Remote Access Dual Automatic Switch Spray

Safe and Predictable Railroads

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Abstract

The RADASS (Remote Access Dual Automatic Switch Spray) system is thought to be the future solution for frozen rail switches. Frozen switches are a yearly reoccurring issue and cause long delays in rail traffic, which require a vast amount of personnel and resources to fix. Spraying chemicals manually by railway workers is the most common method to deal with the issue; the system intends to automatize the process. For the system to be self-going, it will need sensors that measures weather and other prerequisites for dispensing. Sensors are also needed so that the user can be kept informed of the systems well-being and warned if there are risks for malfunctions. The sensors are in focus in this thesis work and are chosen and implemented after specifications made by Solliq (developer of RADASS). A lot of measurements are able to be performed with sensors already on the market, while other measurements or circumstances require innovative uses and development of sensors. One of these innovative attempts is to use accelerometers to measure wind speed and direction.

Sammanfattning

RADASS är tänkt att vara framtidens lösning för frusna spårväxlar. Frusna växlar är årligt återkommande och innebär stora förseningar inom järnvägstrafiken, som kräver stort antal arbetare och resurser för att återgärda. Vanligaste sättet att återgärda problemen är att skicka personal för att spruta diverse kemikalier på spåren. Tanken är att i framtiden skall kemikalierna doseras automatiskt utifrån väderförhållande. För att systemet ska vara självgående behöver det sensorer som känner av väderförhållande och andra förutsättningar för dispensering av medlet. Användare måste dessutom känna till maskinens tillstånd ifall något skulle eller löper risk för att haverera. Just sensorerna står i fokus för arbetet och skall väljas och implementeras utefter de specifikationer Solliq (RADASS tillverkare) lagt fram. Många mätningar går att utföra med redan utvecklade sensorer, medan andra mätningar eller omständigheter kräver nytänkande och en utvecklingsprocess. En utav dessa innovativa metoder är att använda accelerometrar för att mäta vindens hastighet och riktning.

Acknowledgement

I would like to thank Kim Smidje and Solliq for the opportunity to work with the Remote Access Dual Automatic Switch Spray and the experience to work at a start-up company. Being one of few cogs in the machinery meant a responsibility few engineers carry during their education.

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1. Introduction

1.1 Background

Cancelled or delayed trains are a common phenomena during winter. According to SJ (government owned personal train transports) a quarter of the delays during winter are because of frozen rail switches [2]. Between the years 2011 and 2013 Trafikverket spent a total of 3007 million kronor on maintenance and 2308 million on reinvestments [1]. Currently the switches use heat elements trying to melt ice and snow.

Solliq is a newly formed company with the agenda to develop a system, named RADASS, that automatically dispenses anti-frost and lubricant chemicals on switches. They have exclusive rights to a Midwest developed chemical for thawing ice, called "Ice-free", and a lubricant called "Glidex". The chemicals are environmental friendly and are both effective and in fluid state at as low as -50 ^{o}C. Their system requires sensors for both internal and external measures. The user needs to know that the system is working as it's supposed to, and the system needs to know how and when to spray the chemicals onto the rails.

1.2 Problem

- Analyse what sensors the system requires to work.

The thesis work includes studying what sensors fulfil the specifications Solliq has made and what measurements have been overlooked and/or the system could benefit from.

- Study how to implement the sensors.

Actual sensors on the market need to be analysed and implemented in the system. The system uses raspberry pi so it needs to be analysed and tested to know what sensors can be applied to the system.

- Design a weather station.

System needs to be able to analyse the weather, this includes: temperature, wind direction and precipitation. However since Trafikverket has huge issues with people stealing and vandalizing property along the track, they wish to develop and implement a discreet way to measure these weather factors.

1.3 Outline

The report consists of five parts. The first is dedicated to what needs to be measured and theory on how to measure it. The second analyses a set of sensors for each measurement and how to implement them to the system. The third explains the design and implementation of the weather station. Finally the fourth and fifth contain the conclusions from previous chapters and discussions regarding the work done and future work.

2. Analysis

Since the system is under development and parts of it are patent pending, a detailed schematic and description of the entire system will not be presented in this report. Instead there will be a short explanation for each of the different measurement request made by Solliq and measurements that the system could benefit from. Theory on how the different measurement types are generally done will be presented in this part of the report.

2.1 General system outline

The RADASS is a master/slave system where the master consists of a container with pumps, liquid, network hardware and Raspberry Pi. Each master has up to ten outputs to slaves, which are called Quick-Connect-Boxes (QCB). Furthermore QCBs can be connected in series, making it theoretically possible to connect up to a hundred QCBs from one master. The QCBs are placed in close proximity to the switches and contain a Raspberry Pi of their own. See figure 1 for an outline of the system.

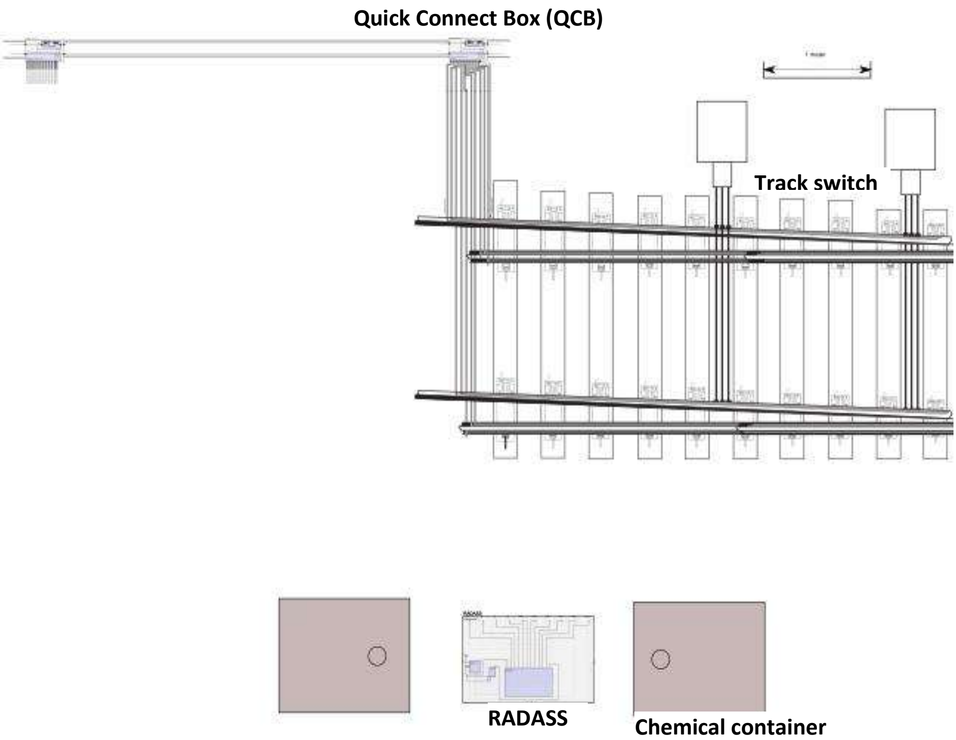

Figure 1. RADASS-schematic

2.2 Specifications

- General system temperature

The system will be encased in a metal container which will contain a wide selection of electrical and mechanical components. Many of them will contain individual temperature sensors; however the manufacturer has requested that a general temperature sensor be implemented. This sensor should be cheap and small, as it will be used in every main RADASS container and QCB.

- Fluid temperature

The chemicals that the system dispenses have a high tolerance for negative temperature down to -50^{o}C, however the lower the temperature gets, the higher its viscosity becomes. This means the pumps need to work harder and the spread of the liquid onto the rails becomes worse.

- Outside temperature

The system needs to know if there is a risk for ice or snow, which would hinder the switch from working properly. Measuring the outside temperature in combination with precipitation and humidity will help the system anticipate and detect snowfall.

- Track temperature

This measurement has been specially asked for by Trafikverket. Knowing the temperature of the track helps the system anticipate if fallen snow will melt or remain in frozen state.

- Wind measurement

The importance of knowing the direction and strength of the wind lays in anticipating snow-drift. Because of snow-drift, the system will need to dispense extra chemicals on one or the other side of the track. This thesis work intends to specifically evaluate the possibility of using accelerometers to solve this measurement and will serve as preparatory work for evaluating use of strain gauges.

- Precipitation

The system needs to know if there's a high risk for the switch to freeze. Too much water risks to wash away the chemical and according to its specifications it can only handle up to 10 centimetres of snow before more needs to be dispensed.

- Chemical amount

The system needs to be able to inform user when it's running low on chemicals.

