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Working title

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Vienna, 2020-03-01

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Abstract

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**Keywords:** smoke detector, Keyword2, Keyword3, Javascript, Tessel 2

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# Introduction (3 pages)

With the introduction of smoke alarm detectors for commercial use in the early 1950’s [1] and for residential use around the 1970’s this market is still growing and interesting market to date [2]. First smoke detectors were used for the military facilities, warehouses or public buildings from the government in order to meet prevalent safety standards. They were not sold to the public until a significant price drop of smoke detectors due to technical developments were achieved. One of the most important developments was the introduction of solid-state electronics [3]. Namely diodes, transistors and integrated circuits, which replaced the previous technology with its cold cathode tubes or vacuum tubes. This allowed manufactures to reduce manufacturing and resource costs, to mass-produce these devices and sell them at reasonable prices to customers. From this moment on, the whole industry started to gain momentum and further developments in terms of detection of smoke, size of the detectors, energy efficiency or to connect multiple detectors to fire alarm systems with steady connections to fire brigades. These allowed for a faster and reliable detection of fire and a prompt alerting of people in the building or structure these fire alarm systems were installed. For consumers smoke detectors which operated by batteries were introduced for easier installment and without the necessity of an expensive fire alarm system.

According to a survey of National Fire Protection Association (NFPA) almost every private household, at around 96 Percent, in the United States of America (USA)has smoke detectors installed in their homes [4] [5]. All these smoke detectors have one major disadvantage: the battery. These must be exchanged at certain intervals are renewal of the whole detector is advised according to manufacturer’s manuals to ensure proper functioning of the detector. In the European Union (EU) however, there is not such a dense distribution of smoke detectors in private households. This is due to higher and more uniform building codes across the EU and which focus heavily on fire prevention then fire detection. Every building according to its designated use must withstand a certain time against fire or fire safety facilities are implemented, whereas standards in the USA are lower or the they are not even adopted all [6]. This means a barely minimum fire safety requirements for new or existing buildings are met in the USA (most houses are built from wood because it is the cheapest resource in the USA). Fire safety regulations in Austria or Germany overachieve minimum fire safety standards of the EU. In Austria they are applied through several guidelines, e.g. “Österreichisches Institut für Bautechnik” (OIB) OIB Richtlinie 2 [7] and “Technische Richtlinie Vorbeugender Brandschutz” (TRVB) TRVB 122S [8]. In Germany there are similar guidelines, e.g. “Deutsches Institut für Normung“ (DIN) DIN 4102-1 and “European Norm” (EN)  
EN 13 501-1 [9].

Although there are many regulations to prevent fire, it is not totally impossible that fire occurs or ignites. If it does, annual statics [9] show around 400 people die from fire worldwide, but only one third dies in the consequence to fire, the other two thirds die in the case of smoke intoxication. 4000 people worldwide suffer long-term damage from burnings and around 1 Billion Euro of fire loss is accumulated worldwide in private households. These figures tell us most people die from smoke not from the actual fire itself. Many of these victims are surprised at night and do not recognize the smoke or fire while sleeping. To reduce the casualties of smoke intoxication almost every manufacturer of home smoke detectors has integrated or combined sensors for smoke / heat or carbon monoxide (CO), acoustic beepers or smart home implementations to receive notifications or ease maintenance [10]. For example, when there are several smoke detectors in every room of a house are installed, they create a mesh network. If there is an alarm, the detecting smoke detector transmits this signal to every other detector in the network and all acoustic beepers trigger at the same time to alert everyone in every room [11]. In Austria it is mandatory to install smoke detectors in habitable rooms or on exit paths in new or refurbished buildings since 2008 [7]. This does not imply that the latest and greatest smart home detectors installed in this new or refurbished buildings.

## Problem Definition (1/3 page)

Ideally, every private household should install smoke detectors in their homes, to protect themselves from fire and the even more dangerous smoke caused by fire. But most people think they are rather expensive, unreliable or are annoyed from changing batteries. This could lead to:

* losing their lifes from smoke intoxication
* damaging or losing their property in the case of fire without insurance covering it
* or treat safety or fire prevention slightly and do not care

Today’s home smoke detectors are well-engineered, reliable, more user friendly then people would think of.

## Aim of this work (1/3 page)

The aim of this bachelor thesis is, to show how state of the art smoke detectors work and to point out the principles of different detections for smoke and fire. A comparison amongst these detectors builds a foundation to decide which type of detection is suited best for a prototype using the Tessel 2 microcontroller. A detection function for this prototype is implemented to detect smoke and fire reliably. Furthermore, a website displays relevant information and the current status of the associated sensor of the microcontroller.

## Personal Motivation (1/3 page)

The topic fire safety is a vital part of my life, since I work as a field engineer for fire alarm systems for one of Austria’s leading companies for around ten years. During my working hours I check, maintain, program or install all kinds of smoke detectors or various parts of our fire alarm systems for our diverse customers. Although there is a lot of routine work, because all parts work almost flawless, it is still a challenge for me to retain this high level of quality, our customers rely on. And this high reliability of our products made me curious how different detectors or parts of our fire alarm systems are constructed and work. Also, many lives were saved because of smoke detectors. In fact, fire deaths were reduced around 50 Percent since the 1970s [12]. Therefore, I would like to design an appropriate smoke detector prototype and a corresponding website. This shall help to engage myself even more with the topic fire safety and to gain in-depth knowledge of the technical fundamentals behind it.

