UNIVERSITEIT TWENTE.

SMART ENVIRONMENTS PROJECT

DOCUMENTATION REPORT

XPTS

Team 19 – XP Transport Systems

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Table of Contents

Chapter 0: Introduction

In current pandemic times this matter could not be more topical, vaccines. But have you ever thought about transporting them or other temperature sensitive goods by yourself?

To transport vaccines properly and safely an array of requirements have to be met, if one or more of these requirements isn't met, it will shorten the storage life/ durability of the vaccine heavily, most often rendering the improperly stored vaccine useless or potentially hazardous/ deadly if administered unknowingly. Because of these risks, the transportation of vaccines (and/or other fragile medicine/ equipment) is most often solely done by big, specialized companies to ensure safe transport.

A big problem with such transport is that it is often sluggish, having to wait for an entire batch to be transported to a central storage facility to then finally being distributed to (the people) It is quite evident that this method of transportation is not tailored for quick transportation of vaccines.

What if we need to vaccinate a small, dedicated group of people to have them protected before the virus sweeps through them?

We realized there is not a solution for doing so available to the public yet.

This is the case our team attempts to resolve, we want to find a faster way of transporting the vaccine without relying on the infrastructure that exists and without a loss of quality or any increased risk whatsoever.

Our Idea is to create a transporting box containing sensors, with which we log the contents of the box, as well as keep the vaccines in an environment where they would not go bad within that box. We then use the data we collected from the box to decide whether contents of the box are safe for use.

Transport of such goods should be something that is available for consumers to do independently. To be more self-reliant in situations where the regular ways of transportation might not be available or to have more control over your own healthcare. Our solution allows for a way to take matters into your own hands, as well as making the transportation of vaccines more reliable in absolute worst-case scenarios, as we then don't have to rely on only one company to deliver the goods.

Our team at XP Transport Systems consisting of:

- M. H. van den Dolder *Expert*
- M. F. Harinck *Innovator*
- O. A. E. M. S. Kamal *Executive*
- T. van Klink *Expert*
- A. A. A. Mahran *Innovator*
- M. de Waal *Executive*
- J. Wang *Teamleader*

will work together to create a solution for this problem.

Which will be to design and build a temperature-controlled container with sensors and actuators. With our product customer should be able to safely transport their own vaccine or other temperature sensitive items while multiple parameters are being monitored during the trip.

In this documentation we will elaborate on our decision making and design process, in case of any questions please feel free to contact us.

Chapter 1: Literature Review

Nuclear disasters

Effect of the Fukushima nuclear disaster on global public acceptance of nuclear energy [1]

The Chernobyl nuclear disaster has sculpted negative views on the subject of nuclear energy and using nuclear power. Working with, or around nuclear energy for research purposes has become more challenging since the Chernobyl explosion. Despite the negative light shined on nuclear energy, a larger percent of energy is taken from nuclear power. The new green energy is with nuclear fission, instead of nuclear fusion. Fission creates less waste and danger to prevent another Chernobyl experience.

Long-Term Mental Health Effects of the Chernobyl Disaster: An Epidemiologic Survey in Two Former Soviet Regions [2]

Chernobyl's nuclear explosion has had a significant effect on the psychology of the people in close proximity to the explosion. Psychopathology levels in people affected, ranging from all age categories, but affecting mostly mothers with children, is way higher than to people with little or no exposure. Men showed less psychopathological signs overall compared to women. This is likely due to the caring nature of mothers being present. Effects can last up to 6 years after the initial explosion and will most likely, compared to other issues, to induce chronic psychopathology.

Drought

Water Scarcity and Drought [3]

Because of poor water management and climate change, droughts are getting an increasingly bigger problem. This causes crops to fail, animals die and families face food shortages and famine. Industries that are impaired with water scarcity have to look for new approaches to be able to remain competitive in the future.

How to tackle repetitive droughts in the Horn of Africa [4]

The United Nations Food and Agriculture Organization (FAO) recently declared that millions of citizens in the Horn of Africa face food shortages. Because there was barely any rainfall between October and December(2017).

Drought: Everything You Need to Know [5]

Drought is often different from other natural disasters, its more covert, and builds over time, drought has often been described as a creeping disaster, drought has affected more people around the world in the past four decades than any other type of natural disaster. Drought is described by a lack of precipitation. For a protracted period of time. Developing nations are

particularly vulnerable to the impacts of climate change, drought in developing nations is notorious for creating water and food insecurity which worsens famines and civil unrest.

Internet

What Would Happen If the Whole Internet Just Shut Down All of a Sudden? [6]

If the internet would shut it would become total chaos, a lot of people won't be able to work, no way of communication through phone, computers and other technologies that require the internet. It would probably cause a global economic collapse. It would also inflict things like critical infrastructure, food supply and emergency response systems.

The Revenge of Distance: Vulnerability Analysis of Critical Information Infrastructure [7]

One network's security is only as good as the other networks it interconnects with. And with many infrastructures managed by private firms there is as of now no clear insight how vulnerable these networks actually are. The focus in these firms is not security but economy, they are all competing with each other. Policies should be made to govern this. As of yet this is a disaster waiting to happen.

Clean drinking water

How Humans Get in the Way of Clean Water [8]
WATER FOR ALL [9]

Water is an essential part for the human body. Worldwide every 1 person in 10 people does not have access to clean drinking water. The United Nations in 2015 decided to come up with 17 global goals named the "Sustainable Development Goals". One of these 17 goals aims towards securing safe water and sanitation for everyone.

Sadly we are in an unsafe situation due to freshwater ecosystems because most of the world's lands are either drained or filled. Only 1% of fresh water in the world is available and accessible to provide human needs for everyday life, and by 2050 population on earth is expected to reach 9.7 Billion which means that feeding 2 billion people more will require an increase in water withdrawals of 15% and an increase of 85% to produce energy.

Prepping

The bunker builders preparing for doomsday [10]

Whereas in the past preppers were often part of political movements against governments or other agencies, nowadays preppers are open and innovative about creating safe spaces for themselves or the public (if you have the funds). Our current pandemic reminds us that it's not just illusional to think that every day a disaster can strike and that preparing us for it isn't that bad of an idea. The social aspect which used to be of lower priority than physical survival now proves to be essential to survive on longer terms. In some cases existing

bunkers (left over from the Cold War or World War 2) can be renovated/enhanced with modern technology. A smart bunker?

Food waste

Analyzing global food waste problem: pinpointing the facts and estimating the energy content [11]

Since the development of food industries, we have multiple choices, and for modern society, people have more wealth and abilities to waste food . Food wasting is not only an economic disaster, but also for the environment, carbon dioxide releasing has increased due to the growing population, and the food wasting issue is getting serious.

Cutting down on food waste [12]
5 ways food waste is destroying our beautiful planet [13]

Food waste has always been an issue worldwide around one third goes to waste annually. The Netherlands is currently trying to tackle this problem due to large amounts of food being thrown away. the food thrown does not just come from readymade food but is also lost from storing, transporting, and harvesting. Wasting food not only wastes your money but also other important resources such as energy ,water, oil, and land.

Moreover, when food is thrown and reaches landfills as it decomposes the gas methane is released. This gas is known to affect global warming, which we already have enough of because of the production process. The goal now for the UN is to decrease food waste globally by 50% by 2030. In order to solve this problem business can aid consumers in wasting less food which can be done for example by selling portions in a much less quantity and providing more accurate expiry dates. The governments are also open to funding research projects that aim to help prevent food waste and a better living environment.

Recycling

PLASTIC IN THE OCEAN [14]

Plastic in nature has been and still is a huge problem in our world. Most of the plastic ends up being dumped into the seas and oceans. Even though pretty much 100 % of the most common type of plastic is being collected (in USA), only about 30% is being recycled. The rest eventually ends up in nature or in the best case, in landfills. This happens when it gets thrown in the trash, it gets contaminated or the recycling systems can’t handle it.

Electronic waste recycling: A review of U.S. infrastructure and technology options [15]

Electronics are all around us, Moore’s law also says that technology keeps advancing every 18 months. This means the life span decreases and once a computer life is over, it is thrown away. We are throwing away our raw materials such as gold but also damaging material like mercury. The trick is to correctly recycle these materials and harvest them to use in the next

version computers. Another solution is to increase the lifespan of computers. Both should be done to create sustainability.

Oil spill/ water pollution

The expanded footprint of the Deepwater Horizon oil spill in the Gulf of Mexico deep-sea benthos [16]

In 2010 the Macondo MC252 oil well leaked it's oil into the water off the coast of Louisiana, it's better known as the Deepwater Horizon disaster. It is the largest marine oil spill on record. It had/ still has huge effects on shallow water and deep-sea ecosystems. These ecosystems lost quite some of its biodiversity.

Drugs in the water [17]

Environmental advocates are getting more and more concerned about the pollution water by means of chemicals from prescription drugs and over-the-counter medications. The chemicals in these drugs are contaminating lakes, rivers and streams. Also products like perfume and sunscreen are becoming a bigger problem. As far as known it doesn't have any harming effects on humans yet. It does affect the aquatic wildlife. A step in the right direction has already been made by means of the drug take-back programs. This way unused medications don't end up in the water.

Chemical disasters

Gezond watermilieu [18]

The use of medicines has been increasing worldwide for years. Therefore, through different distribution routes, the presence of medicines in the environment will also increase. A major problem is that these medicines end up in the water and cannot be broken down in the water purification process.

Effectonderzoek blootstelling CMR-stoffen - nulmeting bij 80 complexe bedrijven en effectmeting bij 29 complexe bedrijven [19]

The Inspectorate SZW inspects companies that work with hazardous substances. From earlier inspections have shown that companies are still insufficiently aware of the dangers of these substances. For example, it is often unclear to what extent employees are exposed to hazardous substances.
The Inspectorate SZW puts the emphasis in its approach on exposure to so-called carcinogens, mutagenic or reprotoxic substances, in short CMR substances. These substances can cause cancer, damage genes or are harmful to reproduction. Examples of CMR substances are chromium-6, welding fumes, formaldehyde and benzene.
Apparently, it is possible to replace CMR substances with less harmful alternatives, but the companies themselves are not yet taking sufficient initiatives in this area.

Smoke related disaster

Fireworks tragedy in Enschede, The Netherlands: Measurements for concentrations, dispersion and deposition of harmful substances: report of the environment study [20]

On 13 May 2000 there were a number of explosions at a fireworks company in Enschede. A large fire started, which destroyed not only the company but also a large part of the houses in the surrounding residential area. Measurements taken during the fire and in the days after show that near the fire, in the smoke, increased concentrations of particles and heavy metals occurred. Carbon monoxide was also found to be present in high concentrations.

Chapter 2: Identification of General Problems and Challenges

General problems and challenges around disasters.
The matching article topic is giving in brackets.

Climate change (Global)

Staying safe during any disaster, lack of general methods to do so. (Global)

Physical and virtual security against attacks on the millions of nodes in the internet. (Internet)

Geographical factors in water management, some regions are not able to establish water cleaning systems. (Clean water)

Awareness about wasting food. (Food waste)

Too much plastic still ends up in nature. (Recycling)

Medications which end up in water bodies after usage. (Water pollution)

Human faults with massive consequences due to the non-rigorous training. (Chemical disasters)

Protection and prediction measures against smoke are far from perfect. (Smoke disasters)

Chapter 3: Identification of Relevant Problems

Five problems which we think are interesting and new and have not been solved as of now.

Vaccine/medical equipment transport

Safe transportation of vaccines or medicine is something only professionals are able to do as of now. They use a lot of expensive and big equipment for this. With the current situation and a future ahead where this might happen again individuals should be less dependent on other parties for this type of transportation in case of emergencies.

References on this subject: [21], [22], [23], [24], [25], [26]

Extreme temperatures

With the ongoing climate change, extreme temperatures are becoming more and more common. Many countries are not prepared to handle such heatwaves yet as they never used to occur.

High temperature not only affects human life, but also affects the entire ecosystem. If the ocean temperature rises, the carbon dioxide inside of the seawater will be released, and this problem will result in more serious climate issues.

And recent years' disasters like forest fires are getting more frequent, so we can say if humans don't do anything about this global warming issue, the frequency of disasters will increase exponentially.

Due to the global warming trend, viruses found in glacier ice could also be released, with possible risks for humans.

References on this subject: [27], [28], [29]

Wasting of food in urban area's

In the most advanced areas of civilization, food waste is a big problem. All while in other parts of the world, food is a limited resource. We prescribe a solution similar to the foodcam implemented at MIT. Where food can be safely given to whoever is hungry at that moment. This reduces food waste, cause it's essentially recycled, and less new food is bought.

References on this subject: [30], [31]

Water management

Now that water levels are rising water management is becoming more important than ever, smaller scale solutions are not yet widely available.

There are many opportunities managing water, for example:

Salt water has a higher density than freshwater. This is seen when you lay down in salt water, and float, vs in a pool, where you sink. Although this is a funny phenomenon, it causes quite a few problems. Where fresh and salt water meet, salinization occurs. This is detrimental to farmers, nature and drinking water companies.

However, the differences in density combined with buoyancy physics, could contribute to green energy creation by having a system switch between the different types of water and with this motion create energy. This would also further research into potentially how to purify water.

References on this subject: [32], [33]

Infrastructure stability regarding electricity

In case of disasters power grid may not always hold. As of now there are little to no backups if the infrastructure does not hold at the sources of the powers. In some country's everyday energy isn't reliable enough to sustain or develop society. For some regions, power outages are still a very regular event, despite us being in the information age.