- Hose pressure

The system needs to be able to anticipate when there is a risk for it to malfunction. A heighten or unusually low pressure could be because of faulty valves, cluttering in the hose or cracks in the hose.

Barometric pressure

Barometric pressure changes are used to predict local weather changes and risk for precipitation.

- Outside Humidity

The lower the relative humidity is, the higher the temperature might be for snow to still fall. That's why humidity is a measurement used to predict snowfall.

- Inside Humidity

Solliq is worried that high humidity would damage the Raspberry and therefore have requested for a humidity sensor inside the Raspberry's case.

2.3 Accelerometer

There are generally four types of accelerometers:

• Piezoelectric accelerometer
• Piezoresistiv accelerometer
• Capacitive accelerometer
• Strain gauge accelerometer

The piezoelectric gauge consists of a mass, a piezoelectric crystal and a metal casing. When accelerating, the mass is pushed against or away from the crystal, thinning it out or expanding its contact to the casing along the sides. This generates an electrical charge which is used to measure the acceleration, see formula 1.

$Q = K * m * a = K * F$

Q = Electrical charge
K = Charge sensitivity
a = Acceleration

Formula 1. Piezoelectric accelerometer

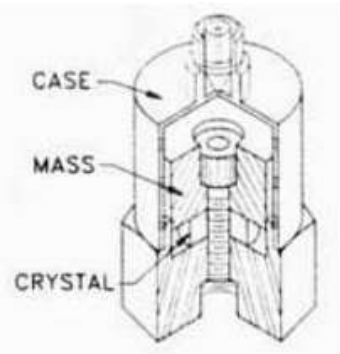

Figure 1. Piezoelectrical accelerometer

The piezoresistive gauge is based on the piezoresistive effect which describes the resistivity change caused by pressure. The gauge can measure up to 1000 g (1 g = 9.81 m/s^2), but is fairly poor at high frequencies. The sensor is connected to a Wheatstone bridge (see Figure 4 and Formula 4), replacing one of the resistors.

The capacitive gauge consists of two metal plates, one fixed and one attached to a mass. The plates together form a capacitor with changing capacitivity depending on the acceleration (see Formula 2).

$C = K * e_0 * A/d$

K = Relative permittivity
e_0 = 8,85 * $^{10-}$12, Vacuum permittivity
A = Overlapping area of plates
d = Distance between plates

Formula 2. Capacitive accelerometer

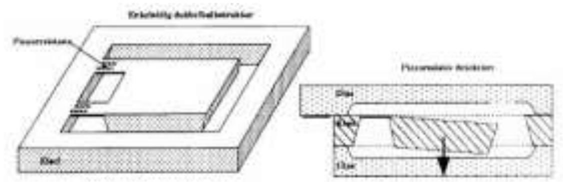

Figure 2. Piezoresistiv accelerometer

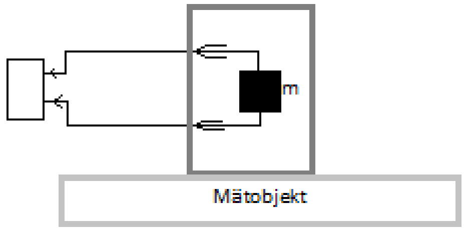

Figure 3. Strain gauge accelerometer

The strain gauge accelerometer consists of a mass attached strain gauges (see Figure 3). These gauges are like the piezoresistive gauge attached to a Wheatstone bridge, replacing two or four resistors. See chapter 4.1.2 for more information on strain gauges.

2.4 Strain gauge

The concept using strain gauges to measure wind strength is not much different from the already developed accelerometers using strain gauges. Instead of a capsule with a mass and gauges attached to each side of the mass, this design has gauges attached directly to a pipe shaped object sticking out on top of the RADASS. Using Pythagoras and a Wheatstone (Figure 4 and Formula 3), the system will be able to calculate the wind's force vector.

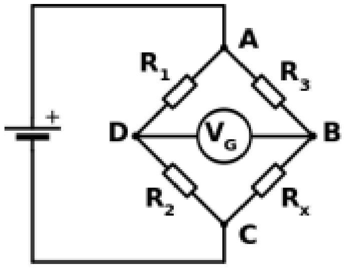

Figure 4. Wheatstone bridge

$$V_G = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right) V_s$$

V_G = Voltage over node B and D
V_S = Supply Voltage
Formula 3. Wheatstone bridge

A strain gauge is based on the formula of a resistors resistivity (see Formula 4). By changing the length of a wire, one changes the resistance and there by unbalances the bridge. This unbalance can be measured according to Formula 3. Like cup-anemometers (see figure 17) using magnets to read amount of impulses over a timespan and referencing the value to a table, so may the strain gauges hopefully output correct wind speed.

$$R = \rho \frac{\ell}{A}$$

ρ = resistivity
l = length
R = Resistance
A = Area
Formula 4. Resistance

The gauge is however weak to temperature changes and will contract or expand if the temperature goes down or up. These changes will be detected as strain and would unbalance the bridge unless it is compensated. Such a compensation may be done by making sure the gauge's wires are made of the same alloy as the object measured, and have one gauge replacing R_x or R_1 and one placed on the opposite side of the object replacing R_3 or R_2 [6]. Doing so will cancel out temperature changes inflicting strain.

2.5 Temperature measurements

There are two general ways of measuring temperature: thermal conduction and thermal radiation [3]. The difference between them is of large practical meaning. The conduction sensor follows the physical theory of thermal equilibrium. The sensor is placed in contact with the object which is measured, this is called thermal contact [4], and will exchange heat with the object in an attempt to reach thermal equilibrium, that is to reach the same temperature. That is why it's important to make sure the sensor doesn't affect the object. Formula 5 shows what variables need to be considered in heat transfer. Energy, which is transferred from the warmer object, must be kept to a minimum. There are a couple of ways of doing this.

- Keeping the mass of the sensor much smaller than the object to be measured. This will result in smaller amount of energy required to either heat the sensor up or less energy that is transferred from the warmer sensor to the object, resulting in the object's temperature being affected at a minimum.
- By preheating the sensor to the same temperature as the object, once again less energy will be transferred. This does however have the downside that user needs to know the objects temperature and that it is hard to keep the sensor at the same temperature after preheating and until it's been applied.
- The third factor is to apply a sensor with a much smaller heat capacity than the measured object. The heat capacity is the amount of energy required to change the temperature (J/K). The sensors heat capacity depends on its volume, material, temperature and pressure.

$$Q = m * c * \Delta T$$

Q = Energy
m = Mass
c = Heat capacity
ΔT = Temperature change

Formula 5. Heat transfer.

$$P = A * \varepsilon * \sigma * T^4$$

P = Power
ε= Emissivity
σ= Stefan-Boltzman's constant
T = Temperature
A = Area

Formula 6. Stefan-Boltzman's law.

Thermal radiation is on the other hand based on Stefan Boltzman's law. According to it, all objects will emit energy based on temperature and the object's emissivity (see formula 6). Some pyrometers are capable to adjust for varying emissivity, while some need the emissivity to be nearly perfect. Perfect emissivity would be a black body with an emissivity factor of 1, while a normal object has an emissivity between 0 and 1. Emissivity is based on a couple of factors:

- Wavelength – Which wavelengths is the sensor absorbing. There are different types of pyrometers that look at different spectrums of emitted wavelengths.
- Angle – The angle from object's surface to the sensors receptor.
- Temperature – The objects temperature. Generally, the warmer an object is, the higher the emissivity.
- Material – Different materials absorb and emit energy differently and this makes up a factor of the objects emissivity.
- Surface structure – A material with light and polished surface has less emissivity than a material with dull and black surface.

For example, polished silver at 38°C has an emissivity of 0.01 (1%) while rusted iron at 25°C has an emissivity of 0.65 (65%) [9].

2.6 Pressure measurement

Pressure is the force executed on a defined area and is either dynamic pressure, pressure that changes with a certain frequency, or static pressure, pressure kept the same over a longer time. This project is mostly interested in static pressure. Pressure sensors measure a fluid's or gas' pressure relative to another pressure. There are three different definitions for these: Absolute pressure, Relative pressure and Differential pressure. Absolute pressure is the pressure relative to vacuum, Relative is the pressure relative to the atmospheric pressure and Differential is the pressure compared to the current pressure from a different gas or fluid.

The pressure sensor often consists of an object that that is deformed by pressure. This deformation is measured by connected electrical circuits. For example a sensor can be constructed much like a strain gauge, consisting of a membrane that is connected to a wheatstone bridge. When deformed by pressure from one side of the membrane, the bridge becomes unbalanced and an electrical signal can be measured. This signal can then be translated into a unit used for pressure measurements.