## Methodological Approach (1/3 page)

At first, a theoretical research of current existing detecting methods, sensors and detectors for smoke and fire is conducted based on relevant literature and from hardware manufactures. In order to choose an appropriate approach for my smoke detector design it is necessary to understand and to highlight all different types of smoke detection. After this, the chosen microcontroller and proprietary modules are assembled and configured to accomplish suitable detection function. Then a website is programmed to showcase the function of the designed smoke detector, both functionally and visually appealing.

## Structure of this thesis (1/3 page)

This thesis is structured in five different sections. The first chapter focuses mainly on background information, my personal motivation and the aim of this bachelor thesis. It also gives an overview of my approach to achieve this aim.

In the second chapter technical fundamentals of different smoke detectors are described. Also relevant information for home smoke detectors and regulations how they are used are mentioned. Then, used hardware and software are briefly discussed to show why they were chosen.

The third chapter covers the actual design from the concept, architecture and to its final implementation. ???

In chapter four … ???

The last chapter concludes … ???

# Technical fundamentals (12 pages)

This chapter covers and provides all relevant knowledge needed to understand underlying principles of smoke detection first. Then an overview which hardware was used to implement and realize a prototype design is presented. Furthermore, this chapter explains which software, protocols or standards where needed to apprehend interaction of each component for the prototype.

## Smoke detector types and principles (8 pages)

The following sections illustrate the variety of relevant state of the art smoke detector types and their principles of smoke detection. Based upon their description a suitable smoke detector is used for the prototype development.

### Factors affecting smoke detection

There are many different factors to be considered when smoke detectors are in use. But these four key factors [12] determine how well smoke is detected and these factors affect detection the most.

The first factor is smoke itself. Nor the amount of smoke emitted, or composition is not the same, depending which materials burns. Every material burns differently thus meaning the size of particles or smoke density change. Some materials produce larger particles when burned (e.g. plastics) or smoldering fires compared to flaming fires which emit smaller particles.

Another factor is smoke entrance resistance i.e. how easy or hard it is for smoke to permeate into a detection chamber. If this resistance is too high (e.g. geometry or structure of a detector, or filters are to narrow), this will affect the rate of smoke detection.

The rate of smoke buildup is factor three. Some materials burn faster than others based on their chemical structure itself [13]. Or for example smaller objects burn faster than larger objects (same material, same weight considered). Due to their increased surface area, more oxygen contributes to oxidation process leading to an increased combustion process [14].

The last factor to be considered is the low propagation velocity of smoke (unless there are no vents or air supply nearby or active). On one side this eases smoke permeating into a detector chamber. On another side this low velocity smoke could cool down and form larger particles i.e. there are less particles for detection and it takes smoke longer from the fire source to reach the detector.

With this comprehension in mind, smoke detectors have different sensitivities based on their varying detection mechanisms and scopes to detect smoke particles.

### Ionization smoke detectors

These type of smoke detectors were the first to be developed, although their principle was discovered accidently around the 1930s and they were granted license to distribute in the 1960s [16]. For detection a small amount of radioactive material, americium-241 (AM-241) is used. This material and two metal plates (one positively and negatively charged) are located inside the detection chamber shown below in Figure 1. The radioactive material is present in the form of a thin foil beneath both plates. When no smoke is present within the detection chamber, AM-241 ionizes air molecules to create a steady current flow between both plates. When smoke enters the chamber this interaction of ionization with the air is disrupted, because AM-241 interacts with smoke particles instead of air molecules thus resulting into a current drop.

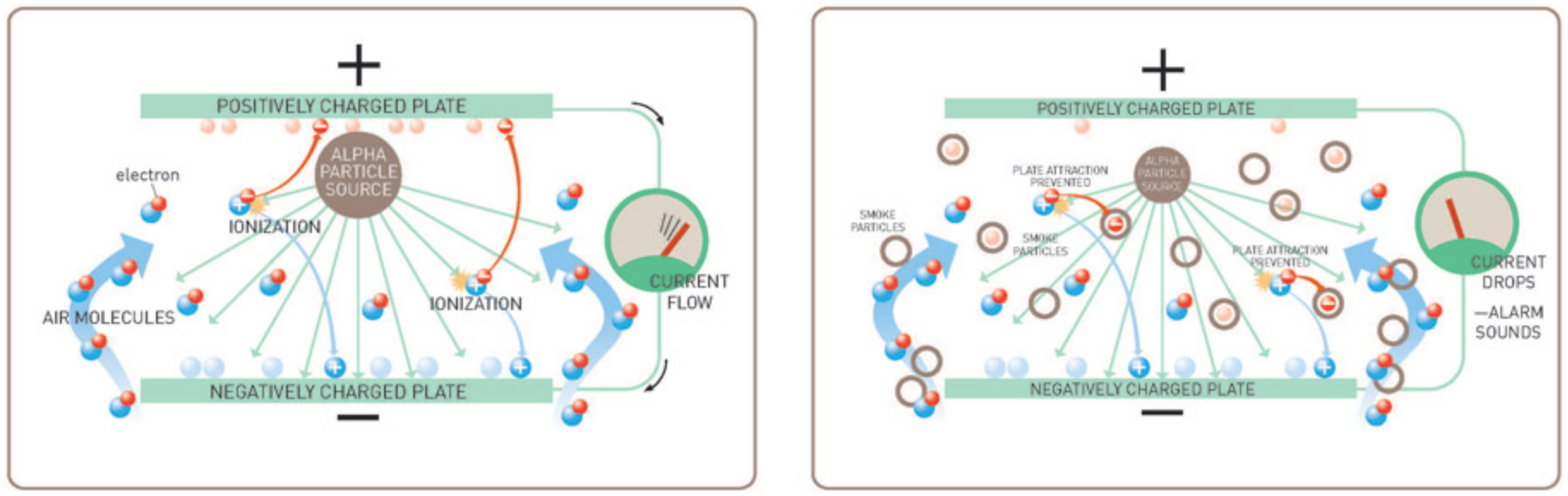


Figure 1: ionization principle [16]

