IMPROVING THE SENSORS COURSE WITH A SENSOR SHIELD

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Chapter 1 Introduction

1.1 Context

In the Creative Technology course student starting their second year can choose to follow the Smart Technology track. This track focuses on engineering courses with one of them being the Sensors course, which is the target of this project. In the Sensors course students will have their first encounter with sensors, how to connect them, calibrate them, and measure with them. The course aims to teach students insight into sensor technology, gaining practical experience in interfacing sensors, and understanding the underlying technical concepts.

Students following the course participate in sessions consisting of a lecture and a practical tutorial, where each session will look at one of six different topics of sensing, for example; data acquisition and measuring, or optical sensing with a grey encoder. Every topic has a case that will be introduced together with background information on the sensing principles. The materials provided for the case is split in theory, things that can go wrong and interfacing examples. The last is done in the tutorial sessions with practical examples using an Arduino for learning and experimenting.

1.2 Problem statement

The Sensors subject for CreaTe module 5 focuses on 6 fundamentally different types of sensors and students are tasked to connect them to an Arduino, calibrate them and do a small experiment. However, most of the available time with the sensors is spent on connecting the sensors to the Arduino and make it work properly after calibrating and trying to write a proper report on the sensor of the week. This leaves too little time for getting to know the actual sensors, play around with them and properly documenting what has been done and how.

1.3 Goal

The overarching goal is to make a sensor shield or improvement of sensor usage for Arduino with at least six fundamentally different types of sensors. These sensors are chosen such that student following the Sensors course in Smart Technology get a feel for the fundamental aspects, physical applications, and possible combinational use for the given sensors. This sensor shield needs to come with a code package and a combined datasheet such that it can be used for educational purposes and possibly entertaining and private purposes as well. The code package needs to be designed in such a way that the student or user can immediately work on the signal processing of the sensor. The connecting to and the calling of the pins will be done in the given code package.
Aside from this focus on the technical challenges is the challenge for changing and improving the sensors course itself. These changes revolve around the implementation of the universal sensor shield such that the learning objectives of the course are most optimally achieved by the students. Taking into account the time constraints the focus for this project lies only in the first topic discussed in the Sensors course; capacitive sensing.

1.4 Research Question

How does the Sensors course need to be restructured after implementing a sensor shield to facilitate the understanding of the students?

1.4.1 Sub-question

- What type of sensor shield or sensor technology facilitates the students in the Sensors course?
- How will the shield look?

1.5 Outline of the report

The Analysis consists of background research on the course, general education for these types of subjects, and other sensor shields and why are they successful. Additionally, here will also be a summary of what the students think they are missing in the subject. Finally this section will close off with a list of requirements that need to be taken into account for the ideation phase.

The designing process is described in the Method and Implementation chapter. All information used whilst making the CreaTe approved datasheet and the sensor shield is portrayed here. The shield takes is made using KiCAD 5.1.0 and is designed to be identical to the currently used capacitive sensing setup. The CreaTe approved datasheet is created to be a concise and effective tool for students to understand the assignments and the underlying principles.

This report closes with a discussion of what obstacles and setbacks occurred, a recommendation on what needs to be done in further research, and answers to the research questions in the conclusion.

Chapter 2 Analysis

At the end of the course, students are acquainted with the fundamentals of sensing and can apply this proficiencies again for later projects. After having successfully completed this course the student should be able to:[1]

- explain meaning, relevance of - and perform basic calculations with - the concepts range, accuracy, resolution, linearity, bandwidth and sensitivity of sensors.
- name various sensors for measuring a given physical phenomenon (i.e. displacement) and describe performance, limitations and use conditions of these sensors.
- explain the physical phenomena used as measurement principle and perform basic calculations
- explain and demonstrate how the discussed sensors (magnetic, resistive, optical, capacitive, acoustic) can be interfaced using microcontroller system (i.e. Arduino)
- change or adapt basic signal conditioning circuits to their needs using for example (negative)offset, amplification, a bridge circuit. - explain the characteristics of noise and other negative influences on measurements and name methods to deal with those.
- explain functioning and aspects of - and perform basic calculations with - resolution, frequency, linearity and range of different AD converter types sensors commonly used for the measurement of these quantities
- explain how to implement a given AD converter circuit (capacitive, R2R) using a microcontroller system
- point out the bottleneck(s) in a given measurement system.

2.1 Education

This literature review is focused on the educational aspect within the sensors course. This review helps with getting a better insight in how general education can be applied for teaching practical subjects and will provide information on what aspects are important to keep or improve with respect to the current Sensors course.

To make sure that the new shield can be applied the best, the lectures need to be restructured as well. To support the changes of the lectures underlying theories on how students can learn practical information without any underlying knowledge need to be investigated. First different tactics of teaching students in a practical setting will be discovered. After that information on students in practical settings and how they react to this will be discovered. Together this will form solid insight in recommendation for the change in lecture setup for the sensors course.

2.1.1 Tactics of teaching students

Tactics of teaching new information to students can be quite a challenge, especially when looking at practical aspects like sensors. Obtained information must be processed quickly in order to apply them in a physical example. One way to improve the efficacy of student when

[1] http://wiki.edwindertien.nl/doku.php?id=education:sensors:00_course_layout

working on such a subject is the idea of a so called Self-Flipped Classroom (SFC). In this SFC student will read into the material before the lectures and apply this during the class in projects, discussions, or cases. For the homework the teacher is always accessible for question via an online platform, around which the whole concept is built. The SFC is loosely based on Piaget's philosophy of constructivism and Papert's theory of constructionism. Constructivism revolves around the idea that an individual comes to an understanding by taking their own knowledge and combining it with other people's understanding. Constructionism takes it one step further by transforming the obtained knowledge into a physical project or artifact, also known as learning by making (Vasilchenko, Cajander, Daniels, and Balaam, 2018).

Taking the SFC approach one step further is the "IDEA" concept: Introduction, Deep dive, Exercise and Application. In this model students can decide their own pace on the subject and will start with a small lecture hosted by the teacher. After this lecture, the student will do their own study and dive deeper into the information provided in the lecture. In the exercise phase student will perform small experiments to gain experience and understanding in the subject so that it can finally be applied in new projects. The big drawback here is that students will take a longer time in getting to the final understanding in comparison to the regular lecture systems. However, even if a student has a lot of knowledge about a subject, the lack of practical experience could lead to this student making more mistakes in applied settings, stressing the importance of hands-on experience Schmafeldt (2018). Patil and Meena (2018) add to this that the information gained by practical experience is easier for students to remember than the information from lectures.

A different take on Papert's constructionism is Kolb's experiential learning theory. This applies its practical function as a feedback loop; generate theory, apply this theory during an experiment and reflect upon how this knowledge is used to generate new theory. Usually the generation of theory and the application of the theory is in a first-hand experience of the student. This way students are capable of quickly learning new (complex) concepts (Falloon, 2019). By applying the knowledge in such a fashion, students are more likely to get motivated in learning new and difficult content (Bradberry and De Maio, 2017). By experiencing the material first hand or in a problem based scenario case, students do not only become more motivated, but also become more confident in their skills. This confidence comes forth from an open ended problem where students are inclined to make their own conclusions based on thinking critically about the scenario and how it could be applied elsewhere (Flores, 2018).

The SFC and "IDEA" concept both rely on students obtaining most of the information by studying and looking up information at home. For the sensors course this would not be very beneficial, as it is heavily reliant on physical interaction with the sensors. This interaction would provide a better insight into the lecture content. Therefore, it is more beneficial to stick to the lecture with the recommendations and not elaborate on the stuff students have to do at home.

2.1.2 Students in practical learning

Both theory and practical experience are profound components of learning. The theory obtained by lectures and listening to what the teacher has to say is applied on the practicals, which in turn enforce the understanding of the theory. Practical experience is more than just some training, it provides students with professional knowledge and general skills suitable for the workplace. Although, it is important to note that there is a lot of difference between the practical experience learning. The first being implicit learning; gaining knowledge without being conscious of what is learned. This could lead to the inability to process the practical information properly to apply it in future situations. Second is deliberate learning, the opposite of implicit learning; the student actively plans situations and processes information to fit these situations. Third, and finally, is reactive learning; unplanned situations that demand spontaneous on the spot solutions to tackle. A combination of deliberative learning together with reactive learning are the most desired when it comes to acquiring new skills. It is important to prepare accordingly for practical scenarios, because otherwise the student might fall back on implicit learning and will stay in their habitual thinking patterns (Ulvik, Helleve and Smith, 2017). In addition to this, Fong, Gilmore, Pinder-Grover and Hatcher (2017) state that checking up with a feedback session halfway through the module will help with student efficacy during the lectures and might spark their interest in the subject if they understand that their feedback on the module is also immediately experienced by them.

On the other hand, both Dannenhoffer (2006) and Bradberry and De Maio (2017) note that student are passive learners, especially in the traditional lecture methods. They go to the lectures, listen to the presentation of the teachers, and go home again. The issue here is that students are hardly motivated with regard to their studies and do not actively seek for more information or understanding regarding the topic. Dannenhoffer (2006) want to tackle this issue by having students take cases as homework and learn from them by looking for the required information by themselves. This information will be tested on an ungraded test followed by discussion of the materials. This approach is similar to Schmafeldt's (2018) IDEA, but fails to mention how this relates to practical scenarios. On the other hand, the use of recognisable cases will improve the satisfaction of student with respect to the learning material. Capobianco, Diefes-Dux and Oware (2007) continue in stating that practicals do not only provide technical experience, but also provide a big contribution to relationship or communication skills. These come as a result of students with similar skill sets interaction with each other and working towards a mutual goal.