Pressure can also be used to measure volume in a canister. Using the formula P = ρ*g*h (ρ is the density of the liquid) it is easy to measure the volume in the tank (see figure 5[10]). A sensor will provide the pressure, while the system must know the dimensions of the canister containing the chemicals and the density of the chemicals. Using those variables, and the previously mentioned formula the volume can be calculated according to formula 7.

$$\frac{P * A}{\rho * g} = V$$

Formula 7. Calculating volume using static fluid pressure.

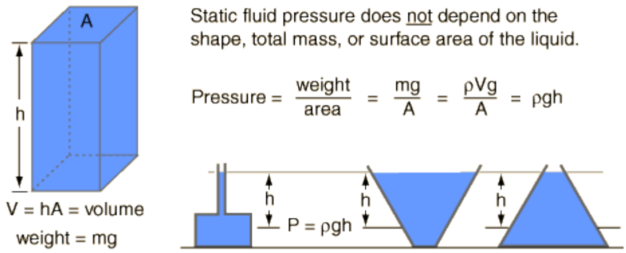

Figure 5 Static fluid pressure

This formula only takes into account the volume above the pressure sensor, so if the sensor is placed above the bottom of the canister, there will be an amount of liquid not taken in consideration. This does not have to have a negative impact on the system, as long as user takes it under consideration.

There are other ways to attempt measuring the volume, for example optical, ultrasound or capacitive sensors. The main issue with these methods is that the canisters, which are not provided by Solliq, would require modifications. The customers must be able to choose to either refill the canisters on spot or replace an empty canister with a filled one.

2.7 Raspberry Pi

The raspberry pi was developed by the Raspberry Pi Foundation [7] in the scope of teaching children in school programing and working with computers. Development began 2006 and it was released in Febuary 2012. The main issue with using the Raspberry is that it only has digital inputs for sensors and no analog inputs. This will require dealing with to avoid the project becoming narrowed to only digital gauges. It runs on a 700Mhz ARM processor with 512 MB RAM. Other specifications[8]:

SoC	Broadcom BCM2835 (CPU + GPU. SDRAM is a separate chip stacked on top)
CPU	700 MHz ARM11 ARM1176JZF-S core
GPU	Broadcom VideoCore IV,OpenGL ES 2.0,OpenVG 1080p30 H.264 high-profile encode/decode
Video outputs	RCA, HDMI (not at the same time)
USB 2.0 ports	2
Low-level peripherals	General Purpose Input/Output (GPIO) pins, Serial Peripheral Interface Bus (SPI), I^2C, I^2S, Universal asynchronous receiver/transmitter (UART)
Power ratings (from board)	700 mA (3.5W)
Power source	5V (DC) via Micro USB

Raspberry Pi specifications

3. Implementation

There are many parts that need to be implemented in the system, which can be seen in the analysis part of the report. Most of these have a wide spectrum of components that can be used. This part of the report mentions a few of these alternatives and the solution that was chosen for the task.

Because of time and resource restrictions, all entries in the analysis have not been actually implemented. However, alternatives have been analysed and recommendations have been made instead. Also, sensors that are implemented for the weather station can be found in the next section.

3.1 Analog Inputs to RPi

There are a lot sensors that output an analog signal according to measurement. Even though there are also many sensors on the market with built in circuits to output digital signals, a solution for analog sensors has been made. This is to prevent that Solliq's system becomes limited to only digital sensors.

3.1.1 Analog to Digital converter: MCP3008

The MCP3008[11] is an analog to digital converter by Microchip Technology. It has 8 analog input channels and one digital output. The output is serial from a shift register (see figure 6) which will output according to the control logic's frequency. The control logic is controlled through SPI interface, which works well with the Raspberry Pi, and requires 3 inputs. Because of the limited number of pins on the RPi, it is a number that needs to be taken in consideration.

$$LSB\ Size = \frac{V_{REF}}{1024}$$

$$Digital\ Output\ Code = \frac{1024 \times V_{IN}}{V_{REF}}$$

Where:

V_{IN} = analog input voltage

V_{REF} = analog input voltage

Formula 8. Calculating the digital output from MCP3008

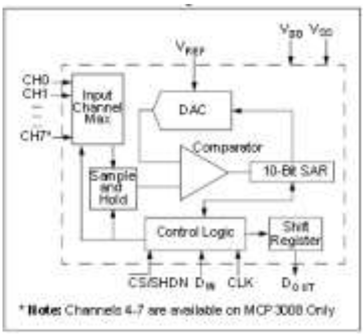

Figure 6. MCP3008 Block Diagram

The converter has a 10 bit resolution, based on a reference voltage that needs to be supplied to the chip. The reference may have a value between 0.25 V and the input voltage to the chip, which should have a value between 2.7 and 5.5 V. With the Raspberry Pi capable of providing 3.3 or 5.5V, this assures that the converter can be used without the need of external power source. It has a sample rate between 75 000 samples per second (75 ksps) and 200 ksps and requires 1.5 clock pulses to be able to retrieve the value from the analog input.

The recommended temperature values for the component are between -40 and 85 degrees, with absolute values between -65°C and 150°C, according to manufacturer, comparing these values to Swedish record low -52,6°C [12], world record -89.2°C and Asian -67.8°C (world's lowest, excluding Antarctic) [13]. These are values that could be troublesome, however the raspberry has a lowest tolerance of -40°C, which will require that the system has some type of heating.

3.1.2 Analog to Digital converter: ADC0808

The ADC0808 [14] is a converter developed by National Semiconductor. The chip requires 5V supply voltage, which the RPi can provide, making it independent from additional external supply voltage. It has 8 analog input channels which are switched between using a mux with 3 input signals for addressing. In total there are 28 pins on the chip (see figure 7 for exact mapping), of which 8 are used for analog input and 8 for digital output. Although three signals are used to control the multiplexer, the RPi can limit the number of required pins according to amount of analog inputs. The chip does however require a high number of pins from the RPi.

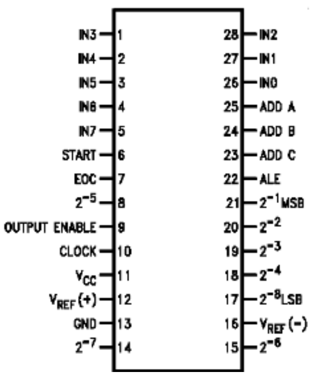

Figure 7. ADC0808 Mapping

The converter is functional in a range between -40°C and 85°C while capable of being stored between -65°C and 150°C. Also the the ADC0808 has a conversion time of 100µs, resulting in 10000 samples per second (10 ksps).

3.2 Temperature

3.2.1 Track temperature: DS18B20

The DS18B20 [15] is a digital thermometer designed by Dallas Semiconductor, now part of Maxim Integrated. It has three pins: GND, VCC and a pin for 1-wire communication. The sensor is commonly used with the Raspberry pi, since it operates within the RPi voltage outputs (3-5.5V) and being that the communication is digital.

The sensor operates between -55°C and 125°C with a ±0.5°C accuracy. With the coldest measured temperature in Sweden being -52.6°C, the sensor is applicable for implementation in Sweden. The sensor is commonly sold by retailers in two different shapes (see figure 8 [16] and figure 9 [17]), one being a TO-92 which can be soldered directly to circuits and the second an isolated TO-92 with 1.5 meter long signal cables soldered to it. The second is also classed as waterproofed and has a diameter of 7 mm.