Although radioactive material is used in these detectors, AM-241 is not dangerous (it only emits alpha radiation which represents a threat when this material gets in the body only) [16]. In Germany [17], Switzerland [18] or Austria [19] these type of detectors are used only for commercial or special use only. After approval they are allowed in areas, where photoelectric smoke detectors would not operate correctly or are explosion prone. Their distribution is restricted heavily in Europe compared to the USA or the United Kingdom (UK), when it comes to radiation protection laws and radioactive waste disposal.

### Photoelectric smoke detectors

These detectors work without a radioactive material inside their detection chamber. They work with a backscatter principle [20]. Inside an (obscured) detection chamber are an infrared (IR) emitter and IR receiver, positioned in an up to 90-degree angle, so both are not in line of sight depicted in Figure 2. When smoke particles are present in the chamber IR waves are backscattered from the particles onto the IR-Receiver. The voltage from the IR-receiver is constantly compared to a reference value. When enough IR waves are reflected onto the IR receiver its value changes due to increased incidence of IR waves. A comparator determines this difference and triggers an alarm signal.

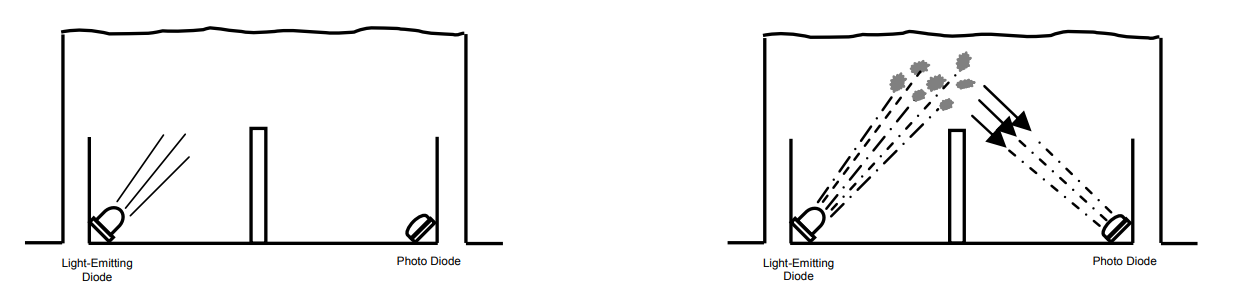


Figure 2: backscatter principe [21]

Photoelectric smoke detectors have an advantage being more sensitive to smoke from smoldering fires compared to ionization smoke detectors being more sensitive to smoke from flaming fires [20]. Typically, these detectors cover a protection area for around 113m2 which means a circular area with a diameter of 12 meters or radius of 6 meters. When other or smaller protection areas are covered these numbers are given in corresponding manufacturers datasheets. In Austria for example, required protection areas which must be covered securely by these detectors are prescribed in TRVB 123 [22]. Also, commercial distributed detectors can only operate properly until a certain height is reached, due to slow propagation velocity of smoke mentioned in Section 2.1.1. Fire tests for various manufacturers have shown, it is safe to mount these detectors up to 9 meters and alert correctly in the case of fire [22].

These type of smoke detectors are primarily used for commercial use in Europe, e.g. public buildings like schools, universities, occupancy accommodations, hospitals, office buildings etc. They are also available for residential use from different manufactures.

### Heat detectors

This type of detectors provide an alternative when ionization or photoelectric smoke detectors are improper to use, e.g. in kitchens, garages, etc. There are two principles to detect heat or temperature. The fixed temperature principle or the rate of rise principle shown in Figure 3. A fixed temperature heat detector uses an eutectic alloy as a heat sensitive element [23]. It changes its state from solid to liquid at a certain temperature, which triggers an alarm state. A rate of rise heat detector uses a thermistor specifically a negative temperature coefficient resistor (NTC). When temperature rises slowly this is ignored but if the value from NTC drops rapidly due to fire being present also an alarm state is triggered.

Heat is conducted slower in air than in solid objects or gases according to Fourier’s Law [24] and airs temperature gradient [25]. This must be considered whether a fixed temperature or rate of rise heat detector should be mounted in its designated installation site. These detectors cover a smaller protection area than photoelectric smoke detectors, their usual protection area is around 28m2 which means a circular area with a diameter of 6 meters or radius of 3 meters [22].

