Energy Efficiency Using IOTA Tangle for Greenhouse Agriculture

Interplanetary Precision Agriculture

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Abstract. Greenhouse farmers around the world face multiple challenges imposed by manual tasks and must deal with complex relationships among growth environment variables. Usually, tasks are accomplished with low efficiency and high uncertainty, which becomes evident when evaluating the impact introduced by adjustments to these variables. These challenges have led to the appearance of the precision agriculture industry, as farmers attempt to automate the agricultural and commercialization processes using solutions based on the Internet of Things (IoT), Artificial Intelligence (AI) and Cloud Computing. Although these novel technological solutions seem to tackle some of the challenges, several concerns about centralization and data silos throughout the supply chain have arisen. Thus, we propose the Interplanetary Precision Agriculture (IPA) project as an alternative to an increasing demand for better technological solutions in the sustainable food supply, required by the long-term presence of humans in any given environment. The current project aims to improve the cultivation process on and off Earth, by implementing solutions based on the IoT, AI, and Distributed Ledger Technologies (DLT). Hence, a "system of systems" is laid out. First, Magrito, a holonomic autonomous rover, is introduced to capture crop performance parameters (output variables). Second, Precision Habitat PRO, the environment controlling device, is deployed to capture growing parameters (input variables). Third, a commercial Bluetooth scale is added. Last, a Farm Management System is utilized to correlate the data captured by IoT devices with business logic. The resulting information is sent to the IOTA Tangle network to render it immutable and interoperable, at zero network processing fees with minimal energy consumption.

Keywords: Agriculture, Internet of Things, Artificial Intelligence, Distributed Ledger Technologies.

1 Introduction

Greenhouse farmers around the world deal with challenges imposed by multiple manual tasks related to agricultural processes, when trying to maximize yield in their crops. Moreover, farmers must manage dozens of environment variables that are interrelated in a complex manner. These repetitive tasks are normally performed with very low efficiency, and the impact on the yield caused by adjustments of crop growing conditions is usually not measured. These challenges have been extensively documented in various studies emphasizing the need for sustainable agricultural systems [1], [2], [3].

The need for better agricultural practices has led to the development of platforms based on exponential technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Cloud Computing or On-Prem Installations [4] that take upon the task of automating, monitoring, and commercializing the agricultural production process. However, the use of centralized architectures, cloud or on-premise, come at a cost that is not evident at first glance. Although centralization facilitates data handling and storage, it introduces a single point of failure and undermines autonomy [5]. Another non-desirable characteristic of centralization is the proliferation of data silos that limit the visibility of information through the supply chain, which in turn leads to additional management procedures that restrict value and decision-making constraints derived from different stakeholders, based on the status of this supply chain [6].

The Distributed Ledger Technology (DLT) industry, through Blockchain, has proposed an alternative to centralized platforms. However, energy consumption, scalability limitations and networks fees have become an impediment for a tangible adoption of this technology by agro-industry. Also, greenhouse farming on-earth has suggested an alternative for traditional farming, but the high energy consumption along with high initial investment is slowing down adoption. These two technologies have an impending requirement: efficient use of energy needs to be considered.

Furthermore, the current space exploration efforts are paving the way to the establishment of human settlements in near-earth celestial bodies. Therefore, farming will eventually play a crucial role in providing food for crew living in microgravity aboard spacecraft [7], or in planetary bases [8]. For instance, greenhouses in planetary bases are envisioned to be composed of large modules with conventional vertical growing areas that will sustain a controlled environment for farming staple crops (e.g., wheat, soybean, potato, and rice). Hence, monitoring and harvesting these crops will represent a challenging human activity for settlers, if not automated. The overarching goal is the expansion of several greenhouses within basecamps and other settlements, that will welcome a source of valuable, rich data for our very first space farmers.

In this context, we propose the Interplanetary Precision Agriculture (IPA) project, based on exponential technologies such IoT, AI, and DLT, and seeking to introduce game-changing aspects to the lives of farmers on and off Earth. IPA utilizes the IOTA DLT Framework applied to the agriculture industry, which has an impact in the following three key areas: IoT communication security, Machine-to-Machine (M2M) payments at zero network fees [9], and energy efficiency.

