. Messages can be printed on car windscreens and windows. The way to do this is to benefit from the fact that the refractive index of glass decides whether a light beam that hits the glass will go through it or get reflected from the surface. Using glass with an appropriate refractive index and a suitable angle at which the light hits the glass, it is possible to print text on a transparent glass.

Windscreens in cars could be used as instrument panels (or to display important warning messages) and wearable computers can communicate by printing messages on the inside of spectacles. Note that only persons standing in the right angle from the inside will be able to see the message.

**Electrorheological and Magnetorheological fluids**

These fluids contain particles that form chains when placed in an electrical or magnetical field. This results in drastic changes in their viscosity. These fluids can be used in tuneable dampers and different types of frictional devices such as clutches and brakes. But there are still many problems to solve such as abrasiveness and chemical instability [UT-Arlington].

## *6.3 Discussion*

As we have seen in this chapter many new smart materials open new possibilities and enables engineers to construct more advanced designs. Obviously it broadens the engineering possibilities when parts of a construction that used to be completely passive and non-smart, now can be replaced with smart materials. This development is very important when it comes to building human-like robots but also when building bridges, roads, clothes and cars. Another useful feature of many smart materials is the possibility of using them both as sensors and actuators.

# 7. Designing a sensor toolbox

## *7.1 Introduction*

There are many different research areas, some of them are described in preceding chapter's, that involve computers that acquire data without human's direct input. Hence, to accomplish this data acquisition, they use all kinds of sensors. A sensor toolbox should, of course, contain as many sensors as possible. It is also beneficial that sensors intended for a certain purpose can almost always be used in other applications as well. For instance when measuring the current flowing through a conductor a magnetic sensor is used. But this sensor can also be used as a door switch that checks if a door is closed or open.

## *7.2 Designing a generic sensor module*

In the beginning of this project the possibilities to design a generic sensor module, onto which different sensors and communication modules could be hooked up, was investigated. It would have been a box with ports for attaching sensors and other equipment. The problem is that such a unit would have to be very small which is not possible to achieve using prototype circuit boards with manually soldered, surface mounted components. As described later on in this chapter, sensors can be divided into different categories. So one might think that each sensor type could have one port on the device but the problem is that the required circuitry is more complex than that. Different sensors require different types of other components to work properly and they might have open collector outputs that must be connected to the battery through a resistor. That resistance does of course vary with different types of sensors.

A thorough calculation showed that a generic sensor module would have to feature at least twenty ports and many internal components. Hence, this generic module would be big and non-flexible. Therefore, it is better for the users of the toolbox to have premade simple electric drawings made for each sensor. When using the toolbox these drawings can be followed to set up sensor circuits and they will be used together with source code modules in which nothing but some parameters has to be altered. This might take a little more time than using a generic sensor module but on the other hand, users will benefit in flexibility, size and accuracy.

## *7.3 Microcontrollers*

### 7.3.1 Selecting a suitable microcontroller system

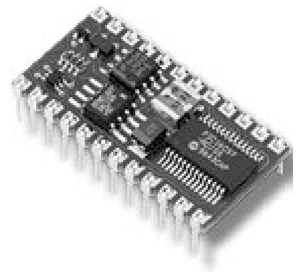
In the applications in mind a microcontroller with some special attributes had to be found. It had to be small, easy to use, and have a low power consumption.

The first option investigated was to manufacture a circuit board using a milling machine. On such a board (which would serve as a motherboard) a voltage regulator is needed along with a microcontroller, PROM and a reset circuit. It would have been something like 1dm$^2$ and not very power efficient. This solution would also have meant low flexibility. Hence, an integrated circuit with all of the facilities mentioned above had to be used. There are a few companies that manufacture so called embedded microcontrollers in which all of the features mentioned above (i.e. voltage regulator, microcontroller etc.) are integrated on one single chip.

One company called Wilke Technology GmbH [Wilke] ventures a series of microcontrollers, designed mainly for industrial purposes. Their smallest version, the Basic Tiger, is a very powerful microcontroller that runs a multitasking version of BASIC. It also features dynamic task prioritising and has plenty of memory. A useful feature is the two optional RS-232 ports, something that otherwise requires an external module. RS-232 is the standard for the serial port on a PC. Since it is using different voltage levels than a microcontroller the two of them cannot communicate directly. But all these great features of the Basic Tiger is, in our perspective, also a disadvantage because with it comes a very high power consumption (up to 400 mW). It also requires a 5 volt power supply, which means that a 9V-battery can't be used unless an external voltage regulator is added. Another factor that has to be considered is that the PROM on the Basic Tiger is not an EEPROM (Electronically Erasable Programmable Read Only Memory) which means that it has to be erased with UV-light before reprogramming.