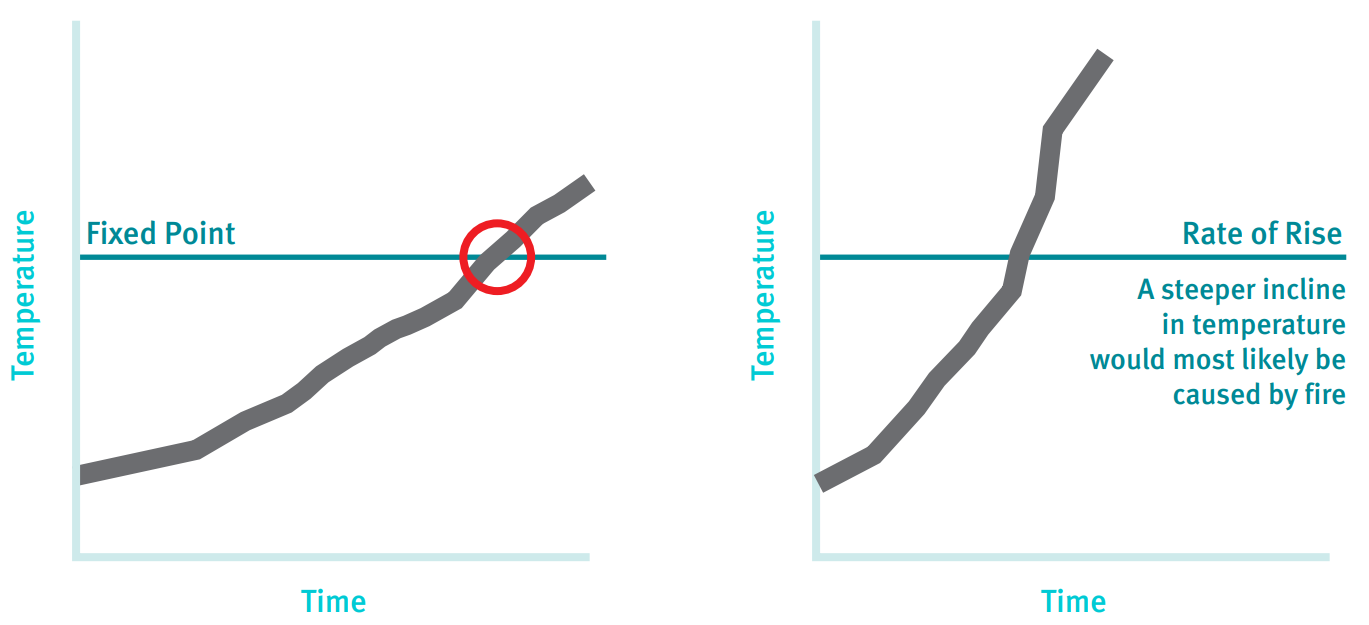


Figure 3: heat detector principles [20]

### Carbon Monoxide detectors

Carbon Monoxide (CO) is the most responsible gas [26] for all victims who die from fires worldwide as previously mentioned in Chapter 1. CO is emitted during combustion processes and is achromatic and odorless, which represents a threat for people. CO binds to hemoglobin in our blood and blocks oxygen transport which, ultimately leads to inner suffocation.

The most reliable method to detect CO is a biomimetic sensor [27]. These sensors mimic biological mechanisms that take place in our body. Such a biomimetic sensor in a CO detector reproduces the same effect CO has on hemoglobin. Inside of the sensor is a gel which changes color as it absorbs CO from surroundings. Another sensor detects this color change to trigger into an alarm state. The biomimetic sensor is designed to change its color at 400 ppm of CO.

Researches have shown that accumulated concentrations exceeding 400ppm in a few minutes are life threatening [26] [28]. If a detector detects such a high concentration or even slower ppm values at a slower rate of rise in the air, an alarm is triggered.

As of today, CO detectors should not replace conventional smoke detectors [21], mentioned in Sections 2.1.2 and 2.1.3. Although in the USA it is mandatory to install CO detectors in every home [29]. However, in Europe they are distributed for special purposes (mostly commercial use) or in combination with photoelectric detectors only [26]. Another thing to be considered is the sensors limited service life upto10 years [30].

### Multiple sensor detectors

These detectors combine detection methods previously mentioned in Sections 2.1.3 to 2.1.5 to enhance detection rate and to reduce false alarms, when different methods are combined. For commercial use it is common practice that, smoke detectors offer a combination of smoke and heat detection and their response characteristic is set via software tools when they are initially activated. This allows for more flexibility and an economic approach in manufacturing since only one detector needs to be produced and can be used individually.

In Austria however, it is mandatory to use only one response characteristic due to missing fire tests from manufactures that prove an enhanced detection rate when more than one response characteristic is evaluated [22]. Normally, these detectors are interconnected to fire alarm systems. Around 4000 detectors distributed on 16 loops could be linked up onto said system [31]. This is achieved due using an equivalent bus system Modbus [31] which resembles the European Installation Bus (EIB) / KNX standard. Also, different operating voltage levels e.g. from 7V to 31V [32] increase the number of detectors on one loop up to 256 elements. These fire alarm systems also work with various protocols like Building Automation and Control Networks (BACnet), Open Platform Communications (OPC) and provide a huge variety of actions when smoke or fire is detected [31] [33].

More recently companies also offer detectors for commercial use which can detect smoke, heat (both fixed and rate of rise temperature) and CO as well [34]. Although there are also companies who distribute multiple sensor detectors for private households which can detect smoke and CO [35] or smoke and heat [36] and offer integration into existing smart home networks. This gives customers more security and reliability but also higher costs per detector. These combined detectors are more or less state of the art, but single response characteristic detectors are more budget friendly and offer easier maintenance for consumers.

### Aspirating smoke detector systems

Aspirating smoke detector systems (ASD) work differently than regular smoke detectors although they use the same backscatter principle as described in Section 2.1.2. In fact, they comprise normally one or two highly sensitive photoelectric smoke detectors (Figure 4).