References on this subject: [34]

Chapter 4: Problem Selection and Motivation

Our selected problem after looking at our newly found and existing problems and challenges:

Vaccine/medical equipment transport

The transportation of non-commercial vaccines is not encouraged. Manufacturers generally don't recommend moving a vaccine, due to the condition it needs to be kept in for sterile safety. Sometimes it's imperative to do so, If a patient needs a vaccine where time is of the essence, time can be lost by transporting the patient to the vaccine. We propose moving the vaccine to the patient, cutting the time in half. This of course is our specific example but can be applied in a broader context. We believe if we keep to CDC guidelines about how to properly store a vaccine, and apply those metrics to our project, we can safely transport the vaccine.

This is an issue that has many facets in our society, the problem of not being able to locate vaccines quickly enough still presents itself often throughout society. The versatility of this project also is a reason as to why we chose it, medical transportation is vital for the whole country during an urgent time like a pandemic.

This is an issue that has many faces in our society, the problem of not being able to locate vaccines quickly enough still presents itself often, think of more rural areas, or less developed countries. This contributes to the reason for choosing this application. Medical transportation is vital for the whole country during an urgent time like a pandemic. But the same idea also could apply to other emergencies, where a quick response time is essential. In addition to that, the problem of allocation of important equipment/vaccines is one that extends across the whole world.

It isn't an issue that is specific in one setting/location, however the way that this problem should be handled might vary slightly depending on the country, climate, infrastructure, accessibility to regions(e.g. Rocky terrain is harder to transport over than flatlands) our aim as a group is to come up with a solution that should work in all the cases mentioned above, given that slight changes to our solution could be made to efficiently solve the problem.

Finding a proper solution for this problem is relevant for securing our future, as valuable time is often wasted on transportation of goods, time that could be spent on solving/ preventing disasters in our future. We are convinced that a solution to this problem could improve the forecasted situation around Covid-19. Several weeks are going to be spent transporting the vaccines to the proper locations where they are needed.

To conclude, vaccines are difficult to transport due to it's hard to regulate environment. We are willing to take a crack at it with this project. Using various sensors for temperature,

humidity, location, and many more, we will be able to transport vaccines. We try to do this as efficiently and as safely as possible.

Consequences of our project could lead to a new age where previously fragile medicine can now safely be transported in an efficient manner. This can be built out to include a whole infrastructure where receiving medicine is autonomous.

Chapter 5: Potential Solutions

Possible solutions to our selected problem. A number of these can be combined in our final product.

Dry Ice [35]

Most vaccine's need to be transported at extremely low temperatures. Active cooling systems often require a lot of energy which is difficult to supply in mobile situations.
Dry ice (solid CO2) could be a possible solution to cool the small, controlled environment for a limited amount of time but without the need of outside energy.
It is easy to produce and is often created as a rest product of many industrial processes.
Also, at hospitals there usually is supply of dry ice available since it is used in multiple treatments. [36] This could be a location to possibly refill the dry ice storage in our solution.

It does have its limitations though. Dry ice cannot be stored for a long time, you lose over 50% of the volume within 24 hours. When this happens carbon dioxide gases will fill the container and therefore it cannot be airtight as the volume expends which would cause it to explode. As CO2 is a hazardous gas it could only be used in reasonable well-ventilated places. Handling the dry ice should also be done in the correct way, due to the extremely low temperatures it can cause freezing burns.

Cooling gels [37]

To enhance cooling performance of existing solutions such as cyclic refrigeration some kind of cooling gel could be implemented in our solution. These gels can help keep the temperature under control and consistent across longer time periods. Alcohol based solutions would be suitable since they would not freeze (pure ethanol alcohol -114 °C) at the temperatures our solution would operate at (about -80 °C). For higher temperatures this would be easier as we would not need to use as strong alcohol-based solutions.

In food transport these gels are already widely used. This results in many available types of these solutions. Most are polymer-based, which do not lose flexibility when frozen. There are differences in the viscosities of the gels. A gel that is too thick (high viscosity) will heat up too quickly but too thin a gel (low viscosity) will leak faster in case of damage.

Using drones

Transporting medical supplies by car, or ambulance, requires infrastructure such as roads. This poses a couple problems, namely, some countries do not have the infrastructure in place where they can reach everyone by road, and the road can be blocked by others using it.

If time is of the essence, a drone could ignore this infrastructure. Since it flies through the sky. Helicopters already do this, and it is a fast way of transporting patients, however

helicopters need to find secure and safe places to land, and due to its size, this is not always in close proximity. You also require formal training to fly a helicopter. A drone would make it more commercial and need less training to fly. Due to its size, it has little drawbacks to that of a helicopter, while still flying.

A drone has a smaller maximum load then helicopters so we cannot transport as large quantities. Because a drone operates independently, we must be aware that it can be intercepted. The medical supplies must absolutely not end up in the wrong hands.

Containers with sensors and actuators [38]

Because vaccines have to be kept in a specific climate, it is necessary to keep an eye on the environment and adjust it if necessary. By placing all kinds of sensors we can measure whether, for example, the correct temperature is maintained. By placing Actuators we can also actually adjust the climate.

It is necessary to pay close attention to which sensors are used. Not all sensors can, for example, measure extreme temperatures.

Actuators to make adjustments should not be too heavy and should not take up too much space. Everything must work as efficiently and environmentally consciously as possible.

Reusing existing equipment in different context

A possible solution for distributing vaccines and/or medications to individuals could be possible by something like an ice cream cart. An ice cream cart is already made to store its products with low temperatures. We could modify such freezing mechanisms to reach even lower temperatures, so it would be compatible with transportation of vaccines and/or medications to individuals.

Hyperloop [39]

This solution would transport the vaccine through a tube, run from the start until the end location. Inside the tube needs to be a vacuum, then through electromagnetic fields applying a forward's force to a pod. This pod houses the vaccine for transport.

A hyperloop is a tunnel, built underground, which lets you transport goods, or people at incredible speeds. Space X claims to travel up to 1000 Km/h. It achieves this speed by making the tunnel a vacuum, this creates no air resistance when the pod is moving. To get up to speed, it tube uses electromagnetic fields and current, to create a force on the pod, making it move forward. This is a very controlled way of transporting goods since if the current is of a constant Ampere, the resultant speed should also be constant.

There are drawbacks to this solution
its expensive, getting materials and pumps to enclose a space air right and then pump out the remaining air to create a low pressurized environment is theoretically possible, yet

practically unlogistic. Another issue is that for a community, these pipes would need to be installed to a variety of safejolds, where vaccines or pharmaceuticals can be collected.

Dataloggers

A device that could be used to measure temperatures within a box can be a data logger, which is a device that has a built in sensor that records temperature data within a specific period of time in our case the process of transporting vaccines. Data loggers are mainly used to monitor transportations in cold chains. At the end of the shipment process the data logger can be plugged in a PC using a chip to gather information and data from the recorded temperature conditions.

Data loggers are very useful because they avoid the time and cost of hiring someone to take measurements in remote areas. Moreover, they give back more precise data than manual recordings, meaning that the data received will be higher quality data. Furthermore, due to vaccines needing to be kept in specific temperatures it is very important to carefully measure the temperature of the shipments and make any necessary adjustments to them. By using the correct sensors, we can know if the right temperature is preserved, also using the actuators as mentioned before we can modify the climate.

Chapter 6: Solution Selection

Our selected solution,

Container with sensors and actuators

We decided that we wanted to be able to transport contents at a cold temperature. The contents could be a vaccine, or other medical supplies, but could also be food. Either way we need to create a container which remains cool and stable during transport to keep the contents in perfect sustainable condition.

Our realistic solution

Our realistic solution will contain a box, a cooling element insulating material and various sensors I.E. Temperature sensor, acceleration sensor, light sensor, pressure sensor and humidity sensor. Pressure, temperature and humidity sensors are needed since we will work with dry ice, and we need to check if the box is still safe to operate with pressures released due to the immense cold of dry ice. The light and acceleration sensor is for tracking and to get an idea of how the box is handled. Geolocation is also a sensor needed. We also need an internet connection so we can globally read and write (if needed) data and make adjustments to the box to keep its contents in optimal conditions.

The container solution is chosen above the Ice cream cart solution since having unmanned vaults with contents can cause unwanted attention. Having it out in the open can attract crime where the contents could be stolen and sold.

For transportation we decided to neither go for the hyper-loop nor the drone. The method of transportation is not the focus of our project, it is to create a device which can be transported. The package can be transported depending on its deployment. In a city, they might use drones, in the suburbs, they might use a car. We just make it possible to transport it. This part of our idea was too ambitious and creating a stable cool box is already quite a hefty project, how to transport the box is up to whoever will transport it.

We would like to include support for common mounting systems used in systems like ours to be able to easily mount it. For example amount for Technimount System bases [40], which are widely used in ambulances all around the world.

Our ambitious solution

Our ambitious plan will be similar to our realistic plan, only we try to expand on it by increasing the carrying capacity, instead of creating a small box carrying contents no larger than a shoe box, an ambitious plan is using the same principles in our realistic solution, and scaling it up to fit a truck or car.

This would increase the carrying capacity. We also want to add a NFC chip to the box, this is to read data from the sensors within the box without opening it. This would be complementary to the screen already in place.

Depending on how smoothly the project goes we could incorporate this into the realistic solution as well since it is a useful feature to have the data easily accessible on the phone. We would need to build a custom app for this which is why it's in the ambition solution.

We divided our solution in different modules to organize our work.

Solution modules

Container	Design of container	Marc, Ahmed, Jinze
Material research	Materials for the product	Marc, Ahmed, Jinze
Programming	Arduino/Processing programming	Monique, Thomas
Calibration	Hardware sensor calibrations	Marc, Jinze
Data collection	Collection of data	Ahmed, Manu, Samy
Validation	Validation of sensor data	Monique
Analysis	Analyzation of gathered data	Ahmed, Manu, Samy
Circuitry	Design of needed circuitry	Marc, Jinze
3D Printing	Printing 3d designed parts	Samy
Presentation	Product presentation and style	Thomas
Graphics	Logo, documentation, branding	Thomas

Chapter 7: Methodology

In this chapter we elaborate on our methodology to create our chosen solution.

Equipment

Our intention with this project is to keep a cool box, that we can use to sense our environment (in our case our box) as well as keep a cool, dry and stable environment to store our contents in. We intend to use the following equipment/ materials for that:

- Building materials (acrylic board, fabric)
- Glasswool (insulating material)
- Various sensors, as described at *Sensors*
- Dry Ice, solid CO2 (5Kg of 9mm pellet ice)
- Arduino Mega
- TFT Touch Screen
- SD-card
- LED lights (in case to display the cooling situation)
- 3D printed Gyro frame for holding the delicate medicine (part of ambitious plan)

Building materials

For our building materials we need to select materials that are able to provide good thermal insulation (preferably for both heat radiation and conduction)

To solve for the heat radiation part, we think aluminum plating is very much up to the task, as it has a good reflectance values across the whole (radiation) emission spectrum.

We have selected the glass wool which we think is sufficient for insulation of the box, the outside of the box will be a plastic.

The material has a high thermal resistance with values of 0.023 and 0.040 W/m.K respectively which is very insulative. By creating a cool environment with regards to the material chosen for insulation it will be more efficient at keeping the contents of the box cold.

Sensors

We need an array of different sensors to be able to correctly sense all we want.

These are:

- Thermal sensor(s): for instance DS18B20 ranges respectively: -55°C to +125°C).
- Accelerometer: MMA7260Q

- Real Time Clock module: PCF8523
- GPS shield: GY-NEO6MV2
- Light sensor: VT90N2
- Humidity sensor: DHT11

Actuators

- 2.4 inch TFT Display Shield – 240*320 pixels – with touchscreen.
- Some generic LEDs

Hardware

- Arduino Mega
- Big breadboard
- Wiring
- Resistors (4 x 4kΩ, 3 x 10kΩ)

Calibration

The values transmitted by the sensors are realistic and meet expectations. Thus, they do not need to be calibrated at all. However, the display did need to be calibrated, this is accomplished by putting a simple program on the Arduino and testing the accuracy of the touchscreen.

The program is a build-in test of the MCUFRIEND_kbv library in Arduino, and results in values that we can then implement in our own code to ensure accuracy.

Controlled environment

In our project we intend to use our sensors in such a way that gives us an insight as how we should control an environment itself, within the box the environment will be controlled, we accept a very wide range of inputs to dictate what an appropriate response to that input will be (for example, with temperature, we only need the sensor to indicate whether it is above or below a certain point, and so a lot of inputs will suffice in giving us an idea as to what we should do)

We are using a special casing to isolate our environment from the outside world, inspiration from the flights and goggles, a dura-wall case can not only provide extra safety protection to the inner stuff but also provide a good heat preservation ability.

Data collection

For our product it is of great importance to keep a constant data tracker on, to make sure that the vaccines and/ or other fragile (medical equipment) hasn’t been tampered with or

gone bad. Not doing so could have terrible consequences for the people we are trying to help.

We intend to collect data by placing different sensors in and/or around the box, and storing them within a Chip/SD card to be able to access them later from the data logger, for our ambitious version, it might be a plan to connect our product to the internet in order to get real-time data. For now, it's not a priority, because we also intend this product to be used in regions where a stable infrastructure and/ or internet connection isn't as stable as we are used to.

To make the transportation easier, there could be a mini monitor to display the information from the inner stuff and also the data's like the medical permission and information about the users themselves for security checking and review.

Data analysis

For our data analysis we have to log different data:

- Time
- Temperature
- Movement *Handling of contents within the box.*

Since the box is not continuously connected to a computer, a clock with the current time must be connected to the Arduino. Such a kind of module is called a RTC, a real time clock. A Real Time Clock module ensures that the Arduino always knows the exact time.

