Ambient Assisted Living Joint Programme

Project full title:

Development of a non-invasive CAPactive sensor oral MOUSE interface for the disabled elderly (CAPMOUSE, AAL-2008-1-203)

Deliverable report:

D2.1: Sensor hardware component, working interface board and a software driver for USB/octopus/PC

AAL project number:
Project starting date: 15/06/2009
Project duration: 30 months

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Contributors: BD, HMC, LOTS
Planned delivery date: 28.02.2011
Actual delivery date: 30.06.2011

1. General

The content of deliverable D2.1 mainly consists of the description of the work done in T2.1 and T2.2

T2.1 Development of sensor hardware and interface

Development of the sensor hardware by Brusell Dental (BD) which will serve as an input to the following sensor development activities as well as into WP3 CAP MOUSE headset development.
Design and development of the hardware link between sensor array and PC. (Initially, in the prototyping phase, HMC will use the industrial version of the sensor hardware and will later switch over to the development solution of BD (at the beginning of T2.1) producing the same signal thus reducing considerably the costs for the finished product, which is an especially important issue for the elderly).
Participants: BD 6,5pm, HMC 3pm, Lots 1pm, PRO 0pm

T2.2 Sensor abstraction layer (driver) development for PC

Low-level PC driver for reading sensor data and possible configuration of the sensor array.
Participants: BD 1pm, HMC 1pm, Lots 0pm, PRO 0pm
(extracted from the project proposal).

Finding a suitable and good sensor is paramount in this project. In this particular case the demand on the sensor performance is really high and will determine the success of the project.

Building capacitive sensors is an art in it selves just because they can easily be influenced by environmental factors over which we have no control (moisture, air temperature etc.).

In this particular case we need to solve a whole set of requirements before we will be able to judge if the sensor solution will work out.

The main aim of T2.1 is to:

- build-up the know how in designing capacitive sensors, literature study
- setting up a list of requirements for the sensor development
- selection of a ready made sensors (industrial types)
- the state of the art in capacitive sensor design, new developments, new exiting electronic components
- building a link to a PC, provide means to develop the algorithm
- set-up a test plan to verify the performance of the sensor
- ideas on how to build an array of sensors
- provide preliminary physical sensor specifications to LOTS so they are able design a prototype headset
- draw conclusions

2. Literature study

2.1. General

From previous development work done the consortium has gained experience with capacitive sensors. However in this case the requirements will be so strict and the technology is moving so fast (new electronic components emerge almost every day) it seems crucial to be well prepared and to make sure we are aware of all capacitive sensor development aspects.

In the study we mainly searched for documents on the internet, documents describing the general operations of capacitive sensors, but also datasheets of ready made sensors and modern electronic components that could be of interest (Materials used are represented in Annex 1).

2.2. Résumé of the information gained from the study

2.2.1. General properties

Capacitance and Distance

Noncontact capacitive sensors work by measuring changes in an electrical property called capacitance. Capacitance describes how two conductive objects with a space between them respond to a voltage difference applied to them. When a voltage is applied to the conductors, an electric field is created between them causing positive and negative charges to collect on each object. If the polarity of the voltage is reversed, the charges will also reverse.

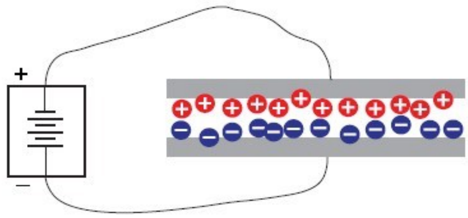

Figure 1

Applying a voltage to conductive objects causes positive and negative charges to collect on each object. This creates an electric field in the space between the objects.

Capacitive sensors use an alternating voltage which causes the charges to continually reverse their positions. The moving of the charges creates an alternating electric current which is detected by the sensor. The amount of current flow is determined by the capacitance, and the capacitance is determined by the area and proximity of the conductive objects. Larger and closer objects cause greater current than smaller and more distant objects. The capacitance is also affected by the type of nonconductive material in the gap between the objects. Technically speaking, the capacitance is directly proportional to the surface area of the objects and the dielectric constant of the material between them, and inversely proportional to the distance between them.

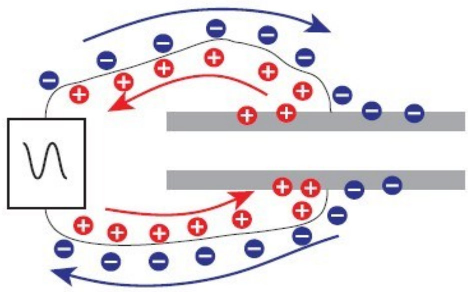

Figure 2

Applying an alternating voltage causes the charges to move back and forth between the objects, creating an alternating current which is detected by the sensor.

In typical capacitive sensing applications, the probe or sensor is one of the conductive objects; the target object is the other. The sizes of the sensor and the target are assumed to be constant as is the material between them. Therefore, any change in capacitance is a result of a change in the distance between the probe and the target.

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Focusing the Electric Field

When a voltage is applied to a conductor, the electric field eminates from every surface. In a capacitive sensor, the sensing voltage is applied to the Sensing Area of the probe. For accurate measurements, the electric field from the sensing area needs to be contained within the space between the probe and the target. If the electric field is allowed to spread to other items or other areas on the target then a change in the position of the other item will be measured as a change in the position of the target. A technique called "guarding is used to prevent this from happening. To create a guard, the back and sides of the sensing area are surrounded by another conductor that is kept at the same voltage as the sensing area itself. When the voltage is applied to the sensing area, a separate circuit applies the exact same voltage to the guard. Because there is no difference in voltage between the sensing area and the guard, there is no electric field between them. Any other conductors beside or behind the probe form an electric field with the guard instead of the sensing area. Only the unguarded front of the sensing area is allowed to form an electric field with the target.