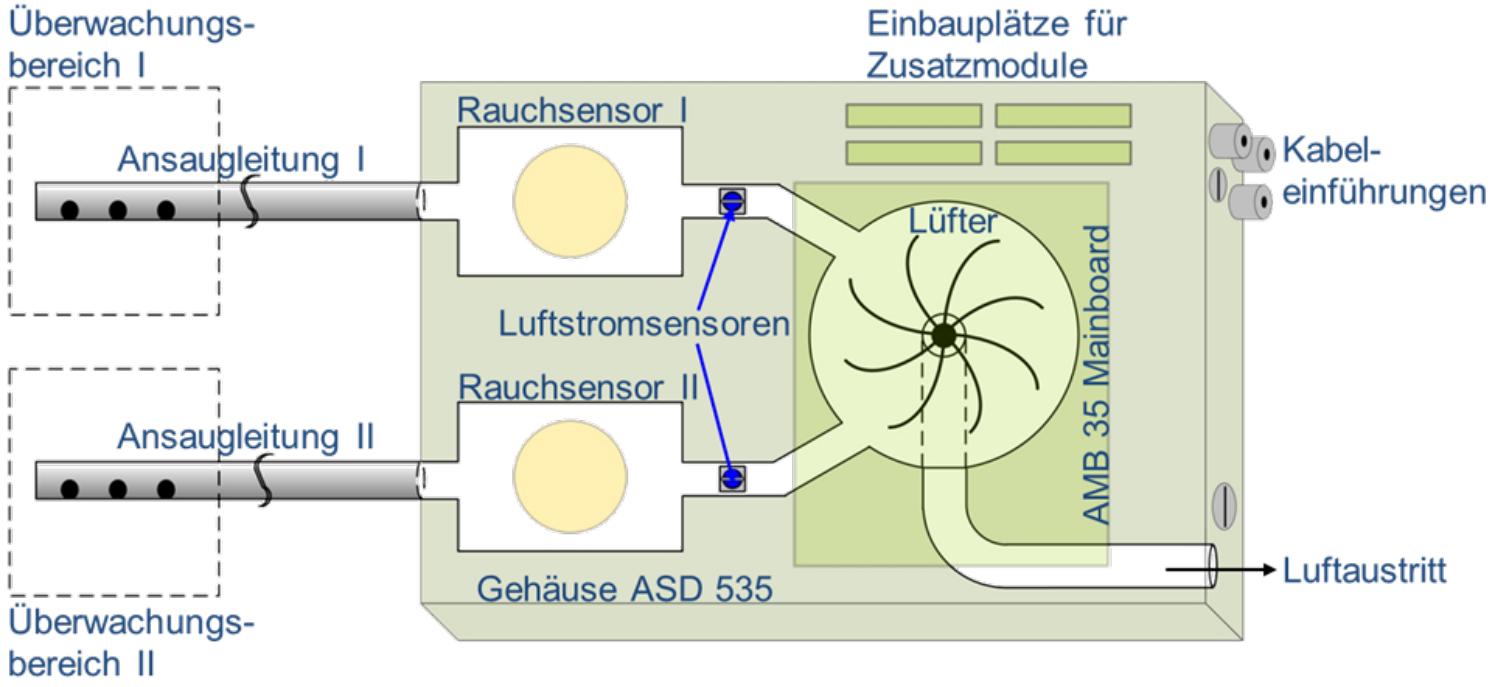


Figure 4: structure of aspirating smoke detector systems [37]

These systems aspirate air through one or two separate pipes (installed in the protection area) with aspiration holes at fixed distances. This is accomplished with a small ventilator inside the system. This stream of airflow is filtered first with filters which are mounted externally. This filtered airflow permeates the smoke detectors inside. If a predetermined alarm sensitivity is exceeded, an alarm signal is triggered from the system. These detectors are often equipped with autolearning functions to accommodate and adjust constantly to their surroundings.

ASDs are used where conventional smoke detectors cannot operate reliably. This occurs e.g. where these detectors could not work (too hot, too cold) or in areas where room height exceeds 9 meters like in high rise storage rooms, theatres, airports etc. They are also installed in clean and sterile rooms, server rooms and data centers. Basically, everywhere where sensitive and valuable electronic equipment needs protection and as early as possible detection in the event of fire. Also, one ASD could cover a much larger protection area than a single detector with up to 5760m2 [37]. Additionally, these systems can detect fire at much faster rates as depicted in Figure 5. They already sense particles when fire ignites, and pyrolysis just started.