IPA's proof of concept was conducted during a five-day experiment in a greenhouse located in the base camp of Mars-Moon Astronautics Academy & Research Science institute (MMAARS) in the Mojave Desert, United States. The objective was to monitor and collect data related to the cultivation of grapes and tomatoes using protocols that analog astronauts can complete in Isolated Confined Environments (ICE). Analog missions are field tests carried out in locations that attempt to reproduce physical characteristics like extreme space environments. There, scientists collaborate by gathering requirements and testing technologies in harsh environments, before they are used in space [10]. In this regard, we were motivated to test our IoT devices – rover, environment controller, and scale – in the extreme conditions of the Mojave Desert with temperatures of up to 45°C, high-speed winds, and dust abundance.

The performance of the hardware tested during the analog mission was sufficient to conduct all the experiments successfully, despite the extreme conditions. The results showed the strengths and weaknesses of the system as a whole and set the targets for improvement in upcoming versions of IPA. The specific contribution of this study is to show that the combination of IoT, AI and DLT is technically feasible, economically viable, and energy efficient, even in energy restrictive conditions.

Following this introduction, Section 2 presents a general overview of the main components of the proposed solution. Section 3 describes the materials and methods implemented in the project. Section 4, provides a brief summary of the theoretical concepts and calculations used thorough this work. Section 5 introduces IPA proof of concept evaluated during the Astronaut Analog Mission. Finally, Sections 6, and 7 present the results of the project and further elaborate on the next steps for the development of IPA.

2 Interplanetary Precision Agriculture Components

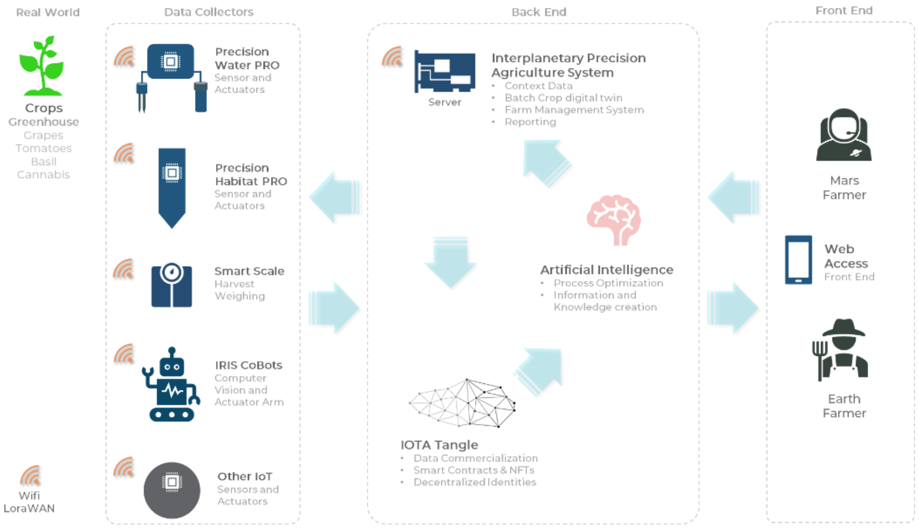


Fig. 1. IPA Conceptual Diagram

IPA is an integral, end-to-end solution which general architecture is depicted as a system of systems (see Fig. 1). First, Magrito v1.0, a holonomic autonomous rover, is introduced to capture crop performance parameters (system output variables). Second, the environment controllers Precision Habitat PRO and Precision Water PRO are tested and deployed to capture the growing parameters (system input variables). However, for the final experiment only Precision Habitat PRO is used. Third, a commercial Bluetooth scale is integrated. Fourth, the Farm Management System (FMS) correlates the data captured by all the devices to provide context and interpretation capabilities (business logic). All the data is forwarded to a private instance of IOTA Tangle. Further development of the system considers Machine Learning (ML) models to be trained on past data to understand crops' behavior under various conditions. This knowledge will allow to determine the optimal growing conditions for future growing seasons.

3 Material and Methods

Three IoT devices, plus a FMS, and a DLT, were implemented.

3.1 Holonomic Autonomous Rover: Magrito

A holonomic omnidirectional mobile robot is an IoT device with three degrees of freedom in a plane. This type of robot can move in any direction with, or without changing their orientation on the plane, giving the rover the ability to avoid obstacles without changing its orientation, moving in constrained spaces, and tracking a target [11].

