Commentary

Share a Tiny Space of Your Freezer to Preserve Seed Diversity

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The Food and Agriculture Organization (FAO), estimates that 75% of crop diversity was lost since the 1900s. That lack of diversity presents a severe risk to the security of global food systems. Without seed diversity, it is difficult for plants to adapt to pests, diseases, and changing climate conditions. Genebanks, such as the Svalbard Global Seed Vault, are valuable initiatives to preserve seed diversity in a single secure and safe place. However, according to our analysis of the data available in the Seed Portal, the redundancy for some species might be limited, posing a potential threat to their future availability. Interestingly, the conditions to properly store seeds in genebanks, are the ones available in the freezers of our homes. This paper lays out a vision for Distributed Seed Storage relying on a peer-to-peer infrastructure of domestic freezers to increase the overall availability of seeds. We present a Proof-of-Concept focused on monitoring the proper seed storing conditions and incentive user participation through a Blockchain lottery. The PoC proves the feasibility of the proposed approach and outlines the main technical issues that still need to be efficiently solved to realize a fully-fledged solution.

1. Introduction

There are over 50,000 edible plants worldwide, but just 15 provide 90% of the world's food energy intake and among these, rice, corn (maize), and wheat contribute up to two-thirds[1]. We have to put all our efforts to preserve those fundamental energy assets.

The need for seed diversity. Seed diversity encompasses the range of plant species, cultivars, and genetic materials available within a given crop. This diversity enhances agriculture's capacity to adapt crop production to climate, local growing conditions, and consumer preferences. Without access to diverse crops, future generations will lack the flexibility to adjust agriculture to their needs and the changing environmental conditions. The Earth is losing plant genetic diversity at an unparalleled rate. In many countries, seed diversity has been irreversibly diminished, limiting farmers' crop options. Climate change, brings extreme events and new forms of pests and diseases. In this evolving scenario, it is fundamental to safeguard and conserve as many types of seeds as possible. This diversity might provide strategies or insights to effectively deal with the emerging challenges. Limited seed diversity means we also risk losing variety in taste and nutrition, , and their central role in traditional cuisines and cultures.

Genebanks. Genebanks store living material, specifically seeds in our case, which contain the genes that make each plant variety unique. Genebanks ensure that this genetic heritage is safely conserved and available for people to use. The diversity in the genetic material is the fundamental assets on which we build the future of our food systems. Specific genes are what make a crop variety resistant to heat and drought, for example, or tolerant to pests and diseases, providing the basis of agricultural adaptation. More than 1,750 national, regional and international institutions around the world, together conserve about 7.4 million samples of crop diversity. Since 2012, they have distributed close to 1 million samples to users in more than 120 countries. Genebanks need to ensure that their holdings remain alive. They periodically check the viability of samples, namely their ability to grow into productive plants, and they produce fresh material when needed. However, the fundamental strategy to preserve such diversity is the availability of good backup systems, namely other genebanks where duplicate samples are delivered for safe keeping. The Svalbard Global Seed Vault in the Arctic Circle is unanimously considered among the best backup systems.

Svalbard Global Seed Vault (SGSV). The Norwegian island of Spitsbergen in the remote Arctic Svalbard archipelago hosts the SGSV[2][1], a secure backup facility for the world's crop diversity. It provides long-term storage for duplicates of seeds conserved in gene banks around the world against threats such as mismanagement, accident, equipment failures, funding cuts, war, sabotage, disease, and natural disasters. In 2019, seeds were returned from Svalbard to restock an international genebank destroyed by the war in Syria. The 2023 SGSV Annual Progress Report[2] reveals that, 1267127 samples deposited by more than 100 genebanks/institutes and representing over 6,000 plant species are stored in the facility. The SGSV now safeguards seeds of more than 250,000 types of wheat, 160,000 types of rice and 46,000 types of maize, the fundamental sources of food energy intake. Spitsbergen lacks tectonic activity and has permafrost, which aids preservation; the location of the SGSV at 130 m above sea level will keep the site dry even if the ice caps melt. Refrigeration units further cool the seeds to -18,-20°C,

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the internationally recommended standard temperature[3]. If the equipment fails, it is estimated to take two centuries to warm to 0°C.