Figure 8. DS18B20

Figure 9. Isolated DS18B20

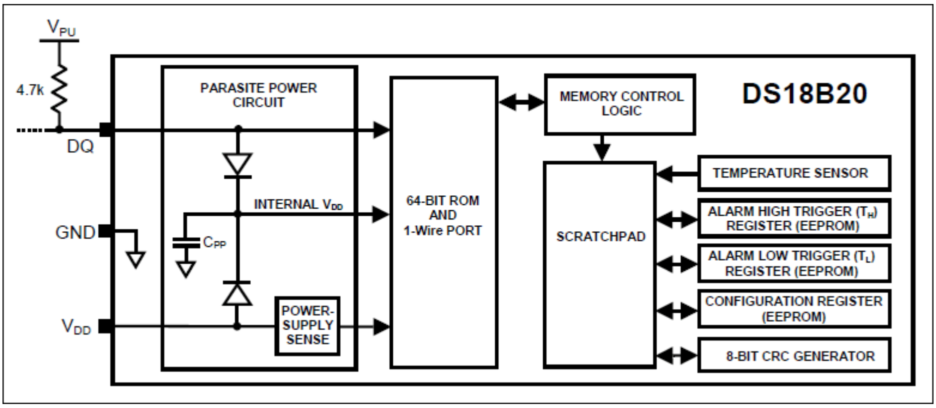

Figure 10. Block Diagram of DS18B20

The sensor has 3 pins and consists of a number of blocks (see figure 10). For the most basic of operations, one DS18B20 sending temperature measurement to its own pin on the RPi, only the 1-wire and GND need to be connected. The DS18B20 has a “parasite power circuit” which leeches power from the 1-wire when the node voltage is high, and stores it in a capacitor. When powering sensors with a supply voltage between 3 and 5.5 volt, the user may connect more than one sensor to the same bus. Each sensor has an individual address stored in it’s ROM, which allows user to choose which sensor to read from at a specific moment. However according to the datasheet adding multiple sensors to one bus will lower the current to each individual, bellow 1.5 mA, and rending them incapable of being powered by the "parasite power circuit" alone. The ROM also stores commands, for example to retrieve temperature. When called upon, the digital thermometer stores the value on an SRAM ("Scratchpad"), before sending the value to the user. It also has extra functions such as CRC and minimum and maximum temperature alarm, however they require external supply voltage.

3.2.2 Track temperature: Pt-100

The Pt-100 [19] is a thin film resistance thermometer. It's based on platinum and nickel (Pt-Ni) connecting wires and works much as a strain gauge sensor. It operates between -70 °C and 550 °C, which is very low and applicable even in the coldest Asian regions.

There are three factors to take in consideration when choosing a resistance thermometer:

1. Temperature interval
2. Temperature coefficient (α)
3. Monetary cost

The platinum constructed sensors have a stable resistance-temperature relation over widest temperature value. Platinum sensors have a recommended temperature range of -220°C to 850°C, compared to copper and nickel that have a range between 0°C and 180°C. This makes platinum the only of the three types capable of measuring below zero degree.

The resistance change according to temperature change is called the sensor's temperature coefficient (see formula 9). A higher alpha makes it easier to detect changes in temperature when using a wheatstone bridge. For best results, the coefficient should be calculated for each sensor in the expected temperature range. Standard alpha is however calculated in the range between 0 and 100 degrees, as in formula 9. Of the three mentioned metals used for the sensor, platinum has the lowest coefficient ($3.925 * 10^{-3} C^{-1}$) while nickel hast the highest ($6.17 * 10^{-3} C^{-1}$). See table below for more detail.

Metall	Recommended temperature range (°C)	Resistance temperature coefficient (C^{-1})
Platinum	-220 – 850	$3.925 * 10^{-3}$
Nickel	0 – 150	$6.17 * 10^{-3}$
Copper	0 – 120	$4.26 * 10^{-3}$

Examples of Resistance temperature coefficients

$$\alpha = \frac{R_{100} - R_0}{100 R_0}$$

R_0 = Resistance at 0°C
R_{100} = Resistance at 100°C

Formula 9. Temperature coefficient

Platinum is also the most expensive of the three, it’s about 5 times as expensive as the others. However because of the range required it is still the only one that can be used, especially since the Pt-100 is one of the most common resistance thermometers found in stores selling temperature sensors.

3.2.3 Fluid temperature: SensyTemp TSP***

The SensyTemp TSP*** [34] are temperature sensors for liquids, manufactured by ABB. The SensyTemp sensors come in three shapes, two designs and each design in multiple versions. The three shapes (see figure 11) differ in including or not a thermowell, capsule for the sensor and including or not a protective fitting. The different designs also come with the option of a LCD screen for direct observation of measured temperature at the sensor.

The sensor a designed to measure either with a thermocouple type of sensor or resistance. The thermocouple comes in three version, using either K-type (NiCr-Ni), J-type (Fe-CuNi) or N-type (NiCrSi-NiSi). All three versions have a minimum range of -40°C and differ at the maximum range, able measure up to 1200°C, 750°C and 1000°C respectively. The thermocouple version also has a maximum deviation of the measured value as low as 1.5°C. All thermocouple versions are capable of withstanding a shock force up to 60g.

The resistance sensor design comes in four versions: Thin film, thin film with increased vibration strength, wire-wound resistors or wire-wound resistors with increased vibration strength. The thin film resistors are capable of measuring within a range of -50°C up to 400°C with a maximum deviation of 2.3°C. The basic thin film is capable of resisting up to 10g shock, while the strengthened version can withstand up to 60g. The wire-wound resistors are capable of measuring up to 600°C and as low as -196°C with similar deviation as the thin film. They are however more fragile, capable of withstanding 3g or 10g.

ABB provides user with circuitry for analog 4-wire measurement, but the sensors can also be provided with transmitters for use of HART, FOUNDATION Fieldbus or PROFIBUS PA. Also as mentioned there is an option for a LCD screen attached to the sensor, which is however limited to -20°C.

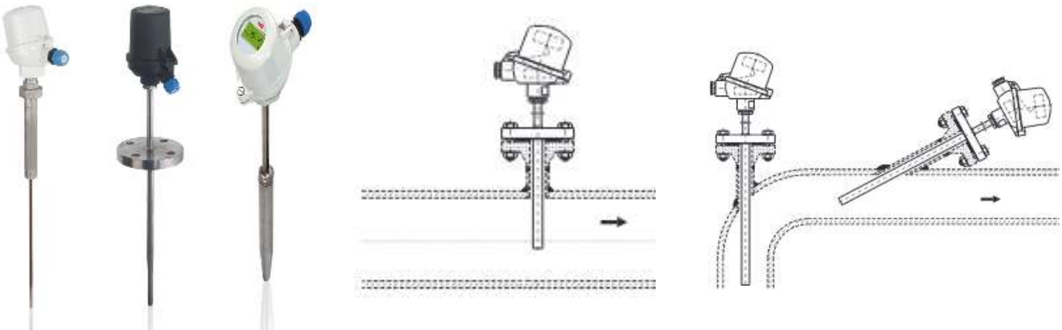

Figure 11. SensyTemp TSP* and how to apply the sensor.**

ABB also provides manual and assistance for implementation of their field devices, and there are alternatives to how to connect the sensors (see figure 11) depending on the hose/pipe. ABB's recommended application of the sensor is the one furthest to the left, however in case the second and third example demonstrates application to a hose or pipe that is too thin.

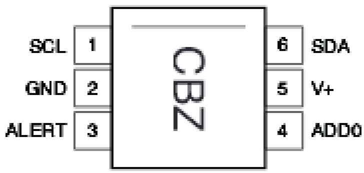

Figure 12. TMP102

3.2.4 General temperature: TMP102

The TMP102 [20] is a very compact digital sensor in a SOT563 capsule, developed by Texas Instruments. It uses a I^2C interface to communicate with the Raspberry Pi. The signal has a 12-bit resolution, sent serially from the SDA-pin (see figure 12). The RPi's SDA is capable of connecting to four sensors at the same time by connecting one of the top four pins to the ADD0-pin. Previous versions of the sensor included two address pins, enabling more sensors to be connected to the same SDA. The 102 version has replaced one of those pins with the "ALERT"-pin, which is supposed to make it easier to implement the sensor in systems. Mainly it switches between high and low when sensor detects temperature below or above certain boundaries. These boundaries are programmed by user and stored in internal registers.

The TMP102 is designed to measure temperature in an interval of -40°C and 125°C, and has a guaranteed precision of 0.5°C between -25°C and 85°C and the signal has a resolution of 0.0625°C. It requires a supply current of max 1 μA and supply voltage between 1.4V and 3.6V which makes it capable of being supported by the RPi and measures between the RPi's functional temperatures. It is also a very cheap sensor, costing as low as 6.50 [21] kroner at European vendors.

3.3 Chemical volume and pressure

3.3.1 Chemical volume and pressure: 266GSH Gauge

The 266GSH [22] is a gauge pressure sensor by ABB. It's manufactured in parallel with the 266ASH sensor which measures the absolute pressure, and in seven models with different measuring ranges. For the RADASS the 266GSH U and R model with spans between 0-30 bar and 0-100 bar could solve its requirements. They also have an overpressure limit at 60 and 200 bar before taking damage. The sensor is also capable of operating in temperatures between -40°C and 80°C and requires 9 to 32 V DC.

The sensor uses three different protocols and a LED display for communicating with user.