Fig. 2. Rover 3D design (left), Rover Prototype (center), and Precision Habitat PRO (right)

Magrito Rover dynamics have the capability to assist with greenhouse-related tasks because its mobility is based on two independent driven wheels placed on both sides of the robot body and an additional castor wheel.

Magrito's mechanical structure allows the incorporation of additional hardware that can further enhance its performance. For instance, the rover has an extra mast that can be utilized to attach an additional navigation camera placed behind the Intel Real Sense Depth Camera. There is also enough internal free space to add a GPS module to geotag video readings and on the upper surface to fix a LIDAR sensor.

In addition, the rover's frame protective cover and wheels can be developed with different material technologies to adapt to a particular environment. Comparing Magrito (Fig. 2) to four-wheel rovers, we find that the solution is more versatile, which remains a key factor when selecting this type of robot for this specific experiment.

Hereby we present a general overview of all the Rover's technical specifications (see Table 1). Thanks to its modularity, the end user can tailor Magrito's feature set to comply with any specific requirements. For example, if the production application requires the recognition of apples or oranges, a Mask R - Convolutional Neural Network (CNN) [12] model can be trained for that specific purpose and the software on the main board can be updated accordingly.

Table 1. Summary of main specifications and technologies of Magrito.

Feature	Description
Dimensions	45.3 cm (W) x 41. 8 cm (L) x 41. 8 cm (H)
Weight	7 kg
Maximum Speed	0.2 m/s
Camera	Real Sense D435i
Software packages	Ubuntu 18. 04, Ros, Melodic, Gazebo
DL algorithm architecture	Mask R-CNN
Battery System	Talent Cell Battery 12 VDC 3000 mAh
Packaging material	White PLA – Thickness 3mm

3.2 Precision Habitat PRO

This IoT device was used to capture data related to the environment. Designed with ESP32 microcontrollers [13] and Wi-Fi connectivity at 2.4 GHz, the average range for this device is 30 meters to an available access point which adequate for greenhouses.

Fig. 3. Grafana dashboard showing temperature, humidity, soil moisture, and CO2

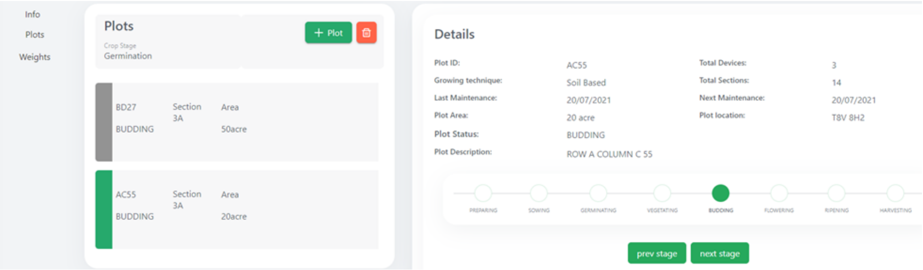
On the other hand, if longer distances are required, the devices are also built to support LoraWAN connectivity. This type of connectivity allows for longer ranges (>1 km) and a higher quantity of devices (or nodes) per gateway (~ 1,000). The static device works as a weather station and integrates five different sensors with two actuators (relays). All the sensors are connected to the ESP32 microcontroller. Since its location is fixed, it does not require a GPS; however, each sensor reading (see Fig. 3) is associated to specific plots or sections within the farm from the FMS (see Section 3.3). The technical specifications of the device can be found in the product datasheet [14].

3.3 Farm Management System

The purpose the FMS is to allow farmers to add and correlate business logic to the data collected by IoT and Deep Learning (DL) and generate information with ML models. In particular, the main use cases deployed in this research project were focused on seed management, plot or section management, and crop planning (see Fig. 4).

The collection of data allows to have a clear understanding of what resources have been used to produce a given crop batch. All the details can be stored locally, in the cloud, or made immutable using IOTA Tangle (see Sections 3.5, 4.1, 4.2).