It is important to let students participate in practical experience since this will not only provide insight in the lecture content, but also contribute to social skills. However, it is important to note that the actual practicals are guided properly to ensure that the students do not accidentally come to solutions. These accidental solutions will not contribute to the actual insight of students with regard to the study material and practical experience (Ulvik et al., 2017).

2.1.3 Conclusion

The goal was to discover teaching methods that can help students learning a new subject in an applied setting. This was essential since the subject of sensors uses real parts in its practice. Without any hands-on experience, students might end up with too little knowledge on the general subject with respect to calibration, troubleshooting and bug fixing. The aspect of an inquisitive mindset provide the students with a mental toolkit to facilitate dealing with these scenarios and continuing to explore the possibilities of sensors. The general solution would be to put students in small groups and have them perform a small experiment or practical based around the sensors. Discussion between students and student groups should pose sufficient in tackling the problems that arise during the experiment.

All sources promote that practical experience and student to student interaction greatly benefits the skill set and abilities of the student. The gain of practical experience improves the functionality, motivation, and confidence of the student. It is key that the goals of the subject are relatively open ended. This will spark discussions between students so they can learn from the understanding from others. By initiating discussion between peers, students will develop a more inquisitive mindset and an overall better skillset, both proving invaluable assets for further development. However, in the Self-Flipped Classroom and the “IDEA” concept the most information gain by students is done themselves by looking up papers, videos, or other information at home. Understanding sensors is much easier when done at with the sensors at hand, favouring the experiential or constructionist approach during the lectures. For the lecture recommendation, this means that the experiments will be relatively open ended such that student can experiment themselves with the sensor shield, whilst not losing too much valuable time on the connecting. Students will need to work in small groups and interact with each other to begin building on their collective understanding of the subject. With critically thinking about the assignments and some guidance by the teacher, the students will come to understand the course contents and further applications of the sensors.

Further research is needed on sensor education for university students specifically. This review only show a small variety of tactics that can be applied for learning practical skills and experience in general, but the general concept of sensors is still missing. Next to that is noted that most of the sources are very recent since they are published in 2017 or later. Older sources are likely to hold useful information regarding both sensor education and teaching in a practical way. Finally, in relation to the sensor shield part of the overarching project, research needs to be done on sensor shields and their implementation into a lecture model. This closes the loop of investigating a proper lecture model for sensor education designed around the sensor shield.

2.2 Sensors

2.2.1 Sensors in the Sensors course

The sensors currently used in the course are a good place to start. The main goal of this project is to create a shield or package that supports the students in experimenting and understanding the principles behind sensor technology.

Table 1: Sensors course topics of sensing and their application

Topic	Theme	Principles	Application	Sensor
Acquisition	Measuring	ADC, switching, characteristics tools	R2R and capacitive DAC	DAC and ADC
Capacitive	Time	capacitor physics, RC network, CCD	LED	Capacitive sliders
Resistive	Voltage	resistor bridge, 1/R, amplification, offset	Strain gauge	Strain gauge and foil-sensor
Optical	Encoding	encoders, PSD, interrupts	Grey encoder	PSD or reflective sensor
Magnetic	Transfer	Hall effect, transformer	Hall rotary	Synchro or Resolver
Acoustic	Wave	time, frequency, Doppler	Radar	Ultrasonic

2.2.2 Sensor shields

There are already a lot of shields available for Arduino. Some of them purely focus on actuators or interfacing and others on sensing. Here a small portion of shields with sensors and similar aspects will be discovered, since they relate well to this project.

The Tinkerkit sensor shield is an Arduino shield specially designed for the use of actuators and sensors. The 3-pin connectors provide the actuators and sensors with the power supply, ground wire, and the "communication" pin for controlling the actuators or gathering data from the sensors. The key of this design is the ease of connecting actuators and sensors with three connector pins, since it is just a direct connection. On the other hand is the complete programming of the sensors and actuators still needed, but this can be given in a basic code package that accompanies the parts.

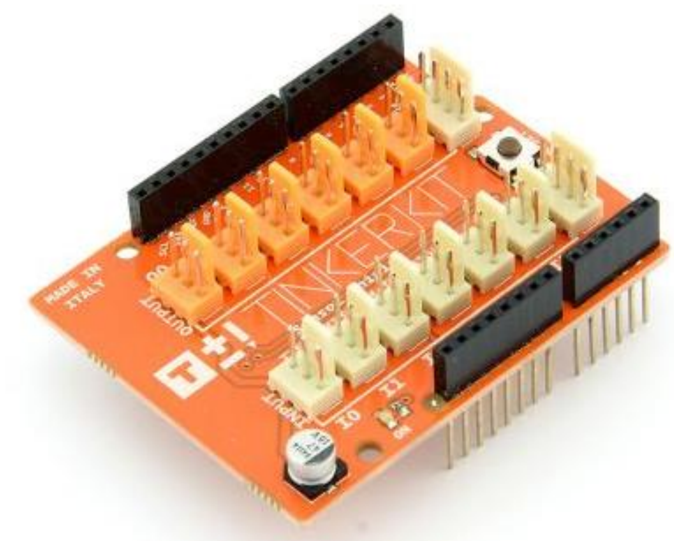


Figure 1 Tinkerkit Sensoe Shield V.2. [2]

The Multifunctional shield quite literally means a shield with multiple functions. An example of such a shield is provided in figure 2. This specific shield can be used as the user desires within the limit of the components provided on this shield. Additionally, there is a code package with examples of using the shield on an Arduino. Similar to this and with sufficient knowledge in electronical circuit, any type of sensor shields can be designed to fit the preferences of the designer.

[2] http://www.farnell.com/datasheets/1581474.pdf

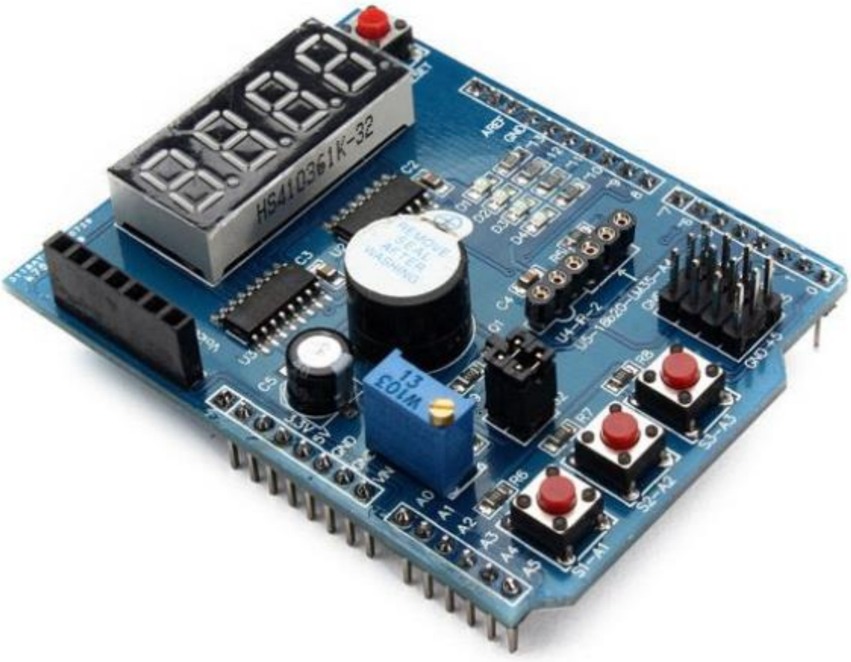


Figure 2 Multi-function Arduino shield with numeric display, buzzer, potentiometer, three tactile buttons and interface connectors.[3]

The Sense HAT is an add-on board for the Raspberry Pi and is composed of a set of sensors and actuators, thus making is an example of a multifunctional shield. The Sense HAT has an 8x8 RGB LED matrix, a five-button joystick and has the following sensors: gyroscope, accelerometer, magnetometer, temperature, barometric pressure, humidity. This board was specifically designed for the Astro Pi mission, launching it towards the ISS. Therefore, these sensors pose interesting when designing a sensor shield that will travel through different atmospheres or climates.