- HART
- PROFIBUS PA
- FOUNDATION Fieldbus

Part of Message	Length in Bytes	Purpose
Preamble	5 to 20	Synchronization & Carrier Detect
Start Delimiter	1	Synchronization & Shows Which Master
Address	1 or 5	Choose Slave, Indicate Which Master, and Indicate Burst Mode
Command	1	Tell Slave What to Do
Number Data Bytes	1	Indicates Number Bytes Between Here and Checksum
Status	0 (if Master) 2 (if Slave)	Slave Indicates Its Health and Whether it did As Master Intended
Data	0 to 253	Argument Associated with Command (Process Variable, For Example)
Checksum	1	Error Control

Table 1. HART Message [24]

HART (Highway Addressable Remote Transducer) [23] is a protocol developed in the late 80's. It implements five of the seven OSI (Open System Interconnection) layers (1, 2, 3, 4 and 7). It uses two different communication modes, point-to-point mode or multidrop mode. The first combines analog and digital signaling, using an analog 4-20mA signal and an overlaid digital signal. The second sets the analog loop current to 4mA and can instead attach multiple instruments to the signal cable. A package using HART protocol has the following structure:

PROFIBUS (Process Field Bus) [25] was developed in the late 80 and was later promoted by Simens. It implements 3 of the OSI layers (1, 2 and 7) [26]. There are two versions of the PROFIBUS in use, DP (Decentralized Peripherals) and PA (Process Automation). The 266GSH uses the second. The lower layers, Physical and Data Link, are basically identical while the differences are in the application layer. The PA was specifically designed for hazardous environments [27] and generally operates over RS485 media. It is also capable of supplying devices with power over the media.

FOUNDATION Fieldbus [28] like the Profibus implements OSI layer 1, 2 and 7. It's a completely digital and serial communications that was designed to replace the analog 4-20mA signal, which the HART uses. There are two commonly used communication implementations used for the Fieldbus, H1 and HSE (High-speed Ethernet). The first has a speed of 31.25 kBit/s and the second a speed of 100 Mbit/s [29].

H1 is still the most commonly used and unlike the HSE is capable to be used for powering over communication media. With the 266GSH, or other ABB field devices, the sensor is connected through H1 to a switch or a system (for example Raspberry Pi) and from the switch it uses HSE (see figure 12 [30]).

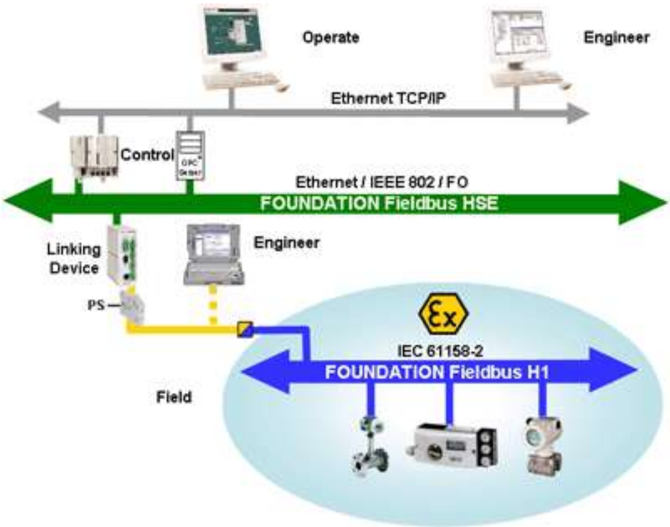

Figure 12. Map of Fieldbus connection

Figure 13. 266GSH

3.3.2 Chemical volume and pressure: 24PCGFM6G

The 24PCGFM6G is a gauge pressure sensor manufactured by Honeywell [31]. It has a range between 0 and 250 psi (pounds per square inch), which is a bit more than 17 bar, and has a max pressure tolerance at 500 psi. It's a very compact sensor (see figure 14) weighing only 3 grams with a quarter inch flow input and four pins (see figure 15). The sensor is capable of operating between -45°C and 80°C. It's also capable of tolerating a sudden shock at 150 g and a frequency up to 2 kHz at 20 g.

Figure 14. 24PCGFM6G

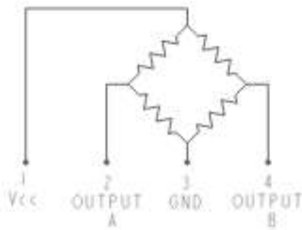

Figure 15. Circuit diagram

The sensor is completely analog and the pressure is measured over a built in wheatstone bridge (see figure 15). The measured voltage spans between 145 and 280 mV with a typical sensitivity of 0.85 mv/psi. However according to the characteristics there is also an offset between -30 and 30 mV. To work, the sensor needs 10-12 V supply voltage and an analog to digital converter.

4. Weather Station Design

Because of a large amount of thefts and sabotages around tracks, there's a wish from Trafikverket that the RADASS-system is designed in such a way that it or its components are not easily stolen or sabotaged. The Weather station will however be outside the RADASS container and exposed, so instead it must be designed in a way that it isn't appealing to saboteurs. Instead of a classic cup-anemometer the project will try to implement a discreet accelerometer based anemometer or strain gauge based anemometer.

4.1 Theory

Meteorology, the study of the atmosphere, is a science commonly used to predict the weather. Applying a few of the measurements that are used by meteorological institutes will hopefully assist with determining the weather. The main targeted weather prediction is snow and frost. Also, snow-drift needs to be detected for focused application of the chemical.

Snow is created when ice crystals in clouds are bunched together. Depending on temperature snowflakes have different sizes and shapes, often larger when closer to zero degrees. Two main prerequisites for snow to land on the tracks is that a cloud capable of producing precipitation and that the ground is cold enough [35]. Cold enough is a relative term, as it is a factor dependent of air humidity. For example, snow may fall at a maximum of +1.5°C at the relative humidity of 100% or it may fall at +4°C if the humidity is 60%. However, snow needs the surface it lands on to be close or below zero degrees. For clouds to be able to produce precipitation, they require to be elevated. This often happens in one of three cases:

- A warm or low front in a low pressure area pushes the air upwards.
- Air is heated passing over a sun heated surface, water or land.
- Heights in the terrain, such as mountains, force the clouds upwards.

The main issue with designing this weather station is designing the anemometer. The most common anemometers for this type of local measurements are cup anemometers (see figure 17). Mechanical anemometers were invented in the 15th century, and the cup anemometer was created 1846 [39]. By measuring the number of laps the sensor does under a certain time, it calculates the current wind speed. Other more modern anemometers use heating wires or ultrasound to detect speed.

The prototype experiments with using an accelerometer based anemometer. The idea is to place it secured inside a pipe or securing it on something much like an antenna. The wind inflicts a force on the accelerometer and the pipe it is in, setting it in motion. The force of the wind can be calculated with Bernoulli's equation for incompressible flow [5] (see Formula 10a) combined with the equation that pressure is equal to the force over a specific area. Removing the force of the pipe trying to return to original state, much like Hooks law (see Formula 10b), results in a total force (see Formula 10c). With some restructuring of the formula, in 10a, the system may calculate the resulting speed of the wind (see formula 10d).

a. $p = \rho * \frac{V^2}{2} \Rightarrow F_B = \rho * \frac{A*V^2}{2}$

b. $F_H = k * x$

c. $F_{tot} = F_B - F_H$

d. $V = \sqrt{2 * a * m/(\rho * A)}$

Formula 10. Calculating windspeed

p:	Pressure (Pa)
ρ:	Fluid Density (kg/m^3)
V:	Speed (m/s)
A:	Area (m^2)
k:	Feather characteristic
x:	Compression (m)
m:	Mass (kg)
a:	Acceleration (m/s^2)

4.2 Methods

The weather station needs to be capable of measuring these different attributes of the weather: temperature, humidity, wind speed and direction, precipitation and atmospheric pressure.

For humidity and temperature, the station will attempt to use a DHT22. It's a digital sensor that uses a capacitive humidity sensor and a thermistor. The capacitive sensor measures the relative humidity. These types of sensors are commonly used for their low cost, high durability and low space requirement. They are however not the most accurate choice, with a 2% margin of error [36]. The DHT22 has in worst case scenario an accuracy fault at up to 5% [37], but is commonly used with the raspberry pi and is well documented for integration with the RPi. It is capsulated and easy to mount. The thermistor is a built in DS18B20 (see 3.2.1 at page 23).

For precipitation the prototype model uses a mechanical liquid flow meter with a built in pinwheel. The sensor emits a pulse for each time approximately 2.25 ml liquid passes. The fault margin is about 10%, however it can be supplied with 5 V DC and only requires that user reads input from one of the RPi pins.