We need an accurate way of measuring the temperature within the box, our plan to do that is to use (multiple) temperature sensors for this, the DS18B20 and the MCP9700 - E/TO sensors have been recommended to us by Alfred de Vries. Both of the temperature sensors fit our temperature requirements. Because the DS18B20 has a wider range and is water resistant, we chose it.

To measure the handling of the box, we will use accelerometers, as they suffice in giving quite accurate measurements of when the box has been handled really improper, it will need a quite high threshold, so we don't have to worry about the error margins as much. The acceleration of the box is measured in G forces, so we know exactly how the box was handled.

We recognize that we have to store a lot of information, so we also need to find a way for good storage of our data, we need to come up with a way of sending the data to a storage device, An SD-card seems optimal for this idea. The display we use has a built-in SD card port. We can not only read data from it but also write data to it, which is ideal for our product.

Actuation

Our initial plan was to just find a way to keep a box cool by putting a coolant with the contents of the box and tracking the temperatures. Now that we have come further in this project, we've seen that if we continue with this plan, our box just might get too cold and stay at that same temperature (of up to -78) and not change, (temperature remains constant in a phase transition)
Seen as those temperatures are beyond what is needed and potentially even have an adverse effect on the quality of the contents of the box we need to come up with a solution for keeping it between a band of selected temperatures.

One such way is to add a separation in the box, we then will store the dry ice in one compartment and the to be transported contents in the other, we then could hook up a fan/ vent to open up whenever the temperature drops below a certain threshold.

We have looked into the use of Peltier elements, but it wouldn't be too viable of an option, as Peltier elements require a lot of energy, which has to be stored in large batteries, that you then would have to carry along with the box, slowing the transport down, we have to keep in mind that our goal with this project is to keep our box highly portable, while remaining to keep a stable environment within the box.

Another way to handle this emergency situation would be start up a semiconductor cooling system but the cooling efficiency would depend on the battery capabilities.

Validation

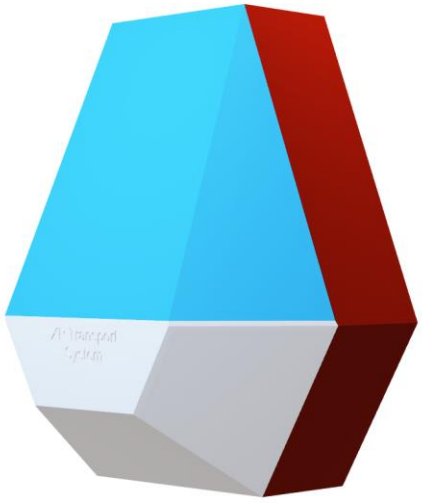
Our final product/prototype should function as we initially planned to do so, that means actually cooling the product inside while monitoring our set parameters and storing them. This will be demonstrated live on the demo day.

To properly validate the operation of the product against the competition we would like to test it against possible similar solutions or other ways which are currently used to transport vaccines. This would be in a controlled environment where circumstances are the same for all products. Sadly this will be difficult regarding the current situation.

Chapter 8: Results and Conclusion

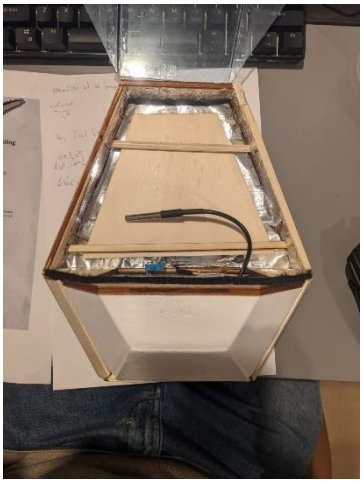
Results

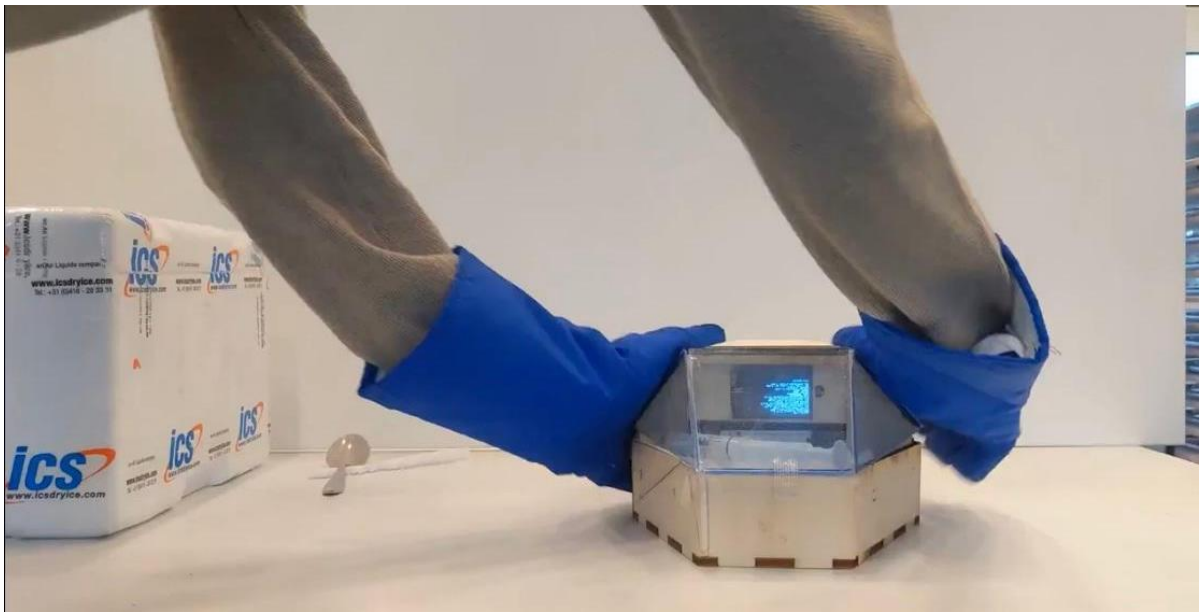
The product:



XPTS Moroz

- Portable
- Ergonomic
- Stable and sturdy
- Visibility and control

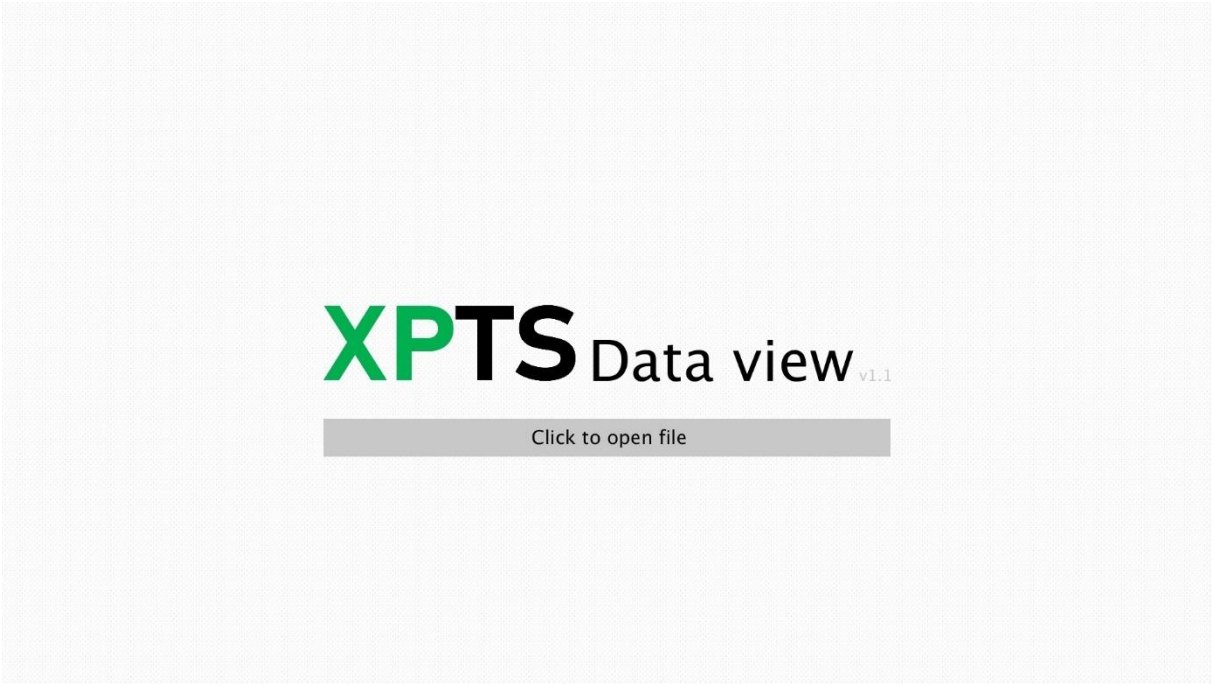


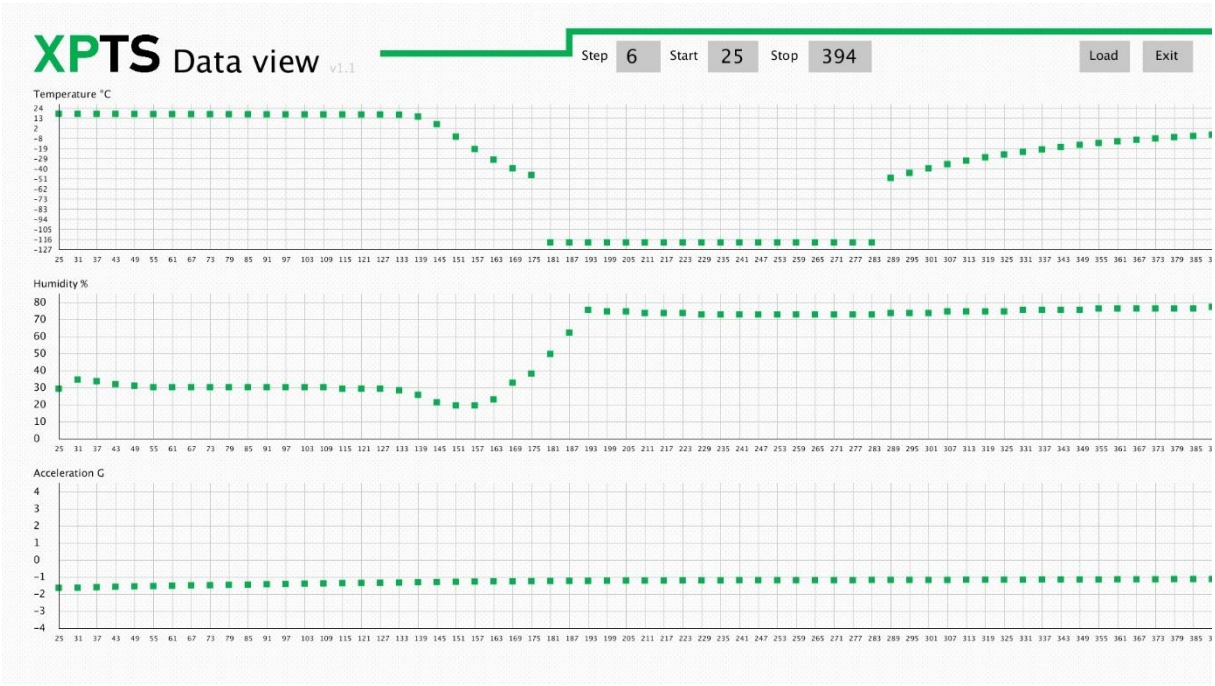


The XPTS Moroz enables the transportation of medical substances. Whether it is medicines or vaccines, it does not matter. The XPTS Moroz ensures that the environment remains under control.

Various sensors monitor, among others, the temperature and humidity. In addition, thanks to the accelerometers, you can immediately see how the package has been handled. The XPTS Moroz can also be tracked at all times. Both on the display of the XPTS Moroz and in the software system (Data View), you can view the analysed data from your trip.

The software:





With this Processing application you can open and visualize log files from the *Moroz*. Almost all logged parameters are displayed.

The log files are stored on the SD-card by the microcontroller and can be easily transferred to a PC with that. A for current days small card (2GB) will suffice for hours of logging.
You can change multiple parameters of the graph such as the step size, start number and stop number. This is done by putting the mouse on the corresponding number and scrolling up and down. The graph will be updated in real time allowing for great insight into the log and trip.

Conclusion

Our initial goal set for this project was to create a container which enables a trained user, to carry a vaccine to a patient, without expensive and heavy equipment to keep the vaccine cold. It turns out there is a reason for the expenses complexity and weight. We refined our idea to create a transporting device which keeps its contents cold and logs the behavior of how the package is handled during transit.

Similar to a vaccine transporting device, only less extreme. We of course have the option to further our project for these extreme cases. Our goal was achieved, we managed to create a container, which reads, temperature inside the box, humidity inside the box, geo-position of the container, if the box is opened via a light sensor and any sudden movements like dropping the container via an accelerometer. All this data needed to be logged, so we stored it on a SD card, connected to the system. This SD card can be used as evaluation to ensure safe and correct transit. We wrote our own interface the analyze the logged data.

We packed all this technology into a body and are now able to reliably transport anything which needs to remain cold.

Our findings of our project are not strictly applicable for the transport of chilled contents. We created a system which is able to track position, temperature, and more, understand that data, and outline answers based on that data, all while keeping the inside condition inside the container stable in temperature.

Testing and verification

Our testing method will be, simply said, comparing data, and drawing conclusions from that data. We have the data logged to an SD card, and a program which reads the data on this SD card. If any change is measured by the package I.E. temperature change, movement change, light level change, etc… The data will reflect this change. With this premise, we will make predictions.