[3] https://opencircuit.nl/Product/10805/Multi-function-Shield

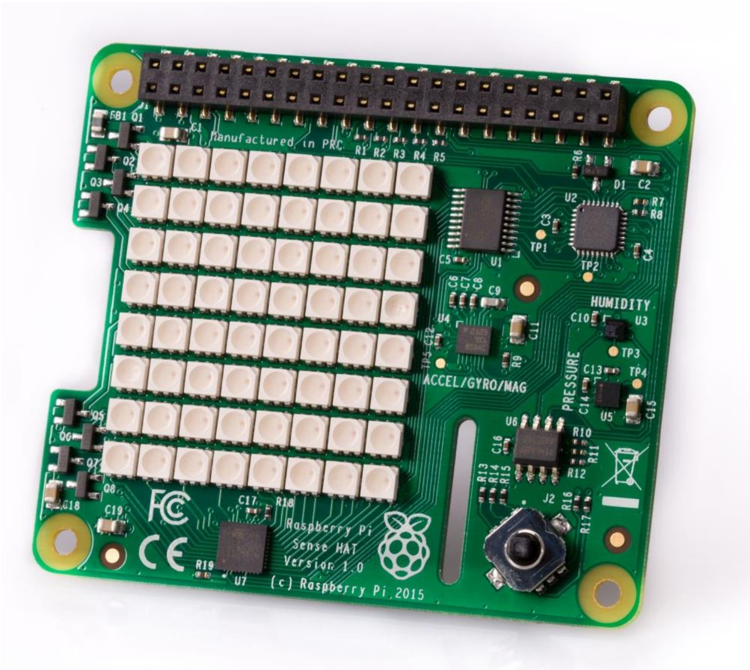


Figure 3 Sense HAT, Raspberry Pi add-on. [4]

37-in-1 sensor kit is not a sensor shield but a buyable collection of actuators and sensors. These actuators and sensors are listed below in table 2. This collection provides buyers with a general set of sensors and actuators that can be used for an elaborate variety of Arduino usage. Although the set consists of many useful sensors and actuators it does not come with an example code package, making it more difficult to get started, but benefits from creative usage. On the other hand, examples are provided on the internet for example via [SOURCE].

Table 2: Actuators and sensors of the 37-in-1 sensor kit [5]

Joystick	Flame	RGB LED	Heartbeat	Light Cup	Hall magnetic
Relay	Linear Hall	SMD LED	7 Color flash	Tilt switch	TEMP 18B20
Big sound	Touch	Two-color LED	Laser emit	Ball switch	Analog temp
Small sound	Digital temp	Mini Two-color LED	Button	Photoresistor	TR emission
Tracking	Buzzer	Reed switch	Shock	Temp and humidity	IR receiver
Avoid	Passive buzzer	Mini reed	Rotary encoders	Analog hall	Tap module and Light blocking

[4] https://www.raspberrypi.org/products/sense-hat/
[5] https://tkkrlab.nl/wiki/Arduino_37_sensors

littleBits takes a very modular approach to electronics. All components are quickly connected by magnets and can function in nearly any way combination. littleBits tries to make coding and using electric component easy such that it can effectively be used as a solid learning experience for (younger) users. Since the issue of connecting is eliminated, users can immediately start exploring the functions and possibilities of all the components and create creative and interesting setups for various experiments. Unfortunately, users will probably not get any insight into the actual workings of the sensors and actuators, making problems in the system even more problematic as they can hardly be understood or be solved.

Figure 4 tiny setup of a littleBits set with sensors and actuators.[6]

Evive is an all-in-one toolkit for projects similar to things you can do with an Arduino and functions as a building, learning and debugging tool. It essentially is an upgraded Arduino with a visual interface, power module, plug and play connection, data acquisition modules, and a set of pins and a breadboard for connecting other devices just like you can with an Arduino. With these implementations, the general user experience is improved when compared to the Arduino since a lot of accessories are already implemented in the device. This allows user to immediately focus on the important aspects of experimenting with electronics instead of setting the all the extra accessories before getting started.
Additionally the Evive is compatible with Arduino, MatLab, Python and other many programs allowing it to be an extremely useful and versatile platform to learn and play with hardware.
Other Evive kits come with additional sensor or actuator packages to make a plant monitoring system or a biomedical check-up device.

[6] https://littlebits.com/

Figure 5 Evive programming toolkit. [7]

The Evaluation Board ESP32 is an enormous microcontroller possessing numerous connectors, integrated hardware components and interfaces. With a size of The integration of such a wide array of components allows the user to focus on the software required for operating different Internet of Things projects. The whole board has a size of 18,5 by 21,0 cm, making it a big as two thirds of an A4 paper. With a basis on the popular Arduino platform and complete documentation with many examples, this board can effectively be used for quick prototyping of projects or products. Whereas the Evive supports the user with a better interface for managing software, the Evaluation board makes ensures that the hardware is easier to be managed by the user.

[7] https://thestempedia.com/product/evive/

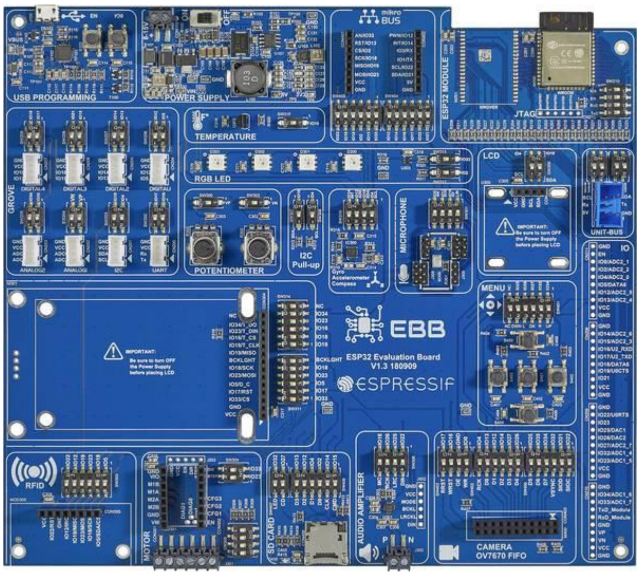


Figure 6 Evaluation Board ESP32.[8]

2.2.3 Conclusion and findings

There is hardly any information on shields for Arduino which only have a set of sensors integrated on them, which would completely nullify the connecting aspect of sensors. However, similar concepts are available such as the multi-functional shield and the SenseHAT; a shield with both sensors and actuators to perform a certain type of function. When these are not provided with an example code package it can be really difficult to get the most out of the shield's design and the importance of connecting parts are not investigated.

Something similar to the Evive would be interesting as the essentials of operating the board are already implemented, but the sensors still need to be connected and coded completely. The addition of a small visual interface could prove invaluable for quick data reading and discovering where the problems are. Additionally the Evive can be used with the Arduino program, possibly making it an interesting addition for students who are struggling with the Sensors course.

Efficient usage with electronic components comes from understanding, experimenting and iterating, all with critical thinking.

2.3 Students input on the actual problem

To narrow down the problem of the course, a questionnaire is created to be held amongst the students who followed the Sensors course during their module 5. This questionnaire is given in appendix A. The questions in this questionnaire are asked such that students themselves indicate where, in their experience, the course fails to deliver its content. The questions ask for general experience, specific content, such as connecting and calibrating sensors, and personal recommendations by the students. It is already known where the general problem in the course material lays, but by doing this questionnaire it is expected to give a better insight

[8] https://www.conrad.nl/p/makerfactory-esp32-board-evaluation-board-1880275?searchTerm=esp32&searchType=suggest&searchSuggest=product

in hindrances that occur during the course. These answers will help with better indicating the problems surrounding the sensors course and enforcing the design concepts surrounding the sensor shield.

2.3.1 Results from the survey

This is the usable summary of the answers from students to the questionnaire. The complete answers to the survey can be found in appendix B. This extends the list of requirements, since this gives more insight in what needs to be achieved with respect to the experience of the students.

Generally the enjoyment of student during the course is pretty good. However, it is noted that the theory is very interesting but the practical fail to convey the same spark of interest with most answers stating that they are boring. The practicals are described as boring because of the hefty focus on the writing on the report instead of actual experimenting with the sensors. Simultaneously, the expectations for the report are quite unclear, there are too little student assistants to help with this, and too often there is no feedback on the weekly reports.

When looking at the issue of connecting it becomes clear that defective or faulty components give the most hindrance in the practical sessions. Some student also have general issues with the connecting of the sensors, but other state that there is enough information online so it is sufficiently doable. Nevertheless, the connecting of the sensors for the capacitive sensing practical was more difficult than the other practical sessions.

Next is the aspect of coding the sensors. Students state that they experience quite the challenge here, especially when trying to translate the theory of the lectures to a workable code. The basics are clear, but not how to perform the step from theory to programming code. Additionally there are some students who note that the data management in excel is quite challenging, but this will always remain a problem within excel and will therefore not be discussed later on.

From here on in the practical sessions, students mention that they have hardly any issues when looking at their own understanding of the use of sensors. The calibrating of and the measuring with the sensors is a doable task for the students at this point. Enough information can be found online when calibrating the sensors, since this basically comes down to finetuning the values used in the measuring process.

Finally, some students expect that if there are fewer sensors, the quality of the course will go up, because each sensor can be explored more elaborately. Combined with more teaching assistants and a better structured list for the report or example reports, it is expected that the subject can improve significantly when looking at what the students learn in those ten weeks.

2.4 Requirements

Based on these findings and inputs, a list of requirements can be made.

- Make a shield or printed circuit board (PCB) with a working capacitive sensing slider. It is important that there will be enough free space left on the board such that the other sensors can be added in a later design. This shield should fit on an Arduino Uno, since this is also the device possessed by all students.

- Make recommendations for changing the way of checking the understanding of students. The report as it is, is not clear enough for the students and burdens the teacher and teaching assistants with a lot reading every week. This needs to be done more efficiently.
- Make recommendations for changing the lecture structure throughout the day. This is done so that the concepts discover before can fit nicely together with the addition of the sensor shield.