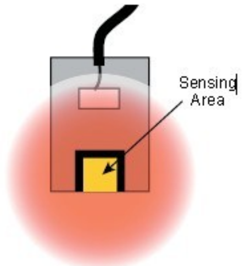


Figure 5

Cutaway view showing an unguarded sensing area electric field

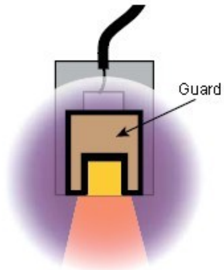


Figure 6

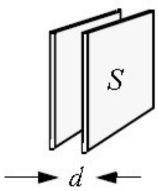
Cutaway showing the guard field shaping the sensing area electric field

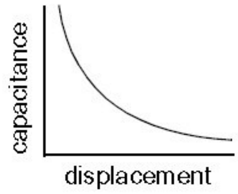
Multiple Channel Sensing

Frequently, a target is measured simultaneously by multiple probes. Because the system measures a changing electric field, the excitation voltage for each probe must be synchronized or the probes would interfere with each other. If they were not synchronized, one probe would be trying to increase the electric field while another was trying to decrease it thereby giving a false reading.

Spacing variation

Spacing variation of parallel plates is often used for motion detection if the spacing change is less than the electrode size. The parallel plate capacitance formula shows that capacitance is inversely related to spacing. This gives a conveniently large value of capacitance at small spacing, but it does often require signal conditioning which can compensate for the parabolic capacitance-motion relationship.





Conclusions

- The sensor to be used in the CapMouse will need to have a high immunity for external Electro Magnetic fields (EN12182), guarding and shielding will be absolutely necessary.
- Experimenting with sensor prototypes has shown that field shaping and or shielding will also play an important role. The sensor should only measure the distance to the cheek and be immune for other objects (e.g. a hand touching the sensor from behind). This could be achieved by just adding a grounding or go for active shielding. Experiments need to show what is feasible.
- From other documents we also noticed that the maximum practical distance we can measure is approx. half of the sensor diameter. A sensor of 8mm could measure 4mm distance.

2.2.2. *Signal condition and measuring techniques*

Signal conditioning circuits convert capacitance variations into a voltage, frequency, or pulse width modulation. Very simple circuits can be used, but simple circuits may be affected by leakage or stray capacitance, and may not be suitable for applications with very small capacitance sense electrodes.

Excitation frequency

The excitation frequency should be reasonably high so that electrode impedance is as low as possible. Typical electrode impedance is 1-100M ohms. Ideally, the excitation frequency will be high enough to reject coupling to power waveforms and also high enough so that the overall sensor frequency response is adequate; about 50 kHz is usually acceptably high. The frequency should also be low enough for easy circuit design, CMOS switches work well at 100 kHz and below.

Excitation waveshape is usually square or trapezoidal, but a triangle waveform can be used to allow a simpler amplifier with resistive feedback and a sine wave offers better accuracy at high frequency. Square wave excitation produces an output bandwidth which can be higher than the excitation frequency by 10x or more, other waveshapes usually result in an output bandwidth 2x or 3x lower than the excitation frequency. Sensors excited with a continuous wave signal usually use synchronous demodulators. This demodulator type offers high precision and good rejection of out-of-band interference.

Pulse operation

A single pulse can be used to sample a variable capacitor, like a microcomputer read pulse, or a train of pulses can be used. This method can result in simpler electronics but will have higher noise.

Oscillator

An R-C relaxation oscillator such as the venerable 555 or its CMOS update, the 7555, converts capacitance change into a change of frequency or pulse width.

Conclusions

- We need to miniaturize the senor. The sensor needs to fit inside the sensor head which is at the end of the headset. Not only the size is crucial but also the weight is very important. Size should be less than 10mm and weight only a couple of grams. Building up the sensor measuring electronics using discrete components is probably not an option due to size and weight. We will need to search for an integrated sensor.
- Depending on the integrated circuit we need to check the datasheet very carefully so the built-in signal conditioning technique suits our needs. Due to our specific usage we will probably use the sensor at its limits.

2.2.3. *Mechanical construction sensor*

In the CapMouse project the sensor needs to be as small as possible to minimize the stigma and due to the fact that we would like to put multiple sensors in one array. A single integrated chip that can scan multiple sensors is the target.

3. Technical sensor requirements

The following includes a list of main requirements for the sensor. During experimenting, testing and trial the list will be extended, more detailed and become mature. The list mainly contains functional aspects and safety features.

A very important aspect is to take into account the regulations which are compulsory for any kind of electronic product at an early stage. A product that does not comply with certain harmonized standards can not be put in the market, even not given away as free samples or used in large scale uncontrolled test environments.

In this particular case we will follow the Medical Directive 93/42/EEC. The main reason is that it will be used in combination with the Octopus and will at first stage mainly be used by handicapped people. This type of product is considered as a Class I medical device.

As the CapMouse potentially will be used as an input for a wheelchair and there could be potentially be part of the wheelchair control loop we need to focus on the standards for electronic powered wheelchairs as well.

The following 2 harmonised standards will be taken into account:

EN 12182 - Technical aids for disabled persons. General requirements and test methods

EN 12184 - Electrically powered wheelchairs, scooters and their chargers. Requirements and test methods

From both standards the most important and applicable clauses will be put in the requirement list, they are mainly concerning the electrical characteristics.

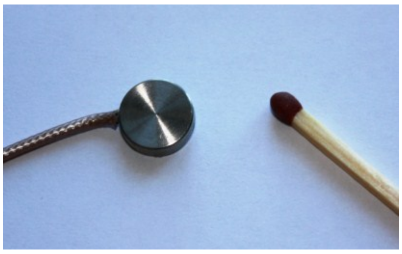
EN 12182	Clause 4.1	Risk Analysis
	Clause 7	Electromagnetic Compatibility
	Clause 10	Surface Temperature
EN 12184	Clause 8.5	Surface Temperature
	Clause 8.7	Environmental protection
	Clause 9	Electrical requirements

In task 2.5 we will go much deeper in this matter, investigate the harmonised standards thoroughly and execute measurements, the results of this investigation will be part of deliverable 2.4. The harmonised standards at our disposal are also not the latest versions; the latest versions will be obtained by the time task 2.5 will be started.