For example, the farmer can record descriptive attributes of the seeds used in a specific crop, its batch number, supplier, and available supply, among other characteristics, and trigger rules based on specific criteria. Having specified the characteristics and production parameters, the system allows the farmer to select specific plots or sections of the greenhouse where a batch of seeds was planted, and automatically correlate sensor data to the crop. As crops evolve in time, the farmer can update this transition from one stage to the next one (i.e., from sowing to harvesting, etc.). During harvesting, a commercial scale connected via Bluetooth or Wi-Fi allows to record the partial weights of a given batch. In upcoming developments, the weight data will be used as a reference variable to estimate the performance of the whole farm. In addition, calculations derived from the DL components will be included, thereby detecting growth variations and aggregating existing data. This set of mechanisms, and further digital twin tracking, will allow the farmer to certify the quality of the final product, by integrating and adding verifiable information throughout the food supply chain.



Crop Stage
Germination

BD27 Section 3A Area
BUDDING 50acre

AC55 Section 3A Area
BUDDING 20acre

Plot ID: AC55
Growing technique: Soil Based
Last Maintenance: 20/07/2021
Plot Area: 20 acre
Plot Status: BUDDING
Plot Description: ROW A COLUMN C 55
Total Devices: 3
Total Sections: 14
Next Maintenance: 20/07/2021
Plot location: T8V 8H2

Fig. 4. Crop Panning use case to manage plots/sections and crop stages

Moreover, the Magrito Rover currently allows the automation of the physical task of surveying. With a robotic arm, other tasks such as cleaning, sampling and harvesting will be possible. The task automation feature is a proposition aligned with the Machine-to-Machine (M2M) economy where machines become autonomous economic agents.

Tasks Automation and Rover Integration. In the current version the rover can be manually paid for specific tasks using IOTA tokens [15] with M2M transactions (see Section 4.3). In future versions of the platform, the system will include an option to pre-program tasks requests automatically, depending on specific needs of the farm's production environment.

The regulated use of energy is a vital responsibility within the crew (see Section 1). For instance, during the analog mission, a clear priority was established among all the crew activities – daily chores, projects, charging devices, and so forth. Moreover, current literature in energy-consumption of CNN deployed in real devices states that the processing consumes high energy because of its computational complexity [16], which signaled us to carefully consider the design of the solution to comply with the available power resources. An online implementation of the Mask R-CNN model is possible, but the energy consumption of the rover would increase.

In this context, the rover was configured to process offline crop recognition, and CNN was trained with a collection of photos of vineyard grapes and cherry tomatoes, which can be requested to any of the authors of this manuscript. Four agents are required for this: the rover, the storage platform (Amazon S3), a droplet (Digital Ocean) containing an API, the Mask R-CNN model for crop recognition, and the IPA's FMS. This solution was done in five steps:

- The Rover sends the unprocessed video captured by the depth camera to the storage platform using a Python executable and the unprocessed video is stored.
- Then, an API developed in python requests this video from the storage platform.
- Later, the feeding and processing with the deep learning algorithm begins.
- Then, the processed video is uploaded to the storage platform.
- Finally, the API requests the processed video from storage and broadcasts the result via the MQTT protocol [17] to the FMS.

3.4 IOTA Private Tangle

Another objective is to provide secure communication and data storage using a DLT with energy efficiency. To implement this, a Raspberry Pi 4 was used to run a private version of IOTA Tangle detached from the public IOTA Network. The private tangle secures the messages from the IoT devices (see Section 3) using IOTA Streams Framework and Channels Protocol (see Section 4.2).

Due to the lightweight nature of the IOTA protocol, a Coordinator and three Hornet nodes can operate in a low power device such as the Raspberry Pi 4, allowing full support for transactions and data streams; the spamming was set up to run at 6 MPS. The three hornet nodes were only propagating messages, and the coordinator was running all the Proof of Work (see Section 4.1), this scenario is known also as Easy PoW [18].

3.5 Proposed Data Flow Towards IOTA Tangle

For data messages from IoT devices, AI, or the FMS the following steps were laid out:

- First, the sensor measures in the IoT device a specific environmental condition and sends an electrical signal to the ESP32 microprocessor of the IoT Devices described in Section 3.
- Second, the ESP32 process the signal and creates a message in JSON format that is sent to a topic in the MQTT Broker. A variation of this is the AI or the FMS sending a JSON message to an MQTT topic.
- Third, Node-RED [19], a web browser-based visual programming tool that allows a user to add, eliminate and connect nodes, is listening the MQTT topics, thereby receiving the message with data.
- Fourth, the IOTA Streams API encrypts and routes the data to any of the three load-balanced hornet nodes running in the Raspberry Pi 4 where the private tangle is implemented by using the IOTA Streams Framework and implementing the IOTA Channels Protocol. It primarily has three functions: CreateAuthor, SendOne, and FetchAll that have been developed following the IOTA Streams Specification for "Single Branching" (see Section 4.2). Each function operates as follows:
  - CreateAuthor: Creates the author for the data stream and announces a Channel.
  - SendOne: Imports the author to send a message to the tangle with the Keyload and starts the sequence counting.
  - FetchAll: Creates a subscriber, receives the channel address to listen and returns the messages sent by the author.