Chapter 3 Methods & implementation

The capacitive sensing shield and the new concept for teaching the course take two different ways of methodical designing and implementing. Therefore, these two topics will be discussed separately.

3.1 Sensor Shield

Starting off with the general design of the capacitive sliders. There are currently three different types used for the practical sessions, shown in figures 6, 7, and 8.

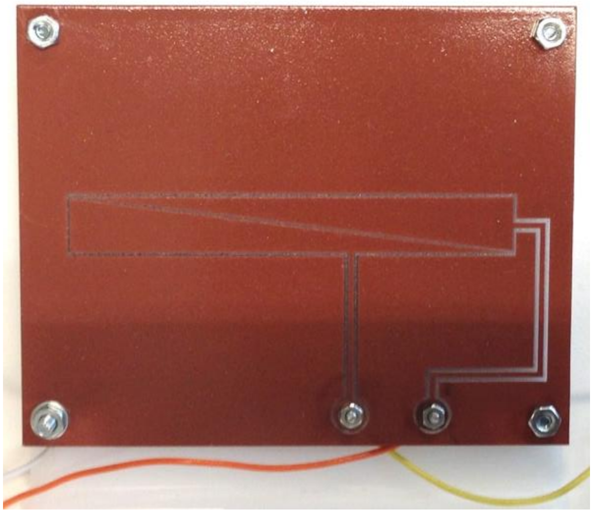


Figure 7 Two-part capacitive slider used for the practical session.[9]

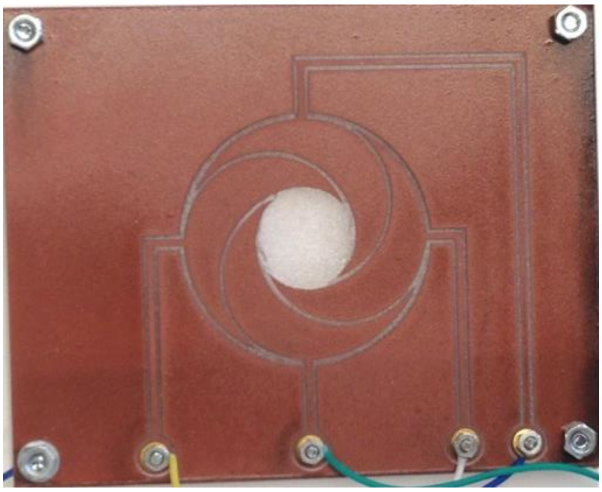


Figure 8 Four-part circular capacitive sensor.[9]

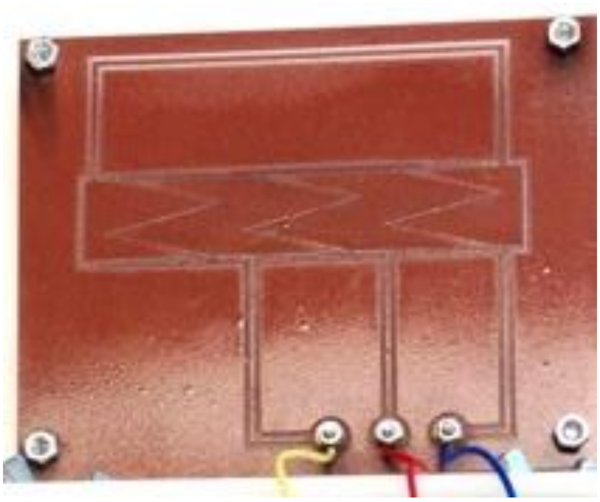


Figure 9 Four-part linear capacitive sensor.[9]

Currently, all 3 setups are used during the practical sessions. This is because there are not enough setups of one type to support all students at the same time. The circular capacitive sensor needs a larger surface area when compared to the linear sliders and since there needs to be a sufficient amount of space left on the shield for other sensors and connector, the initial choice falls on the linear sliders. The two setups consisting of four parts use the same

[9] http://wiki.edwindertien.nl/doku.php?id=education:sensors:02_capacitive_sensing

underlying principle as the setups with two capacitive plates, but are a bit more complicated to get started with. Therefore, it would be more beneficial to implement the two part capacitive slider on the sensor shield.
First, a schematic layout is needed with all the connections clearly laid out, making it easier to transform it into a working prototype. Figure 9 essentially gives all the information needed to get started; a sending pin powering the circuit and the safety resistor which split to the receiving pin and the capacitive sensing plate.

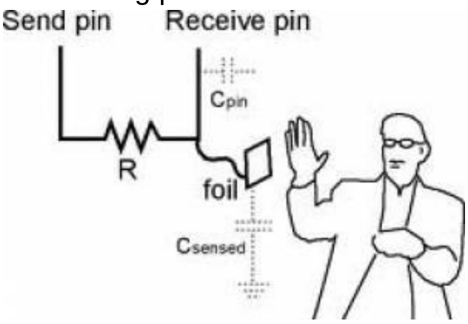


Figure 10 Basic schematic for a capacitive sensing circuit.[9]

Following the schematic of figure 9, four pins would be needed to create the complete circuit. Fortunately, only one sending pin would suffice to provide the whole circuit with the necessary power. This information combined leads to figure 10, where the triangle shapes denote the capacitive sensing plates that make up the linear slider, similar to the setup of figure 6.

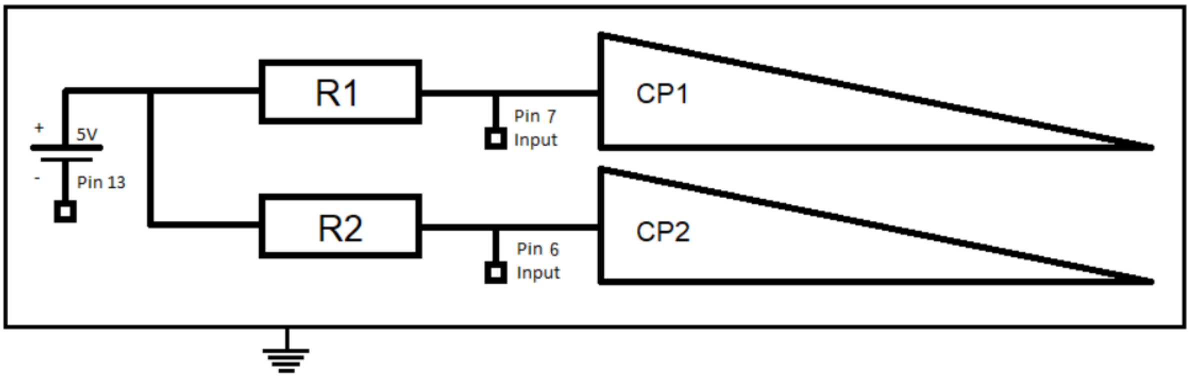


Figure 11 Schematic layout of the capacitive sensing components, with grounded surroundings.

Now that the sketched schematics are in order, it needs to be translated to a digital schematic. For this KiCAD 5.1.0 is used, because is was the recommended program in the first place and it additionally allows to create elaborate circuit boards with custom components, such as the capacitive plates needed for this project. The choices for the pin numbers are chosen purely for the simplicity. Since pin 13 is often used as a high output, it will also function this way for the sensing shield. Pin 6 and 7 are often used as an input and are therefore used as receiving pins for this circuit as well. This information results in the KiCAD schematic shown in figure 11. One extra thing that is added in the circuit is an LED. This is simply for the reason of troubleshooting, whether there is a current coming out of pin 13. If the rest of the shield is still not functioning properly, you will know that the problem lies somewhere in the capacitive plates or their corresponding receiving pins. The values for the resistors are taken from the wiki-page[9] for capacitive sensing.

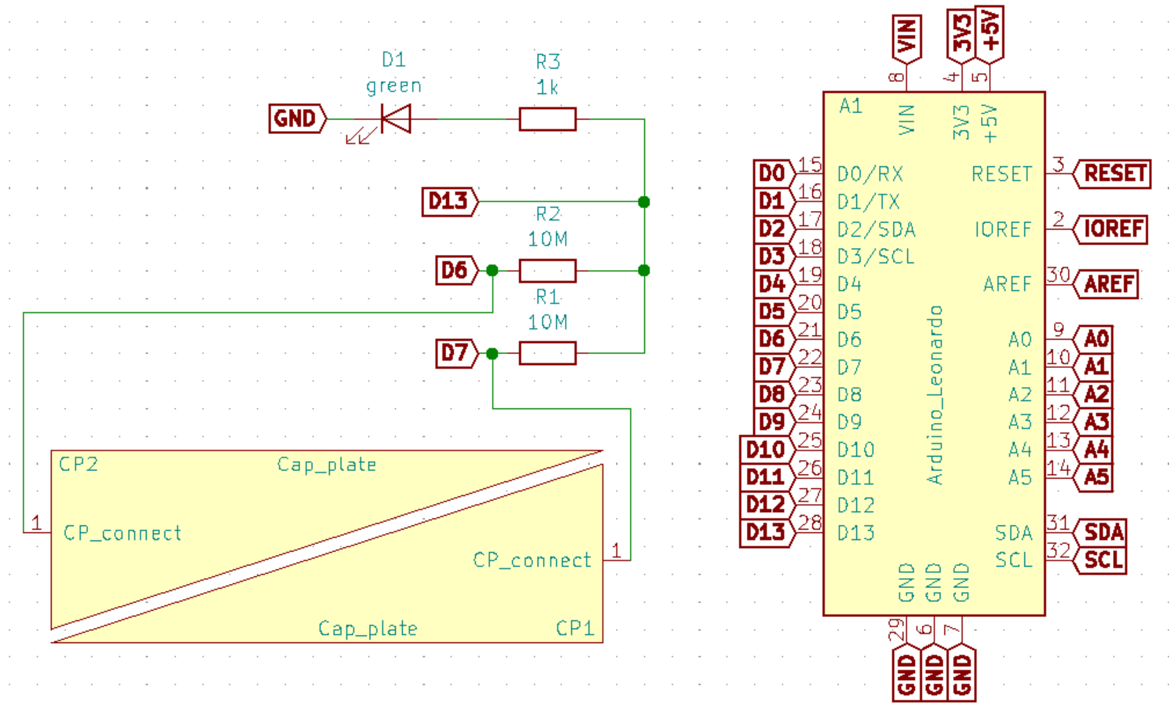


Figure 12 KiCAD schema for the capacitive sensing part.