Functional	
Mechanical	
Size	Single Sensor 8mm Diameter, 4mm thickness Array 20mm Diameter, 4mm thickness
Weight	Less than 15 Grams
Number of sensors in array	1 to 3/4 sensors (TBD 3 or 4)
Fluctuation distance to cheek Vibration (distance variation and frequency) that should not cause a false signal	TBD
Electrical	
Power consumption	As low as possible, aim for battery powered conditions
Supply voltage	Safe user voltage < 12V, fully isolated to the user
Immunity from other objects	Immune for objects other than the cheek closer than 10mm from the non sensitive side of the sensor
Calibration	Software Calibration, manual and automatic
Measure distance	Minimal 4mm, 6 to 8 mm optimal
Connectivity	
Electrical	A 3 or 4 wire cable with a maximum diameter of 3mm. All sensors in the same area must be connected to the same cable. In case of multiple separate sensors they will ne be connected in bus based manner
Protocol	Any serial protocol will be suitable as long as the bandwith is sufficient to have at least a readout of 15Herz/Sensor
Integrity	False data needs to rejected if not correct (some king of CRC or data checking.
Harmonised Standards	
EMC	
Immunity	EN12182 10V/m 800Mhz - 2GHz EN12184 20V/m 26Mhz - 1GHz
Emissions	EN12182/EN12184 30Mhz - 1GHz - CISPR 11 CLASS B - EN55022 CLASS B
ESD	EN12182 8kV contact discharge, 16kV air discharge EN12184 6kV contact discharge, 8kV air discharge
Environmental Protection	
Ingress of liquids	Fully sealed, no ingress allowed
Temperature	EN12184 Operating and storage temperature according to ISO 7176-9 Operating -25..+50°C, Storage -40 + 65°C
Surface Temperature	surface temperature below 41°C
Other	
Risk Analysis	According to EN1441:1997
Clinical evaluation	user tests
Biocompatibility and toxicity	list of materials used, ROHS

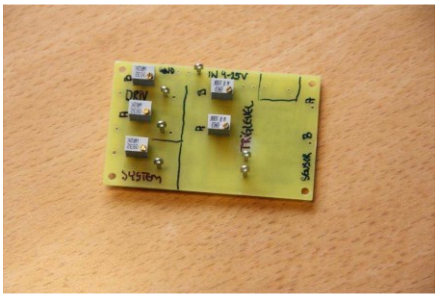
Existing industrial sensors overview

A search for a capacitive sensor that met these requirements was performed and sensors from SIE/Balluff were selected for the first prototypes we developed.



10mm industrial standard capacitive sensor from SIE/Balluff.

The SIE sensors are analog and require a stable supply voltage of about 7 volts. Tests were made with a common supply but each sensor had different characteristics so one stabilized supply was needed to every sensor. A small power supply was developed around the LM317 with a 15 turn potentiometer. This solved the balancing problem and it was possible to chose a voltage with a resolution of less than 0.05 volts. The output was fed to a comparator and again a 15 turn potentiometer was used to choose the trigger level.

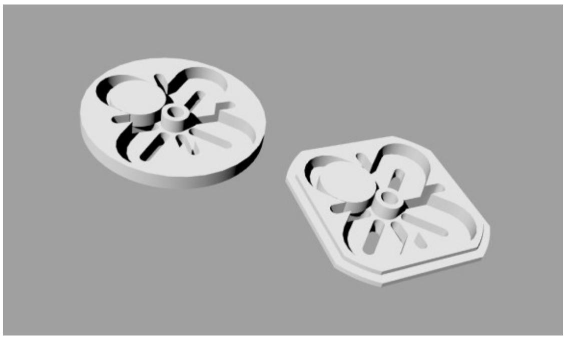


Interface to SIE industrial sensor.

Several prototypes were built for extensive tests, first with a LED as an indicator of the function but also with an interface to the Octopus.

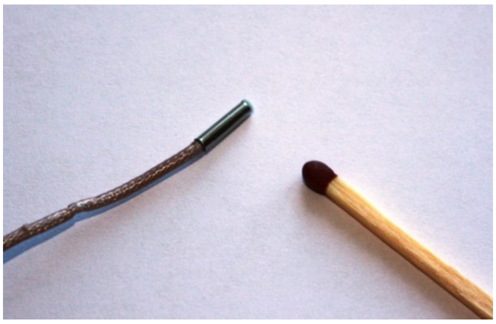
Interface between two SIE sensors and the Octopus.

Several headsets were tested with these sensors in different sensor heads and configurations. Each test gave valuable information and this knowledge was implemented in the later developed in house sensor.



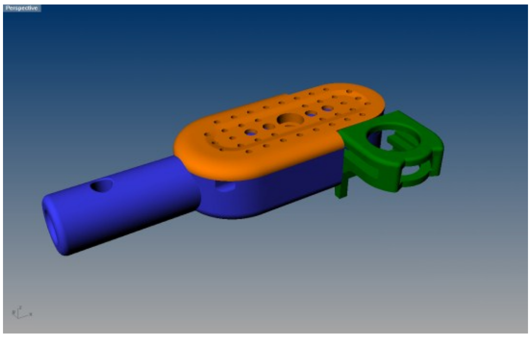
Circular head for four (10mm) SIE sensors.

To achieve a full mouse function, five sensors were used. This resulted in a quite big sensor head. Instead we started development with the 2mm SIE sensor to be able to build a smaller head.



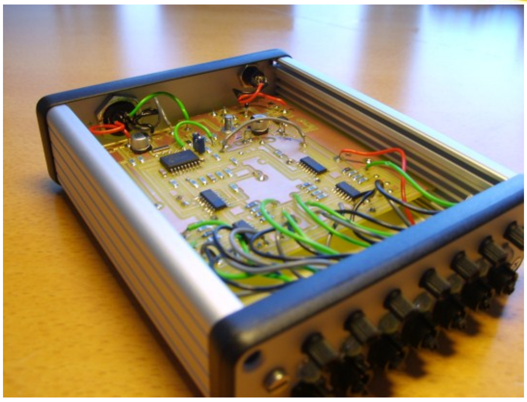
2mm industrial standard capacitive sensor from SIE/Balluff.

This resulted in a much smaller head and by using combinations of the sensor outputs only 3 sensors were needed to achieve a full mouse function.



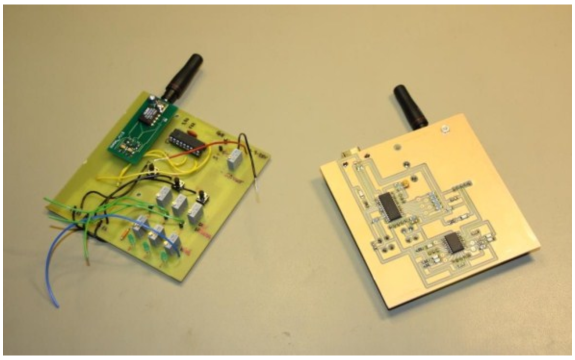
Rectangular head for up to four (2mm) and one (10mm) SIE sensors.