For value transactions, the user enters data such as the amount, an additional transaction message and the receiving address. Then the front-end generates a JSON message that is sent to a custom API that supports the IOTA wallet (IOTA Wallet API was developed by Zignar Technologies). The wallet API organizes the data, prepares it, and sends the transaction to the tangle. Once the transaction has been approved, the API obtains a transaction identifier from the tangle and forwards it to the frontend to be shown to the user. Finally, the user can view the details of the completed transaction, with the option of verifying the transaction in the IOTA explorer.

4 Theory and Calculation

In this section, the core technologies and concepts that allow interoperability between machines for the purpose of IPA are summarized and explained.

4.1 Distributed Ledger Technologies

It is important to differentiate Blockchain from DLT as separate concepts [20]. Blockchain is a data structure that was first proposed in 1982 [21], and Bitcoin is the most popular implementation of this data structure, especially because of the secure techniques applied when transmitting messages from one node to another [22].

The IoT and AI industries require a secure communication layer that can be used when transmitting data, or messages generated by IoT-enabled smart meters or small sensors. This platform should be capable of meeting three basic requirements: accepting data, transmitting data, and fetching data, with the additional need of being energy efficient and frictionless [23].

Nevertheless, all Blockchains rely on miners and fees to secure the network. This fact has two main implications; first, energy required by miners to process transactions; second, the fees required to process transactions that create friction because each message comes at an additional cost. Also, Proof of Work (PoW) is one of the methods used by blockchains to secure the network and consists in finding a correct combination expressed by a hashing function such that the output begins with a certain number of zeros in its binary representation [24]. PoW is expensive in terms of calculation and energy consumption, when utilized in the specific manner that blockchain requires (i.e., miners competing for fees).

An alternative data structure that promises to solve and improve on the limitations inherent to a blockchain is the Directed Acyclic Graph (DAG). DAGs are by design more expressive than a linear model. Also, when implemented properly, their data structure is nimbler and more lightweight. Therefore, this approach can be utilized to solve diverse problems.

One of the first DLT projects that proposed the use of a DAG as data structure was IOTA [25]. In the paper of IOTA-Next Generation Blockchain [26], the authors mentioned that “The Tangle is a new data structure based on a Directed Acyclic Graph. As such it has no Blocks, no Chain, and no Miners”.

The IOTA token has been designed for IoT optimizing micropayments (value) and messaging (data) within the same protocol [27]. The Tangle as a data structure eliminates the need for specialized hardware and excessive energy consumption required by blockchain to secure the network. Due to all these characteristics, IOTA is an energy efficient choice when it comes to designing applications for distributed communication of IoT devices. Therefore, adopting the Tangle as the supporting DLT is naturally a much better option for this research project, as opposed to Blockchain technology.

4.2 IOTA Streams and IOTA Channels

IOTA Streams is a tool that structures and navigates secured data through the Tangle. The protocol organizes data by ordering it in an interoperable structure. It has been created by the IOTA Foundation to allow the development of cryptographic protocols on top of The Tangle.

IOTA Streams provides a toolset for structuring and transforming data for application-specific purposes, to be communicated over any transportation layer. IOTA Channels is a protocol that operates within IOTA Streams and provides a secure offline messaging implementation on top of IOTA layer one protocol as a transportation layer [28]. The main features of IOTA channels are the following:

- Maintains Streams state through an internal link store mechanism.

- Allows for numerous predefined message types (Announce, Signed Packets, Keyloads, tagged packets, Subscribe, Unsubscribe, and Sequence).
- Provides decentralized transportation and storage through the usage of the Tangle.
- Message types for managing cryptographic access control to data branches.
- Uses a pub/sub model with key sharing for access management.