The schematic is a basis for the physical layout design of the sensor shield. After assigning a physical component in KiCAD to each symbol, an actual working layout can be made. This layout can be seen in figure 13. The location for the capacitive plates are fixed. Here the plates can be the longest whilst not claiming too much of the available space on the Arduino sized sensor shield. The total length of the capacitive sliders combined is 5 cm still leaving a little bit of space for the wires to connect to the associated pins. The wiring and the placement for the resistors is not optimal in their current position, but this done purposely so that all connections can easily be seen. In the end they need to be replaced anyways when adding the other components to make the complete sensing shield.

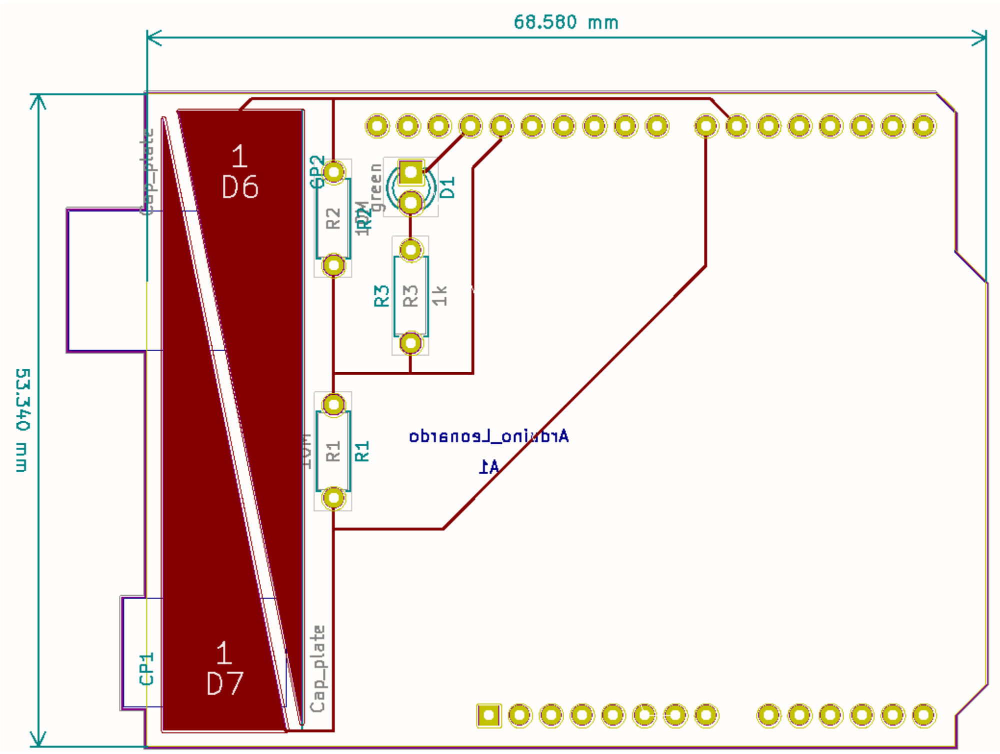


Figure 13 PCB layout of the sensor shield.

The resulting 3D view of the layout of figure 12 can be seen below in figure 13.

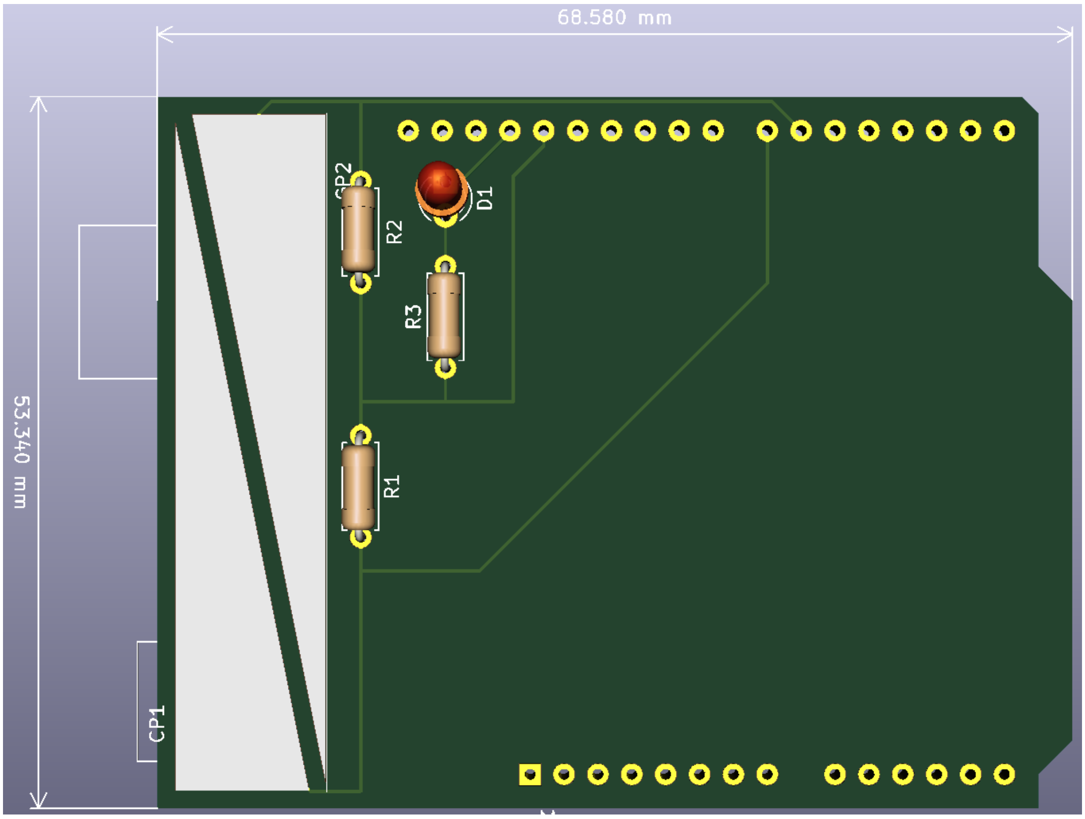


Figure 14 3D view of the PCB for capacitive sensing.

The use of through-hole-technology (THT) instead of surface-mounted-devices (SMD) is chosen for the sake of troubleshooting and replaceability. If a THT component breaks, it can easily be replaced by removing it and soldering on a replacement. This would be more difficult for SMD components. As seen in figure 14, SMD's might be more space-efficient and better looking, THT allows for quick check-ups with a multi-meter to see if all the components are working as intended. Students could also do the troubleshooting themselves if something is not responding properly. This will also contribute to a better insight in the underlying principles. The benefits of the THT components outweigh the benefits of SMD components in the educational setting, because it will help with providing better insight in what is going on.

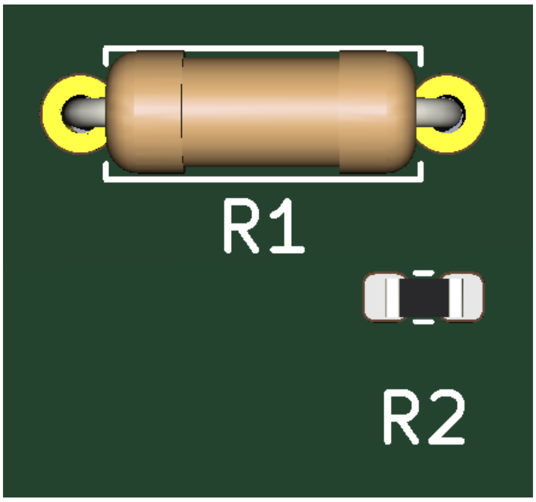


Figure 15 THT resistor (R1) compared to SMD resistor (R2).

3.2 Lecture model

Changing the current model is quite the challenge. It can range from a complete overhaul to just some minor changes. A big overhaul could be designing a new method from scratch, based on the approaches of Piaget or Papert or by looking at similar programs in other universities. Minor changes could simply be an addition of extra materials for students, like videos, papers, or example setups of the discussed sensors. However, students don't benefit from only adding a bit of extra material, because the problem is not only the connecting and coding and extends to the report. So, taking a complete constructionistic approach will not suffice for this project. A big overhaul will probably be too much for this project alone. Additionally, the essence of the course is solid, but the students get lost finding the correct information to apply in the practical session and write down in their report. Unfortunately, the concepts found in chapter 2 are too elaborate too work as a new lecture model and these concept require students to have more time to work on all assignments, which is simply not available.