An interface to a PC was developed. It used the PS2 connection and emulated a Microsoft Mouse. To be able to use all four directions plus three buttons it was possible to connect 7 sensors to this interface.



7 sensor interface for industrial sensors to a PC via PS2.

A wireless solution was built with a 432 MHz data link. The protocol used was NMEA.



Mouse emulating wireless interface to a PC.

All these prototypes work well and are stable. It is possible to interface both the Octopus and a PC. On the downside has been high supply voltage and power consumption. The sensors active detection distance was also limited to 1-2 mm. The price of the SIE sensors was high, about 150 EUR. Sizes were too big to build a sensor head fitted within the area of the cheek where one was able to use the tongue comfortably.

A solution for solving these issues has been to develop our own in-house sensor.

4. *In-house sensor development and component selection*

4.1. General

Capacitive sensors technology is already described in *Nature 1907*, so the principle is already know for more than a century. For many years the technology was only used in very specialized devices or industrial environments.

The sensors were built using discrete components and quite big. Because there were no built-in CPU's used the calibration was static and manual recalibration using potentiometers was often needed.

However since a couple of years manufacturers of integrated circuits explored new means of building capacitive sensors. They created dedicated ASIC'S (Application-Specific Integrated Circuit) which included a measuring circuit and a CPU (Central Processing Unit). The combination of the analog and digital part made it possible to built a capacitive sensor with minimal external components.

One on the pioneers was Quantum Research with their range of QT sensor chips (Quantum Research is now acquired by ATMEL) however recently most major manufacturers of electronic components have one or more devices in the portfolio.

Since there are multiple vendors and many devices available it is not easy to make a selection. A selection purely based on a study of the datasheet is risky; the datasheet does not always contain all the necessary data and many of the devices were developed to be used in low cost simple applications; e.g. controlling an MP3 player, controlling a cooking stove etc. In these applications there is a very distinct difference when the sensor is touched or not. The finger is on the surface of the senor or it is not, and this causes quite a important change in capacitance.

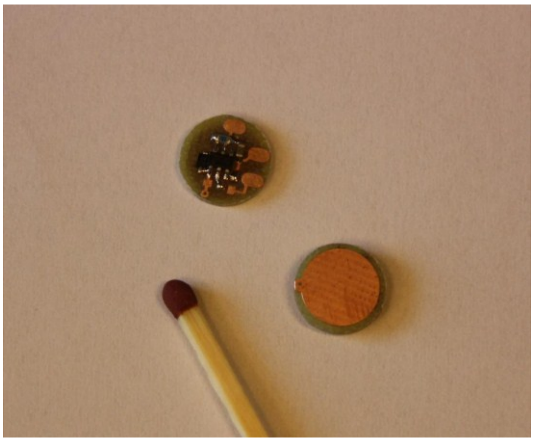
In the CapMouse design we need to be able to distinguish between minute changes in the capacitance. The cheek will move far less than a finger and if we make contact with the skin the difference in capacitance will be the tongue pressure on the inside of the cheek.

Because we will be using the sensor beyond its intended use we will need to test the selected (on their datasheet) integrated circuits and do a full test in order to figure out if they will be usable.

It would be wise to have a least 2 candidates. If we base the whole project on a single source component that would be very dangerous if that specific component becomes obsolete.

4.2. *Tests with Microchip PIC Controllers*

To overcome the downsides of the industrial sensor we decided to build our own sensor. It is based on the smallest microcontroller available on the market and measures capacitance on the "charge and discharge" principle. It runs on 1,8 to 5 volts and the consumption is less than 1 mA. It can directly interface the Octopus. The working measurable distance is 0-15 mm. The software is written in assembly language and incorporates filters and auto calibration. Component cost is less than 1 Euro.



Back and front of Brusell developed capacitive sensor.

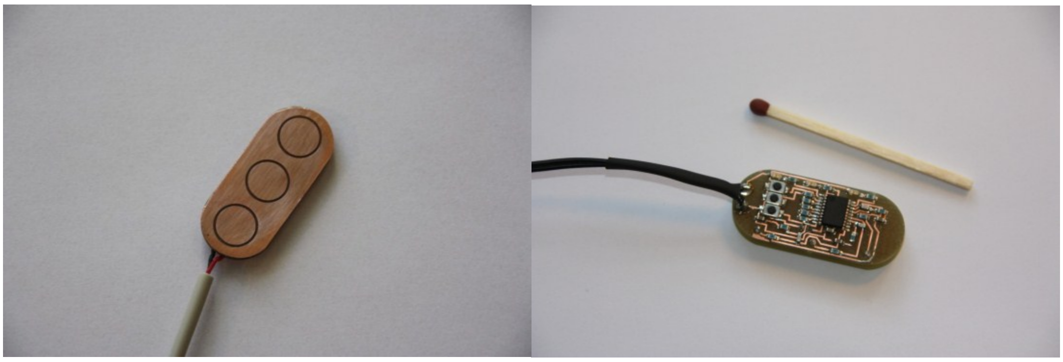
To be able to connect the sensors to a PC an interface was developed around a microcontroller with USB capability. The software was developed in house and both mouse and keyboard emulation is possible. It is supplied via the USB bus and draws less than 10 mA including three sensors.

These digital sensors have been developed and used, integrated in headsets, for collecting the user requirements from the end users.

In house developed single sensor on headset.

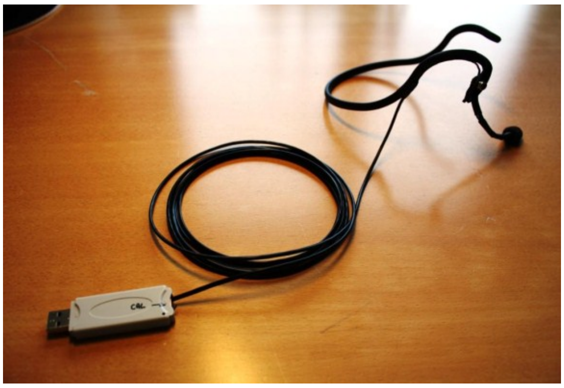
These in house developed sensors will be used in the low end product for double click and click of the PC/Mac.

To emulate a mouse with five sensors the sensor head gets fairly big, to overcome this, a three sensor prototype was developed. It is easier to move your tongue in only one direction instead of two. All four directions and the click are derived from combinations of the three sensors.