Say if we move the package 50 meters east from its starting location. We expect to see a gradual change in the data logged over time, ending at 50 units from its original value in the data, translating to position earlier in time. This same testing method will be used for temperature, light level, humidity. We then compare these dynamic scenarios to a stable one, where temperature, position, light level, etc is not changed. The difference between the stable package, and the dynamic one, is the test.

Since we should be able to predict these values with a degree of accuracy, we can also verify that the product works. Recapping, we make predictions about what would happen if we induce a situation to our package, then we Indicate that situation, and see the data change. The changing data is the validation.

Problems

Connecting the sensors presented few unexpected problems. The temperature sensor, humidity sensor, light sensor and the real time clock module gave valid values almost immediately. The touch screen display had to be calibrated, but with a simple program that was also easily done.

The accelerometer gave the right values, but they had to be converted to g-forces. This could be done with the following formula: g-force = ((5 * (input / 1024)) - (3.3 / 2)) / sensitivity. With this formula the measured voltage is converted into g-forces. The 5 is the voltage the normal output pins give, 1024 is the maximum value the analog input can read. 3.3 is the input voltage over VCC. We divide this by 2 because we want both negative and positive values. The negative values represent the opposite directions. The sensitivity depends on the type of accelerometer, and in our case is 0.8.

Moreover, the GPS module. At the time of writing, this one still does not seem to connect to the satellites. Therefore, all the values I can measure are 0, invalid.

In addition, we ran into a problem with the SD card. The SD card can be plugged into the display and data can be read and written to it. However, this works on the Arduino uno, but not on the Arduino mega. This is because the ports on which the Arduino mega communicates with the SD card, does not support the correct protocols. It took a while to

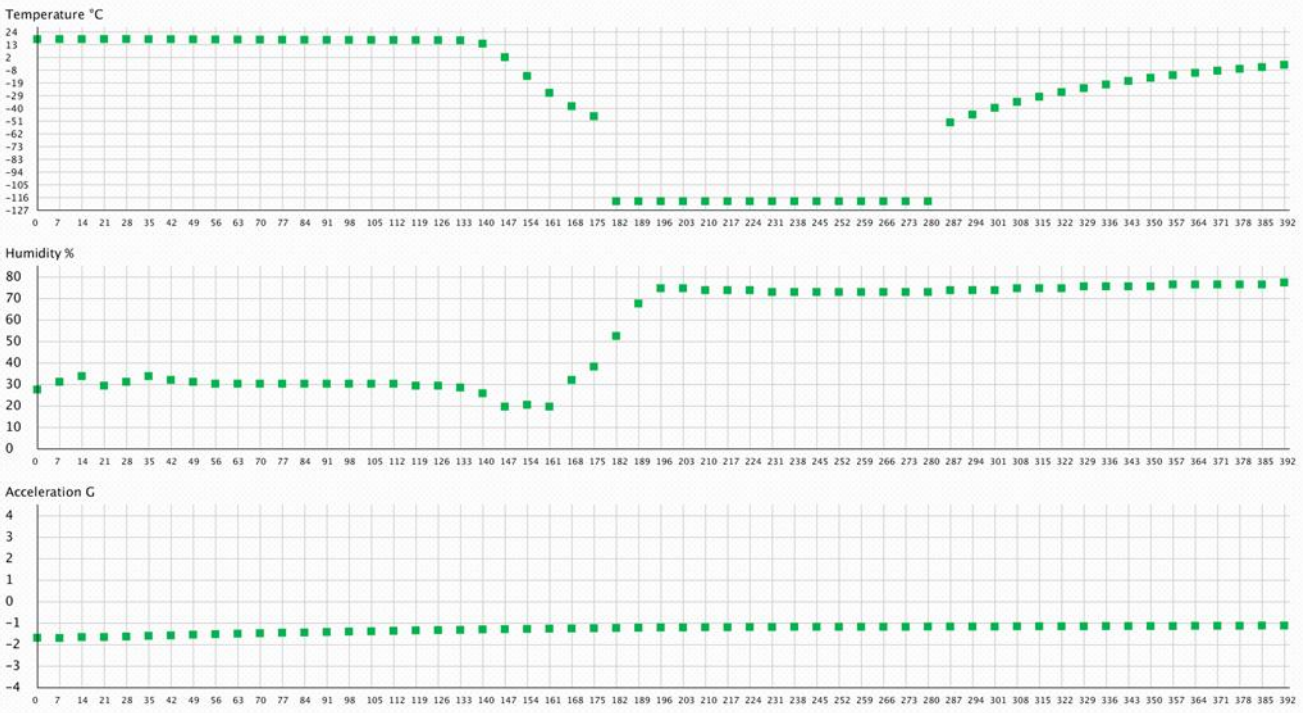
find the solution. In the end, we connected the entire shield with wires to the appropriate pins, rather than directly to the Arduino mega. It was also necessary to rewrite the corresponding library.

Finally, one of the most challenging problems encountered was working together during the lockdown. This affected us in so many ways, working online was not as productive as when we would meet up physically and work on the project. Furthermore, at some point there would always be someone who was somewhat behind on some of the stuff that was mentioned in previous group meetings. Also, we would start getting things done towards the end of the due date which did not leave much room for us to gather the information we have worked on and recheck it before submitting. However, with all of this we still managed to get things done and submitted in time.

Data

In the appendix there are multiple test runs with log data where the Moroz was filled with dry ice, our preferred cooling fuel. These reflected our expectations and performance was even a bit better than expected, causing the temperature to go beyond the range of our sensor (-127 degree Celsius).

These can be analyzed in XPTS Data View.
Dry ice run 2 (LOG3.TXT) generates the following graph:



At sample 140 the dry ice was added what resulted in a big drop of temperature and rise in humidity. The container didn't move much so there is no change in acceleration.

At sample 182 the temperature was beyond the sensors range what resulted in a overload value of -127 degrees as can be seen at the flat graph from 182 to 280.

After about 30 seconds the environment in the container stabilized and the temperature slowly started to rise again (sample 287). The humidity remained high, as the container was still closed.

This proves data our collected that can be actually used for analysis of a trip with the Moroz.

Discussion

For our project, We decided to stick with the basic version of our plan: everchanging corona measures difficulties on planning and coming together made us choose for this scenario. Our ambitious plan included making the logged sensor data readable via NFC, and/ or finding a way to transport the contents of the box via a backpack or even a drone. If not for the pandemic, we assume we would have been able to make the backpack and NFC communication work.

Arguably, it would have been wise to begin various tests earlier. In fact, we should have started testing the extreme values of the sensors before we put everything together. Then, if something was wrong, it would be easier to replace it.

In addition, we had some delays in putting the design together. It took longer than expected for us to get our hands on the parts. The sensors were not available during the vacations, which also meant that we did not start developing the software. We also did not have the other materials readily available. As a result, we could not yet assemble our final product. We should have taken such delays into account in advance.

Unfortunately, in the last week we found out that the design had not taken into account, among other things, the material requirements. Our prototype does not (yet) meet expectations at this time. To make the prototype meet our requirements it should be improved on the following points:
First, the format. Our prototype is too small to incorporate the technology, also the battery barely fits in it.
In addition, more space is needed to store the dry ice and medical supplies.
In addition, some of the material needs to be replaced. The transparent part allows light to pass through, while some substances need to be stored in a dark environment. Also, the current material does not insulate enough to keep the substance to be transported cool on long stretches.
Finally, the display needs to be placed in a different location, as it is now inaccessible during transport. Also, there is currently no interaction possible with the touchscreen.

Besides, if we had had more time, we would have liked to modify the user interface of the display. Moreover, there are many more possibilities with the current touch display. For example, one option was to ask for user input. The user is then able to indicate the acceptable ranges for the sensors themselves. This also directly makes our product more attractive. In such a case, it is more widely applicable and easier to operate.

Potential

Our solution could be suitable for a Kickstarter. This could, perhaps after some market research, be a suitable business case too. After this global pandemic people will want to be better prepared for another similar pandemic in the future and being one of the few solutions that can be found in our field which will benefit us.

With enough funding we could improve our design with better materials and better sensing capabilities. There are plenty of features we can still add to make it more useful in specific situations or to make it better in general.

Deployment

Its size enables it to be easily stowed on an ambulance motorcycle. These are used in just cities but have less varying capacity than a traditional ambulance. We could create a controlled and cold environment for medicine on a motorcycle.

If in harsher areas like forests or mountains, transporting necessary medicine to a patient may only be possible by foot. The light weight makes it. Our design enables the contents to be cold right up until the patient receival of said medicine.

Depending on humidity, and outside temperature, the container's contents might get affected. This would limit the deployment to areas which don't experience intense heat.

Feasibility

The project was somewhat high profile due to COVID-19 measures. We could hardly get together and collaborating on physical things at a distance is particularly difficult.

Despite circumstances, we managed to put something together. We believe that under normal circumstances the ambitious plan was feasible.

Scalability

Our solution in low in cost and easy to replicate. After a few developments, our product would scale well. Moreover, our solution is suitable for various purposes and circumstances. It is certainly not excluded that it can serve underdeveloped areas.