The PicStick is a less advanced microcontroller from Micromint, Inc [Micromint]. It comes in four versions, PicStick 1 through 4. It is programmable in assembler, PBASIC and C. It is very fast and useful even though it is very small. The PicStick is a lot more suited to the applications we have in mind than the Basic Tiger. The clock frequency is only 4 MHz but that is well compensated by the high level of parallelity. The only instruction that requires more than one clock cycle to execute is branches within the program. The possibility to program the PicStick in assembler and low-level C is attractive but the software modules in the sensor toolbox much be extremely easy to use so PBASIC is a better alternative. Even though the PicStick seems quite appropriate, the embedded microcontroller that was found to be the most suitable for a sensor toolbox was the Basic Stamp II from Parallax, Inc [Parallax]. It will be described in the next section.

### 7.3.2 The Basic Stamp 2



**Picture 5:**
**The Basic Stamp II**
*Source: http://www.hth.com*

Basic Stamp-technology has been around for a couple of years and is mainly used in home automation systems and simple control applications. The name originates in the use of an advanced basic dialect called PBASIC and that it is the size of a post stamp. Few other technologies are competitive in this application domain. In this project the Basic Stamp II has been used (abbreviated "BS2-IC"). It's a sequel of the first version and it has more memory, higher clock frequency, 16 instead of 8 I/O-pins and also some additional PBSIC instructions. It has a very low power consumption, typically 7mA, but it can also take a nap during which it only uses 50µA.

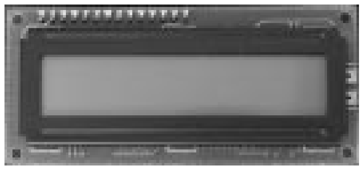
The used PIC, 16C57 from Motorola semiconductors Inc, is an 8-bit RISC processor with a built-in PBASIC interpreter. On one singe board, the size of a 24-pin DIL, which is about $5cm^2$, there is a 20MHz microcontroller and a voltage regulator that allows the user to feed the circuit with 5-12V. However, one drawback is that the maximum output current of the Basic Stamp on one pin is only 20mA and the in total it can source 50mA (Equal to a power of 250mW). The PROM used is a 2kb EEPROM. This means that you don't need UV-light to erase previously stored information (EE stands for Electronically Erasable). UV-light erasing is cumbersome and simply a waste of time. But with the Basic Stamp you automatically overwrite the previously stored information when reprogramming the EEPROM. The EEPROM can also be used to store run time information that should not be lost when deconnecting the power supply. Furthermore the Basic Stamp has a reset circuit and a 4V-brown out reset to make sure that the microcontroller doesn't get damaged due to low battery voltage.

Another very useful feature is the easy analogue I/O handling with the Basic Stamp. It can generate fake PWM signals (Pulse Width Modulation) to enable analogue output, DMTF tones for telephone applications or any other wanted frequency below 32kHz. The reason why the PWM signals are called "fake" is that they do only assure that the average output voltage between 0-5V is correct but it is still not true PWM-signals. When monitored with an oscilloscope the signal seems completely random.

The Basic Stamp II meets all the requirements we had and in addition, it features some very useful commands and functions that the other investigated microcontroller do not. Hence, the BS2-IC was the choice for the toolbox.

### 7.3.3 Debugging autonomous units

It is easy to build a programming cable allowing the BS2-IC to communicate with a PC and while they are connected variables can be downloaded to the PBASIC editor on the PC from the BS2-IC. But when it is unconnected, working autonomous, communication could be rather difficult. Simple output and notifications can be performed with LED's. Voltages and currents can be measured using a multimeter. But some things aren't measurable such as the time it takes to decharge a capacitor. Hence to debug a program and to get reliable data a better communication medium is required. This is why a LCD is very useful. It can communicate serially with the BS2-IC allowing the user to debug the program as well as to monitor the input from other peripherals e.g. sensors.



**Picture 6:**
**LCD backpack**
*Source: http://www.hth.com*

The LCD is of course also very useful in applications where many interactions are required. Using some switches and buttons to input data and a LCD for output one has got a very user friendly and effective interface. There are ways of using simple key pads with the BS2-IC but most of the times there is no need to input large amounts of data into the stamp.

