DIGITIZING PRODUCTS:
CREATING DEMONSTRATORS
FOR FUTURE EDUCATION

digi demo

Indoor air quality monitor

Demonstrator classification and documentation

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Project consortium

Dissemination level

Code	Access granted to	
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Legal Disclaimer

About the DigiDemo project

Environmental challenges and digital transformation are two of the main drivers changing the world and the way business will be is done in the future. Therefore, it is essential to enable future employees to address these drivers. The skills and competences needed to develop digitalized products and awareness of the environmental challenges are therefore crucial for the European workforce and industry to continue being competitive in a future green economy and to maintain jobs across Europe.

The DigiDemo project addresses these challenges by developing demonstrators especially for higher education allowing to improve mainly mechanical engineering studies by integrating skills and competences allowing them to understand, develop and commercialise connected products. The results will be publicly available and can be used by every institution interested in integrating this type of training in their cursus.

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Revision history

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1.1	2022-12-02	Iversen	Updated with sustainability information from Transnational meeting in Dornbirn
1.2	2023-03-20	Vutborg	Finalising electronics part.

Document status

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Abbreviations

ESTA	ESTA Belfort (France)
FHV	Fachhochschule Vorarlberg (Austria)
FiV	Fagskolen i Viken (Norway)
UCN	University College Nordjylland (Denmark)
UBB	Universitatea "Babes-Bolyai" din Resita (Romania)
VOC	Volatile Organic Compound
SBC	Single Board Computer
IoT	Internet of Things
BLE	Bluetooth Low Energy

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1 Introduction

This demonstrator focuses on collecting data on the quality of air in indoor living quarters. The monitored parameters could be dust particles, smoke, airborne frying oil particles and various gasses, in particular CO2 levels. The chosen parameters will depend on which sensors are accessible at a reasonable cost.

The output from the sensors will be collected and can be used either to activate some form of alert, i.e., a light or sound signal, or in a more advanced version, the sensor data can be used to control the activation or speed of fan assisted air exchange, foreseeable in the form of control of the kitchen extraction hood, that is found in most modern homes.

2 Overview

The key properties of the focus project are:

Table 1: Specification of key properties of the focus project

Key Property	Value
EQF level	5 (Technician)
Year of study	2
Domain	Mechatronics
Objective	Hands-on
Workload	5+ ECTS (depending on setup)
Keywords	Internet of Things (IoT), CO2, Volatile Organic Compounds (VOC), Micro Controller Unit (MCU), Distributed Programming, Embedded Programming

The demonstrator is centred around an embedded microcontroller connected to an air quality sensor as well as a temperature and humidity sensor as well as a LI-ion battery pack. The embedded unit should be encased in an enclosure that allow for sufficient airflow, as to not hinder the sensing of the embedded unit. As reliable temperature measurements are needed the case will also need to allow for heat venting. As a possibility, the case could be designed with ventilation holes/slots in the bottom and top of the case, so that convection of the heat from the electronics, will force ait circulation in the case, thus ensuring fresh airflow for the air quality sensor.

The microcontroller collects air quality, temperature and humidity data from the IMUs at a given sample interval, filters and pre-processes the collected data and transmits it to a Raspberry Pi[1] single board computer (SBC) over Bluetooth Low Energy (BLE). The Raspberry Pi functions as a central hub and handles connections one or more embedded units, as well as collating and further analysing the data. The Raspberry pi can then transmit control signals to control units that are attached to various air extractions systems. These control units are outside the scope of this demonstrator.

The demonstrator is thought to be interdisciplinary from mechanics over electronics to SW development.

3 Description of fulfilment of keywords/characteristics

The demonstrator will improve teaching, by showing digitalization and value-adding of a well-known object.

The demonstrator will be replicable, as most of the hardware will be based on readily available modules, and further instructions on system fitting will be provided.

The demonstrator will be interdisciplinary, covering the following fields: Integrating and programming electronic sensors for pickup of air quality, temperature, and humidity as well as data transmission to central unit for further processing and control algorithm - mechanics for durable containment with focus on low investment and circulation.

Table 2: Description of fulfilment of demonstrator characteristics for the focus project

Characteristic	Description
Teaching improvement	The focus project allows the students to go through the entire process of development of a mechatronic product starting with requirements, through design, implementation, test and integration of both mechanical and electronic components with software. They work in interdisciplinary teams.
Sustainability awareness	In this project the sustainability awareness is relating to UN World goal 12, Responsible consumption and production, by providing good quality of air for indoor living quarters, without excessive ventilation and the related extra loss of heating energy. The project also relates to UN World goal 3, Good health and well-being.
Replicability	The demonstrator is implemented using off the shelf components, which are easy to replicate.
Industry needs	Implementing this demonstrator into existing air extracting products, has the potential to increase sales, as improving indoor air quality is a significant factor in overall health, and customers are getting increasingly aware of this.
Interdisciplinarity	The demonstrator requires both electrical and mechanical engineers to cooperate in implementing a mechatronic system. Software components are also part of the project, both PLC and microcontroller programming.