Chapter 9: References

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Chapter 10: Appendix

Moroz Microcontroller (Arduino Mega, C++)

```
//-----XP TRANSPORT SYSTEMS-----
//-----MONIQUE DE WAAL-----
//-----2021-01-21-----
//-----CREATE Y1M2 SMART ENVIRONMENTS PROJECT-----
//for inprovements/suggestions, please contact: m.dewaal@student.utwente.nl

//currently running on arduino mega: display, temperature sensor, real time clock (rtc)
module, accelerometer, humidity sensor, gps module (with no signal :(), ldr, SD card slot;
//see file "sensors.txt" for additional info and sources on the equipment/code.

int counter = 0;
bool uhoh = false; //check if something is wrong, hereafter referred to as uhoh
int UHOH = 29; //pin with uhoh led

//-----DISPLAY-----
#include <Adafruit_GFX.h>
#include <MCUFRIEND_kbv.h>
MCUFRIEND_kbv tft;
#include "TouchScreen.h"
#define MINPRESSURE 100
#define MAXPRESSURE 1000

// copy-paste results from TouchScreen_Calibr_native.ino
#define YP A3  // must be an analog pin, use "An" notation!
#define XM A2  // must be an analog pin, use "An" notation!
#define YM 9   // can be a digital pin
#define XP 8   // can be a digital pin
//240x320 ID=0x9341
const int TS_LEFT = 109, TS_RT = 919, TS_TOP = 75, TS_BOT = 893;

TouchScreen ts = TouchScreen(XP, YP, XM, YM, 300);

//define colors
#define BLACK   0x0000
#define BLUE    0x001F
#define RED     0xF800
#define GREEN   0x07E0
#define CYAN    0x07FF
#define MAGENTA 0xF81F
#define YELLOW  0xFFE0
#define WHITE   0xFFFF

#include <stdio.h>
#include <stdint.h>

uint16_t height, width;

//-----TEMPERATURE-----
#include <OneWire.h>
#include <DallasTemperature.h>
float maxTemp;
float minTemp;
float totalTemp;
float avgTemp;


// Temperature Data wire is plugged into pin 31 on the Arduino
#define ONE_WIRE_BUS 31
```

```
// Setup a oneWire instance to communicate with temperature sensor
OneWire oneWire(ONE_WIRE_BUS);

// Pass our oneWire reference to Dallas Temperature.
DallasTemperature sensors(&oneWire);


//-----REAL TIME CLOCK-----
// Date and time functions using a PCF8523 RTC connected via I2C and Wire lib
#include "RTClib.h"

RTC_PCF8523 rtc;

char daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday", "Wednesday", "Thursday",
"Friday", "Saturday"};


//-----ACCELEROMETER-----
#define x_axis 15 //x-axis on pin 15
#define y_axis 14 //y-axis on pin 14
#define z_axis 13 //z-axis on pin 13

int sampleSize = 50; // used in moving average
float gmax = 0;



//-----HUMIDITY-----
#include <dht11.h>
#define DHT11PIN 37 //humidity sensor on pin 37

dht11 DHT11;
float h;
float maxh;
float minh;
float totalh;
float avgh;


//-----GPS-----
//NOTE ON GPS: got most of the coding from the fullexample in the tinygps++ library
#include <TinyGPS++.h>
#include <SoftwareSerial.h>

static const int RXPin = 35, TXPin = 33;
static const uint32_t GPSBaud = 9600;

// The TinyGPS++ object
TinyGPSPlus gps;

// The serial connection to the GPS device
SoftwareSerial ss(RXPin, TXPin);


//-----LDR-----
const int LDRPIN = 41; //LDR input on pin 41
int light = 1; //when exposed to light this turns to 0

//-----SD Card-----
#include <SPI.h>
#include <SD.h>
const int SSPIN = 53;
File logFile;
File testFile;
```

```
//-----SETUP-----
void setup() {
  Serial.begin(9600);
  pinMode(UHOH, OUTPUT);
  digitalWrite(UHOH, LOW);

  //-----DISPLAY SETUP-----
  tft.reset();
  uint16_t ID = tft.readID();
  if (ID == 0xD3D3) ID = 0x9486; // write-only shield
  tft.begin(ID);
  tft.setCursor(0, 0);
  tft.setRotation(1);
  tft.fillScreen(BLACK);
  width = tft.width();
  height = tft.height();
  tft.setTextColor(WHITE);

  //-----TEMPERATURE SETUP-----
  sensors.begin();

  //-----RTCSETUP-----
  if (! rtc.begin()) {
    Serial.println("Couldn't find RTC");
    uhoh = true;
    Serial.flush();
    abort();
  }
  if (! rtc.initialized() || rtc.lostPower()) {
    Serial.println("RTC is NOT initialized, let's set the time!");
    // When time needs to be set on a new device, or after a power loss, the
    // following line sets the RTC to the date & time this sketch was compiled
    rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
    // This line sets the RTC with an explicit date & time, for example to set
    // January 21, 2014 at 3am you would call:
    // rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));
    //
    // Note: allow 2 seconds after inserting battery or applying external power
    // without battery before calling adjust(). This gives the PCF8523's
    // crystal oscillator time to stabilize. If you call adjust() very quickly
    // after the RTC is powered, lostPower() may still return true.
  }

  // When time needs to be re-set on a previously configured device, the
  // following line sets the RTC to the date & time this sketch was compiled
  // rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
  // This line sets the RTC with an explicit date & time, for example to set
  // January 21, 2014 at 3am you would call:
  // rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));

  // When the RTC was stopped and stays connected to the battery, it has
  // to be restarted by clearing the STOP bit. Let's do this to ensure
  // the RTC is running.
  rtc.start();

  // The PCF8523 can be calibrated for:
  //        - Aging adjustment
  //        - Temperature compensation
  //        - Accuracy tuning
  // The offset mode to use, once every two hours or once every minute.
  // The offset Offset value from -64 to +63. See the Application Note for calculation of
offset values.
  // https://www.nxp.com/docs/en/application-note/AN11247.pdf
```

```
  // The deviation in parts per million can be calculated over a period of observation.
Both the drift (which can be negative)
  // and the observation period must be in seconds. For accuracy the variation should be
observed over about 1 week.
  // Note: any previous calibration should cancelled prior to any new observation period.
  // Example - RTC gaining 43 seconds in 1 week
  float drift = 43; // seconds plus or minus over oservation period - set to 0 to cancel
previous calibration.
  float period_sec = (7 * 86400);  // total obsevation period in seconds (86400 = seconds
in 1 day:  7 days = (7 * 86400) seconds )
  float deviation_ppm = (drift / period_sec * 1000000); //  deviation in parts per million
(µs)
  float drift_unit = 4.34; // use with offset mode PCF8523_TwoHours
  // float drift_unit = 4.069; //For corrections every min the drift_unit is 4.069 ppm (use
with offset mode PCF8523_OneMinute)
  int offset = round(deviation_ppm / drift_unit);
  // rtc.calibrate(PCF8523_TwoHours, offset); // Un-comment to perform calibration once
drift (seconds) and observation period (seconds) are correct
  // rtc.calibrate(PCF8523_TwoHours, 0); // Un-comment to cancel previous calibration

  Serial.print("Offset is "); Serial.println(offset); // Print to control offset

  //-----GPS SETUP-----
  ss.begin(GPSBaud);

  //-----LDR SETUP-----
  pinMode(LDRPIN, INPUT);

  //-----SD SETUP-----
  Serial.print("Initializing SD card...");
  if (!SD.begin(SSPIN)) {
    Serial.println("initialization failed!");
    uhoh = true;
  } else {
    Serial.println("initialization done.");
  }
  //Test at startup
  sdDataFile();
  if (uhoh) {
    digitalWrite(UHOH, HIGH);
  }
}

//////////LOOP//////////
void loop() {
  tft.fillScreen(BLACK);
  tft.setCursor(0, 0);
  logFile = SD.open("log.txt", FILE_WRITE); //Opens or creates the log file on the SD card;
  if (!logFile) {
    // if the file didn't open, print an error:
    Serial.println("error opening log.txt");
    tft.println("error opening log.txt");
  }
  counter++;
  logFile.print(counter);
  tft.print("counter: ");
  tft.println(counter);
  realtimeclock();
  temperature();
  humidity();
  mygps();
  ldr();
  acceleration();

  tft.println();
```

```
  //check whether the display is being touched
  TSPoint p = ts.getPoint();
  if (p.z > MINPRESSURE && p.z < MAXPRESSURE) {
    Serial.print("X = "); Serial.print(p.x);
    Serial.print("\tY = "); Serial.print(p.y);
    Serial.print("\tPressure = "); Serial.println(p.z);
    delay(5000); // if the display is being touched, pause 5 sec. This gives the user time
to read the values.
  }
  //reset the pinModes because of ts.getPoint();
  pinMode(XM, OUTPUT);
  digitalWrite(XM, LOW);
  pinMode(YP, OUTPUT);
  digitalWrite(YP, HIGH);
  pinMode(YM, OUTPUT);
  digitalWrite(YM, LOW);
  pinMode(XP, OUTPUT);
  digitalWrite(XP, HIGH);
  if (logFile) {
    // if the file didn't open, print an error:
    Serial.println("File updated.");
    tft.println("File updated.");
  }
  logFile.close();
  if (uhoh) {
    digitalWrite(UHOH, HIGH);
  }
  delay(1000);

}
//////////END LOOP//////////

void sdDataFile() {
  testFile = SD.open("test.txt", FILE_WRITE); //Opens or creates the file on the SD card;
  if (testFile) {
    Serial.print("Writing to test.txt...");
    testFile.println("This is a test at startup:");
    DateTime now = rtc.now();
    testFile.print(now.day(), DEC);
    testFile.print('/');
    testFile.print(now.month(), DEC);
    testFile.print('/');
    testFile.print(now.year(), DEC);
    testFile.print(' ');
    testFile.print(now.hour(), DEC);
    testFile.print(':');
    testFile.print(now.minute(), DEC);
    testFile.print(':');
    testFile.println(now.second(), DEC);
    // close the file:
    testFile.close();
    Serial.println("test file done.");
  } else {
    // if the file didn't open, print an error:
    Serial.println("error opening test.txt");
    uhoh = true;
  }
}

void temperature() {
  // call sensors.requestTemperatures() to issue a global temperature
  // request to all devices on the bus (in our case 1)
  tft.print("Requesting temperatures... ");
  sensors.requestTemperatures(); // Send the command to get temperatures
```

```
  float temp = sensors.getTempCByIndex(0);   // Why "byIndex"?: You can have more than one
IC on the same bus. index 0 refers to the first IC on the wire
  //temperature calculations
  totalTemp += temp;
  avgTemp = totalTemp / counter;
  if (counter == 1) {
    maxTemp = temp;
    minTemp = temp;
  }
  if (temp > maxTemp) {
    maxTemp = temp;
  }
  if (temp < minTemp) {
    minTemp = temp;
  }
  //print to display:
  tft.println("DONE ");
  tft.print("Current Temperature is: ");
  tft.print(temp, 2); //Print temperature with 2 decimals after the .
  tft.println("C");
  tft.print("Max  experienced temperature: ");
  tft.print(maxTemp);
  tft.println("C");
  tft.print("Min experienced temperature: ");
  tft.print(minTemp);
  tft.println("C");
  tft.print("Average experienced temperature: ");
  tft.print(avgTemp);
  tft.println("C");

  //print to file:
  logFile.print(temp, 2);
  logFile.print(' ');
  logFile.print(maxTemp);
  logFile.print(' ');
  logFile.print(minTemp);
  logFile.print(' ');
  logFile.print(avgTemp);
  logFile.print(' ');

  if (temp > 40) { //test threshold for uhoh
    uhoh = true;
  }
}

// the realtimeclock gives the exact date and time, even when the arduino isn't connected
to a computer.
void realtimeclock() {
  DateTime now = rtc.now();
  //print to display:
  tft.print(now.year(), DEC);
  tft.print('/');
  tft.print(now.month(), DEC);
  tft.print('/');
  tft.print(now.day(), DEC);
  tft.print(" (");
  tft.print(daysOfTheWeek[now.dayOfTheWeek()]);
  tft.print(") ");
  tft.print(now.hour(), DEC);
  tft.print(':');
  tft.print(now.minute(), DEC);
  tft.print(':');
  tft.print(now.second(), DEC);
  tft.println();
```

```
  //print to file:
  logFile.print(' ');
  logFile.print(now.day(), DEC);
  logFile.print(' ');
  logFile.print(now.month(), DEC);
  logFile.print(' ');
  logFile.print(now.year(), DEC);
  logFile.print(' ');
  logFile.print(now.hour(), DEC);
  logFile.print(' ');
  logFile.print(now.minute(), DEC);
  logFile.print(' ');
  logFile.print(now.second(), DEC);
  logFile.print(' ');

}

void acceleration() {
  float x = 0;
  float y = 0;
  float z = 0;
  float gx = 0;
  float gy = 0;
  float gz = 0;

  // moving average for noise compensation
  for ( int i = 1; i <= sampleSize; i++)
  {
    x += analogRead(0);
    y += analogRead(1);
    z += analogRead(2);
  }
  x = x / sampleSize;
  y = y / sampleSize;
  z = z / sampleSize;

  //calculate g-force
  //((V*(x/totalanalogread)) - (VCC / 2(both negative and positive values))) / sensitivity;
  gx = ((5 * (x / 1024)) - (3.3 / 2)) / 0.8;
  gy = ((5 * (y / 1024)) - (3.3 / 2)) / 0.8;
  gz = ((5 * (z / 1024)) - (3.3 / 2)) / 0.8;

  if (abs(gx) > abs(gmax)) {
    gmax = gx;
  }
  if (abs(gy) > abs(gmax)) {
    gmax = gy;
  }
  if (abs(gz) > abs(gmax)) {
    gmax = gz;
  }

  //  Serial.print("X");
  //  Serial.print(x);
  //  Serial.print(", Y");
  //  Serial.print(y);
  //  Serial.print(", Z");
  //  Serial.println(z);

  //print to display:
  tft.println("Current g-forces: ");
  tft.print("gX: ");
  tft.print(gx);
  tft.print("g, gY: ");
  tft.print(gy);
```

```
  tft.print("g, gZ: ");
  tft.print(gz);
  tft.println("g");
  tft.print("Max experienced g-force: ");
  tft.print(abs(gmax));
  tft.println("g");

  //print to file:
  logFile.print(gx);
  logFile.print(' ');
  logFile.print(gy);
  logFile.print(' ');
  logFile.print(gz);
  logFile.print(' ');
  logFile.println(abs(gmax)); //println because last data that is printed on 1 line at the
log file.

  if (abs(gmax) > 2.5) { //test threshold for uhoh
    uhoh = true;
  }

}

void humidity() {
  int chk = DHT11.read(DHT11PIN);
  h = (float)DHT11.humidity;

  totalh += h;
  avgh = totalh / counter;
  if (counter == 1) {
    maxh = h;
    minh = h;
  }
  if (h > maxh) {
    maxh = h;
  }
  if (h < minh) {
    minh = h;
  }
  //print to display:
  tft.print("Current Humidity is: ");
  tft.print(h, 2);
  tft.println("%");
  tft.print("Max  experienced humidity: ");
  tft.print(maxh);
  tft.println("%");
  tft.print("Min experienced humidity: ");
  tft.print(minh);
  tft.println("%");
  tft.print("Average experienced humidity: ");
  tft.print(avgh);
  tft.println("%");

  //print to file:
  logFile.print(h);
  logFile.print(' ');
  logFile.print(maxh);
  logFile.print(' ');
  logFile.print(minh);
  logFile.print(' ');
  logFile.print(avgh);
  logFile.print(' ');

  if (h > 50 || h < 20) { // test threshold for uhoh
    uhoh = true;
```

```
  }
}

void ldr() {
  if (light == 1) {
    light = digitalRead(LDRPIN);
    if (light == 1) {
      tft.println("content is NOT exposed to light");
      logFile.print('1');
      logFile.print(' ');
    } else {
      tft.println("CONTENT IS EXPOSED TO LIGHT!");
      logFile.print('0');
      logFile.print(' ');
      uhoh = true;
    }
  } else {
    tft.println("CONTENT IS EXPOSED TO LIGHT!");
    logFile.print('0');
    logFile.print(' ');
    uhoh = true;
  }

}

//NOTE ON GPS: got most of the coding from the fullexample in the tinygps++ library
void mygps() {
  gps.encode(ss.read());
  Serial.print("LAT=");  Serial.println(gps.location.lat(), 6);
  Serial.print("LONG="); Serial.println(gps.location.lng(), 6);
  Serial.print("ALT=");  Serial.println(gps.altitude.meters());
  Serial.println(gps.speed.kmph());
  Serial.println(gps.satellites.value());

  //functions printFloat and printInt: see below
  tft.print("LAT: "); printFloat(gps.location.lat(), gps.location.isValid(), 11, 6);
  tft.println();
  tft.print("LONG: "); printFloat(gps.location.lng(), gps.location.isValid(), 12, 6);
  tft.println();
  tft.print("GPSAGE: "); printInt(gps.location.age(), gps.location.isValid(), 5);
  tft.println();
  tft.print("SPEED: "); printFloat(gps.speed.kmph(), gps.speed.isValid(), 6, 2);
  tft.println();
}

static void printFloat(float val, bool valid, int len, int prec)
{
  if (!valid)
  {
    while (len-- > 1)
      tft.print('*');
    tft.print(' ');
  }
  else
  {
    tft.print(val, prec);
    int vi = abs((int)val);
    int flen = prec + (val < 0.0 ? 2 : 1); // . and -
    flen += vi >= 1000 ? 4 : vi >= 100 ? 3 : vi >= 10 ? 2 : 1;
    for (int i = flen; i < len; ++i)
      tft.print(' ');
  }
}

static void printInt(unsigned long val, bool valid, int len)
```

```
{
  char sz[32] = "*****************";
  if (valid)
    sprintf(sz, "%ld", val);
  sz[len] = 0;
  for (int i = strlen(sz); i < len; ++i)
    sz[i] = ' ';
  if (len > 0)
    sz[len - 1] = ' ';
  tft.print(sz);
}
```

XPTS Data View (Processing, Java)