The biggest disadvantage of the BS2-IC is not its operating speed. Though having a 20MHz clock frequency the drawback of using an interpreted language instead of a compiled language makes the BS2-IC quite slow. In most applications the 4000 lines of code executed each second is more than enough, but when used as a controller it sometimes is too slow. But the problem that can constitute a real problem in time critical applications is that interrupts can't be used which will really slow things down.

### *7.4 Types of sensors in the toolbox*

There are different categories of sensors and many of them can be divided into three of the categories below:

- Voltage changing
- Resistance changing
- Capacity changing

A distinction can also be made between analogue and digital sensors on one hand and linear and non-linear sensors on the other. The digital sensors are basically switches e.g. is there movement in the room or not. They are hence very simple (on/off). The non-linear can be linearised in software or hardware and then treated as linear sensors.

The voltage changing analogue sensors can't be read directly since a microcontroller is a digital device. An A/D converter is required to transform the analogue voltage signal into digital serial data

The other two types, resistance and capacity changing sensors, can be handled with a common method. The fact that the time it takes to decharge a capacitor through a resistance can easily be computed, is used. This means that an unknown capacity can be decharged through a known resistance and by measuring the time taken it's possible to compute the capacitance. This method can of course also be used if the resistance is unknown but the capacity is known. Hence all different types of sensors can be handled with just a few simple methods. But there are also sensors that require much signal processing. It is of course not appropriate to perform such calculations on a small microcontroller running Basic, but a BS2-IC can be used to collect and to monitor the data and then communicate it to a PC.

### *7.5 Tested sensors*

In this project all three types of sensors were tested. The selection of sensors was made by browsing a catalogue of electronic equipment and buying everything they had. The sensors were:

**Temperature sensor**

A temperature sensor handles temperatures from 2°C to 150°C with a sensitivity of 10mV/°C. A temperature sensor is very useful in many applications because too high or too low temperatures must often be avoided. It can also be used as a simple thermometer or for detecting human presence.

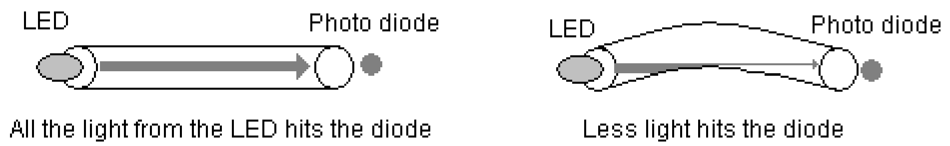
**Humidity sensor**

This Philips humidity sensor changes its inner capacitance with the air humidity. This could be used to control bathroom fans, rain detectors, detect humans breathing etc. It has quite a small capacitance at normal air humidity levels (122pF at 43% RH) which slightly lessens the accuracy.

**Photo diode – visible spectrum**

When the diode is exposed to light, a current can flow through this solid state device. The function is similar to when minority carriers are injected in the bas of a transistor to allow current to flow. Photodiodes can be difficult to use because the light in the environment changes. So if calibrating a prototype in the middle of the day it will loose its accuracy later at night when the sunlight isn't as strong. But they have proven to be very useful to detect the amount of bending in for instance a tube or in other closed

**Picture 7: Using photo diodes to decide tube bending.**




applications.

If a LED is placed in one end and a photo diode in the other the diode will be exposed to a maximum amount of light when the tube is unbent and less when the tube is bent. This has been used in robot hands to detect finger positions.

**Photo diode – IR spectrum**

The IR photo diode works like the photo diode for the visible spectrum but it is (or at least should) only be sensitive to IR-light which has a longer wavelength. Using IR can be useful to avoid humans from seeing the signals. Typical applications include wireless transmission such as remote controls.

**LDR resistor**

LDR is short for Light Detecting Resistor. It changes its resistance linear to the amount of light that hits its surface. It is easier to read than photo diodes and is used for the same types of applications. It is most sensistive at 560nm and has a darkness resistance of 500kΩ.

**Optic switch**

The optic switch is another light sensor. It has an open collector output that goes high when the sensor gets exposed to light. It is very easy to read but cannot give an analogue signal. During tests it has proven to be more sensitive to IR-light than visible light in contradiction to the manufacturers specification.