Full mouse function with three sensors via USB. Front and back side.

A version, aimed for demonstration purposes, was developed with functions suitable for PowerPoint presentations. With a time sensitive input it is possible to give three commands; next page, previous page and blank screen.



Demonstration headset with PowerPoint commands.

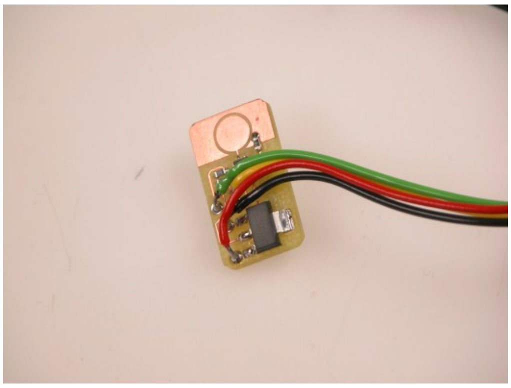
4.3. Tests with the ASIC Freescale MPR121

Description

The MPR121 (Freescale) is the second generation sensor controller after the initial release of the MPR03x series devices. The MPR121 features increased internal intelligence in addition to Freescale's second generation capacitance detection engine. Some of the major additions include an increased electrode count, a hardware configurable I2C address, an expanded filtering system with debounce, and completely independent electrodes with auto-configuration built in. The device also features a 13th simulated electrode that represents the simultaneous charging of all the electrodes connected together to allow for increased proximity detection in a touch panel or touch screen array.

Prototype

We have built a prototype based on this integrated circuit.



Conclusions

According to the datasheets this could be a good candidate (http://www.freescale.com/files/sensors/doc/data_sheet/MPR121.pdf). It can connect up to 12 sensors, the size is small (only 3x3mm) and price is low, below 1 Euro (1K volume).

The ASIC was mounted on the board. However we were not able to bring it to live in the prototype. The datasheets contained parts which were not consistent and some of the registers were not readable over I2C. Therefore we decided to temporarily skip this device until we receive consistent datasheets.
We also decided to order a development kit which will help us to determine the fault.
At the moment of this deliverable we did not receive the development kit. In T2.4 we should have received the development kit and we will do further testing.

Accuracy	10 Bit
Complexity	Complex
Number of sensors	12
Number of I2C slave addresses	4
Power Supply	1V71 .. 3V6
Maximal Capacitance Measurement	2000pF
Reference	Internal Ref Cap
AC Shield (Field Shaping)	No

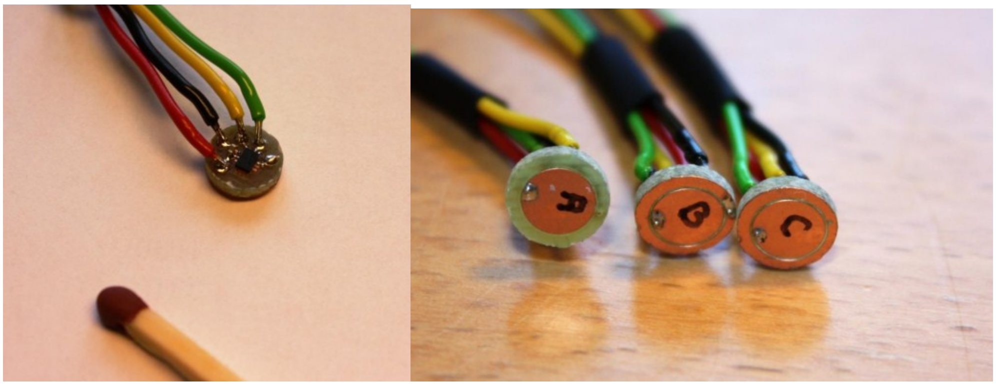
4.4. *Tests with the ASIC ST Micro Electronics STMPE321*

Description

The STMPE321 is a 3-channel capacitive touchkey controller. Capacitance measurement is implemented in fully optimized hardware. All 3 I/Os can be configured via an I2C bus to function as either capacitive touchkey, or as GPIOs (general purpose I/O).

Prototype

We have built a prototype based on this integrated circuit.



Prototype of STMPE321. Front and back side.

Conclusion

This integrated circuit looks as being usable. However resolution of the CDC is with 7 bit low. The resolution is only 40fF, so in theory sufficient. It can connect up to 3 sensors, the size is very small (only 2.2x1.5mm) and price is low, below 1 Euro (1K volume). We were able to connect this integrated circuit and read the registers from MATLAB. Full test results will be obtained in the following tasks.

Accuracy	8 Bit
Complexity	Simple
Number of sensors	3
Number of I2C slave addresses	1
Power Supply	1V85
Maximal Capacitance Measurement	40pF
Reference	External Ref Cap
AC Shield (Field Shaping)	No

4.5. Tests with the ASIC Analog Devices AD7147

Description

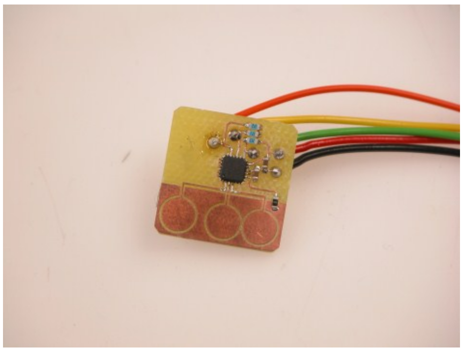
The AD7147 CapTouch™ controller is designed for use with capacitance sensors implementing functions such as buttons, scroll bars, and wheels. The sensors need only one PCB layer, enabling ultrathin applications. The AD7147 is an integrated CDC with on-chip environmental calibration. The CDC has 13 inputs channeled through a switch matrix to a 16-bit, 250 kHz sigma-delta (Σ-Δ) converter. The CDC is capable of sensing changes in the capacitance of the external sensors and uses this information to register sensor activation. By programming the registers, the user has full control over the CDC setup. High resolution sensors require minor software to run on the host processor. The AD7147 is designed for single electrode capacitance sensors (grounded sensors). There is an active shield output to minimize noise pickup in the sensor.

The AD7147 has on-chip calibration logic to compensate for changes in the ambient environment. The calibration sequence is performed automatically and at continuous intervals as long as the sensors are not touched. This ensures that there are no false or no registering touches on the external sensors due to a changing environment.