Main

```
//-----XP TRANSPORT SYSTEMS-----
//-----THOMAS VAN KLINK-----
//-----2021-01-21-----
//-----CREATE Y1M2 SMART ENVIRONMENTS PROJECT-----
//for inprovements/suggestions, please contact: t.vanklink@student.utwente.nl

//Version
String version = "v1.1";

//GUI
int screen = 1; //Decides which case to use and with that what to draw
boolean isOverFile, isOverLoad, isOverExit; //Boolean for button checks
String file; //Stores the file path of the data file
boolean fileCheck = true; //Boolean for the file type check

//Graphics
PImage logo, background;

//Data parameters
int dataLength;
int step = 1;
int start = 0;
int stop = 0;

//Graph
Graph temperature; //Graph object temperature
Graph humidity; //Graph object humidity
Graph acceleration; //Graph object acceleration

void setup() {
  //Settings
  fullScreen();
  rectMode(CENTER);
  textMode(CENTER);
  //Images
  logo = loadImage("logo.png"); //Load logo image for main header
  background = loadImage("background.jpg"); //Load background image
}

void draw() {
  background(255);
  image(background, 0, 0, 1920, 1080); //Main background image

  switch(screen){ //Switch for handeling what screen of the program to show
    case 1: //Launch / load screen
      noStroke();
      image(logo, width/2-450, height/2-60, 400, 120);
```

```
      fill(0);
      textSize(90);
      text("Data view", width/2-30, height/2+60);
      fill(200);
      textSize(25);
      text(version, width/2+400, height/2+60); //Version number
      if (!isOverFile){ //Change color depending on mouse position (hover effect)
        fill(200);
      } else {
        fill(180);
      }
      rect(width/2, height/2+150, 900, 60); //Button
      fill(0);
      textSize(30);
      text("Click to open file", width/2-120, height/2+160);

      if (!fileCheck){ //Pop up for incorrect file type.
      fill(200,0,0);
      textSize(30);
      rect(width/2, height/2+265, 900, 120);
      fill(255);
      text("Selected file is not of the correct type, please try again...", width/2-400,
height/2+250);
      text("Supported are: .txt, .TXT", width/2-200, height/2+300);
      }
    break;

    case 2:
      //Main logo and title
      image(logo, 50, 50, 200, 60);
      textSize(50);
      text("Data view", 270, 110);
      fill(200);
      textSize(20);
      text(version, 520, 110);

      //Decorative green lines
      noStroke();
      fill(0, 179, 80);
      rect(750, 80, 300, 10);
      rect(900, 65, 10, 40);
      rect(1415, 45, 1040, 10);

      //Display step
      fill(200);
      rect(1010, 85, 70, 50);
      textSize(20);
      fill(0);
      text("Step", 920, 90);
      textSize(30);
      text(str(step), 990, 95);

      //Display start
      fill(200);
      rect(1000+160, 85, 80, 50);
      textSize(20);
      fill(0);
      text("Start", 920+140, 90);
      textSize(30);
      text(str(start), 990+150, 95);

      //Display Stop
      fill(200);
      rect(1000+260+70, 85, 100, 50);
      textSize(20);
```

```
      fill(0);
      text("Stop", 920+240+60, 90);
      textSize(30);
      text(str((dataLength-stop)-1), 990+250+60, 95); //Datalength counter

      //Display load
      if (!isOverLoad){ //Change color depending on mouse position (hover effect)
        fill(200);
      } else {
        fill(180);
      }
      rect(1000+750, 85, 80, 50);
      fill(0);
      textSize(20);
      text("Load", 1000+725, 90);

      //Display exit
       if (!isOverExit){ //Change color depending on mouse position (hover effect)
        fill(200);
      } else {
        fill(180);
      }
      rect(1000+850, 85, 80, 50);
      textSize(20);
      fill(0);
      text("Exit", 1000+830, 90);

      textSize(12); //Standard text size for the graphs

      //Display graphs
      temperature.display(step, start, stop);
      humidity.display(step, start, stop);
      acceleration.display(step, start, stop);
    break;
  }
}

void mouseWheel(MouseEvent event){ //Handeling scroll events
  int scroll = event.getCount(); //Variables for direction of mouse wheel.

  if ((mouseX > 975) && (mouseX < 1045) && (mouseY > 60) && (mouseY < 110)){ //Check if
mouse is over Step box
    if((scroll == 1) && (step > 0)){ //On scroll down increase the step of the graph by one
      step = step+1;
    } else if((scroll == -1) && (step > 1)){ //On scroll up decrease step by one
      step = step-1;
    }
  }

  if ((mouseX > 975+160) && (mouseX < 1045+160) && (mouseY > 60) && (mouseY < 110)){
//Check if mouse is over Start box
    if((scroll == 1) && (start > -1) && (start < dataLength)){
      start = start+1; //On scroll down increase the start number of the graph by one
    } else if((scroll == -1) && (start > 1)){
      start = start-1; //On scroll up decrease the start number of the graph by one
    }
  }

  if ((mouseX > 975+320) && (mouseX < 1045+320) && (mouseY > 60) && (mouseY < 110)){
//Check if mouse is over Stop box
    if((scroll == 1) && (stop > -1) && (stop < dataLength)){
      stop = stop+1; //On scroll down increase the stop number of the graph by one
    } else if((scroll == -1) && (stop > 0)){
      stop = stop-1; //On scroll up decrease the stop number of the graph by one
    }
```

```
  }
}

void mouseMoved(){ //Handeling mouse events
   if ((mouseX > width/2-450) && (mouseX < width/2+450) && (mouseY > height/2+150-30) &&
(mouseY < height/2+150+30)){ //Check if mouse is over Start box
     isOverFile = true;
   } else {isOverFile = false;}

   if ((mouseX > 1000+750-40) && (mouseX < 1000+750+40) && (mouseY > 60) && (mouseY <
110)){ //Check if mouse is over Start box
     isOverLoad = true;
   } else {isOverLoad = false;}

   if ((mouseX > 1000+850-40) && (mouseX < 1000+850+40) && (mouseY > 60) && (mouseY <
110)){ //Check if mouse is over Stop box
     isOverExit = true;
   } else {isOverExit = false;}
}

void mousePressed(){ //Handeling mouse press events for the buttons
  if(isOverFile){ //On press of the "Load file" button when the mouse is over it run the
function to select
    selectInput("Select a file to process:", "fileSelected"); //Open native OS dialog to
select file
  }

  if(isOverLoad){ //On press of the "Load" button when the mouse is over it return to the
launch / load screen
    screen = 1;
  }

   if(isOverExit){ //On press of the "Exit" button when the mouse is over it exit the
program
    exit();
  }

}

void fileSelected(File selection) {
  if (selection == null) {
    println("User closed window was closed or the user hit cancel.");
    fileCheck = false;
  } else {
    println("User selected a file, check pending");
    file = selection.getAbsolutePath();
    if ((file.endsWith(".txt")) || (file.endsWith(".TXT")) ){
      fileCheck = true;
      load();
      screen = 2;
      println("File correct, load and change screen");
    } else {
      fileCheck = false;
      println("File incorrect, try again");
    }
  }
}

void load(){

String[] raw = loadStrings(file); //Loading data from file
  dataLength = raw.length-2;

  //Arrays for the different data sets logged by the Arduino
  float counter[] = new float[raw.length];
```

```
  float day[] = new float[raw.length];
  float month[] = new float[raw.length];
  float year[] = new float[raw.length];
  float hours[] = new float[raw.length];
  float minutes[] = new float[raw.length];
  float seconds[] = new float[raw.length];
  float temp[] = new float[raw.length];
  float maxTemp[] = new float[raw.length];
  float minTemp[] = new float[raw.length];
  float avgTemp[] = new float[raw.length];
  float hum[] = new float[raw.length];
  float maxHum[] = new float[raw.length];
  float minHum[] = new float[raw.length];
  float avgHum[] = new float[raw.length];
  float ldr[] = new float[raw.length];
  float gx[] = new float[raw.length];
  float gy[] = new float[raw.length];
  float gz[] = new float[raw.length];

  for (int i = 0; i < raw.length-2; i++) { // For the length of the input array run split.

    String[] input = split(raw[i], ' '); //Splitting raw data

    counter[i] = float(input[0]); //Assinging data to correct array.
    day[i] = float(input[1]);
    month[i] = float(input[2]);
    year[i] = float(input[3]);
    hours[i] = float(input[4]);
    minutes[i] = int(input[5]);
    seconds[i] = float(input[6]);
    temp[i] = float(input[7]);
    maxTemp[i] = float(input[8]);
    minTemp[i] = float(input[9]);
    avgTemp[i] = float(input[10]);
    hum[i] = float(input[11]);
    maxHum[i] = float(input[12]);
    minHum[i] = float(input[13]);
    avgHum[i] = float(input[14]);
    ldr[i] = float(input[15]);
    gx[i] = float(input[16]);
    gy[i] = float(input[17]);
    gz[i] = float(input[18]);
  }

  //Create instances of the Graphs while passing the correct data from the file.
  temperature = new Graph(1,50,150,dataLength,temp,counter, 390, 270);
  humidity = new Graph(2,50,450,dataLength,hum,counter, 390, 270);
  acceleration = new Graph(3,50,750,dataLength,gx,counter, 390, 270);

}
```

Graph class

```
/*
Class for the graph
 */

class Graph {
  int type;
  int posX;
  int posY;
  int dataLength;
  float[] data;
  float[] units;
```

```
  float[] avg;
  int graphX;
  int graphY;
  int block = 30;


  Graph(int type, int x, int y, int data, float[] input, float[] units, int graphX, int
graphY) {
    this.type = type;
    this.posX = x;
    this.posY = y;
    this.dataLength = data;
    this.data = input;
    this.units = units;
    this.graphX = graphX;
    this.graphY = graphY;
  }

  void display(int step, int start, int stop) {

    int division = 0;

    switch(type) {
    case 1:
      division = ((graphY-30)/15);
      break;
    case 2:
      division = 100/10;
      break;
    case 3:
      division = 100/10;
      break;
    }



    for (int i = 0; i < division-1; i++) {
      stroke(200);
      fill(0);
      switch(type) {
      case 1:
        text(str(int(-127+10.8*i)), posX, (posY+(graphY-30)-division*i)+5);
        line(posX+40, posY+(graphY-30)-division*i, posX+(map(dataLength, 0, dataLength,
posX+graphX, 40)+dataLength*(block/step)-6-start*(block/step)), posY+(graphY-30)-
division*i);
        break;
      case 2:
        text(str(int(10*i)), posX, (posY+(graphY-30)-division*(2.7*i))+5);
        line(posX+40, posY+(graphY-30)-division*(2.7*i), posX+(map(dataLength, 0,
dataLength, posX+graphX, 40)+dataLength*(block/step)-6-start*(block/step)), posY+(graphY-
30)-division*(2.7*i));
        break;
      case 3:
        text(str(int(-4+1*i)), posX, (posY+(graphY-30)-division*(2.7*i))+5);
        line(posX+40, posY+(graphY-30)-division*(2.7*i), posX+(map(dataLength, 0,
dataLength, posX+graphX, 40)+dataLength*(block/step)-6-start*(block/step)), posY+(graphY-
30)-division*(2.7*i));
        break;
      }
    }

    for (int s= start; s< dataLength-stop; s= s+step) {
      float xmap =0;
      float ymap =0;
      switch(type) {
```

```
      case 1:
        xmap = map(dataLength, 0, dataLength, graphX, 40)+(s*(block/step))-
start*(block/step);
        ymap = map(data[s], -135, 40, graphY-30, 0);
        break;
      case 2:
        xmap = map(dataLength, 0, dataLength, graphX, 40)+s*(block/step)-
start*(block/step);
        ymap = map(data[s], 0, 100, graphY-30, 0);
        break;
       case 3:
        xmap = map(dataLength, 0, dataLength, graphX, 40)+s*(block/step)-
start*(block/step);
        ymap = map(data[s], -4, 4, graphY-30, 0);
        break;
      }
      stroke(200);
      line(posX+(xmap), posY+10, posX+(xmap), posY+(graphY-30));
      fill(0, 179, 80);
      noStroke();
      rect(posX+(xmap), posY+(ymap), 10, 10);
      fill(0);

      int countStep;
      if(step >1){
       countStep = step-1;
      } else {
       countStep = 0;
      }


      if(step < 2 || step == 2){
        textSize(13);
      } else if (step > 2){
        textSize(11);
      } else if (step > 4){
        textSize(9);
      } else if (step > 6){
        textSize(8);
      }

      text(str(int(units[s])+countStep-step), posX+(xmap)-6, posY+(graphY-10));
      line(posX+40, posY+240, posX+(map(dataLength, 0, dataLength, posX+graphX,
40)+dataLength*block-6), posY+240);
    }

    String header = new String();
    switch(type){
      case 1:
      header = "Temperature °C ";
      break;
      case 2:
      header = "Humidity % ";
      break;
      case 3:
      header = "Acceleration G ";
      break;
    }

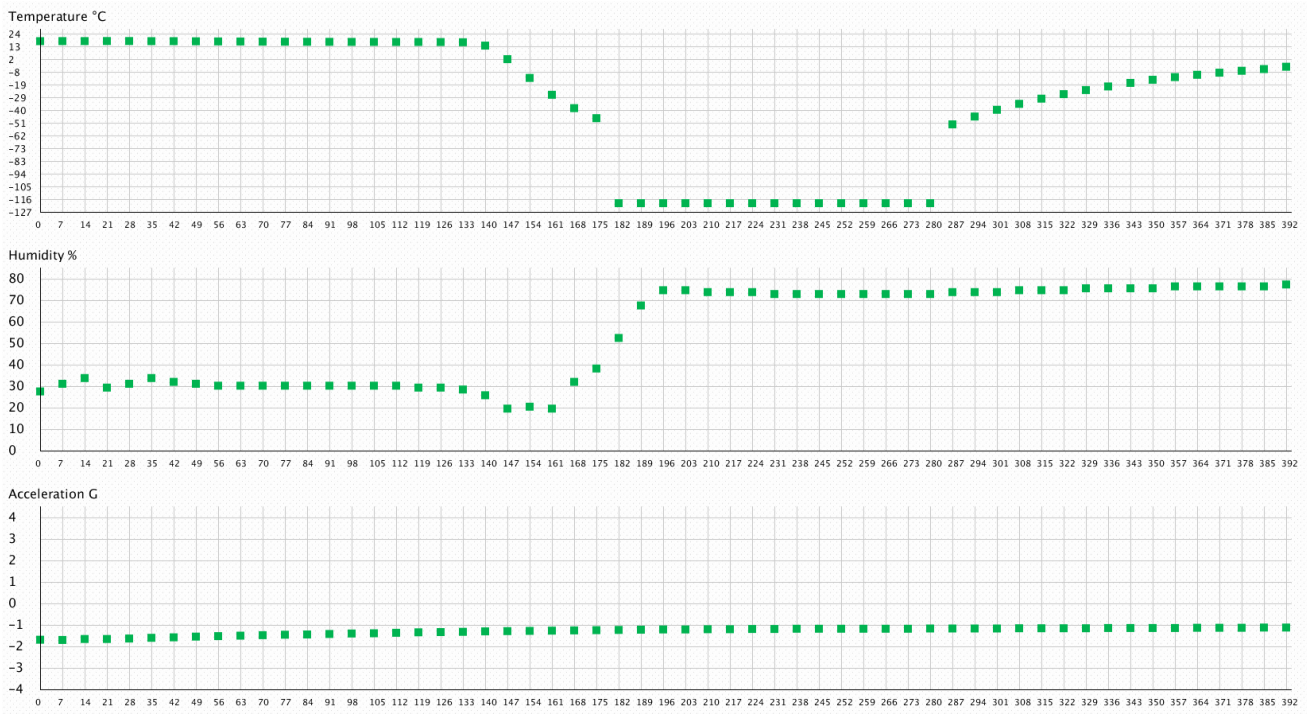
    textSize(16);
    text(header, posX, posY);

    stroke(0);
    line(posX+40, posY+240, posX+(map(dataLength, 0, dataLength, posX+graphX,
40)+dataLength*(block/step)-6-start*(block/step)), posY+240);
```

```
    line(posX+40, posY+10, posX+40, posY+240);
  }
}
```