4 Classification according to the dimensions

The size of the setup will make it possible to be wall mounted. Therefore, in the teaching and evaluation phase, fixing will be generic, most probably based tape or other less permanent adhesives, to allow for moving.

Table 3: Classification of the focus project according to the dimensions

Dimension	Property	Value
Value chain	development	☑
	production	☑
	sales	☐
	after-sales-support	☐
	end-of-life	☐
Chain of technology	mechanical structure	☑
	sensors	☑
	electronic circuits	☑
	edge device	☑
	data transmission	☑
	cloud	☐
Sustainability	energy reduction	☑
	material reduction	☐
	better materials	☐
	better production	☐
	reparability	☐
	recycling	☐
Physicality	physical setup	☑
	simulation	☐
Degree of student freedom	demonstrated	☐
	guided	☑
	coached	☑
	autonomous	☐
Transportability	fixed	☐
	transportable	☐
	portable	☑
Costs (implementation)	EUR	300 – 1500
Costs (operation)	EUR	NA

Indoor air quality monitor

Dimension	Property	Value
Workload (implementation)	Hours	10 – 30
Workload (operation)	Hours	30 – 60
Size	m	< 1
Weight	kg	< 1
Special requests	no/yes, if yes: which	no

5 Educational information

5.1 Electronics Development

The demonstrator is to be used by students with a minimum of one semesters experience in low/mid-level programming, as well as knowledge about digital electronics. The following description assumes that C++ is used for programming the embedded ESP32 based unit. The learning goals are written based on Biggs work[2].

5.1.1 Intended Learning Outcomes

The demonstrator is thought to be used over several teaching sessions with exercises. These sessions consist of 4 modules of 45 minutes each. It is expected that the student after the demonstrator sessions session can

- ❖ Explain the workings of the I2C protocol
- ❖ Read a technical datasheet and extract information
- ❖ Implement driver functions to communicate with a digital sensor over I2C
- ❖ Explain how to establish a Bluetooth connection and use BLE attributes
- ❖ Design, order and produce a PCB suited for electronics module integration
- ❖ Design and produce code for low power applications

The students are taught I2C protocol, data filtering and encoding, Bluetooth Low Energy protocol and profiles, in particular GATT and GAP, sleep states in C++, as well as PCB design, layout and production and are then asked to solve the following exercises:

1) Initial design, testing and validation

a) Connect an SGP40 air quality sensor module and a DHT11 temperature and humidity sensor. As shown in the schematic:

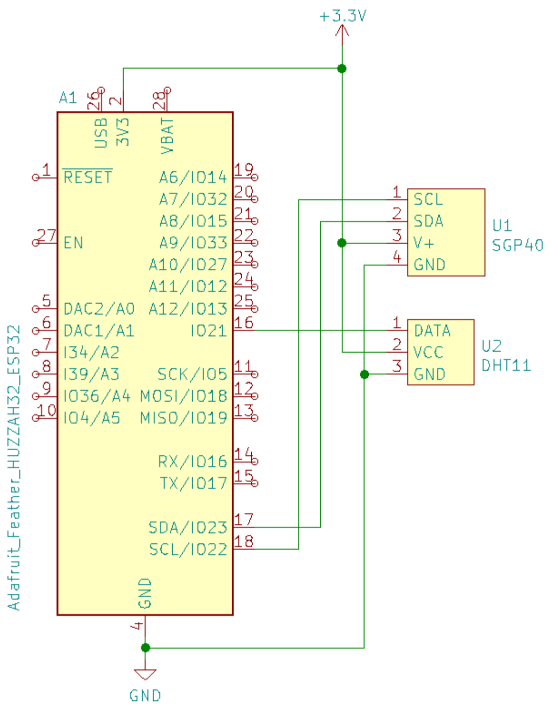

Figure 1: Electronics schematic

   b) Connect USB cable to PC with Arduino IDE installed and using the "Adafruit_SGP40.h" library, program the microcontroller to read raw TVOC values and at a regular interval print these to the serial port. Verify that the data changes as by breathing on the sensor.
   c) Include the "DHT11.h" library and expand you code to read temperature and humidity as well. Print these to the serial port as well, so that the readings can all be viewed in the serial plotter from the Arduino IDE.
   d) Expand your code with Bluetooth LE functionality. Verify that each of the following steps are functioning correctly with a BLE scanner app (e.g.: the one from bluepixel technologies)
      i) Program the device so that it will start advertising as a connectable device, when not currently connected.
      ii) Create characteristics for each measurement; TVOC, temperature and humidity
      iii) At regular intervals, update the values of these characteristics, and push notifications
   e) Run the host application on the Raspberry Pi and verify that it connects to the embedded unit and receives data

2) Prototype design
   a) Using your preferred PCB design layout software, create a carrier board for your ESP32 board and the two sensors.
   b) Take into consideration the physical dimension constraints that might exist from mounting/enclosure, battery placement etc. See the mechanical part of the project.
   c) Generate production files e.g., Gerber files, and have your design produced. Once produced, verify that your existing code still works.

3) Software improvements
   a) Implement a deep sleep state, when no connections are available, to save on battery life when not in use.
   b) Implement temperature and humidity compensation by transmitting the read values to the SGP40 sensor.