Open problem. The SGSV is conceived as a secure backup facility, and it has been designed with the highest safety and security standards to preserve its priceless seed collection. The depositors are the genebanks/institutes that store a backup of their seed in the vault.

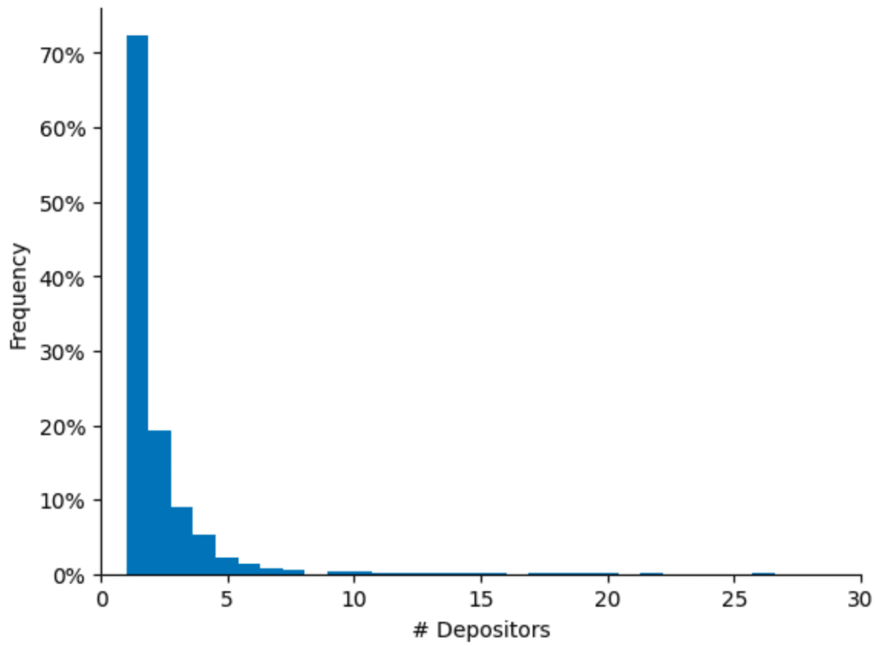

Figure 1. The distribution of depositors for species in the SGSV. The majority have a single depositor posing a potential threat to seed availability.

Figure 1 shows the distribution of depositors for species in the SGSV obtained analyzing the data from the Seed Portal[3]. The vast majority of Species have a single depositor. In other words, the samples are only available at SGCV and at the depositor. As an example, Oryza sativa (i.e. the Asian cultivated rice) is the most common rice cultivated as a cereal. Querying the Seed Portal by keyword *Species: Oryza sativa* we get 29 depositors, 171193 accessions and 136 countries of collection. The same query with *Species: Hygroryza aristata*, gives 1 depositor, 4 accessions and 1 country of collection. Rice is by far more "important" than Hygroryza for food supply, however, the Hygroryza is a crop wild relative (CWR) of rice[4]. CWRs are wild plant species that are closely related to domesticated crops. They are important because they contain genetic diversity that can be used to improve cultivated crops, making

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them more resilient to environmental stresses such as diseases, pests, droughts, floods, and extreme temperatures. The Genesys[4] online platform, provides information about plant genetic resources for food and agriculture conserved in genebanks worldwide, including the SGSV, and confirms that the only institution providing accessions for the Hygroryza is the International Rice Research Institute.

The low level of redundancy in the availability of seeds samples backups for the majority of the species, might have serious consequences. The question we aim at investigating in this paper is whether is possible to further increase the overall availability of seeds by a robust and resilient backup infrastructure capable to preserve seed diversity with limited investments.

Contributions of the paper. Interestingly, the temperature conditions in domestic freezers, can fulfill the international standard for long-term conservation of seeds[3][5]. The main idea of this paper is to develop a system inspired by the principles of the shared economy, capable of safely storing the seeds in our home freezers, thus contributing to the development of a Distributed Seed Storage (DSS) that can increase the availability of seeds and the overall resilience of the world's crop diversity. To our knowledge, this paper is the first attempt to build a peer-to-peer infrastructure to preserve seed diversity. We first identified a set of requirements, and then we built a proof-of-concept of the DSS that proves the technical feasibility of two fundamental tasks, namely the IoT monitoring activity of seed conservation conditions in domestic freezers and the interaction of the IoT node with a Blockchain smart contract to autonomously manage a lottery to incentive users participation. The development of this PoC, allows us to identify the main issues that need to be investigated in future work.