IOTA Channel supports two configurations: "Single Branching" and "Multi Branching". These refer to the delineation for participant management within a channel and the sequencing model that all participants in the channel will be configured with.

4.3 Machine-to-Machine Economy

The M2M Economy implies machines becoming independent economic entities that make decisions on their own and react to the world around them without waiting for specific instructions. For example, a parked autonomous vehicle contracting a micro insurance with provider A and switching to insurance provider B when driving on the highway, all of this without asking to the owner, but taking the best decision based on predefined owner's interests [29], [30]. This concept can be extended to space settlements where machines will be providing or buying services at different levels to other machines and humans.

4.4 Energy Consumption with IOTA Streams

Firstly, the energy consumption of a greenhouse farm is a sensitive matter, especially for operations that apply artificial lighting to speed up the growth process of crops. This consumption increases proportionally according to the location's latitude in order to keep the environment temperature at acceptable levels for the crops.

Secondly, the availability of energy for space settlements is very limited. For instance, the International Space Station produces on average 84 to 120 kWh of electricity with eight solar arrays [31].

For the experiment, two EF ECOFLOW Portable Power Stations (3300W) were used to store all the energy collected by solar panels. The ECOFLOW power stations were powering one Precision Habitat PRO, and two Raspberry Pi 4 Single Board Computers; the first Raspberry Pi 4 was running the full IPA FMS application, including backend and frontend, with a friendly Avahi Protocol [32] address defined as agri-mars.local. The second Raspberry Pi 4 was hosting the private tangle at friendly address defined as tangle-mars.local.

According to calculated benchmarks, the energy requirement to write the IoT data to a private tangle under Easy PoW (see Section 3.4) is *1.18* millijoules at *100* Messages Per Second (MPS) and *1.21* millijoules at *50* MPS [18]. These referential values are used to calculate the linear regression function (see Equation 1) to estimate the energy cost per transaction at *6* MPS, where x is the MPS, and y is the energy in millijoules.

Then, at *6* MPS the estimated energy per message/transaction is *1.23* millijoules or $3.41x10^{-10}$ kWh.

$$y = -0.0006x + 1.24 \tag{1}$$

The set frequency for our IoT controllers was one JSON message every minute.

$$Messages = days * \; hours * \; minutes \tag{2}$$

The mission run the equipment for three days, giving us a total of 4320 messages (see Equation 2).

$$\text{Energy} = \text{messages} * \text{energy} / \text{message} \tag{3}$$

The estimated total energy spent to process the *4320* messages was *5.313* joules (see Equation 3) or $1.47x10^{-6}$ kWh.

As part of the experiment, value transactions were also performed between the platform and the rover to pay for surveying the farm. These transactions were confirmed in the private tangle showing that the technology can also be used as a payment layer for machines, at a very low energy cost.

Using IOTA Tangle, the energy cost required to issue one value transaction is equivalent as the one required for one data message. As previously calculated in our experiment, it equals *1.23* millijoules. This amount of energy is trivial when compared to the energy requirements of centralized payment networks such Visa, where a single transaction within the network consumes around *10,566* joules or $2.935x10^{-3}$ kWh [33], [34]. Furthermore, the energy required by PoW of a single Bitcoin transaction is calculated to be *1827.75* kWh, as of September 2021 [35], [36], and a single Hedera Hashgraph transaction consumes $39.70x10^{-6}$ kWh [34]. In perspective an average north American household consumes about *877* kWh/month [37].

Thus, since energy is a very limited resource for on-earth and off-earth farming, it makes sense to implement a comprehensive solution that uses this resource most efficiently. The IOTA network amply meets the criteria.

5 Case Study: Astronaut Analog Mission

The case study was conducted on an MMAARS' greenhouse (referred to as "GreenHab") located in Mojave Desert, California, USA, during a five-day analog mission (see Fig. 2). The GreenHab was used for research of different types of vegetables. It also intends to closely reproduce Martian environmental conditions.