The weather station uses a barometer to try to predict snowfall and allow user to apply the chemicals shortly before it occurs. Together with the rest of the sensors, the system and user will be capable of making a more informed decision. The used sensor is the MPL115A2 which uses I^2C [38] and can be supplied by the RPi. It also has a ±1.5hPa resolution, which makes it detailed enough reading.

Finally for drift snow, an accelerometer based anemometer is used. The basic theory on accelerometers can be found on page 15 in this report. For the prototype, the MPU6050 [40], a digital triple axis accelerometer, was chosen. The sensor uses I^2C interface to communicate with the RPi and is well within the limits of using the RPi for supply voltage.

Together they are to be mounted on the back of the complete system (see figure 18) in a way that doesn't attract too much attention.

Figure 17. Cup anemometer

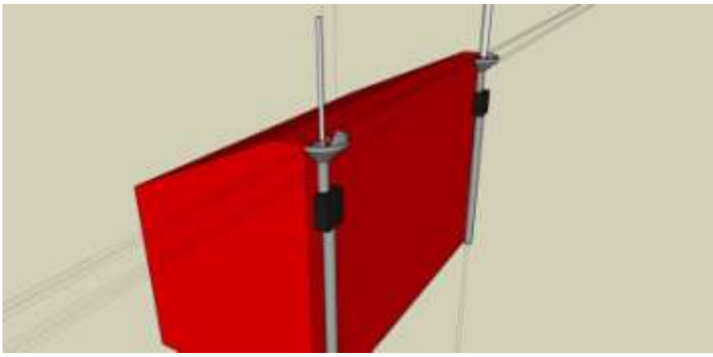

Figure 18. Design of complete system

4.3 Results

4.3.1 DHT22: Temperature

The DHT22 outputs ten values during a period of one minute. The mean value is used as a result from the DHT22 and compared to Norwegian metrological institution [41], Swedish metrological institute [42], Finish private owned weather forecasting company Foreca [43] and the weather station at Lund University [44].

Temperature(°C) Time	DHT22	SMHI Helsingborg	SMHI Malmö	Foreca	Yr.no	LU CanMov
20:00	6	6.3	6.3	6	6	6.3
21:00	5.6	5.9	6.1	6	6	6,1
22:00	5.6	5.8	5.5	5	5.5	5.9
23:00	5.3	5.6	6	6	5.5	5.7
00:00	4.6	5	5.3	5	4.8	5.3
01:00	4.5	4.3	4.5	4	4	4.9
02:00	3.9	3.2	4.3	3	4	4.8

Table 2a. DHT Temperature

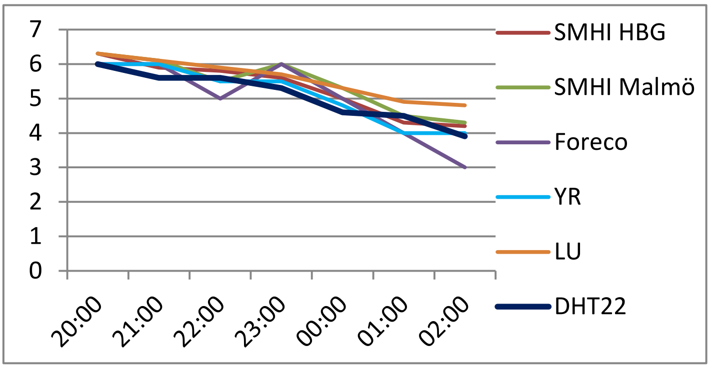

Chart 1a. DHT Temperature

Temp (°C) Time	DHT TMP	SMHI Hbg	SMHI Malmö	Foreca	Yr.no	Lu
16:00	-1.8	-2.7	-1.5	-2	-2	-1.8
17:00	-2.4	-2.9	-1.7	-2	-3	-1.9
18:00	-2.4	-2.9	-1.9	-2	-4	-2
19:00	-2.3	-3.1	-1.9	-2	-4	-2
20:00	-2.3	-3.1	-1.9	-2	-4	-2
21:00	-2.2	-3.3	-1.9	-2	-4	-2
22:00	-2.4			-2	-4	-2

Table 2b. DHT Temperature

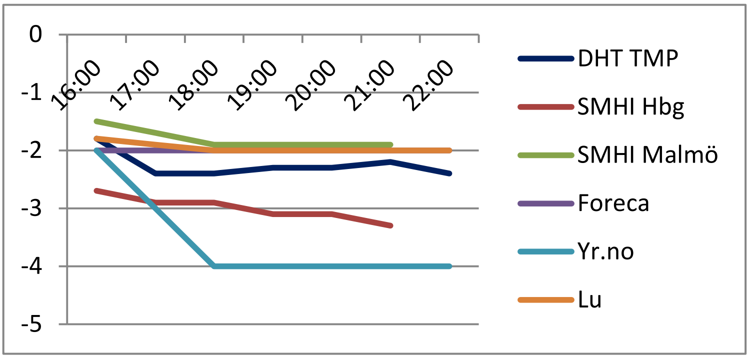

Chart 1b. DHT Temperature

4.3.2 DHT22: Humidity

The same measurement method is used for humidity, as for temperature. The difference is that the weather station at Lund University does not have a humidity sensor.

Humidity (%) Time	DHT22	SMHI Helsingborg	SMHI Malmö	Foreco	Yr.no
19:00	98.7	96	100	100	95
20:00	98.3	96	100	100	95
21:00	97.7	92	100	93	95
22:00	98.2	92	100	100	90
23:00	98.5	94	100	100	86
00:00	98.8	95	99	100	90
01:00	98.8	94	100	100	93
02:00	98.2	94	100	100	96

Table 3a. DHT Humidity

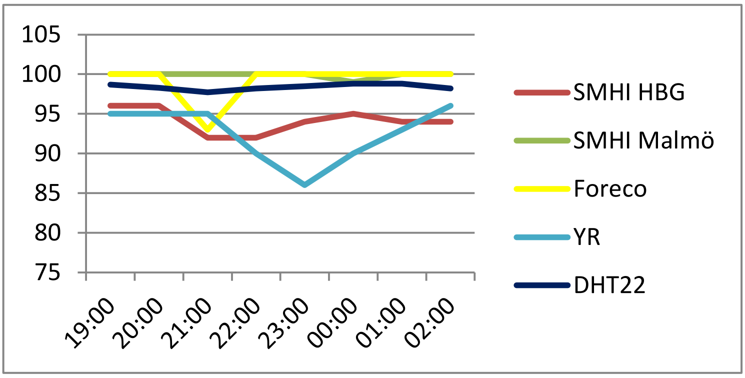

Chart 2a. DHT Humidity

Hummidity(%) Time	DHT HUM	SMHI Hbg	SMHI Malmö	Foreca	Yr.no
16:00	67.7	73	72	64	78
17:00	69.7	75	73	65	80
18:00	69.3	76	72	65.3	84
19:00	69.7	76	73	65.3	83
20:00	70.3	76	74	71.2	89
21:00	70	77	75	65.4	89
22:00	70.6			71.2	82

Table 3b. DHT Humidity

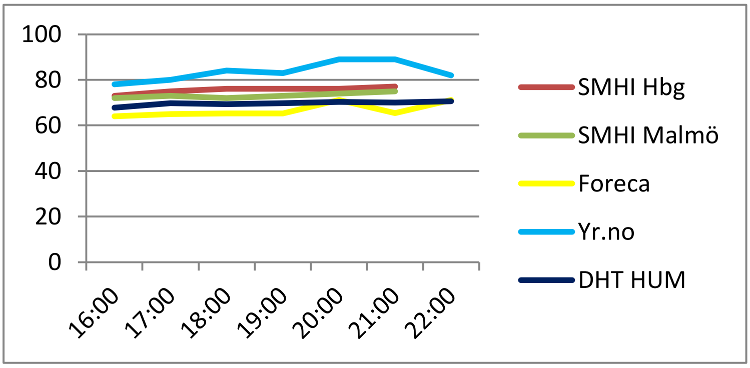

Chart 2b. DHT Humidity

4.3.3 MPL115A2: Pressure

The sensor outputs ten values during a period of two minutes. The mean value is used as a result and compared to that of SMHI, Foreca, Yr and Lund University.