2. Background

Efforts to preserve Seed Diversity. Genesys[5] is an online platform populated with information about plant genetic resources for food and agriculture conserved in genebanks worldwide. There are 56 data providers that aggregate data by international, regional and national genebanks, including the SGSV. Among these, here we only mention the Millennium Seed Bank's (MSB). While the focus of the SGSV is on conserving as much as possible of the diversity within crop species and the crop wild relatives in their gene pool (intraspecific diversity), MSB focuses on the conservation of as many species as possible (interspecific diversity) prioritizing those that are endangered, endemic, or economically important.

Conditions to preserve seeds. Moisture, temperature, and the proportion of oxygen are key environmental factors that affect seed deterioration and loss of viability[6]. Reducing seed moisture content (MC) to certain thresholds increases longevity predictably for approximately 90% of species. These species are classified as being *orthodox* in their seed storage requirements, and generally retain viability and germinability even after storage for long periods under suitably dry, cool conditions. In general, most of our food energy intake from plants is orthodox.

The Food and Agriculture Organization (FAO) standardized the process for long-term storing of orthodox seeds[3][5]. We require our system to comply with these standards, as specified in R1, section 3.

IoT and Shared Economy. We share the definition of shared economy by Frenken et al. *“consumers granting each other temporary access to under-utilized physical assets (idle capacity), possibly for money.”*[7].

Example of shared economy ranges from carpooling (e.g. BlaBlaCar), to share rooms in an apartment (e.g. Airbnb) or to utilize transport capacity that may be wasted in inefficient transport operations (e.g. Shiply), just to mention few examples. In our case, the idle capacity is a tiny portion of the freezer sufficient to store the seeds.

The shared economy can benefit from the integration with the Internet of Thing (IoT)[8]. IoT can be used to monitor the availability of the idle capacity and to verify that some requirements are meet (see for example **R1** section 3).

Encourage Users Participation by Incentives. The success of this project depends on the active participation of a sufficiently high number of users. The nature of the project, and the limited freezer space required to store the seeds, give us hope for a proactive and numerous participation. However, suitable incentives might clearly help. Indeed, as discussed in[9], enjoyment, economic incentive, reputation, and self-fulfillment are the main motivations behind the participation to the shared economy. In particular, we are interested in evaluating how the Blockchain technology can distribute such incentives. In[10], the authors discuss Blockchain-based incentive mechanisms. In this paper the participation to a lottery is the incentive to participate: only peers actively contributing to the DSS can buy tickets and hope to win.

3. Requirements

In this section we describe the main requirements that drive the design of the DSS proof-of-concept.

- **R1.** Storing conditions of seeds in domestic freezers must comply with[3][5]. In this paper, we focus on long-term storage of orthodox seeds. Specifically we assume that after drying, samples meant for long-term storage are packaged under controlled conditions, in clearly labelled airtight containers (Standard 4.2.2[3]) and then samples are ideally stored at -18°C ± 3 percent and relative humidity of 15 ± 3 percent (Standard 4.2.3[3]). Figure 4 of[5] is a summary diagram of the workflow and activities for drying and storage and clarifies that the use of subzero freezers is acceptable if ideal conditions are not available.

The success of this project relies on the active and numerous participation of users. To encourage the participation, the system should:

- **R2.** Simplify the installation without requiring any specific technical skill or infrastructure. The installation of the system should be user friendly and based on off-the-shelves equipment. We only assume users have a WiFi at home.
- **R3.** Not require unnecessary cables which complicates and limit the installation options.
- **R4.** Run for at least 1 year without the need of intervention by the user.
- **R5.** Support the implementation of suitable incentive mechanisms.