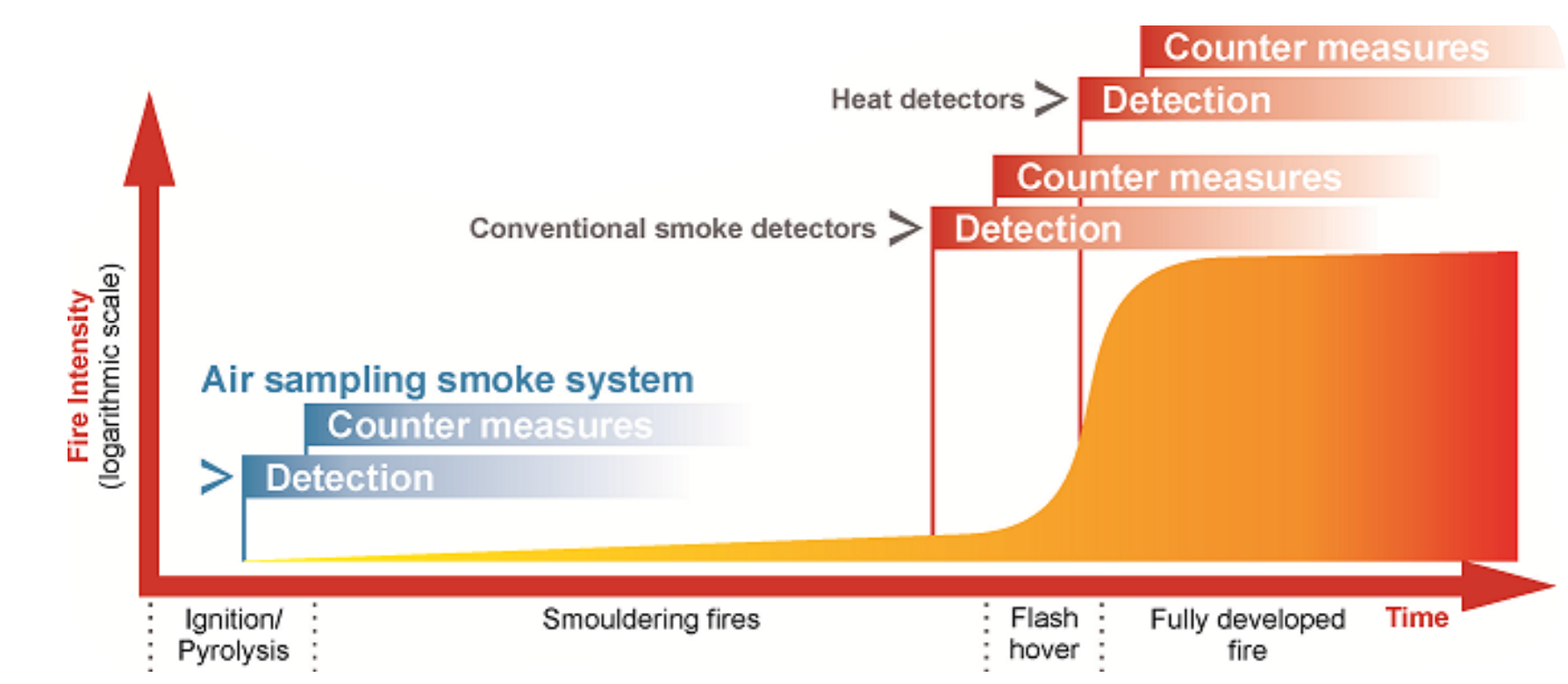


Figure 5: comparison of smoke detection rates [38]

For an even higher reliability and faster response rates Very Early Smoke Detection Apparatuses (VESDA) were developed around the 1970s in Australia. These operate with the nephelometer light scattering principle, which allows to detect even the smallest smoke concentrations [39]. Inside of this system is a tube with a light source, one inlet and outlet for air samples. For detection there are xenon or laser diodes with photo-diode receivers. These photo receivers measure the wavelengths of scattered light (red 700nm, green 550nm and blue (450nm) [40]. They are calibrated to detect a deviation of these wave lengths when aerosol or smoke particles are present.

To note almost every ASD is used for commercial purposes only and is not sold to personal households, due to their intended purpose, high costs and costly installation.

### Linear detectors

These detectors work with an obscuration principle [20]. An IR light beam is emitted from a transmitter and this light beam is received from a receiver on the other side of the protection are. When smoke particles or aerosols are in the air the receiver detects a reduction of signal strength and an alarm condition is met. There are two ways linear detectors are used. Either with a separate transmitter and receiver or with dual transmitter/receiver and a reflector as depicted in Figure 6.

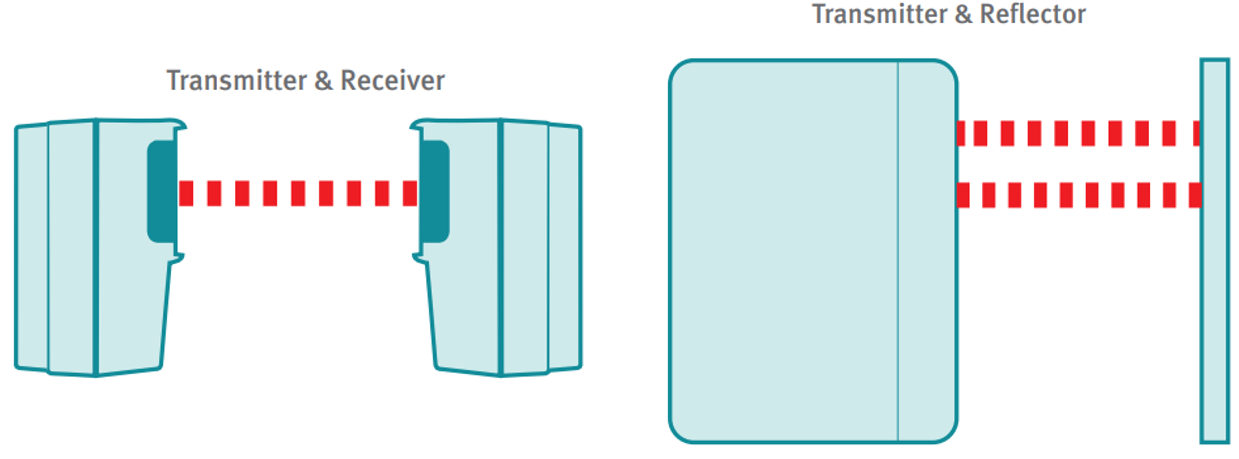


Figure 6: linear detectors [20]

Usually linear detectors are installed in exposed heights and unwanted obstructions e.g. flying birds, workers on hydraulic lifts need to be suppressed. Integrated algorithms can determine if fire or an unwanted obscuration took place. Furthermore, auto-realign functions ensure that transmitter and receiver are and stay in line of sight.