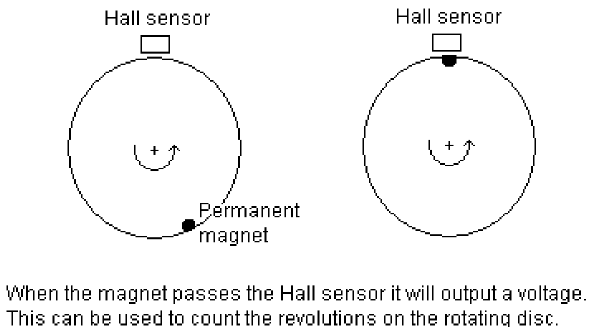
**Movement sensor**

A movement sensor is actually an IR sensing device that detects movement but false alarms can of course be triggered by other IR sources. Since it has a range of about 5m it can be used in automatic door applications. It is a digital sensor and doesn't give a grading of the amount of movement. This type of sensor can also be used for automatic lighting. The lights are only on if the sensor detects movement in the room.

**Hall sensor**

This sensor is based on the Hall effect [Streetman 1995] and is used to measure the density of a magnetic field. It basically consists of a p-doped semiconductor bar. It can be used as a current sensor or as a proximity sensor.

**Picture 8: Hall effect sensor used as a revolution counter**




**Magnetic sensor**

This magnetic sensor is employing the magneto-resistive effect of thin film permalloy. Can be used as a current sensor and as a proximity sensor. By attaching a magnet to a rotating shaft or flywheel it can be used as a revolution counter. Every time it detects a magnet one rotations has been performed.

**Accelometer**

An accelometer detects acceleration (forces). It can be used as a step counter for runners and they can also be integrated into objects to detect whether the object is moving or not (assuming that the velocity never is zero). Some accelometers can be used to detect vibrations but they are usually very expensive.

### *7.6 Communication*

Different applications must meet different requirements e.g. autonomity, smallness, robustness and low power consumption. These requirements can be met but sometimes there is a trade off involved. One might have to sacrifice autonomity to achieve a very small product or maybe loose some robustness to low power consumption.

When designing a sensor or microcontroller unit one must decide whether it is supposed to be autonomous or not. If it doesn't have to be autonomous there is a great reduction in the work required because:

- Power supply is no problem (through wire).
- Wires are used as communication media.
- Debugging can be done directly on a PC.

On the other hand, if the unit should be mobile and hence autonomous, many problems could arise:

- The unit has to be battery powered (implies limited life time and greater weight as well as size).
- Communication must be wireless.
- Debugging and monitoring is more problematic.

The communication issue can be dealt with in several ways. The most common is to use radio or IR. One good thing is that many radio transmitters and receivers, designed to be used in microcontroller circuits, accept serial data. There also IR devices that can communicate serially with high bandwidths. Radio transmission has the benefit over IR that the receiver doesn't have to be close (and visible) to the transmitter. But using radio also means higher power consumption and bigger units.

### 7.6.1 IP communication

In the future smart things in our homes will not only be smart enough to sense or affect the environment; they will also have communication possibilities. Hence it would be very good if all objects could be given an IP address to enable Internet communication. A company called iReady has designed an Internet tuner. A small chip with all the Internet layers in hardware making it very power efficient, cheap, reliable and ubiquitous. This chip can be integrated into all types of devices making them ready to hook up to the Internet. Also, connecting them to a LAN and to the Internet would open many other new possibilities. Configuring, testing and monitoring could be performed via a web-browser and information from the microcontroller units would be available on a network.

There are of course other advantages of using the Internet Protocol stack instead of designing new protocols for each application. It would give the toolbox a more generic approach and also increase the possibilities of appending new equipment.

### 7.6.2 IR communication

IR is a very easy and reliable way of transmitting data. Hence it is used in applications like remote controls. However, to transmit data over longer distances other communications media are more suitable. The semiconductor photo diode works almost like a transistor but instead of the base controlling the current through the device, the amount of IR light does. The current through a semiconductor is depending on the creation of minority carriers in the depletion region. These minority carriers can be generated by light, as is the case in the IR diode. The reason why IR is better than short distance radio is that the IR rays can only be emitted at a narrow angle which is letting the receiver know where the transmitter is located. Whereas using radio, the electromagnetic waves spread in all directions, this is not possible.