The masters course Image Processing and Computer Vision (IPCV) uses a homework sheet that provided both information and requires the students to fill in a series of questions based on the results they get from using MATLAB. Small bits of information are provided throughout the assignment such that it provides students with the necessary basic information for each question. Students following this course proclaim that these sheets are very useful for the homework assignments and easy to use. This looks like something that would also be useful for the Sensors course and this idea quickly took root since this is similar to what dr. Dertien envisioned. So this concept, a homework assignment in combination with little bits of information for the basics, needs to be worked out. From here, the sheet concept will be further expanded and will be limited to one A4 sized sheet, a so called "CreaTe approved datasheet".

This datasheet should help students with both the theory and the practical aspects. On one hand, it should provide information on how to connect the shield and how to code it so that the desired sensing device can be used. On the other hand, it should provide small bits of theory that help students with understanding the principles of the sensors on the shield. Therefore, the following things need to be implemented on the datasheet: context of the sensor, how it works, connection information, hints for the code, and results of the students. However, since the sheet is only limited to a single sided A4 paper it needs to be as concise as possible. Since this is a very limiting factor, some of the trivial and very detailed information can and will be left out. If students really need some of this information, they can either look for it themselves online or use the wiki. Not everything needs to be chewed out and looking up information also requires students to actively think about what pieces of information they actually need.

Replacing the report does not only give the students a more focussed assignment, it also helps the teacher and possible teaching assistants. Instead of having to read approximately 20 to 30 reports every week and review them, it will be reduces to just checking the essentials written down by the students. Students felt that they were writing the reports for nothing, because only a few out of all of them were reviewed. This feedback for students is essential as it gives them a confirmation that they are not simply doing something because there needs to be something.

The CreaTe approved datasheet will replace the function of the report in the lecture model. The changes for the lecture model itself with respect the layout of the lecture, tutorial and practical session are practically non-existing. The choice for this is that the current model uses tactics similar to the SFC and IDEA discovered in chapter 2. However, the information gathering phase is sped up by providing the necessary information in the form of a lecture presented by a teacher. The tutorial and the practical session have enough time and space for the students to get to know the theory better, experiment with the available material, and get experienced with the physical components. This will speed up the process of learning new information and getting familiar with all the aspects.

In the end, the assignment sheet requires the student to understand the same principles and write down the same information. It could be argued that report writing is an important skill for students to possess, whilst this is true in the current Sensors course it is mostly overdone. During other courses and projects, students will extensively learn everything about writing proper academic articles and doing literature research. During the Sensors course students are hastily writing their reports to make sure it’s finished in time, straying away from the essentials of academic writing.

A CreaTe approved datasheet for the capacitive sensing topic has been made and can be seen on the next page. The text in blue indicates what information students need to create themselves by using the sensor.

Capacitive sensing

Student 1:

Student 2:

Introduction can be found on the wiki [9]

A capacitor consists of two conductors separated by a non-conductive region called the dielectric medium (though it may be a vacuum or a semiconductor depletion region chemically identical to the conductors). A capacitor is assumed to be self-contained and isolated, with no net electric charge and no influence from any external electric field. The conductors thus hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field. In SI units, a capacitance of one farad means that one coulomb of charge on each conductor causes a voltage of one volt across the device.

Principles

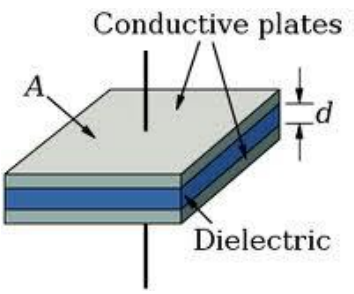


Figure 16 Schematic of a plate capacitor.[10]

Q1: Give a formula for determining capacitance. Hint: It consists of a relation between surface area (A), distance between plates (d) and dielectric permitivity of the material in between (ε).

Q2: Using two rolls of aluminum foil (i.e. 35 micron thickness, 10 meter length, 30 cm wide) and a similar size sheet of paper, what size capacitor can you make (how many farad?)

Translating this information to Arduino:

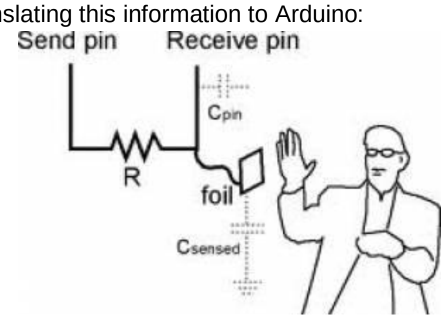


Figure 17 Sensing external capacitance using Arduino.[10]

Connecting

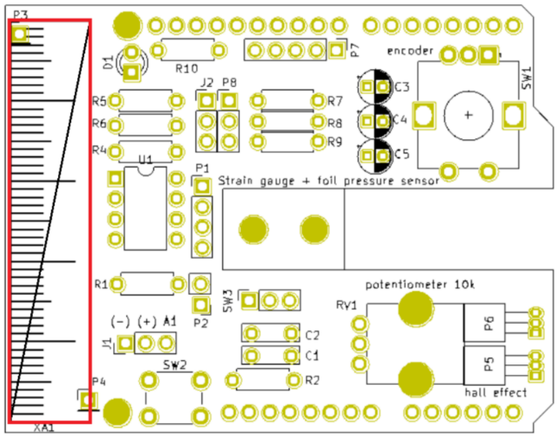


Figure 18 Schematic layout of the sensor shield. Capacitive sensing part is highlighted in red.

Note that the capacitive slider is in total 5 cm long. This is also marked by ruler printed on the shield. The capacitive plates are powered by Pin 5. Plate 3 (P3) is further connected to Pin 6 and R5. Plate 4 (P4) is further connected to Pin 7 and R6.

Q3: Sketch a schematic for the capacitive sensing circuit.

Q4: What value of resistance would you use for capacitive sensing and why?

Coding

Write your own code yielding a finger position in SI units [mm/cm]

Check the Arduino Capacitive sensing library or the LEDsense[11] example. You can use the geometry of the sliders to aid you in creating a formula. How would you translate the input on the capacitive slider to a distance? You can use the difference in capacitance divided by the total capacitance. This should give values resulting between -1 and 1 and 0 being in the middle.

[Fill in important piece of code that is the essence of the program, i.e. the piece of code translating sensor input to a usable value for distance]

Results

[Insert calibration graph and accuracy, range, and resolution]

[Include resulting findings of the capacitive sensor also include effects such as: hysteresis, drift, and repeatability]

10 http://wiki.edwindertien.nl/doku.php?id=education:sensors:02_capacitive_sensing

11 https://playground.arduino.cc/Main/CapacitiveSensor/

Chapter 4 Conclusion

The Sensors course as it is was not completely successful in conveying all of the goals to the students, especially with the underlying principles of sensors. Students failed to translate theory to code, did not understand the theory to connect the sensors, experienced broken sensors, or felt the course was boring as a result of writing inconvenient report every week. To support students in understanding the information better, a sensor shield and a so called CreaTe approved datasheet have been developed. The shield will help the students with connecting the sensors faster and easier to the Arduino to save valuable time. The sheet will replace the report as a weekly assignment. This sheet contains bits information on the principles behind the sensors, how everything is connected, and will ask the students to fill in some questions regarding the results of the experience with the sensor. The results students need to fill in are similar to what students need to do in the current

It needs to be noted that both the shield and the datasheet are recommendations for improving the Sensors course. As such, changes can always be made to either to better fit in the module. This can be done before or after seeing how the shield and sheet perform in the actual sensors course.

Chapter 5 Discussion

The initial goal for this project was to create a complete sensor shield together with a complete lecture overhaul for the Sensors course. However, due to inexperience in both creating PCB's and designing lecture models it was deemed not reasonable to finish this all in the appointed time. Therefore, the main goal switched from designing a complete shield with lecture model to only focus on the capacitive sensing topic. This change both influenced the general state of the art research and the main research questions. Whilst still very useful, more specified information could have been gathered, especially taking into account that the change occurred only halfway through the project.

Instead of beginning with researching all other aspects for this project, the questionnaire should have been handed out almost immediately after beginning. The input of the students is of essence when changing something to the course. This would have saved a lot of redundant research and allowed for gathering more specified information.

The goals for this project were quite clear. This resulted in a very straightforward approach and designing phase with little iteration over different concepts. This falls also under the research bias, selecting only pieces of information that suit the project

This straightforward approach unfortunately also resulted in too little user testing is done too see whether or not the new lecture structure will actually be effective. Additionally, these test are rather small scale as compared to the complete course content. However, the recommendations and designs created during this project are based on the complaints of students during previous instalments of the Sensors Course in combination with the effective aspects of the course as it is, so it is expected that this will already greatly improve the experience of the students following this course.

Chapter 6 Recommendations and future work

The first thing that needs to be done is a full scale test to see whether the implementation of a sensor shield with an assignment sheet will actually benefit the course. As of now, only small scale tests are done and while they show promising results, they are not statistically determining for the efficacy of the complete course overhaul. Next to checking if it fits properly, the datasheets may need to be elaborated to fit neatly in the assigned space for students. Otherwise, the implementation of an overarching assignment or report could be implemented to fill the gaps in the time available for the course. For now, the CreaTe approved datasheet is aimed to fit all necessary info on a single A4, but it does not guarantee that it contains all the actual information students would need or that it neatly fills up the time made free by removing the report.