4. Proof-of-concept

The main purpose of this section is to demonstrate the feasibility of the proposed approach by the implementation of a Proof-of-Concept (PoC) of the Distributed Seed Storage driven by the above requirements. The PoC will also outline the main technical problems that still need to be efficiently solved to realize a fully fledged solution.

The airtight container storing the seeds is equipped with a humidity and temperature sensor (the DHT22) connected to an IoT sensor node, in our case the Esp32 Devkit V1 (Esp32 in the following), which implements the logic to acquire the sensor readings and to deliver them to the smart contract in charge of dispensing the incentives to the participants.

The Esp32 delivers the data to the smart contract by the on-board WiFi. WiFi access points are nowadays largely available in homes (see **R2**) making this technology appropriate for the project, furthermore, the nature of the phenomenon to be monitored does not require frequent data acquisition; temperature and humidity in the freezer do not suddenly change. For this reason, the node alternates long period of *deep sleep* with a short active period where two main tasks are performed, namely data acquisition and communication. In *deep sleep* mode, only the RTC Timer and RTC Memory are active, reducing the consumption to 10μA. The resulting low duty cycle prolongs the lifetime of the node, and allows us to meet the requirement **R4** as quantified in section 4.3.

To satisfy **R3**, the Esp32 is powered by a 3.6V LiFePo4. This solution does not require any voltage regulator that would introduce losses. In the future, we plan to design a more efficient custom board without all unnecessary components.

The ESP32 operating temperature range[6] is from -40 to $125\ ^{\circ}$C, so in principle it can also be placed into the freezer together with the DHT22 temperature and humidity sensor, however, the wifi connectivity could be severely hindered. In our experiments, when the ESP32 is placed into the freezer, more then 40% of the packets do not reach the server. Furthermore, it is well known the the efficiency of batteries decreases significantly in cold temperatures: at -20°C to -40°C, a LiFePo4 battery may only achieve about 60% to 40% of its rated capacity[7]. Finally, despite being small, the ESP32 steal some further space in the user's freezer. For these reasons, the DHT22 is placed into the freezer and it is connected to the ESP32 placed outside, by three tiny wires. This solution is not fully consistent with **R3**, but it is acceptable and the arguments discussed above togheter with the simplicity of the installation, makes it compliant with **R2**.

A sketch of the architecture of the Proof-of-Concept is shown in Figure 2. The PoC is build with PlatformIO[8] and the code is available on *https://github.com/andreavitaletti/PlatformIO/tree/main/Projects/web3E_SC*.

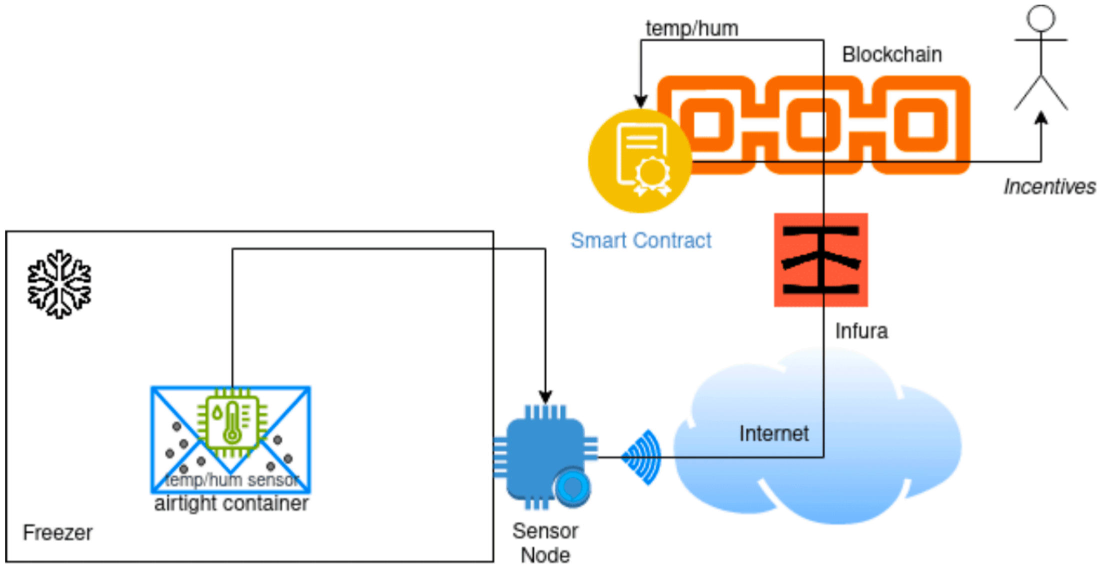

Figure 2. The architecture of the Proof-of-Concept. A temperature and humidity sensor is placed into the freezer and it is connected to an IoT sensor node placed outside. The node communicate the reading to a smart contract in charge of dispensing incentives to encourage users' participation.