IR light is not visible to the human eye and has wavelengths from 700nm up to 1mm. We perceive it as heat. IR rays can not penetrate walls or doors, but does pass through glass partitions, and reflects very well off walls. Communication with IR is very useful whenever there is a need to transfer data between digital units. It simplifies all such operations e.g. digital camera to PC, PC to PC or PC to printer. Other applications include networking or making an automated payment at a point of sale. The weak part of IR communication is the limitations e.g. operating distance and the need for the transmitter and the receiver module to be visible to each other.

A fascinating fact of IR-transmission is that a higher data rate gives lower power consumption (one would think that high data transmission rates would cost more power). But since energy only is used when lighting the IR-diode to transmit a logical 1, keeping the lengths of the transmission down lessens the energy used. Hence, for mobile units communicating with IR the bandwidth should be as great as possible.

**The IrDa standard**

A standard in infrared communication has been established by a group of over150 companies, the Infrared Data Association [IrDa]. The member's list holds big companies e.g. Ericsson, Apple and Hewlett-Packard. The physical aspects as well as the software protocols are standardised.

IrDa standards are defined with the following technological key features in mind [CounterSys]:

- Range from 0 to 1 meter (minimum and maximum distance from device to device)
- Point to point communication (line of sight, not diffuse)
- IR Beam Angle limited to +/-15 degrees to control interference
- Supports speeds from 9600 to 4Mbit/sec with low cost parts.

Other considerations are low cost, low power consumption and high noise immunity. One of the objectives of IrDa is to make these opto-electronic parts and their implementation cheaper than the corresponding wire or cable set-ups. This is fulfilled using low cost components and integrated circuits.

### 7.6.3 Radio communication

Small radio receivers and transmitters are very useful in wireless applications. They don't need "free sight" like IR transmission and they can communicate over long distances with high bandwidth. However, Swedish law regulates the sending power which of course limits the range of the system. The system used in this project broadcasts with a power of only about 0.25mW. A SILRX-433-F FM radio receiver was used together with a RXM-433-F receiver from Low Power Radio Solutions Ltd. The system has such a great sensitivity that despite its low power broadcasting it has a range of several hundred metres in good conditions. Possible applications include alarms, lighting control, garage door openers and remote monitoring systems.

The problem with radio communication is that it only allows one way communication or maybe half duplex communication. Full duplex is of course not possible since the receiver of each module would pick up its own transmission and there would also be a considerable amount of interference. Half duplex requires a protocol that disables the two units to start sending at the same time e.g. a master/slave protocol or something like a token ring.

**Radio transmitter**

The TXM-433-F transmitter is a $3cm^2$ SIL, powered with 3V. This means that the transmitter requires a separate battery since the BS2-IC voltage regulator gives 5V. It accepts both digital and analogue data. It is very easy to send serial data to the transmitter with the BS2-IC. The microcontroller itself do not need to know whether the interface used is radio or wire. It just sends the data serially through one of its pins and the rest is taken care of by peripherals.

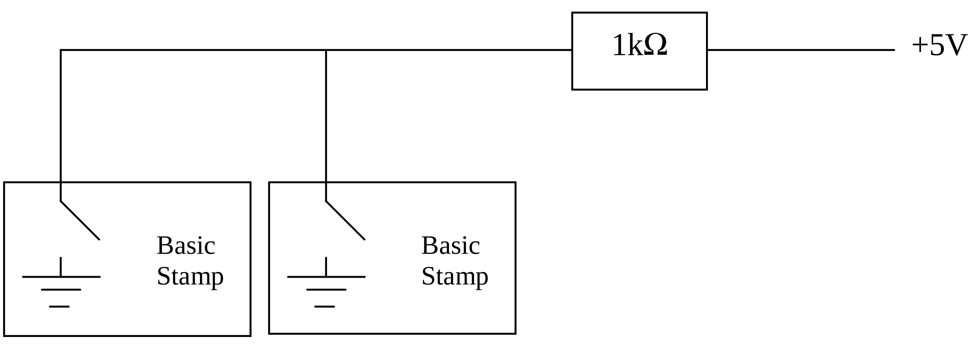
**Radio receiver**

The SILRX UHF FM superhet receiver is a 10-pin SIL, powered with 4-9V. Hence it can be powered through the BS2-IC unless many other peripherals are used in which case the maximum current limit of the BS2-IC prevents it. Then it can be hooked up to the battery immediately but the performance is better when the supply voltage is 5V. The receiver has both digital and analogue output, which can be very useful in control applications.