5.2 Mechanical Development

The embedded unit should be encased in an enclosure that allow for sufficient airflow, as to not hinder the sensing of the embedded unit. As reliable temperature measurements are needed the case will also need to allow for heat venting. As a possibility, the case could be designed with ventilation holes/slots in the bottom and top of the case, so that convection of the heat from the electronics, will force air circulation in the case, thus ensuring fresh airflow for the air quality sensor.

For student projects, the casing will be produced using additive manufacturing, but as part of the mechanical student workload, drawings for an enclosure aimed at high volume production (plastic injection molding) should be made. Injection molding is a phase-shifting process, that requires consideration of a large number of parameters, to make well-functioning parts.

5.3 Sustainability – questions for reflection

The questions below are meant as inspiration for the teacher using the demonstrator. The aim is to strengthen the student's awareness regarding sustainability through reflecting upon questions related to the demonstrator. The questions can be used during the lecture or as the starting point for individual or group work, connected to the lecture. It is recommended that the students will answer the questions in groups and then present the result of their discussion on class.

The questions below are divided into three main categories, (1) general considerations, (2) recycling/reuse, and (3) product integrity, where the last two categories are addressing the specific demonstrator.

(1) General considerations

- Does the making or use of the product create pollution?
  - Looking at transportation of the components
  - Energy used during production
  - Energy used during product life (at the consumer and at the sales chain)
- Can the material and energy used to make or use this product be reduced?
  - Are there any stations for collecting the product for reuse?
  - Are there in the city/municipality any plants which can reuse/recycle the product or parts thereof?
- Can nature regenerate the resources used to make or use this product?
- Why would you want/need an Air Quality Device?

(2) Recycling/reuse

- What are the main materials used for the Air Quality Device (the addon to the extraction hood)?
- Can all the materials be recycled – are they "pure"?
- How should the parts be connected in order to be reused?
- Can the unit be moved to the next extractor hood (e.g., you move to a new house or flat)?
- Which extraction hoods are the easiest to implement the Air Quality Device into?

(3) Product integrity

- What are the key aspects to obtain a durable product, in terms of construction and material?
- What are they most important components to be able to maintain (e.g., changing battery, recharging battery, or creating a test button (so the consumer can be ensured that the product still works))?
- Do you foresee the need to update any components in order to maintain the integrity of the product (e.g., the sensors)?
  - Informing the consumer about the capability of the sensors (e.g., it is operating at 80% of maximum capability)?
- Are there any standard interfaces that can be used in the product (e.g., a wireless interface)?
- Would it make sense to integrate the product into a SmartHome application for the consumers mobile phone?

Can you see further ways to increase the life quality of the product?

6 Organizational information

6.1 Electronics Development

The following requirements apply

- Project duration: 4 sessions during a semester. Each session consists of 4 modules of 45 minutes per module.
- Group size: Ideally individual or in smaller groups, depending on the number of available microprocessor boards and IMUs, and to a smaller extend batteries.
- Prerequisites: Either preprogrammed Raspberry PI or an interdisciplinary group structure where the students also develop the Raspberry PI based data collection application.

6.2 Software Development

The following requirements apply

- Project duration: The SW part is thought to run over 4 sessions during a semester. Each session consists of 4 modules of 45 minutes per module.
- Group size: 2 to 4 students must team up and solve the exercises using the DigiDemo boards
- Prerequisites: Either preprogrammed DigiDemo boards or an interdisciplinary group structure where the students also have to assemble the board.

7 Description of the technology and the setup

7.1 Bill of Materials

The following table will outline the materials needed to produce the demonstrator. Note this is the equipment for one group of SW developers and must be multiplied with the number of groups.

Table 4: Classification of the focus project according to the dimensions

Quantity (Unit)	Description	Price (per Unit)	Price (total)
1 pc	Raspberry Pi 4B, 4 GB	64 €/pc	64
1 pc	Black Aluminum Case for Raspberry Pi 4B	30 €/pc	30
1 pc	16 GB micro SD card	12 €/pc	12
1 pc	USB type-c Powersupply	14 €/pc	14
5 pc	Embedded Unit (see below)	46 €/pc	230
			350

Embedded Unit:

Quantity (Unit)	Description	Price (per Unit)	Price (total)
1 pc	Adafruit HUZZAH32 - ESP32 Feather Board	18 €/pc	18
1 pc	GravityDHT11	5 €/pc	5
1 pc	Adafruit SGP40 Air Quality Sensor	13 €/pc	13
1 pc	Lithium Ion Battery - 3.7v 2000mAh	10 €/pc	10

Cables for connection the sensors are not included in the embedded unit, as they are custom to the specific setup.

8 References

[1] Raspberry Pi, “Teach, learn and make with raspberry pi,” 2021. [Online]. Available: https://www.raspberrypi.org/. [Accessed: 24-Feb-2021].

[2] John Biggs and C. Tang, *Teaching for Quality Learning at University*, 3rd ed. McGraw-Hill/Society for Research into Higher Education & Open University Press, 2007.