In the following, we discuss the implementation of the two main tasks performed by the PoC during the active period, namely monitoring the correct storage of seeds and delivering the observed data to the smart contract in charge of incentive users participation.

4.1. Monitoring the Correct Storage of Seeds

The temperature and humidity conditions at which seeds are stored in the freezer, are monitored by a DHT22 sensor (see **R1**). It features excellent technical specifications also in terms of power consumption. The sensor can be queried by a single wire protocol: when the sensor node sends the start signal, the DHT22 change from stand-by-mode (40 μA) to measuring-mode (1 mA). The DHT22 will get back to stand-by-mode again upon the completion of the data acquisition.

Figure 3 shows the results of a monitoring activity on a domestic freezer (BOSCH KGN39X23) set at -18 $^{\circ}$C of temperature. Samples are taken every 5 minutes. After an initial transient period, the observed temperature oscillates significantly. These conditions do not fulfill the Standard 4.2.3[3] but are consistent with the acceptable subzero conditions indicated in[5] when the ideal ones are not

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available. The implications of these conditions in seed conservation and the possibility to reach the ideal ones in domestic freezer are object of future studies.

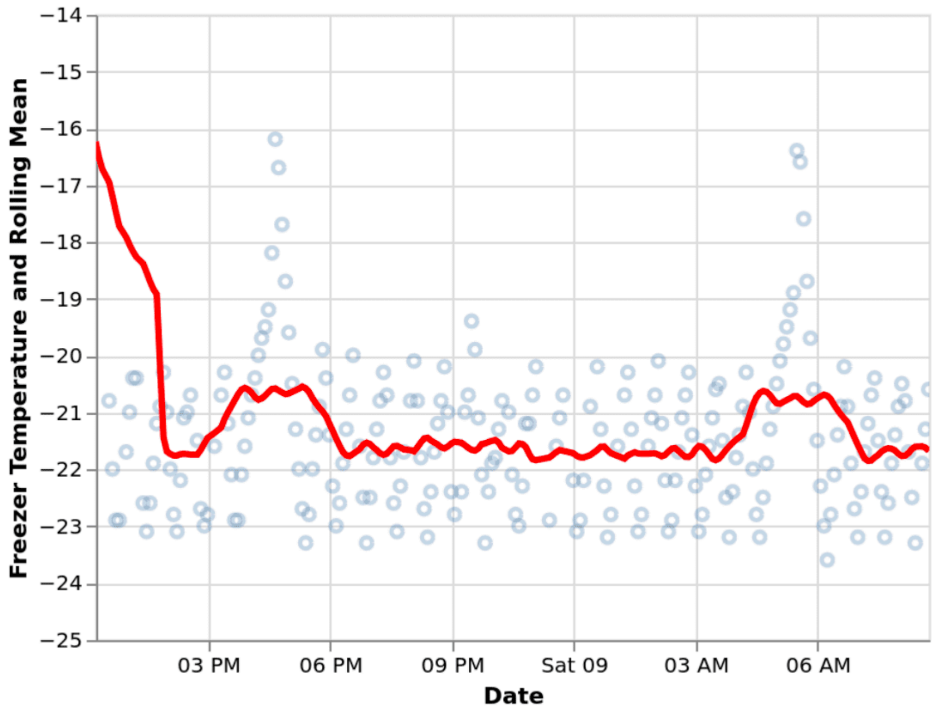

Figure 3. The observed temperature drops immediately after the placement of the sensor into the freezers, then fluctuates noticeably.