### 7.6.4 Networking Basic Stamps

The Basic Stamp has two internal power rails, one for Vcc(+5V) and the other for ground. When outputting a logical 1 the output pin is simply connected to the +5V power rail. The problem is that the input pin on the other Basic Stamp is connected to ground – short circuit and the Basic Stamps will be destroyed. At first the voltage regulator of the outputting Basic Stamp will burn causing dysfunction and maybe permanent errors. This problem can be addressed the following way:

**Picture 9: Avoiding short circuit**




*When the Basic Stamp outputs a zero the output switch is connected to the ground rail. When it should output a one it will be left unconnected. This assures that a shortcircuit cant occur.*

The Basic Stamps must also have a common ground because otherwise the data transmission will not work. A simple test can be done by hooking up two stamps together. Then, by letting one of them transmit a request for a number and the other respond with a random number the requester can display this number on a LCD. When connecting two or more Basic Stamps with wires some type of protocol might be required to prevent them from talking at the same time and loosing data. Token ring protocols are very easy to implement and they will assure that the Basic Stamps only transmit data when they are in possession of the token.

## *7.7 Other components in toolbox*

To build a complete circuit basic components like capacitors, resistors and wire are required. But there is also a need for other components. It is difficult to predict which components that users will need but some components are very common and must be included.

**A/D-converter**
An A/D-converter is used to convert analogue voltages to digital serial data. Many sensors output an analogue voltage so this component is essential. The converter used in the toolbox is a Maxim 170, which is an 8-pin DIL with relatively low power consumption. The A/D-converter is synchronous which means that the Basic Stamp has to give a clock signal during conversion. However there is source code for a subroutine called ADCONVERT which can be used in any program.

**Field Effect Transistors**
A field effect transistor can be treated as an electrical switch. In the toolbox there are both small low effect transistors and high power MOSFET's.

**Bipolar Junction Transistors**
Bipolar junction transistors can be used for amplification, which is very useful, since the Basic Stamp has limitations in how much current it can source. Hence a low current signal from the Basic Stamp can be amplified with a BJT.

**Operational amplifiers**
Operational amplifiers can be used in many ways. They can generate square waves, amplify a signal with unity gain and be used as comparators.

**Miscellaneous**
Other components in the toolbox include for instance fuses, diodes, diode bridges and mechanical switches.

## *7.8 Software*

The BS2-IC uses a Basic dialect called PBASIC. It resembles assembler and it does also have many very useful I/O instructions not found in standard Basic.

### 7.8.1 Using software modules

For a sensor toolbox to be useful it must be simple to assemble software for the microcontroller running the circuits. Commands like READSENSOR are very good. But, since the PBASIC and the BS2-IC have got so many useful built in ready-to-use features and commands there is little need for creating big software modules because reading a sensor can at many times be done with just one command. For instance when reading a sensor that changes its inner resistance or its capacitance the command used is simply RCTIME. However, other operations require more than just one or a few lines of code. For instance an A/D conversion is done in about 10 lines of code.

But of course the code can't do anything on its own. It needs an external circuitry and of course a sensor or some other device to deliver information. The sensor toolbox includes source code for several applications and for all the sensors.

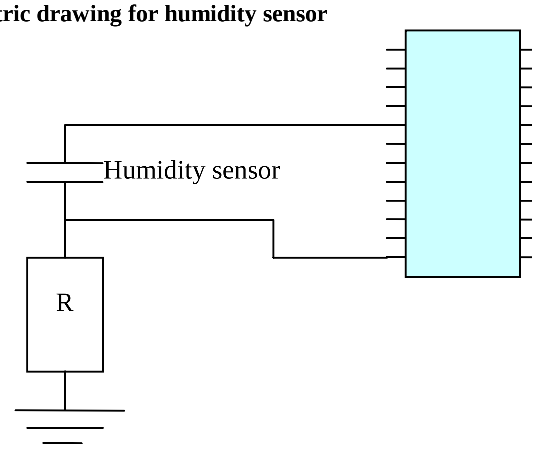
# 8. How to use the toolbox

In the previous chapter the components of the toolbox are described. In this chapter a more thorough and detailed description on how to use the toolbox is given.

## *8.1 Designing a microcontroller circuit*

Everything must start with an idea of a prototype solution. Assume that we want to build a microcontroller unit that measures the air humidity in a room. The best way to start the design process of a new prototype is to use pen and paper to sketch a prototype circuit using the premade electric drawings included in the toolbox documentation.