Pressure (hPa) /Time	MPL	SMHI HBG	SMHIMalm	Foreca	Yr	LU
17:00	1014.1	1023	1022.6	1022	1023	1020
18:00	1014.7	1023.2	1022.9	1022	1023	1020
19:00	1014.6	1023.4	1023.2	1022	1024	1020
20:00	1015	1023.5	1023.3	1022	1024	1021
21:00	1015.2	1023.8	1023.6	1023	1024	1021
22:00	1015.2	1023.9	1023.8	1023.8	1024	1021
23:00	1014.9			1023	1024	1021

Table 4a. MPL Barometric pressure

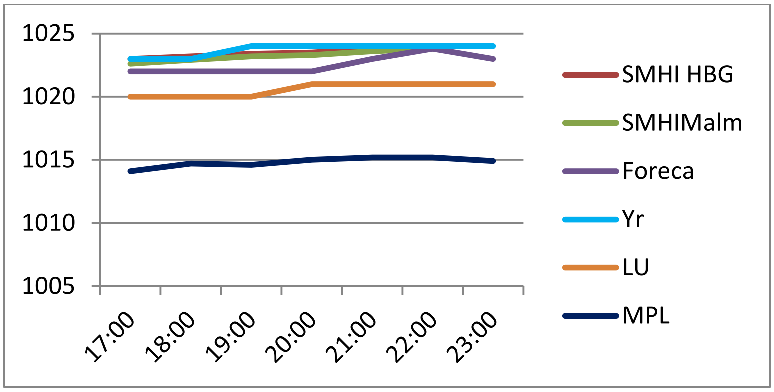

Chart 3a. MPL Barometric Pressure

Pressure (hPa) /Time	MPL	Foreca	SMHI Hbg	SMHI Malmö	Yr.no	Lu
18:30	1014,4	1023	1023,2	1024,1	1023	1021
19:30	1013,2	1022	1022,4	1022,9	1022	1019
20:00	1013	1021	1021,4	1021,6	1022	1019
21:00	1012,3	1020	1021,4	1021,6	1021	1020
22:00	1012,1	1020	1020,4	1020,7	1020	1018
23:00	1011,3	1019	1019,7	1020,2	1020	1017
00:00	1010,8	1019	1019	1019,5	1020	1017
01:00	1011	1019	1019	1019,5	1019	1017
02:00	1011	1018	1019	1019,2	1019	1017
03:00	1009,4	1018	1019,1	1019,2	1019	1016
04:00	1010	1018			1019	1016

Table 4b. MPL Barometric pressure

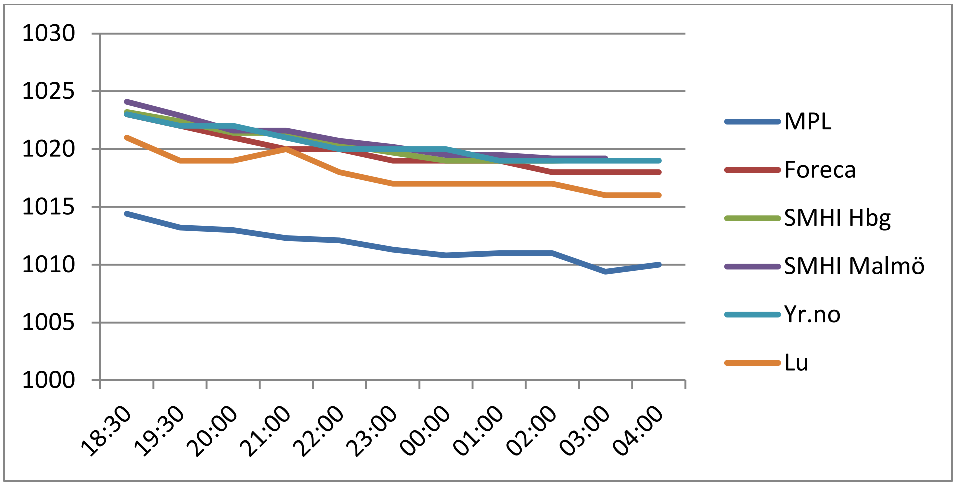

Chart 3b. MPL Barometric pressure

4.3.4 MPU6050: Wind speed and Direction

First plot shows 3 different output from the accelerometer in m/s^2 when put in motion by the wind speed of 18.9 m/s. See Appendix B for plots of measurements between 2.8 m/s and 32.75 m/s.

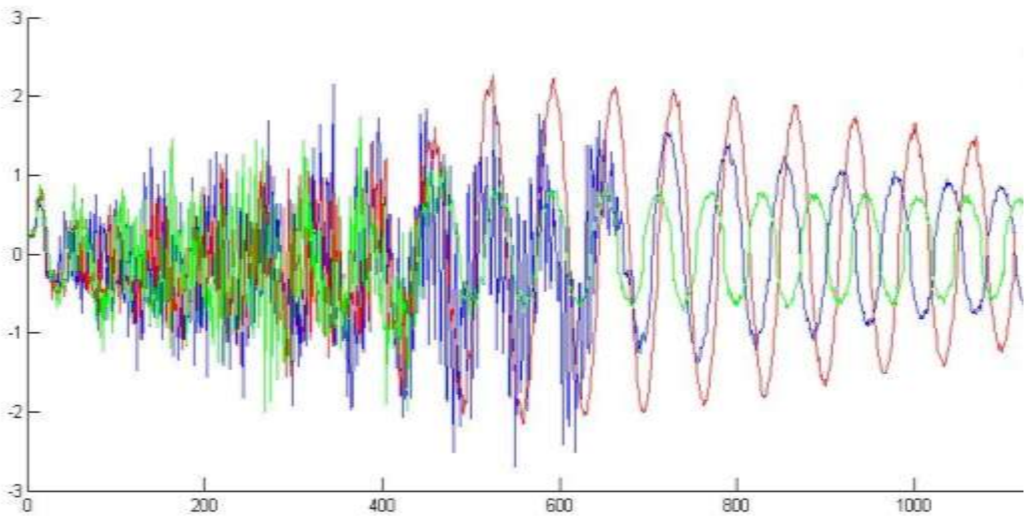

Chart 4. Free acceleration at 18.9 m/s

Wind Speed (m/s)	Output 1 (m/s)	Direction 1 (m/s^2)	Output 2 (m/s)	Direction 2 (m/s^2)	Output 3 (m/s)	Direction 3 (m/s^2)
2.8	2.27	X:-3.6 Y:-0.12	2.26	X:-3.6 Y:0.04	2.26	X:-3.6 Y:-0.11
5.5	2.1	X:-3 Y:-0.6	2.1	X:-3.6 Y:-0.5	2.07	X:-3 Y:-0.4
6.7	3.78	X:-1.8 Y:-9.9	3.42	X:-7.5 Y:3.3	3.2	X:-6.68 Y:2.5
8.4	2.63	X:-4.82 Y:0.42	2.42	X:-3.9 Y:-0.2	2.4	X:-4 Y:-0.4
9.8	3.3	X:7.5 Y:0.9	3.25	X:-7.3 Y:0.6	3.2	X:-6.5 Y:2.7
12.4	3.1	X:-6.8 Y:0.1	3	X:-6.4 Y:0.3	2.94	X:6 Y:-0.9
14.9	2.86	X:-5.4 Y:-2.1	2.85	X:-5 Y:-2.7	2.84	X:-5.4 Y:-1.7
16.5	2.6	X:-4.2 Y:-2.3	2.53	X:-4 Y:-2.3	2.49	X:-3.7 Y:-2.3
21.9	4	X:11.6 Y:0	3.62	X:-8.7 Y:-3.1	3.5	X:-8.7 Y:-0.6
26.3	4.27	X:-12.7 Y:0.87	4.1	X:-11.3 Y:-3	3.97	X:-11 Y:0
32.8	3.88	X:-10.2 Y:2.8	3.87	X:-9.6 Y:-4	3.77	X:-9.5 Y:3

Table 5. Wind speed and Direction

Table 7 shows measured values processed using formula 10d,

$V = \sqrt{2 * a * m/(\rho * A)}$.

5 Conclusion

5.1 Solution: Analog to Digital Converter

There are three attributes that differ greatly between the MCP3008 and ADC0808, the sample rate, the size and that one is serial and the other parallel. Size is a great issue for the Raspberry Pi since the amount of pins are limited and the ADC0808 requires not only eight pins for retrieving converted signal, but also extra pins for voltage references and enabling output. This also means that serial communication will be favoured in front of parallel. Serial only requires one pin while the parallel requires 8 for maximum resolution. The advantage of parallel would be that it might be easier to handle with the RPi, however thanks to manuals and the RPi community retrieving correct signals over serial communications should not be a problem.

Finally the sample rate is vastly faster with the MCP3008, allowing faster changes in the analog signal when measuring. The conversion speed needs to be taken in consideration when choosing analog sensors. Since there are no disadvantages to the MCP3008 over the ADC0808, the first will be implemented for the system.