Domestic freezers are occasionally opened to access the frozen products. We performed a simple experiment to evaluate the impact of this activity on the temperature. We left the freezer close for 1 hour and then we opened it for 30 secs., a more than sufficient interval of time to access the frozen products; the impact on the temperature is marginal at the first decimal figure of the temperature.

4.2. Delivering the observed data to the smart contract

Once data have been acquired, they are delivered to the blockchain smart contract in charge of distributing the incentives to encourage users' participation (see **R5**). In our PoC, we envision the development of a blockchain lottery, where users can participate (and possibly have higher chances of winning) if and only if they are active peers of the DSS. The lottery is implemented with a simple smart contract similar to that available at https://github.com/Scofield-

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Idehen/Lottery_Contract/blob/main/Lot_Contract.sol. The function *enter(uint temp, uint hum)* allows the participation only of active DSS users, namely users that provide data on temperature and humidity in the acceptable range. The function *fund*, allows anyone to fund the lottery. The code of the smart contract, together with some sample transactions, can be accessed at https://sepolia.etherscan.io/address/0x19aeacb63eba19e5e159a5870fa6afce5d3b37ec.

A more complex lottery and a through study on the most suitable incentive mechanisms to be implemented in the smart contract is beyond the scope of this paper and will be investigated in future work.

Most solutions interfacing IoT nodes with smart contracts on the Blockchain, relays on gateways. This would greatly simplify the integration, but we cannot expect that all the houses have the necessary skills and tools to deploy such a relatively complex infrastructure (see **R2**). For this reason, all the code to interact with the smart contract through the Infura API[9] is contained in the firmware of the resource constrained ESP32. This might be a pretty challenging solution due to the limited memory available on the ESP32, indeed our code, based on the WEb3E library[10], occupies 93% of the available flash. This solution foresees only outgoing transmissions (from the home to the Internet), thus increasing the security against possible network threats.

DHT22 readings are given as floating numbers that are not supported by Solidity. To simplify the management of readings by the smart contract also for negative values, we applied the following simple formula $40 + rount(temp)$ with $temp$ ranging from -40°C to 80°C, as defined in the technical specification of the DHT22. Consequently, the value transmitted to the smart contract is a single byte representing a value between 0 (-40°C) and 120 (80°C). The transactions can be accessed at the same URL of the smart contract. Floats can be also encoded in 4 bytes using the IEEE 754 standard, but this makes more complex the logic of the smart contract.

4.3. Energy Consumption

In this section we report on the experiments to evaluate the energy consumption through an INA219[11]. The Esp32 devkit V1, has an always on red led, with a fix consumption of 10mA. We unsoldered the led and the consumption dropped to less than 4mA, however still pretty far from the nominal $10\mu A$ in deep sleep. In the following, to evaluate the potentials of our work, we assume to achieve the nominal current consumption during the sleeping period.

We sampled several active periods and Figure 4 shows the current consumption in one of those periods; similar values have been observed for the others. Active periods are made of two tasks, the *init* task where all the necessary components are initialized, and the *com* where the data are read by the DHT and are transmitted to the smart contract. The *init* task lasts about 2400ms (≈0.0007h) at about 50mA, namely ≈ 0.03mAh, while the *com* task lasts about 3160ms (≈0,0009h) at about about 100mA, namely ≈ 0.09mAh. We assume the duration of the sleep period is X hours at $10\mu A$, namely $0.01X$ mAh. The whole consumption for a cycle is $0.03mAh + 0.09mAh + 0.01XmAh$. The ESP32 is powered by a common 3.6v, 1.5Ah LiFePo4 battery. This guarantees a number of cycles $1500mAh/(0.12 + 0.01X)mAh$. The length of a cycle is $0.0016 + X$ hours. The whole duration in hours will be $1500/(0.12 + 0.01X) \cdot (0.0016 + X)$ and with $X \geq 0.73$ hours, we meet requirement **R4**, namely a duration of 1 year.