The AD7147 has an SPI-compatible serial interface, and the AD7147-1 has an I2C®-compatible serial interface. Both parts have an interrupt output, as well as a GPIO. There is a VDRIVE pin to set the voltage level for the serial interface independent of VCC. The AD7147 is available in a 24-lead, 4 mm × 4 mm LFCSP and operates from a 2.6 V to 3.6 V supply. The operating current consumption in low power mode is typically 26 μA for 13 sensors.

Prototype

We have built a prototype based on this integrated circuit.



Conclusion

This integrated circuit looks the most promising. The manufacturer Analog Devices is not only the reference for analog circuits they also provide good datasheets and application notes. One disadvantage is that the integrated circuit is very elaborated and the datasheet alone is 72 pages long. The IC contains close to 500 registers which need to be set or interpreted. The advantages are, up to 13 sensors, a drive shield (could be interesting for field shaping), 16 bit CDC. The size is small (only 4x4mm) and price is reasonable, below 2 Euro (1K volume). We were able to connect this integrated circuit and read the registers from MATLAB. Full test results will be obtained in the following tasks.

Accuracy	16 Bit
Complexity	Very Complex
Number of sensors	13
Number of I2C slave addresses	4
Power Supply	3V3
Maximal Capacitance Measurement	28pF
Reference	Internal Ref Cap
AC Shield (Field Shaping)	Yes

5. *MATLAB as development environment*

5.1. *General*

I order to evaluate the sensors and to able to device an analyzing, calibration and normalization method (T2.3, T2.6) we need to create a tool on a PC and interface the sensor to the PC.

5.1.1. *AT command style.*

The first idea was to use a serial communications protocol based on an AT command style. The protocol and hardware interface board were developed (see D2.2) however during testing of the PIC16F689 we have seen this approach was not realistic for that type of processor. The flash size in the processor does not allow the implementation of the necessary port driver. We needed to switch over to a bigger physical size which did not allow integration into the headset. Also the accuracy of the PIC was not that great.

5.1.2. *MATLAB.*

During testing with other types of integrated circuits we came to the conclusion that a combination of MATLAB and an interface to I2C looked more promising.

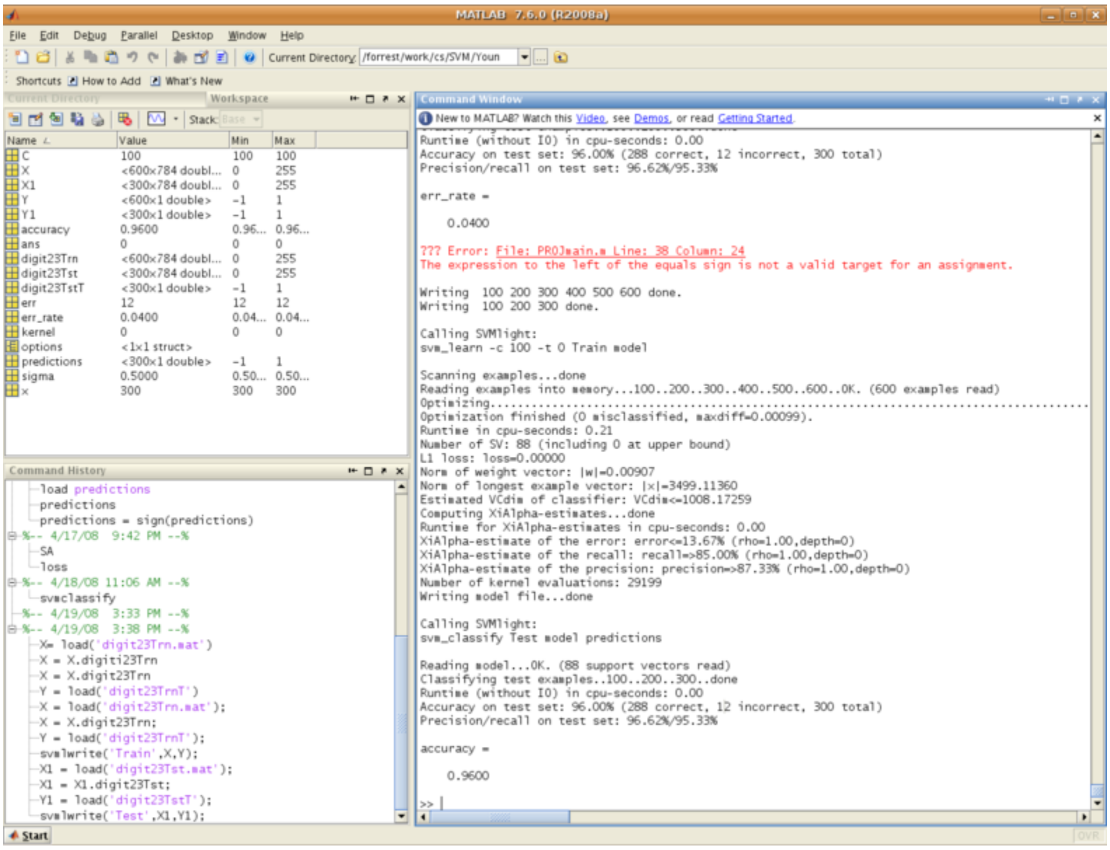
MATLAB is a unique tool that could help us to create the best environment to devise a well-functioning calibration and sensor measurement method and algorithm.

5.2. *MATLAB Principles*

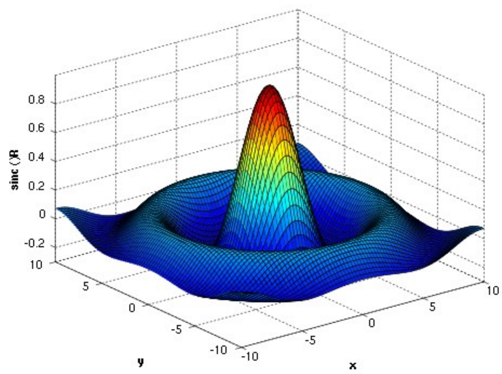
MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems.

In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises.




```
[X,Y] = meshgrid(-10:0.25:10,-10:0.25:10);
f = sinc(sqrt((X/pi).^2+(Y/pi).^2));
surf(X,Y,f);
axis([-10 10 -10 10 -0.3 1])
xlabel('{\bfx}')
ylabel('{\bfy}')
zlabel('{\bfsinc} ({\bfR})')
```



5.3. *Connect CapMouse sensor to MATLAB*

5.3.1. *General*

The 3 integrated circuits MPR121, AD7147 and STMPE321 all have an I^2C (Inter-Integrated Circuit) bus connection. The devices were also selected because of that feature. If all devices I^2C the same PC interface can be used to verify and test the different types of sensors.