**Picture 10: Example of electric drawing for humidity sensor**




Then its time to set it up. In this first step a so called breadboard is very useful. On the breadboard all the components can be set up including the power supplying battery. It is very easy to change and rearrange the circuit. All the sensors in the toolbox have electric drawings and also software examples for easiest possible design process. To test the set-up the BS2-IC requires software. How the downloading of the software is performed is described below. When the circuit mock-up is fully tested and working all right the components can be soldered onto a prototype circuit board. This is a single sided circuit board with lines of copper that can either be used as a conductor or, when drilled open, to cause separation of two conductors.

When programming the Basic Stamp a 4-pin bus is connected to the serial port of a PC. Thus, it is wise to solder a 4-pin bus at the programming pins of the Basic Stamp on the circuit board to enable reprogramming of an already soldered circuit. With the example above (capacity changing humidity sensor) the software module for capacity changing sensors would be used.

```
' module for computing a capacity by measuring the time it takes to
' decharge the capacity through a known resistance

RESISTANCE  con 1        'Resistance in kOhms
TIME        var WORD
```

```
CAP         var WORD

DIRS =%1111111111111111


HIGH 0

Loop:
PAUSE 300
HIGH 7
PAUSE 1
RCTIME 7,1,TIME         ' Time resolution=2us
IF TIME=0 THEN TooBig
IF TIME=1 THEN TooSmall
CAP=TIME/(2*RESISTANCE) ' unit:nF
END

TooSmall:
PAUSE 100
GOTO Loop

TooBig:
PAUSE 100
GOTO Loop
```

The TooSmall and TooBig sections can be used to output an error message on a LCD or to light an error indicating LED. This software module has to be partially rewritten and code must be added but it gives the user a starting point and also advices on how to proceed. When this is done the software is downloaded to the BS2-IC and the circuit is ready to use.

## *8.2 Application of the toolbox – Virtually living together*

### 8.2.1 Background

This project performed by Konrad Tollmar, Stefan Junestrand, David Eklöf and the author, aims to find a way to overbridge the distance of two generations that live separately. Some hundred years ago, before the industrial revolution, several generations lived together in one home but today that is very unusual. This has invoked a need for contact and communication between generations. In this project we tried to create a way to communicate the level of activity in one home to another home. Typically a parent would like to know the activity in the home of a grown up child. Since no one wants to loose all privacy the monitoring must not be too revealing. Most people wouldn’t accept that parents could monitor them through surveillance cameras or by registering the amount of power or water used.

Although not scientifically proven the power consumption is intuitively a good measure of the activity in a home. Hence, we wanted to measure the amount of current used in the home. To display this activity measure in the other home a lamp was used. During high activity periods the lamp shines very bright but when the activity drops, the lamplight is damped. With this simple window lamp that changes its brightness we hope to achieve a more subtle and abstract form of togetherness without any loss of integrity.

When discussing the integrity loss of the person who's power consumption is measured it is important to have in mind that users of this product install the sensor themselves and that they give the lamp as a present to someone that they trust.

### 8.2.2 Technical solution

In the prototype a Hall effect sensor was used to measure the magnetic field around the main power line that supplies the home (the magnetic field strength is proportional to the current in the conductor). This signal was read and A/D converted to reduce noise and to enable digital signal processing. The acquisated digital data was sent serially through a bus to another Basic Stamp circuit integrated in the base of the lamp. Since this was a prototype we didn't solve the problem of transmitting the data over vast distances. The ready product must communicate the data using telephony/GSM or the Internet.

The magnetic field of the power line in a house can be simulated using a permanent magnet. However, there is a difference that requires an alteration of the used software when using the prototype on a real power line. A permanent magnet generates a constant magnetic field whilst the field around a power line follows the changes in the alternating voltage.

To control the lamp three different solutions where considered. The first was to use a high power BJT with a very high amplification. Since the BS2-IC is a purely digital device with no internal D/A converter it has to generate virtual analogue voltages. This is very easy since it has a built in PWM (Pulse Width Modulation) command designed for generating analogue voltages. By outputting a rapid stream of 1's and 0's the BS2-IC can generate an analogue voltage by using different distributions. A logical 1 is +5V and a logical 0 is close to 0V. Hence by outputting 50% 1's and 50% 0's the average voltage appearing on the output pin will be 2.5V. This distribution can of course be changed to generate other voltages within the range 0-5V. One might think that this stream of bits would make the lamp flicker but the changes are so fast that the human eye will smoothen the image just as it does when watching TV.