Visualized data in XPTS Data View, dry ice run.

392 samples, step size 7, start 0, stop 394



Logged data, dry ice run 1 (LOG2.TXT)

Formatted in as:

Counter Date Date Date Date Date Date Temperature Temperature Temperature Temperature Humidity Humidity Humidity Humidity Light Accelerometer Accelerometer Accelerometer Accelerometer

1 28 1 2021 13 31 59 21.44 21.44 21.44 21.44 31.00 31.00 31.00 31.00 1 -1.92 -1.93 -1.93 1.93
2 28 1 2021 13 32 2 21.44 21.44 21.44 21.44 33.00 33.00 31.00 32.00 1 -1.79 -1.80 -1.80 1.93
3 28 1 2021 13 32 5 21.44 21.44 21.44 21.44 32.00 33.00 31.00 32.00 1 -1.95 -1.96 -1.96 1.96
4 28 1 2021 13 32 8 21.50 21.50 21.44 21.45 32.00 33.00 31.00 32.00 0 -1.95 -1.95 -1.96 1.96
5 28 1 2021 13 32 10 21.50 21.50 21.44 21.46 33.00 33.00 31.00 32.20 0 -1.94 -1.95 -1.95 1.96
6 28 1 2021 13 32 13 21.50 21.50 21.44 21.47 33.00 33.00 31.00 32.33 0 -1.95 -1.95 -1.96 1.96
7 28 1 2021 13 32 16 21.50 21.50 21.44 21.47 34.00 34.00 31.00 32.57 0 -1.94 -1.95 -1.95 1.96
8 28 1 2021 13 32 19 21.50 21.50 21.44 21.48 35.00 35.00 31.00 32.88 0 -1.93 -1.94 -1.94 1.96
9 28 1 2021 13 32 22 21.50 21.50 21.44 21.48 35.00 35.00 31.00 33.11 0 -1.91 -1.92 -1.92 1.96
10 28 1 2021 13 32 25 21.50 21.50 21.44 21.48 37.00 37.00 31.00 33.50 0 -1.93 -1.93 -1.93 1.96
11 28 1 2021 13 32 28 21.50 21.50 21.44 21.48 38.00 38.00 31.00 33.91 0 -1.93 -1.93 -1.93 1.96
12 28 1 2021 13 32 30 21.50 21.50 21.44 21.48 39.00 39.00 31.00 34.33 0 -1.92 -1.93 -1.93 1.96
13 28 1 2021 13 32 33 21.50 21.50 21.44 21.49 40.00 40.00 31.00 34.77 0 -1.92 -1.93 -1.93 1.96
14 28 1 2021 13 32 36 21.50 21.50 21.44 21.49 39.00 40.00 31.00 35.07 0 -1.92 -1.92 -1.92 1.96
15 28 1 2021 13 32 39 21.50 21.50 21.44 21.49 38.00 40.00 31.00 35.27 0 -1.89 -1.89 -1.89 1.96
16 28 1 2021 13 32 42 21.50 21.50 21.44 21.49 37.00 40.00 31.00 35.38 0 -1.88 -1.89 -1.89 1.96
17 28 1 2021 13 32 45 21.50 21.50 21.44 21.49 37.00 40.00 31.00 35.47 0 -1.75 -1.76 -1.76 1.96
18 28 1 2021 13 32 47 21.50 21.50 21.44 21.49 36.00 40.00 31.00 35.50 0 -1.89 -1.90 -1.90 1.96
19 28 1 2021 13 32 50 21.50 21.50 21.44 21.49 36.00 40.00 31.00 35.53 0 -1.58 -1.59 -1.59 1.96
20 28 1 2021 13 32 53 21.50 21.50 21.44 21.49 35.00 40.00 31.00 35.50 0 -1.89 -1.90 -1.90 1.96
21 28 1 2021 13 32 56 21.56 21.56 21.44 21.49 34.00 40.00 31.00 35.43 0 -1.89 -1.90 -1.90 1.96
22 28 1 2021 13 32 59 21.56 21.56 21.44 21.50 33.00 40.00 31.00 35.32 0 -1.89 -1.90 -1.90 1.96

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24 28 1 2021 13 33 5 21.56 21.56 21.44 21.50 33.00 40.00 31.00 35.13 0 -1.88 -1.90 -1.89 1.96
25 28 1 2021 13 33 7 21.56 21.56 21.44 21.50 33.00 40.00 31.00 35.04 0 -1.88 -1.89 -1.89 1.96
26 28 1 2021 13 33 10 21.56 21.56 21.44 21.51 33.00 40.00 31.00 34.96 0 -1.87 -1.89 -1.89 1.96
27 28 1 2021 13 33 13 21.56 21.56 21.44 21.51 33.00 40.00 31.00 34.89 0 -1.87 -1.89 -1.88 1.96
28 28 1 2021 13 33 16 21.56 21.56 21.44 21.51 34.00 40.00 31.00 34.86 0 -1.87 -1.89 -1.88 1.96
29 28 1 2021 13 33 19 21.56 21.56 21.44 21.51 35.00 40.00 31.00 34.86 0 -1.87 -1.88 -1.88 1.96
30 28 1 2021 13 33 22 21.56 21.56 21.44 21.51 36.00 40.00 31.00 34.90 0 -1.86 -1.88 -1.87 1.96
31 28 1 2021 13 33 24 21.50 21.56 21.44 21.51 36.00 40.00 31.00 34.94 0 -1.86 -1.88 -1.87 1.96
32 28 1 2021 13 33 27 21.50 21.56 21.44 21.51 39.00 40.00 31.00 35.06 0 -1.86 -1.88 -1.87 1.96
33 28 1 2021 13 33 30 21.50 21.56 21.44 21.51 40.00 40.00 31.00 35.21 0 -1.85 -1.87 -1.87 1.96
34 28 1 2021 13 33 33 21.50 21.56 21.44 21.51 40.00 40.00 31.00 35.35 0 -1.85 -1.87 -1.86 1.96
35 28 1 2021 13 33 36 21.44 21.56 21.44 21.51 39.00 40.00 31.00 35.46 0 -1.85 -1.87 -1.86 1.96
36 28 1 2021 13 33 39 21.44 21.56 21.44 21.51 38.00 40.00 31.00 35.53 0 -1.84 -1.87 -1.86 1.96
37 28 1 2021 13 33 41 21.44 21.56 21.44 21.51 38.00 40.00 31.00 35.59 0 -1.84 -1.86 -1.85 1.96
38 28 1 2021 13 33 44 21.44 21.56 21.44 21.50 38.00 40.00 31.00 35.66 0 -1.83 -1.85 -1.84 1.96
39 28 1 2021 13 33 47 21.44 21.56 21.44 21.50 37.00 40.00 31.00 35.69 0 -1.83 -1.85 -1.84 1.96
40 28 1 2021 13 33 50 21.44 21.56 21.44 21.50 37.00 40.00 31.00 35.72 0 -1.82 -1.84 -1.84 1.96
41 28 1 2021 13 33 53 21.44 21.56 21.44 21.50 37.00 40.00 31.00 35.76 0 -1.82 -1.84 -1.83 1.96
42 28 1 2021 13 33 56 21.44 21.56 21.44 21.50 36.00 40.00 31.00 35.76 0 -1.82 -1.84 -1.83 1.96
43 28 1 2021 13 33 59 21.44 21.56 21.44 21.50 36.00 40.00 31.00 35.77 0 -1.82 -1.84 -1.83 1.96
44 28 1 2021 13 34 1 21.44 21.56 21.44 21.50 36.00 40.00 31.00 35.77 0 -1.81 -1.83 -1.83 1.96
45 28 1 2021 13 34 4 21.37 21.56 21.37 21.49 36.00 40.00 31.00 35.78 0 -1.81 -1.83 -1.82 1.96
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58 28 1 2021 13 34 41 21.19 21.56 21.19 21.44 35.00 40.00 31.00 35.55 0 -1.77 -1.80 -1.79 1.96
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65 28 1 2021 13 35 1 21.06 21.56 21.06 21.41 34.00 40.00 31.00 35.38 0 -1.75 -1.78 -1.77 1.96
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77 28 1 2021 13 35 35 20.94 21.56 20.94 21.35 34.00 40.00 31.00 35.17 0 -1.72 -1.75 -1.74 1.96
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81 28 1 2021 13 35 47 20.94 21.56 20.94 21.33 34.00 40.00 31.00 35.11 0 -1.71 -1.74 -1.73 1.96
82 28 1 2021 13 35 50 20.94 21.56 20.94 21.32 34.00 40.00 31.00 35.10 0 -1.70 -1.74 -1.73 1.96
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84 28 1 2021 13 35 55 20.87 21.56 20.87 21.31 34.00 40.00 31.00 35.07 0 -1.70 -1.74 -1.72 1.96
85 28 1 2021 13 35 58 20.87 21.56 20.87 21.31 34.00 40.00 31.00 35.06 0 -1.70 -1.73 -1.72 1.96
86 28 1 2021 13 36 1 20.87 21.56 20.87 21.30 34.00 40.00 31.00 35.05 0 -1.70 -1.73 -1.72 1.96
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91 28 1 2021 13 36 15 20.81 21.56 20.81 21.28 34.00 40.00 31.00 34.99 0 -1.68 -1.72 -1.71 1.96
92 28 1 2021 13 36 18 20.81 21.56 20.81 21.27 34.00 40.00 31.00 34.98 0 -1.68 -1.72 -1.70 1.96
93 28 1 2021 13 36 21 20.81 21.56 20.81 21.27 34.00 40.00 31.00 34.97 0 -1.68 -1.72 -1.70 1.96
94 28 1 2021 13 36 24 20.81 21.56 20.81 21.26 34.00 40.00 31.00 34.96 0 -1.67 -1.72 -1.70 1.96
95 28 1 2021 13 36 27 20.81 21.56 20.81 21.26 34.00 40.00 31.00 34.95 0 -1.67 -1.71 -1.70 1.96
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99 28 1 2021 13 36 38 20.75 21.56 20.75 21.24 34.00 40.00 31.00 34.91 0 -1.66 -1.71 -1.69 1.96
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101 28 1 2021 13 36 44 20.75 21.56 20.75 21.23 34.00 40.00 31.00 34.89 0 -1.66 -1.70 -1.68 1.96
102 28 1 2021 13 36 47 20.75 21.56 20.75 21.22 34.00 40.00 31.00 34.88 0 -1.66 -1.70 -1.68 1.96
103 28 1 2021 13 36 49 20.75 21.56 20.75 21.22 34.00 40.00 31.00 34.87 0 -1.65 -1.70 -1.68 1.96
104 28 1 2021 13 36 52 20.75 21.56 20.75 21.21 34.00 40.00 31.00 34.87 0 -1.65 -1.70 -1.68 1.96
105 28 1 2021 13 36 55 20.75 21.56 20.75 21.21 34.00 40.00 31.00 34.86 0 -1.65 -1.69 -1.68 1.96
106 28 1 2021 13 36 58 20.75 21.56 20.75 21.20 34.00 40.00 31.00 34.85 0 -1.65 -1.69 -1.68 1.96
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109 28 1 2021 13 37 7 20.69 21.56 20.69 21.19 34.00 40.00 31.00 34.83 0 -1.64 -1.68 -1.67 1.96
110 28 1 2021 13 37 9 20.69 21.56 20.69 21.19 34.00 40.00 31.00 34.82 0 -1.64 -1.68 -1.67 1.96
111 28 1 2021 13 37 12 20.69 21.56 20.69 21.18 34.00 40.00 31.00 34.81 0 -1.63 -1.68 -1.67 1.96
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113 28 1 2021 13 37 18 20.69 21.56 20.69 21.17 34.00 40.00 31.00 34.80 0 -1.63 -1.68 -1.66 1.96
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131 28 1 2021 13 38 9 20.62 21.56 20.62 21.10 32.00 40.00 31.00 34.55 0 -1.59 -1.64 -1.63 1.96
132 28 1 2021 13 38 12 20.56 21.56 20.56 21.10 31.00 40.00 31.00 34.52 0 -1.59 -1.64 -1.62 1.96
133 28 1 2021 13 38 15 20.50 21.56 20.50 21.09 31.00 40.00 31.00 34.50 0 -1.59 -1.64 -1.62 1.96
134 28 1 2021 13 38 18 20.44 21.56 20.44 21.09 32.00 40.00 31.00 34.48 0 -1.59 -1.64 -1.62 1.96
135 28 1 2021 13 38 21 20.31 21.56 20.31 21.08 33.00 40.00 31.00 34.47 0 -1.58 -1.64 -1.62 1.96
136 28 1 2021 13 38 24 20.06 21.56 20.06 21.07 33.00 40.00 31.00 34.46 0 -1.58 -1.63 -1.62 1.96
137 28 1 2021 13 38 26 19.69 21.56 19.69 21.06 33.00 40.00 31.00 34.45 0 -1.58 -1.63 -1.62 1.96
138 28 1 2021 13 38 29 19.25 21.56 19.25 21.05 32.00 40.00 31.00 34.43 0 -1.58 -1.63 -1.61 1.96
139 28 1 2021 13 38 32 18.81 21.56 18.81 21.03 31.00 40.00 31.00 34.40 0 -1.58 -1.63 -1.61 1.96
140 28 1 2021 13 38 35 18.25 21.56 18.25 21.01 29.00 40.00 29.00 34.36 0 -1.57 -1.63 -1.61 1.96
141 28 1 2021 13 38 38 17.37 21.56 17.37 20.99 29.00 40.00 29.00 34.33 0 -1.57 -1.63 -1.61 1.96
142 28 1 2021 13 38 41 16.25 21.56 16.25 20.96 27.00 40.00 27.00 34.27 0 -1.57 -1.62 -1.61 1.96
143 28 1 2021 13 38 44 14.94 21.56 14.94 20.91 27.00 40.00 27.00 34.22 0 -1.57 -1.62 -1.61 1.96
144 28 1 2021 13 38 46 13.38 21.56 13.38 20.86 26.00 40.00 26.00 34.17 0 -1.57 -1.62 -1.60 1.96
145 28 1 2021 13 38 49 11.56 21.56 11.56 20.80 24.00 40.00 24.00 34.10 0 -1.56 -1.62 -1.60 1.96
146 28 1 2021 13 38 52 9.56 21.56 9.56 20.72 24.00 40.00 24.00 34.03 0 -1.56 -1.62 -1.60 1.96
147 28 1 2021 13 38 55 7.31 21.56 7.31 20.63 23.00 40.00 23.00 33.95 0 -1.56 -1.62 -1.60 1.96
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390 28 1 2021 13 50 29 -3.25 21.56 -127.00 -35.18 87.00 87.00 22.00 59.99 0 -1.41 -1.47 -1.45 1.96
391 28 1 2021 13 50 32 -3.06 21.56 -127.00 -35.10 87.00 87.00 22.00 60.06 0 -1.41 -1.47 -1.45 1.96
392 28 1 2021 13 50 35 -2.69 21.56 -127.00 -35.02 87.00 87.00 22.00 60.13 0 -1.41 -1.47 -1.45 1.96
393 28 1 2021 13 50 38 -2.00 21.56 -127.00 -34.93 87.00 87.00 22.00 60.20 0 -1.41 -1.47 -1.45 1.96
394 28 1 2021 13 50 41 -1.44 21.56 -127.00 -34.85 87.00 87.00 22.00 60.27 0 -1.41 -1.47 -1.45 1.96
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396 28 1 2021 13 50 46 -0.56 21.56 -127.00 -34.68 87.00 87.00 22.00 60.40 0 -1.40 -1.47 -1.44 1.96
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Logged data, dry ice run 2 (LOG3.TXT)