To connect an I^2C slave to a PC we need an interface. PC's are not equipped with I^2C, at first stage we will try to use commercially available I^2C to RS232/USB converters.

5.3.2. *I^2C what is it?*

In the early 1980's, NXP Semiconductors developed a simple bi-directional 2-wire bus for efficient inter-IC control. This bus is called the Inter-IC or I2C-bus. At present, NXP's IC range includes more than 150 CMOS and bipolar I2C-bus compatible types for performing communication functions between intelligent control devices (e.g. microcontrollers), general-purpose circuits (e.g. LCD drivers, remote I/O ports, memories) and application-oriented circuits (e.g. digital tuning and signal processing circuits for radio and video systems).

All I2C-bus compatible devices incorporate an on-chip interface which allows them to communicate directly with each other via the I2C-bus. This design concept solves the many interfacing problems encountered when designing digital control circuits. I2C has become a de facto world standard that is now implemented in over 1000 different ICs and is licensed to more than 50 companies.

The I2C bus physically consists of 2 active wires and a ground connection. The active wires, called SDA and SCL, are both bi-directional. SDA is the Serial DAta line, and SCL is the Serial CLock line.

Every device hooked up to the bus has its own unique address, no matter whether it is an MCU, LCD driver, memory, or ASIC. Each of these chips can act as a receiver and/or transmitter, depending on the functionality. Obviously, an LCD driver is only a receiver, while a memory or I/O chip can be both transmitter and receiver.

The I2C bus is a multi-master bus. This means that more than one IC capable of initiating a data transfer can be connected to it. The I2C protocol specification states that the IC that initiates a data transfer on the bus is considered the Bus Master. Consequently, at that time, all the other ICs are regarded to be Bus Slaves. Bus masters are generally microcontrollers.

5.3.3. I^2C converters

To save time and effort we will try to use commercially available converters. We selected 2 commercially available converters that suit our needs:

1. **The Bus Pirate** (available from SparkFun electronics). A ready made I^2C to USB interface. We tested and after a while we got it to work. One major drawback is the overload on the USB bus. All communication is done in ASCII and the USB propagation delay causes serious delays prohibiting real time fast reading of the sensors. As a first test it works well and it is good to debug the hardware but in the final test set-up it will probably too slow.

2. **The I2C for PC** (available from I2CChip.com). A ready made I^2C to UART/USB interface. We also got it to work. It has up to 3 separated I2C busses (time division use, only one I2C functional at a time). Compared to the Bus Pirate there is much less data overhead. It also uses ASCII commands but they are much shorter. Since it also has a UART connection (RS232) we can get around the USB latency if we would use a PC with at a built-in RS232 connection.

However both converters are lacking an input for an external interrupt. The integrated circuits we use have an interrupt output which is set when a conversion is done and the chip has data ready to be read. Since the integrated circuits act as an I2C slave they can not initiate a data transfer. Only the Bus Master can initiate the transfer, the interrupt output of the IC is used to let the Bus Master know it is time to collect the data. Since none of the converters have such input for an interrupt we need to work with polling. Polling is time consuming and due to USB bus propagation delays we loose the timing. Any digital filtering used in the calibration will require that samples are being taken at fixed intervals.

We will continue testing with the converters but we already see now problems with the communication speed.

6. Mechanical Design considerations for LOTS

6.1. General

During the work done so far we can already give some design recommendations to LOTS. Most of the recommendations are a bit preliminary and could be subject to change later on. However any input we can give to LOTS at this stage is probably more than welcome.

6.2. Recommendations

6.2.1. High dielectric strength

It is very important to choose a plastic with a high Dielectric Constant. The higher the Dielectric Constant of the plastic, the better.

Capacitance is determined by Area, Distance, and Dielectric (the material between the conductors). Capacitance increases when Area or Dielectric increase, and capacitance decreases when the Distance increases.

The higher the Dielectric Constant the lower the impact will be of the housing.

A figure of at least 3 is wanted e.g. Plexiglas (Polymethylmethacrylaat) is cheap and easily available.

6.2.2. Fully encapsulated

If we take into account the harmonised standards it will be best to encapsulate the sensors completely into the plastic of the headset. This will solve ingress of fluids, ESD issues and makes the sensor fully isolated towards the user. The thickness of the plastic on the sensor surface should however be limited, to thick plastic will limit the sensitivity of the sensor, too thin can cause ESD to penetrate the plastic and hit the sensor area. Use the table in 7.3 to make the right choice. In the tests we need to withstand 16kV but to be on the safe side take into account at least 24kV.

6.2.3. Size

The exact size of the sensor array is not known yet. The sizes mentioned in the list of requirements are still the aim.

6.2.4. Shape

The sensor array could be made flat or curved. Curved is probably best because the cheek is curved as well. If a plastic with a high dielectric strength is used it could allow to create a curved shape while still using a flat PCB

6.2.5. Flexible PCB

For the time being we are working with rigid PCB's, if necessary it would also be possible to work with a flexible PCB.