During the project, the focus shifted from making a complete sensor shield for the Sensor course in combination with a complete lecture overhaul to just a design and overhaul recommendations for the first part of the course; the topic of capacitive sensing. Naturally, this has to be followed up with a complete design for the sensor shield and complete overhaul for the structure of the lecture. The lecture restructuring can and should be based on the same model used as recommendations from this project. This is to ensure that all lectures follow the same style and will not take students by surprise making them completely change their input and expectations towards the course.

A complete sensor shield has already been designed in KiCAD by Edwin Dertien and can be seen in figure 20. This shield includes all other connectors or sensors needed for the sensors course in addition to the capacitive sensor slider. These additions include connectors for the rotary encoder, a potentiometer, and three-pin connectors for other sensors such as an ultrasound sensor or a distance sensor (position sensitive detector).

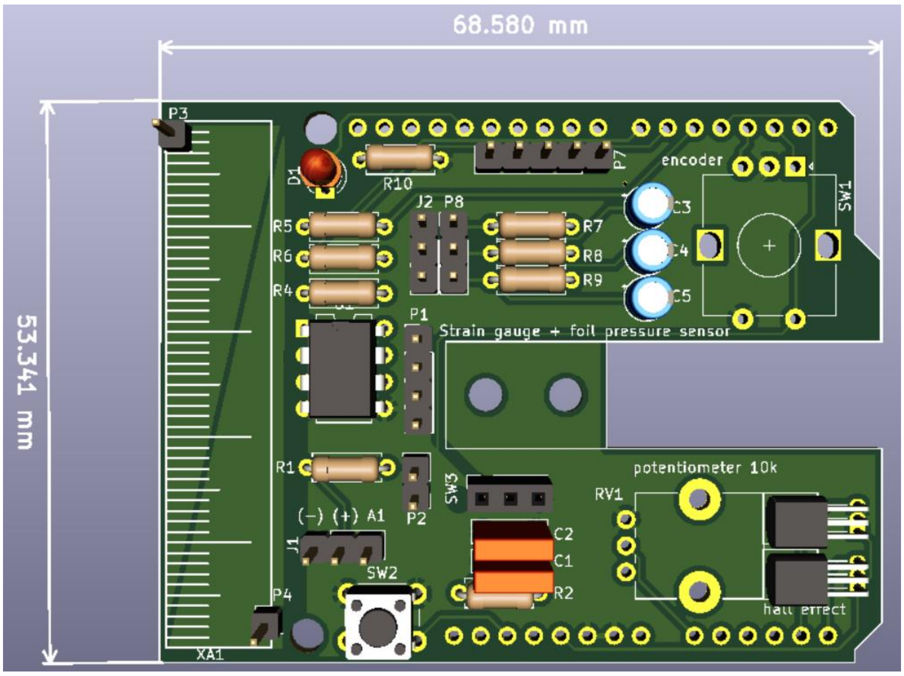


Figure 19 Complete shield design created by Edwin Dertien.[12]

12 https://www.ram.ewi.utwente.nl/e13/ sensorshield.zip in the \create\sensors\ folder

Chapter 7 Appendices

All other information or extra documents used during the project can be found here. These documents are too specific or too obtrusive to fit into the normal text. Very elaborate pieces and other files can be found in the rest of the .zip file.

7.1 Appendix A: Questionnaire Smart Technology students

Hi, my name is Thijs de Kleijn and for my Graduation Project I am currently working on a device that can help students with understanding and following the Sensors course better from Smart Technology module 5.
This questionnaire consists of 7 closed questions (with motivation) and 3 open questions. The answers to these questions will be fully anonymous and the information obtained will be used to possibly facilitate the Sensors course better in the future.

Q1: When did you participate in the Sensors course?

- This year, 2018-2019
- Last year, 2017-2018
- Before that

Q2: Did you enjoy the Sensors course?

- Yes, very much
- Yes, quite
- Somewhat
- No, hardly
- No, it was the worst

Please explain why

Q3: Did you have difficulties with connecting the sensors on the breadboard and the Arduino?

- Not at all
- A little bit
- Quite a bit
- A lot
- I still haven't managed it

Please explain why

Q4: Did you have difficulties with coding the sensors in the Arduino program? (i.e. taking the example code and expanding this to fit your experiment)

- Not at all
- A little bit
- Quite a bit
- A lot
- I still haven't managed it

Please explain why

Q5: Did you have difficulties with calibrating the sensors? (i.e. finding reference materials, doing experiments to set a reference value)

- Not at all
- A little bit
- Quite a bit
- A lot
- I still haven't managed it

Please explain why

Q6: Did you have difficulties with using the sensors to measure (i.e. taking or using one sensor as reference for the other and measure the requested properties)

- Not at all
- A little bit
- Quite a bit
- A lot
- I still haven't managed it

Please explain why

OpenQ1: What other difficulties did you experience during the sensors course, if any?
[open answer]

Q7: Do you think you achieved the learning goals of the Sensors course?
The goals are: yielding insight into sensor technology, gaining practical experience in interfacing sensors, and understanding of underlying technical problems.

- Yes, completely
- Almost completely
- Some of it
- No, none of them

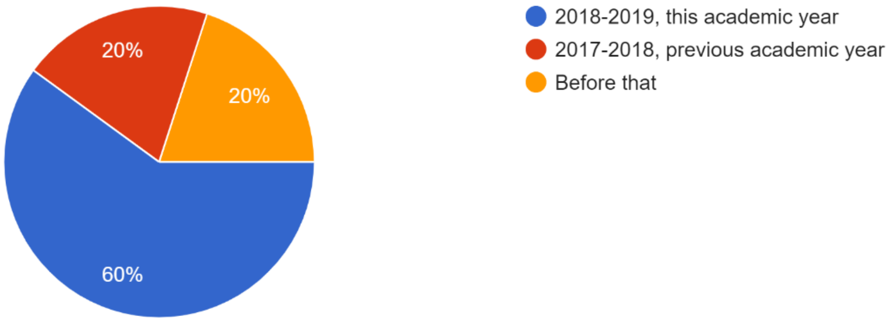
OpenQ2: What was for you the most difficult, annoying, or otherwise negative part of the Sensors course?
[open answer]

OpenQ3: What could, in your opinion, improve the Sensors course?
[open answer]

7.2 Appendix B: Complete answers to Questionnaire

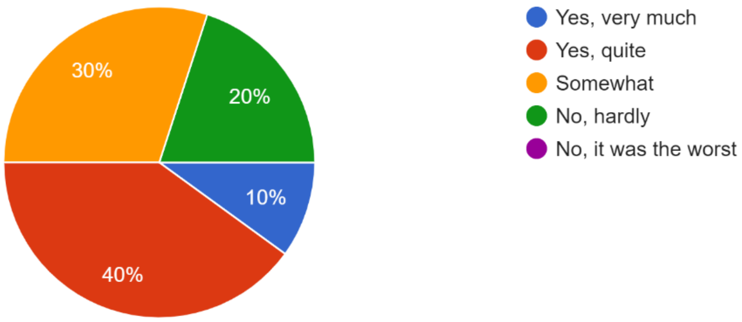
1: When did you participate in the Sensors course?

10 responses



2a: Did you enjoy the Sensors course?

10 responses

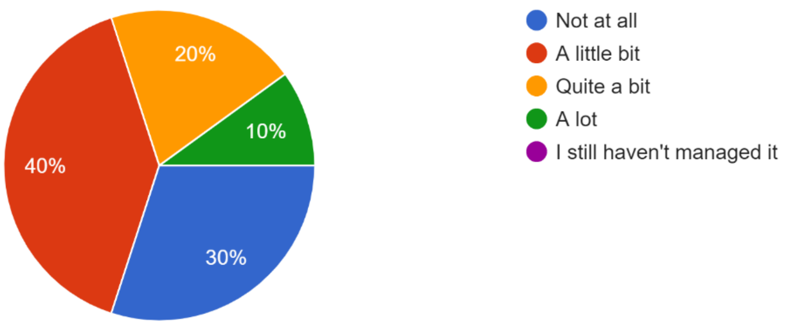


2b: Please explain why

It was fun to play around with sensors but the report and deadline are a bit too formulaic and boring
I like Arduino/electronics in general, the used sensors were cool. However, the assignments were boring, every week: "calibrate this sensor and write report". Meh
The theory was fun, however we had to do a lot of boring work to learn a little amount
I don't like practical stuff and sensors was a lot of doing. The theory was quite interesting I thought.
I like how we learned how to analyse a sensor: accuracy, precision and inner workings. I use that knowledge at the moment in my graduation project. However, the sensors that we discussed sometimes did not work, that was very annoying. But overall, it was one of the modules that convinced me that I want to continue with sensor technology
Very practical, hard if you don't do anything but easily doable if you put some effort into it
It was interesting finding out how to change the data from the sensor to linear data
It was an interesting course, but the explanations and directions left a bit to be desired.
Interesting topic, great lectures by Edwin
The course itself was interesting but the labs every week was really tiring. In the end we just wrote reports without really understanding how the sensors work. It would have made more sense to focus on less sensors to learn more.