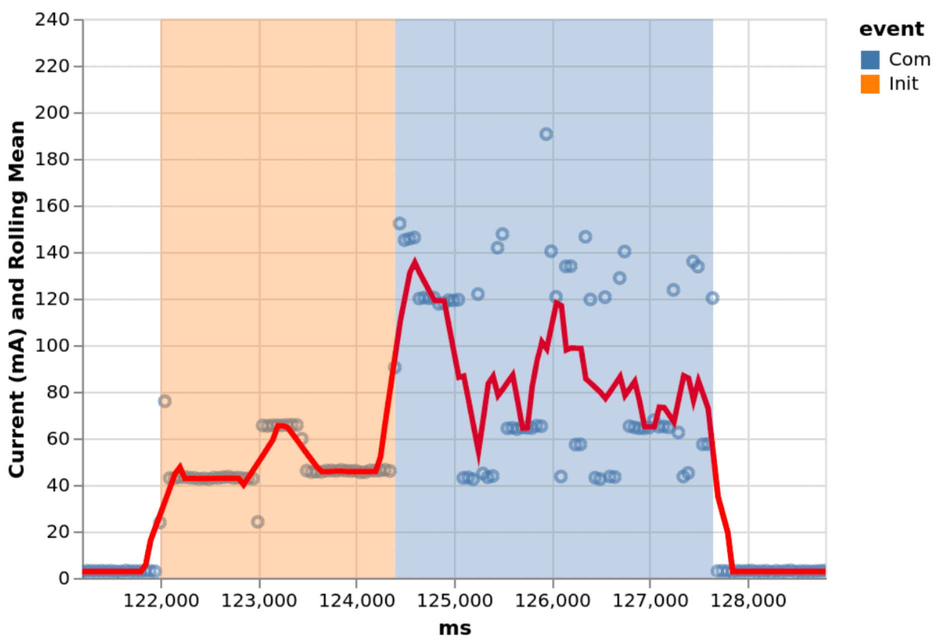

Figure 4. Sampling current consumption with the INA219

Note that the smart contract gets in input an unsigned int made of 32 bytes, so we can pack up to 32 readings (they need 1 byte), into a single call, thus reducing the overall number of required transmissions.

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5. Conclusions and Future Work

We lay out a vision for Distributed Seed Storage (DSS), a novel shared economy concept for long-term storage of seeds in domestic freezers. This concept aims to contribute to the fundamental goal of preserving seed diversity through the employment of IoT to monitor the correct preservation of seeds and Blockchain technologies to distribute incentives to encourage user participation. The PoC proves the feasibility of the main technical components of our vision and a future collaboration with fridge producers, might support the development of new products supporting the DSS functionality since the design, also on industrial refrigerators. The PoC also allowed us to identify the priorities to be investigated in future work as summarized below.

The monitoring activity confirms that acceptable subzero conditions are achievable in domestic freezers, however to what extent we can better approach the ideal conditions prescribed in Standard 4.2.3[3] and the implications on seed conservation of the observed fluctuations, need further investigation. While the current board proves the feasibility of the proposed approach, the power consumption can still be optimized and more energy-efficient custom boards, such as the trigboard[12], can significantly improve the performance. The PoC relies on periodic transmission of the observed conditions, the use of an alternative approach based on the communication of abnormal events only, possibly based on Ultra Low Power Coprocessor Programming, should be evaluated. In this work, a simple lottery incentives users' participation. We have to better understand the complexity beyond a distributed network of a significant number of devices, and to design an indexing service to understand and manage the distribution of the seeds in the network of participants.

Beyond technical feasibility, we have to evaluate the costs of this solution and to study the most suitable mechanisms to incentivize user participation, not only through more advanced tokenomics mechanisms, , but also by supporting simple notification services on dangerous conditions for the food stored in the fridge.

Footnotes

[1] https://education.nationalgeographic.org/resource/food-staple/

[2] https://www.seedvault.no/

[3] https://seedvault.nordgen.org/Search

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[4] https://www.genesys-pgr.org/

[5] https://www.genesys-pgr.org/

[6] https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

[7] https://www.evlithium.com/Blog/lifepo4-battery-temperature-range-capacity-voltage.html

[8] https://platformio.org/

[9] https://www.infura.io/

[10] https://github.com/AlphaWallet/Web3E

[11] https://www.ti.com/lit/ds/symlink/ina219.pdf

[12] https://trigboard-docs.readthedocs.io/en/latest/

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Declarations

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