6.3. *List of plastics and their Dielectric Constant.*

Plastic	Dielectric Strength		Dielectric Constant			Dissipation Factor		
Abbreviation (chemical name) Brand name	Volts/0.001"		@	@	@	@	@	@
	0.001"	0.005"	1KHz	1MHz	1GHz	1KHz	1MHz	1GHz
ECTFE (ethylene chlorotrifluoro ethylene copolymer)	5000 6000	-------	2.6	2.6	------	0.002	0.013	--------
ETFE (ethylene tetrafluoro-ethylene copolymer) Tefzel	5000	2500	2.6	2.6	2.4	0.0008	0.005	0.0005
FEP (fluorinated ethylene-propylene copolymer) Teflon FEP	6500	2000	2.0 2.5	2.0 2.05	2.05	<0.0002	0.0003	0.0015
PFA (perfluoroalkoxy) Teflon PFA	4000 5000	-------	2.0 2.1	2.0 2.1	2.0 2.1	0.0002	0.0002	0.00045
PCTFE (polychlorotrifluoro-ethylene)	3000 3900	2700 3300	2.5 2.7	2.3 2.4	2.3	0.022 0.024	0.009 0.017	0.004
PTFE (polytetrafluoroethylene) Teflon	2200 4400	1000 2000	2.0 2.1	2.0 2.1	2.0 2.1	<0.0001	<0.0001	<0.0001
PVF (polyvinylfluoride) Tedlar	3500	1700	8.5	7.4	------	1.6	--------	--------
PVDF (polyvinylidenefluoride) Kynar	--------	-------	8.4	------	------	0.019	--------	--------
(polycaprolactam) Nylon6	(0.002") 1300	-------	3.7	3.0	------	0.016	0.036	--------
PC (polycarbonate) Lexan	6300	2000	2.99	2.93	2.89	0.0015	0.010	0.012
PET (polyethyleneterephthalate) Mylar	7500	3400	3.2	3.0	2.8	0.005	0.016	0.003 0.008
LDPE (low density polyethylene)	5000	3000	2.2	2.2	2.2	0.0003	0.0003	0.0003
LLDPE (linear low density polyethylene)	5000	3000	2.2	2.2	2.2	0.0003	0.0003	0.0003
HDPE (high density polyethylene)	5000	3000	2.3	2.3	2.3	0.0005	0.0005	0.0005
UHMWPE (ultra high molecular weight polyethylene)	(0.010") 1300	-------	2.3	2.3	2.3	0.00023	--------	--------
PI (polyimide)	7000	3600	3.5	3.4	3.3	0.0025	0.010	0.004
PMMA (polymethylmethacrylate) Plexiglas	--------	-------	3.5 4.0	3.0 3.5	2.58	0.040	0.030	0.009
PP (polypropylene)	8000	2700	2.2	2.2	2.2	0.0003	0.0003	0.0003
PS (polystyrene) Styron	5000	-------	2.4 2.7	2.4 2.7	2.4 2.7	0.0005	0.0005	0.0005
PVC (polyvinylchloride)	--------	-------	3.0 3.3	2.7 3.1	2.8	0.009 0.017	0.006 0.017	0.019
PVDC (polyvinylidenechloride) Saran	--------	-------	3.9 4.5	3.0 4.0	2.7	0.052 0.063	0.050 0.080	0.016

7. Conclusions

We will continue testing with the commercial I2C to USB converters but we already see problems with the communication speed (see topic **I²C converters**) as we want to achieve (see requirement list) at least a sampling frequency of 15 samples/second. Probably we will need to build our own converter board.

At this stage we have already given some design indications to LOTS.

Some of the work done earlier, mainly the idea of creating a RS232 bus with an AT style command set has been brought to the background. The idea is still viable but at this stage we need to gain more insight in the exact process we need to follow concerning data interpretation. Also we found a number of integrated circuits that combine multiple sensors in one chip; this eliminates the need to create a bus with multiple nodes because multiple sensors can be connected to the same node.

Most of the integrated circuits have a built in calibration and compensation algorithm. However in the case of the CapMouse this is not usable because the operation mode is quite different than the intended use of the integrated circuits.

Since we will now use MATLAB as a development environment that means we partially need to redo the ***"T2.3 Development of sensor measurement and analyzing tool for PC"*** and update ***"D2.2 Software tool for PC".***
This will cost extra effort and time but we are sure it gives us a much better chance to success. One of the HMC engineers has some experience in MATLAB (from school time) so we do not have to start from scratch however it will take quite some work to master, however MATLAB has also quite some libraries which can be used to create a software tool fast and efficient.

In ***"T2.4 Sensor analysis, verification and selection***" we will combine the results from T2.3 and lab testing to devise a good algorithm.

8. Annexes

8.1. Literature links

http://www.lionprecision.com/tech-library/technotes/tech-pdfs/cap-0020-cap-theory.pdf

http://www.eetimes.com/design/analog-design/4009869/Building-a-reliable-capacitive-sensor-interface/

http://www.capsense.com/capsense-wp.pdf

http://focus.ti.com/lit/an/slaa363a/slaa363a.pdf

http://focus.tij.co.jp/jp/lit/an/slaa379/slaa379.pdf

http://www.silabs.com/Support%20Documents/TechnicalDocs/AN447.pdf

http://electronicdesign.com/print/analog-and-mixed-signal/measure-capacitive-sensors-with-a-sigma-delta-modu.aspx

http://www.st.com/stonline/books/pdf/docs/15791.pdf

http://www.atmel.com/products/overview_touch.asp?category_id=170&source=microcontrollers

8.2. Data Sheets Integrated Circuits

http://ww1.microchip.com/downloads/en/devicedoc/41262e.pdf

http://ww1.microchip.com/downloads/en/DeviceDoc/41239D.pdf

http://www.newark.com/pdfs/techarticles/microchip/01334A.pdf

http://www.freescale.com/files/sensors/doc/data_sheet/MPR121.pdf

http://www.analog.com/static/imported-files/data_sheets/AD7147.pdf

8.3. Data Sheets Industrial Sensors

http://www.balluff.com

http://www.balluff.com/Balluff/dk/ProductsChannel/Product+Detail/en-gb/ProductDetail.htm?ProductID=BCS+G04T4D-XXS10C-EP02-GZ01-002&ProductGroupGuid=%7b525B064E-2662-4FAA-910C-44B4919824A7%7d&ProductGroupName=Capacitive+Sensors&DocumentPage=5

http://www.balluff.com/NR/rdonlyres/83E72113-C3A6-40E1-B781-2DDAAF783C4F/0/162566_SIE02_MiniSen.pdf

8.4. EMC and Harmonized standards

http://www.elliottlabs.com/documents/IEC%2060601%20for%20Conformity%20DEC%202005.pdf

8.5. MATLAB

http://www.mathworks.com/help/techdoc/learn_matlab/f0-14059.html#f0-10672

http://www.mathworks.com/products/matlab/description1.html

http://www.mathworks.com/products/matlab/technicalliterature.html

http://en.wikipedia.org/wiki/MATLAB

http://www.mathworks.com/matlabcentral/fileexchange/19193-diode-temperature-sensor-using-i2c-bus-adm1034

http://www.robot-electronics.co.uk/acatalog/I2C_Tutorial.html

http://www.nxp.com/documents/application_note/AN10216.pdf

http://www.esacademy.com/en/library/technical-articles-and-documents/miscellaneous/i2c-bus/general-introduction/i2c-bus-protocol.html

http://www.sparkfun.com/products/9544

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