Formatted in as:

Counter Date Date Date Date Date Date Temperature Temperature Temperature Temperature Humidity Humidity Humidity Humidity Light Accelerometer Accelerometer Accelerometer Accelerometer

1 28 1 2021 14 11 5 16.75 16.75 16.75 16.75 39.00 39.00 39.00 39.00 1 -1.93 -1.95 -1.97 1.97
2 28 1 2021 14 11 8 16.75 16.75 16.75 16.75 40.00 40.00 39.00 39.50 1 -1.90 -1.92 -1.95 1.97
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4 28 1 2021 14 11 13 16.75 16.75 16.75 16.75 40.00 40.00 39.00 39.75 1 -1.87 -1.89 -1.92 1.97
5 28 1 2021 14 11 16 16.75 16.75 16.75 16.75 40.00 40.00 39.00 39.80 1 -1.86 -1.87 -1.91 1.97
6 28 1 2021 14 11 19 16.69 16.75 16.69 16.74 40.00 40.00 39.00 39.83 1 -1.85 -1.87 -1.90 1.97
7 28 1 2021 14 11 22 16.69 16.75 16.69 16.73 40.00 40.00 39.00 39.86 1 -1.84 -1.86 -1.90 1.97
8 28 1 2021 14 11 25 16.69 16.75 16.69 16.73 40.00 40.00 39.00 39.88 1 -1.84 -1.85 -1.89 1.97
9 28 1 2021 14 11 28 16.69 16.75 16.69 16.72 40.00 40.00 39.00 39.89 1 -1.83 -1.85 -1.89 1.97
10 28 1 2021 14 11 30 16.62 16.75 16.62 16.71 40.00 40.00 39.00 39.90 1 -1.83 -1.84 -1.88 1.97
11 28 1 2021 14 11 33 16.62 16.75 16.62 16.70 40.00 40.00 39.00 39.91 1 -1.82 -1.84 -1.87 1.97
12 28 1 2021 14 11 36 16.62 16.75 16.62 16.70 40.00 40.00 39.00 39.92 1 -1.82 -1.83 -1.87 1.97
13 28 1 2021 14 11 39 16.56 16.75 16.56 16.69 40.00 40.00 39.00 39.92 1 -1.81 -1.83 -1.87 1.97
14 28 1 2021 14 11 42 16.56 16.75 16.56 16.68 40.00 40.00 39.00 39.93 1 -1.81 -1.82 -1.86 1.97
15 28 1 2021 14 11 45 16.56 16.75 16.56 16.67 40.00 40.00 39.00 39.93 1 -1.80 -1.82 -1.86 1.97
16 28 1 2021 14 11 47 16.50 16.75 16.50 16.66 41.00 41.00 39.00 40.00 1 -1.80 -1.82 -1.85 1.97
17 28 1 2021 14 11 50 16.50 16.75 16.50 16.65 41.00 41.00 39.00 40.06 1 -1.80 -1.81 -1.85 1.97
18 28 1 2021 14 11 53 16.50 16.75 16.50 16.64 41.00 41.00 39.00 40.11 1 -1.79 -1.81 -1.85 1.97
19 28 1 2021 14 11 56 16.50 16.75 16.50 16.63 41.00 41.00 39.00 40.16 1 -1.79 -1.81 -1.84 1.97
20 28 1 2021 14 11 59 16.44 16.75 16.44 16.62 41.00 41.00 39.00 40.20 1 -1.78 -1.80 -1.84 1.97
21 28 1 2021 14 12 2 16.44 16.75 16.44 16.62 41.00 41.00 39.00 40.24 1 -1.78 -1.80 -1.84 1.97
22 28 1 2021 14 12 4 16.44 16.75 16.44 16.61 41.00 41.00 39.00 40.27 1 -1.78 -1.79 -1.83 1.97
23 28 1 2021 14 12 7 16.37 16.75 16.37 16.60 41.00 41.00 39.00 40.30 1 -1.77 -1.79 -1.83 1.97
24 28 1 2021 14 12 10 16.37 16.75 16.37 16.59 42.00 42.00 39.00 40.38 1 -1.77 -1.79 -1.83 1.97
25 28 1 2021 14 12 13 16.37 16.75 16.37 16.58 41.00 42.00 39.00 40.40 1 -1.77 -1.79 -1.83 1.97
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32 28 1 2021 14 12 33 16.19 16.75 16.19 16.51 43.00 43.00 39.00 40.81 1 -1.75 -1.77 -1.81 1.97
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```

100	28	1	2021	14	30	41	18.12	18.12	16.94	17.65	40.00	44.00	39.00	41.70	1	-1.64	-1.68	-1.68	1.93
101	28	1	2021	14	30	44	18.12	18.12	16.94	17.66	40.00	44.00	39.00	41.68	1	-1.64	-1.68	-1.68	1.93
102	28	1	2021	14	30	47	18.12	18.12	16.94	17.66	40.00	44.00	39.00	41.67	1	-1.64	-1.68	-1.67	1.93
103	28	1	2021	14	30	50	18.12	18.12	16.94	17.66	40.00	44.00	39.00	41.65	1	-1.63	-1.67	-1.67	1.93
104	28	1	2021	14	30	52	18.12	18.12	16.94	17.67	39.00	44.00	39.00	41.63	1	-1.63	-1.67	-1.67	1.93
105	28	1	2021	14	30	55	18.12	18.12	16.94	17.67	39.00	44.00	39.00	41.60	1	-1.63	-1.67	-1.67	1.93
106	28	1	2021	14	30	58	18.12	18.12	16.94	17.68	39.00	44.00	39.00	41.58	1	-1.63	-1.67	-1.67	1.93
107	28	1	2021	14	31	1	18.19	18.19	16.94	17.68	39.00	44.00	39.00	41.55	1	-1.63	-1.67	-1.67	1.93
108	28	1	2021	14	31	4	18.19	18.19	16.94	17.69	39.00	44.00	39.00	41.53	1	-1.62	-1.67	-1.66	1.93
109	28	1	2021	14	31	7	18.19	18.19	16.94	17.69	39.00	44.00	39.00	41.50	1	-1.62	-1.66	-1.66	1.93
110	28	1	2021	14	31	10	18.19	18.19	16.94	17.70	39.00	44.00	39.00	41.48	1	-1.62	-1.66	-1.66	1.93
111	28	1	2021	14	31	12	18.19	18.19	16.94	17.70	39.00	44.00	39.00	41.46	1	-1.62	-1.66	-1.66	1.93
112	28	1	2021	14	31	15	18.19	18.19	16.94	17.70	39.00	44.00	39.00	41.44	1	-1.62	-1.66	-1.66	1.93
113	28	1	2021	14	31	18	18.19	18.19	16.94	17.71	39.00	44.00	39.00	41.42	1	-1.62	-1.66	-1.65	1.93
114	28	1	2021	14	31	21	18.19	18.19	16.94	17.71	39.00	44.00	39.00	41.39	1	-1.61	-1.65	-1.65	1.93
115	28	1	2021	14	31	24	18.19	18.19	16.94	17.72	39.00	44.00	39.00	41.37	1	-1.61	-1.65	-1.65	1.93
116	28	1	2021	14	31	27	18.19	18.19	16.94	17.72	39.00	44.00	39.00	41.35	1	-1.61	-1.65	-1.65	1.93
117	28	1	2021	14	31	29	18.19	18.19	16.94	17.73	39.00	44.00	39.00	41.33	1	-1.61	-1.65	-1.65	1.93
118	28	1	2021	14	31	32	18.25	18.25	16.94	17.73	39.00	44.00	39.00	41.31	1	-1.61	-1.65	-1.65	1.93
119	28	1	2021	14	31	35	18.25	18.25	16.94	17.73	39.00	44.00	39.00	41.29	1	-1.60	-1.65	-1.64	1.93
120	28	1	2021	14	31	38	18.25	18.25	16.94	17.74	39.00	44.00	39.00	41.28	1	-1.60	-1.65	-1.64	1.93
121	28	1	2021	14	31	41	18.25	18.25	16.94	17.74	39.00	44.00	39.00	41.26	1	-1.60	-1.64	-1.64	1.93
122	28	1	2021	14	31	44	18.25	18.25	16.94	17.75	39.00	44.00	39.00	41.24	1	-1.60	-1.64	-1.64	1.93
123	28	1	2021	14	31	47	18.25	18.25	16.94	17.75	39.00	44.00	39.00	41.22	1	-1.60	-1.64	-1.64	1.93
124	28	1	2021	14	31	49	18.25	18.25	16.94	17.76	39.00	44.00	39.00	41.20	1	-1.59	-1.64	-1.64	1.93
125	28	1	2021	14	31	52	18.25	18.25	16.94	17.76	39.00	44.00	39.00	41.18	1	-1.59	-1.64	-1.63	1.93
126	28	1	2021	14	31	55	18.31	18.31	16.94	17.76	39.00	44.00	39.00	41.17	1	-1.59	-1.64	-1.63	1.93
127	28	1	2021	14	31	58	18.31	18.31	16.94	17.77	38.00	44.00	38.00	41.14	1	-1.59	-1.63	-1.63	1.93
128	28	1	2021	14	32	1	18.31	18.31	16.94	17.77	38.00	44.00	38.00	41.12	1	-1.59	-1.63	-1.63	1.93