These detectors are used in large open areas, atriums, areas with monument protection (where smoke detector cannot be installed) or in areas where height exceeds 9 meters. They can be installed at a height up to 40 meters and their range can be up to 100 meters [20].

### Wireless smoke detectors

They utilize the same backscatter principle as photoelectric smoke detectors. Although each detector works independently of any wired connections and is battery powered. Usually they are connected in mesh networks to dedicated gateways (which are connected to a fire alarm system themselves). A certain range and as less obstruction as possible are criteria which need to be met. The network operates with two separate short-range device wave bands (SRD) with either 870 Mhz or 435 Mhz. In the case of an error, a channel switch on the main band is initiated first, then the wave band is changed automatically [41]. Inside these networks only a defined number of hops to transfer to a signal to the gateway are allowed to maintain standards defined in EN 54-1 [9].

This hop limitation reduces time to a minimum to transfer alarm states from an element to the gateway and allow as much as possible elements connected to one gateway. When nodes on one of the primary routes fail to transfer, there must at least exist one or more secondary routes to transfer the alarm condition as shown below in Figure 7.

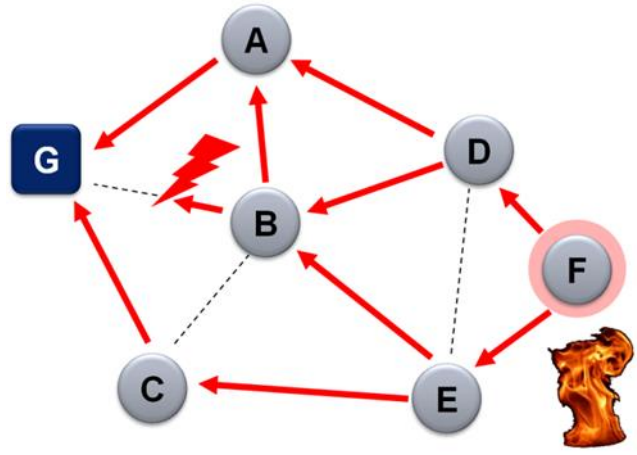


Figure 7: smoke detector mesh network [42]

Wireless smoke detectors are commercially used only in structures where building codes restrict wiring due to monument protection, e.g. historic buildings, museums.

### Smoke detectors for home use

For private usage smoke detectors are sold to customers wireless and battery powered exclusively. They are meant to work standalone or in combination with others to build up a mesh network (but not connected to a gateway mentioned in Section 2.1.9). They offer a wide variety in terms which detection principle is used. There are photoelectric but also more costly designs which offer multiple sensors for smoke and heat or smoke and CO previously described in Section 2.1.6. Depending on a customer’s budget they also provide an integration into their existing smart home network [35]. This allows notification to smartphone, simplified maintenance, current status of detectors is accessible or alarm forwarding among each element in a mesh network. The latter helps, when a detector is installed in every room and fire is detected in the basement for example, then every detector beeps to alert, shown below in Figure 8.