5.2 Solution: Track temperature

The Pt-100 has a higher precision with a measuring range that covers all possible temperatures of the track. The cost for the sensor alone is half of the DS18B20, 43 kronor compared to 89. The downside is that it will require a lot of extra components to work. First of all the sensor would need to be attached to a wheatstone bridge, either using the raspberry’s 5V output or a separate voltage source. The extra components shouldn’t cost more if the bridge is built inside a quick-connect box, however this would affect the resistivity (see formula 4) and require calibration and maybe even customize each bridge’s resistors. An alternative to this would be to build a small capsule incorporating the sensor and bridge to be attached to the track.

The DS18B20 however doesn’t require any extra components and comes with 1.8m wires, only requiring a small amount of extra wire. The fact that it might also be connected without a supply voltage might save space and current from the raspberry, however not a priority. The sensor is also already well isolated, making it more likely to survive a longer period in the environment. What is strongly in the DS18B20’s advantage is that Trafikverket uses clamps on tracks to hold up metal bars that are heated with electrical power. The sensor fits perfectly inside these clamps, which solves placement issue. However to make sure the sensor doesn’t loose precision because of the isolation, it required testing. A piece of track was painted black and placed inside an oven. The temperature of the track was measured with the sensor, a pyrometer and an IR-camera (see table 6 and figure 11).

Time (HH:MM)	IR-Camera (°C)	Pyrometer (°C)	DS18B20 (°C)
10:51	33	32	32
11:15	38	37	36.5
11:35	42	41	40
12:11	44	43	41
12:40	46	45	44
13:00	46	46	44
13:30	48	48	47
14:00	50	50	48.5
14:30	51	52	49.5
15:00	52	52	50

Table 6. Temperature measurement of rail.

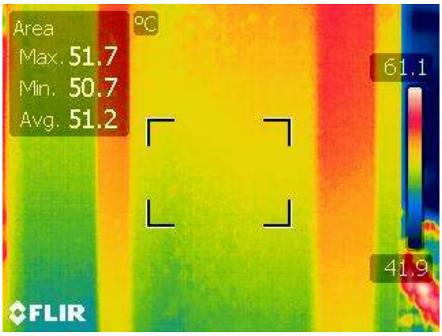

Figure 11. IR-picture of rail in oven.

From the results it's deducted that the output from the DS18B20 is very close to that of the sensors measuring thermal radiation. The error margin is good enough for use with a prototype, however testing should be done in a freezing environment to test precision below 0°C.

The greatest advantage of the DS18B20 is that it is well used in the Raspberry Pi community, making it easier to implement (see Appendix A for implementation code). With a short time span to create the first prototype, the DS18B20 will be used.

5.3 Solution: General System temperature

The requirements are that the sensor is small and cheap, so that it doesn't take up much space in either the system or when kept in stock. There are two sensors commonly used for this type of measurement with the Raspberry Pi: The TMP102 and DS18B20. The latter can either be bought in a TO-92 casing or in a protected casing with pre-soldered and isolated wires (see figure 9). The DS18B20 is the runner-up of the two for the purpose of measuring general temperature. It only costs 20.5 [21] kroner at European vendors (when bough it numbers of 500+). It's advantages are that it doesn't require any supply voltage to function, that it has a wider temperature measuring range and that it is easy to solder to a board.

The TMP102 on the other hand is cheaper and smaller than the DS18B20. Also, since the sensors will be placed in close proximity to the RPi, using a supply source will not be an issue. The TMP102 uses a factor 10^{-3} less supply current than the competition, making it more efficient. Its disadvantages are that the SOT563 is harder to solder to a board than the TO-92. Since the internal temperature shouldn't go bellows 0°C, the range shouldn't be a disadvantage and is why TMP102 is the recommended option.

As a compliment to the TMP102, the RPi CPU temperature can be retrieved using firmware, to control heating and ventilation of the container. Code for this and implementation of TMP102 can be found in Appendix A.

5.4 DHT22 Temperature

The DHT22, which contains a DS18B20, is a thermistor that follows actual temperature well. In the first results (a), the different sources are at most 1.9 °C apart, whilst the DHT22 and local sensor at Lund's University barely differ 1°C. In the second set of results, the different sources differ a bit more, with yr.no differing from SMHI by 2.1 °C. The weather station at Lund's University barely differs 0.5 °C. These results are very similar to the ones in table 3 and infer that the sensor would be a wise choice for the prototype or even for future use. It's also easy to use and implement, with instructions for basic setup provided by the reseller Adafruit [45]. Furthermore, the sensor has a low minimum range (-40 °C) and is easily mounted. Since the lowest mean value measured in Sweden is -27 °C [12], and was measured in Lappland, the sensor ought to do well in the southern regions of Sweden.

On the down side, it's rather expensive compared to analogue sensors and its shell is made of plastic. This would easily affect the durability of the sensor and might become a problem. Also the sensor might not respond well to the most northern regions of Sweden. The sensor is also quite large in comparison to analogue sensors and a smaller sensor would be better concealed.

The sensor remains untested in freezing temperatures and will require such before it is fully approved for mass production. The support from community and vendors is a huge plus, making it easy to focus on using and testing the sensor without wasting time on implementing.

5.5 DHT22 Humidity

These results aren't as clear as the temperature results. It follows the values from two of the references used, however it differs strongly from the measured values by Yr.no. Compared to Foreca and SMHI-Malmö, it stays well within the 5% fault margin in both chart 'a' and 'b'. The greatest weakness is however the lack of a local reference sensor and should be tested for best quality determination. For better quality determination, the sensor should also be tested in a larger variation of humidity combined with a larger variety of temperatures.

5.6 MPL115A2: Pressure

The results from this sensor show clearly that the sensor and code written for it prints out a clear offset. This offset can however be easily removed in the software code. What's also interesting is that there is an offset between the local sensor placed at Lunds University and the pressure announced by the metrological institutions. This could be because they don't have actual weather stations in Lund.

5.7 MPU6050: Wind speed and Direction

Starting with the positive from the results is that the sensor is capable to give a good sense of wind direction. The results are from a simulated wind-force along the X-axis. Although the results aren't perfect, the solution lies in improving the code. The sensor will move back and forth, which means the output will be both the positive and negative amplitude. The code needs to discern between the force from the wind and the force pulling it back into original position.

Measuring the speed is however very inaccurate. There could be many reasons for this. The two most prominent would be either that the formula is faulty or that the measuring environment and equipment was badly chosen and set-up.
The formula does not take gravity into consideration, although it should have resulted in larger amplitude. The formula from 10d does not take the force, holding the acceleration back, into consideration. This factor differs greatly depending on the material the accelerometer is placed on. For improvement, the feather constant needs to be analysed and the distance from original state must be measured each time the sensor moves.

The measurement was done first on a cup anemometer for reference and then on the sensor. For more accurate results, the actual wind speed needs to be better controlled.

6. Discussion

6.1 Implementations

The report has narrowed the study down to a total of nine sensors, however more were taken in consideration and even more will need studying as the RADASS progresses. These sensors have been studied to fulfil the product’s basic needs, but once the RADASS is put to use a continuous study will be needed.

One future measurement would be to detect the rails position, whether it has been switched or not. This would make the system more independent from manual spraying. Since the system applies both a defrosting and lubrication, this sensor could also measure if spraying is needed based on the speed of switching rail position.

Some of the sensors have not yet been tested and most of them require testing outside the laboratory environment. While required sensors for a functioning prototype have been tested and recommended, a budget will have to be set aside by Solliq to apply the more complex and costly sensors, like for example the more costly, robust and advanced 266GSH instead of the very basic 24PCGFM6G.

6.2 General Discussions and Conclusions

The weather station uses many sensors that are both compact and cheap, making them favourable for the RADASS system. However the choice to use an accelerometer or a cup anemometer need still be made. The accelerometer solves direction, but lacks speed precision and is also a costly alternative that will require a proper casing. A cup anemometer will however require a wind wane to solve both speed and direction. While they are more spacious and attract attention, they may be very cheap in comparison and are widely used. One suggestion would be to initially combine the cup anemometer with the accelerometer designs to replace the wind wane. A much more costly option is to implement an ultrasonic wind sensor, such as the “Wind Observer 65” [46]. Such a sensor would attract less attention than the cup anemometer with wind wane and be more precise at measuring the wind speed and direction. On the other hand, it would be more expensive and require more work on implementing it in combination with the Raspberry Pi. Also, if knowledge would spread of its value, it would be an easy and common prey for thieves. Another cheap suggestion would be to replace the accelerometer in the current design, with strain gauges. This would require more from installers of the RADASS system and that a cup anemometer is used in combination with gauges.

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