3a: Did you have any difficulties with connecting the sensors on the breadboard and the Arduino?

10 responses

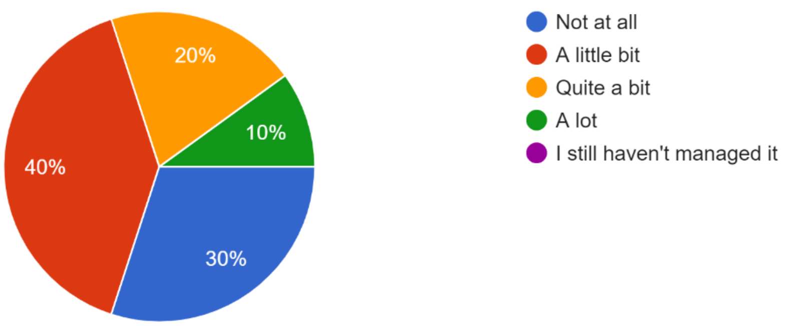


3b: Please explain why

Sometimes the sensor is faulty leading to faulty data but we didnt know if it is the sensor or our execution that caused the issue during data collection.
I'm the Arduino master
We had bad luck with broken cables, components etc that we and the SA's had trouble with
You were pretty much left on your own, there weren't many instructions. This made it hard sometimes. However figuring it out was doable.
Not all sensors that sensed the same property were interfaced the same. Maybe this was on purpose to challenge students, maybe not.
Well, it is a breadboard, not that hard
I do not remember exactly, but I remember one of the sensors was a capacitive sensor which was very hard to connect. There was no clear information on it and a lot of people struggled with this.
Most sensors were quite intuitive to connect and there was plenty of documentation available online.
usually interfacing was pretty straight forward
I remember the magnetic sensor was tricky about the polarity and how to connect. Otherwise it was fine.

4a: Did you have difficulties with coding the sensors in the Arduino program? (i.e. taking the example code ...expanding this to fit your experiment)

10 responses



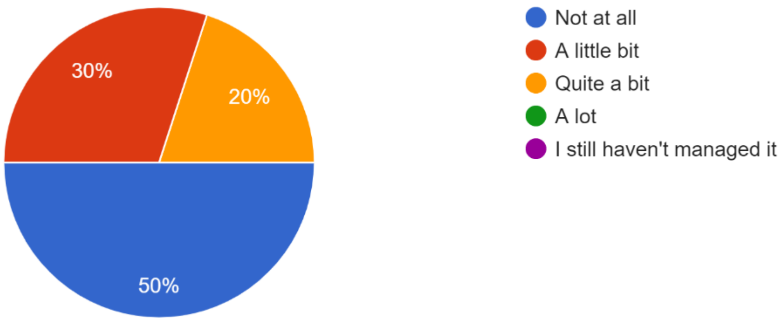
4b: Please explain why

The codes are readily available and if it isnt, there are plenty of tutorials and student assitants for reference
I also am the code master

.
I worked together with a good programmer so for him it was very doable :)
Not enough prior knowledge I think. An introduction on how to acquire curve fitting formulas with sensed data and excel would have helped I think.
I am a bit better at hardware than coding
One of the sensors was quite hard, but I really liked the challenge.
The basic physical concepts were clear, but making the transition from theory to code was hard.
sometimes it was hard, but very sensor dependant
Maybe it wasn't the code, but figuring out what to do. We spent hours and hours on last few sensors.

5a: Did you have difficulties with calibrating the sensors? (i.e. finding reference materials and doing experiments to set a reference value)

10 responses

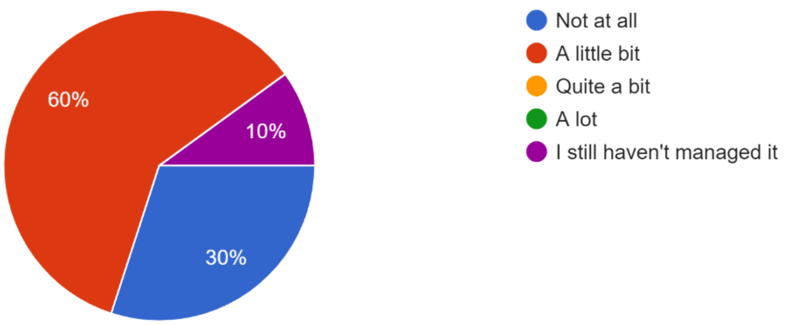


5b: Please explain why

See q3b
I'm just awesome
Lol we used "Karlijns laptop" as a unit of force
I don't remember that well
Enough material available on the internet and that is also how students will learn how to do research on this kind of stuff. Also they learn the workings for different types within a kind of sensor.
No, offsets are easily found and tuned
Didn't have trouble with this, always went fine.
The code needed to be correct first, which was hard to accomplish for me.
a new concept and therefore I found it hard to get a good feeling for it
The distance sensor was really tough to linearize reliably. The readings we got from magnetic sensor didn't make sense most of the time.

6a: Did you have difficulties with using the sensors to measure? (i.e. taking or using one sensor as a reference for...and measure the requested properties)

10 responses



6b: Please explain why

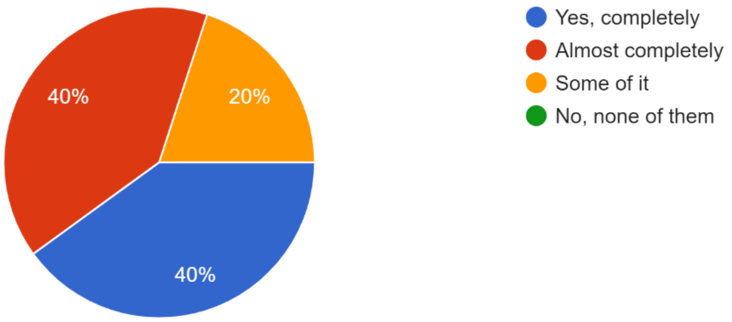
Again 3b
See ^
Only when the reference did not work
I don't remember exactly
As long as the relation was linear it was okay.
Just easy
Sometimes the second sensor was just as hard to calibrate/connect to the Arduino as the sensor the tutorial was about.
Once the code worked, the rest was quite easy to do.
some noise but usually worked pretty good
We simply didn't have enough time for that on distance sensor. We might have done it on flex sensor. It has been a while, I'm not sure.

7: What other difficulties did you experience during the Sensors course, if any?

Lack of guidance and template for the report. We soon figured it out eventually
Nah
Mainly defects
Not that I can remember
Mostly coding
Lack of TAs, unclear explanations, unclear expectations of the report, VERY late grading.
making graphs, was own responsibility and was quite time consuming since my excel skill isn't the best
The course was about creating convincing reports, turning nobs many many times, then a lot of guess work at the exam.

8: Do you think you have achieved the learning goals of the Sensors course?

10 responses



9: What was for you the most difficult, annoying, or otherwise negative part of the Sensors course?

LOOK AT 3B;
Boring assignment each week, calibrate this sensor. No creative input whatsoever
Again, things braking and the hours of troublehooting in an already bussy module
All the practical assignments
Defective sensors because you think it is your fault but actually the material is broken
Coding
Only two out of eight reports were graded (or looked at even!) which was very demotivating for those reports. There was a possibility to let your report be checked by a TA but they were always too busy with the sensors to check the reports.
The lack of TAs, who were also not always completely sure what to do.
see 7
Too much work, for too little learning.

10: What could, in your opinion, improve the Sensors course?

I'd say a project where you can make a product based on using the sensors we've learned how to use but I do understand the time constraints so this may not be advisable.
Creative implementations of the sensors rather than just calibrating and writing a report. Eg. Control a game, control a motor/display/actuator, or an end-assignment in which you use at least 2 of the taught sensors.
No idea
Less practical, however that is probably just me
Decide for yourself what kinds of sensors you want to interface. Have like 15 kinds and you can chose 8 that you are going to interface
I was quite impressed with the course
Example reports available for students, more TAs.
recommendation on graph software, or at least a basic introduction to making simple plots/adding axis/swapping axis
Less sensors please. The focus on quantity of sensors diminished both quality and quantity.

Chapter 8 References

8.1 Literary sources

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8.2 Websites and other links

This list contains all other sources used for small bits of information or figures and tables.

1. http://wiki.edwindertien.nl/doku.php?id=education:sensors:00_course_layout
2. http://www.farnell.com/datasheets/1581474.pdf
3. https://opencircuit.nl/Product/10805/Multi-function-Shield
4. https://www.raspberrypi.org/products/sense-hat/
5. https://tkkrlab.nl/wiki/Arduino_37_sensors
6. https://littlebits.com/
7. https://thestempedia.com/product/evive/
8. https://www.conrad.nl/p/makerfactory-esp32-board-evaluation-board-1880275?searchTerm=esp32&searchType=suggest&searchSuggest=product
9. http://wiki.edwindertien.nl/doku.php?id=education:sensors:02_capacitive_sensing
10. http://wiki.edwindertien.nl/doku.php?id=education:sensors:02_capacitive_sensing
11. https://playground.arduino.cc/Main/CapacitiveSensor/
12. https://www.ram.ewi.utwente.nl/e13/