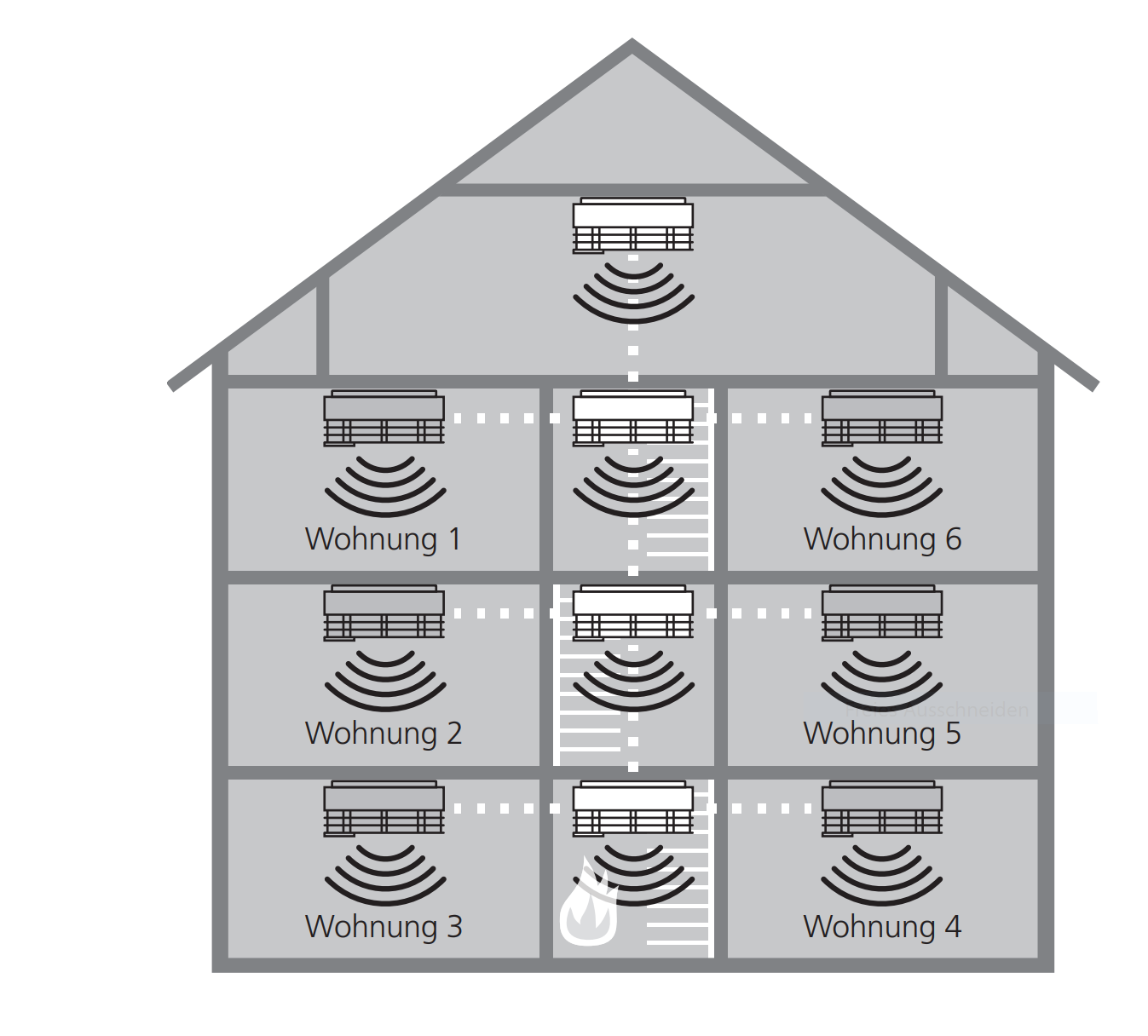


Figure 8: alarm forwarding of wireless smoke detectors [43]

## Hardware (2 pages)

The hardware, which was used, to design a prototype was a smoke detector from building center and the Tessel 2. Latter is responsible for handling inputs and outputs, running scripts, establishing a network connection and interacting with the user’s smartphone.

### Smoke detector

After research which smoke detectors are available and how their principles work, a simple photoelectric smoke detector was chosen. This smoke detectors comes with an CS2105 GP-M12 Integrated Circuit (IC) on board from manufacturer Semic, which is pin compatible to a better documented MC145012 IC [44]. This chip offers all necessary outputs and inputs needed to realize a prototype. It provides good smoke detection, a test function, a horn, and a flash LED. This detector runs on an integrated 9V-battery. It is yet cheap but conducted tests proven its reliability. Illustrate the design and the schematic from the detector? Very short explanation and technical specification???

### Tessel 2

Refer to provided hardware docs from website see in hardware documentation /schemata etc.

(Abschätzung 1/2 Seite)

## Software / Protocols (2 pages)

### Node.js

### Node package manager

### T2 Client

### JavaScript

### HTML5

### CSS

### HTTP

### TCP/IP

# Design (12 pages)

## Concept (1/2 pages)

Mention how it is implemented and heat or CO are not evaluated or measured due to hardware restrictions on the available modules or on tessel IO Ports

## Architecture (1 page)

Block diagram, give overview which components are linked

## Method of operation (1/2 page)

Description how all components work together

## Implementation (10 pages)

### Initial setup for Tessel 2

Installation, setup, prerequisites, etc.

### Input and output detection

Pegel / GPIO Pins

### Smoke alarm

respective .js file

### Test function

respective .js file

### html configuration

static html file, embedded script within html file

### css configuration

layout design, tessel 2 include file (needed for booting)

### Webserver configuration

runs on tessel 2 , .js webserver file

### Processing on tessel 2

.js webserver

### Communication user browser and webserver

get / response

# Results and Discussion (2 1/2 pages)

## Market Situation (1/2 page)

Current existing products with similar specifications and functions

## Costs (1/2 page)

How expensive are similar products prescribed in 4.1

## Security and Reliability (1/2 page)

How reliable are smoke detectors (specifically for end consumers). How secure is the integration into a smart home (are there threats or attack surfaces to do harm to a user’s smart home)

## Future Advancements (1/2 page)

What could have been improved after finishing this work, which functions or feature could be implemented and improve performance or usability

## Conclusion (1/2 page

What went good, what went bad, lessons learned

# Summary (1/2 page)

What was achieved

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# List of Abbreviations

|  |  |
| --- | --- |
| AM-241 | Americium 241 |
| ASD | Aspirating Smoke Detector Systems |
| BACnet | Building Automation and Control Networks |
| CO | Carbon monoxide |
| DIN | Deutsches Institut für Normung |
| EIB | European Installation Bus |
| EN | European Norm |
| EU | European Union |
| IC | Integrated Circuit |
| IR | Infrared |
| NFPA | National Fire Protection Association |
| NTC | Negative Temperature Coefficient |
| OIB | Österreichisches Institut für Bautechnik |
| OPC | Open Platform Communications |
| SRD | Short Range Device |
| TRVB | Technische Richtline Vorbeugender Brandschutz |
| UK | United Kingdom |
| USA | United States of America |
| VESDA | Very Early Smoke Detection Apparatuses |
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# Appendix A

# Appendix B