Since the BS2-IC also must do other things such as receiving the data from the sensor unit it cannot output a voltage all the time. But by using a RC-circuit it is possible to let the capacitor store the output voltage while the BS2-IC is doing other things. But of course the voltage will start dropping when the circuit that needs the analogue voltage uses the charge in the capacitor. The leakage current in the capacitor is neglectable since the current used by the circuit (in this case connected to the base of the transistor) is relatively large. To solve this problem an operational amplifier was used. The op.amp. was used in unity gain mode which means that it outputs the same voltage as it has on its input. But with a big difference; the op.amp can power the transistor from the battery so that the energy in the capacitor only has to power the amplifier itself.

The problem with this solution is that the transistor will dissipate much power. Since it is only a prototype this might be acceptable but in a commercial product it is not. Even though this solution gives the best control possibilities and the best accuracy another solution must be used.

To avoid the gigantic power dissipation it is better to chop the current into pieces using a high power MOSFET as a switch or using a thyristor. The thyristor solution would require the use of at least two optical connectors to synchronise the chopping with the AC frequency. But with the MOSFET solution the Basic Stamp can output logical high to open the transistor or logical low to close it and no other components are required. Since the net AC frequency in Sweden is 50Hz and the Basic Stamp can chop with a frequency of 4000Hz there will be no problem with flickering light. But there is another problem with the Basic Stamp. Since it can use interrupts, receiving data constitutes a big problem. It was solved using a bus with sex wires the constantly transmits data in parallel. This means that the BS2-IC at any time can read the bus without requesting or waiting for the other BS2-IC to transmit.

In summary the following components of the sensor toolbox were used:

- 2 Basic Stamps
- Hall effect sensor
- A/D converter
- High power MOSFET
- Resistors, capacitors, switches, LED's and a fuse

### 8.3 Discussion

The toolbox has, in the Virtually Living Together project, proven to be very useful for rapid prototyping and building small microcontroller units. However, its flexibility and usability is unfortunately greatly depending on the knowledge of the user. An experienced user can easily append new components and software modules to the toolbox whilst a novice probably will follow the given electric schemes and examples strictly.

But there are also many examples of Basic Stamp applications on the Internet[21]. Many hobby and professional users publish their work that way. These application examples can of course be used as they are or serve as inspiration for other projects. The main point is that almost anyone with some basic engineering skill can use the sensor toolbox to build small microcontroller objects.

However, the Virtually Living Together project has shown that the Basic Stamp is not well suited for control applications. Since it does not have an interrupt feature, getting asynchronous information takes too long. Hence in this specific application it would have been better to use a PIC programmable in C or assembler enabling the use of interrupts.

But the Basic Stamp did not only display its drawbacks. Using the earlier tested circuits and software modules in the toolbox documentation it was very easy to set-up a unit that could read a sensor, A/D-convert that signal, process it, and then send it in parallel over wire. This shows that the sensor toolbox is a very effective tool to build up small modules for information gathering and for setting up communication units.

# 9. Conclusions

In this project the needs for rapid prototyping in many research areas has been established. The use of the sensor toolbox will help to overcome some of the problems raised. Furthermore, it has been found that it is neither efficient nor useful to build a sensor device containing all the required circuitry and components into one generic unit. It is better to have components and sensor modules that can be combined using ready made electric drawings and software modules. This increases flexibility and usability. A modularity approach also assures the possibility of appending new modules to the toolbox.

When using the toolbox in the virtually living together project it was clear that the toolbox is very useful for rapid prototyping. Although the Basic Stamp did display some of its weaknesses the toolbox can be used for a disperse variety of applications. But it is clear that the drawbacks of the Basic Stamp are the biggest limitation of the toolbox. On the other hand replacing the Basic Stamp with another microcontroller will disable people without low level programming skills, in Assembler or C, to use the toolbox.

A continuation of this thesis might be to investigate the possibilities of giving IP-addresses to autonomous objects. There are already companies manufacturing hardware Internet interfaces that are very small, reliable, cheap and have a low power consumption. With one such IP-chip, a microcontroller and an IR-transceiver it is possible to build mobile units that can access an Ethernet through the IR and hence also the Internet.

Another possible continuation is to investigate the possibilities of using more advanced microcontrollers with software modules that less experienced users can assemble into complete programs. This would undoubtfully extend the number of areas in which the sensor toolbox can be used.

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