The objective of this case study was to monitor and collect data derived from the cultivation of grapes and tomatoes in the GreenHab through analogous protocols, routines, and methodologies that astronauts could perform and reproduce in Isolated Confined Environments (ICE), considering constraints on internet connection, Wi-Fi signal, energy supply, coupled with extreme temperatures of up to 43°C (113°F). Moreover, the dust lifted by the strong winds of the Mojave Desert seeped into the hardware and caused some glitches. Therefore, we defined the following objectives for the experiment to validate the success of the proof of concept of IPA:

- Magrito's Recognition Algorithm shall accurately recognize and count most of the grape and tomato fruits that are in the GreenHab.
- Habitat Precision PRO shall gather environment data such temperature, humidity, soil moisture, and CO2.
- IOTA Private Tangle shall secure the data and value with greatly reduced energy consumption.

Throughout the five-day Analog Mission conducted by the MMAARS institute, IPA was implemented on the first days of the mission. The experiment was performed in the afternoons of August 22nd, 23rd, 24th to harness colder temperatures. The referential location of the Habitat (basecamp) was seven miles northeast of the Best Western Hotel, California City.

5.1 Space Analog Mission Protocols

As part of the simulation, some tomatoes and grapes were planted on the first tier of the GreenHab racks to be detected by Magrito's camera. Also, the Precision Habitat PRO was installed next to the crops with its sensors. During the analog mission, A. M. Flores, the crew member responsible of IPA, conducted a two-hour protocol to run the experiments. First, the Precision Habitat PRO module was plugged into the power supply; then, the local Wi-Fi Network was initiated along with the IPA server and then private tangle was started. Later, the system started to collect data. Finally, Magrito's work plan in the GreenHab followed a route that covered all the crops in the GreenHab.

6 Results

The standard security protocols to grant access to third parties to the data require the setup of private and centralized TCP/IP networks (VPNs) or Web APIs. The proof of concept showed that multiple types of data sources (IoT, FMS, AI) can write data messages through the IOTA Channels Protocol, allowing data to be fetched from third parties using the same protocol without centralized VPNs or Web APIs.

For the agriculture industry, this enables traceability and interoperability since the digital twins of crop batches can be accessed by third parties to audit the production data, information, or knowledge related to the end products.

Furthermore, the calculations introduced in Section 4.4, estimate *1.23* millijoules per message. The set up included one IoT Device (see Section 3) sending data every minute, the IPA system, and the private tangle. Two EF ECOFLOW Portable Power Stations (3300W) were used to support these systems demonstrating that the energy required to write/read data on IOTA network is very low. Even when processing value transactions the energy consumption is trivial compared to networks like VISA. During the experiment message spammers were set to a required minimum of 6 MPS to keep the network running. In a real scenario, spammers can be deployed on other nodes communicating through IOTA network and reaching higher numbers of MPS.

Fig. 5. Deep Learning algorithms identifying tomatoes (N=167) and grapes(N=8)

On the other hand, we can appreciate that the Mask R-CNN is framing the recognized grapes and tomatoes (See Fig. 5), respectively; in the lower right corner of the image, the algorithm is counting the number of recognized fruits.

Finally, the DL model is accurately framing the fruits but is failing to count the exact number. This can be improved by tuning hyper-parameters in the layers of the Mask R-CNN and testing the model's performance by comparison in each tuning [38]. Nonetheless, the first implementation in extreme conditions of this algorithm demonstrates good potential for future improvements and capabilities to add more data collectors.

7 Discussion and Conclusion

The specific contribution of this study during the Analog Astronaut Mission is to show that the combination of IoT, AI and DLT is technically feasible, economically viable, and energy efficient. The feeless DLT enables M2M communication and monetary transactions without friction, as shown in Sections 4.4 and 3.3. Its implementation in a hostile environment was motivated due to the possible identification of strengths and weaknesses in the current IPA's systems version. Despite the extreme environmental conditions, and energy constraints, the performance of data collectors selected was not affected. In fact, valuable crop data and observations were collected during the analog mission that will serve to the betterment of the general concept of IPA.

These exponential technologies can be developed and integrated with the goal of increasing yield by extending the automation in a greenhouse on-earth. As result, the cost of the crop production decreases significantly [39], [40]. In addition, the low energy consumption and the portability of the systems allow replicability required for off-planet missions. As on-earth greenhouse adoption increases, along with its automation [41], the performance and capabilities of the proposed systems may improve. These more advanced versions would increase its usefulness for future off-earth greenhouses.

Future improvements will entail an increase in the deep learning model's precision used for identifying and counting the fruits, the addition of a robotic arm for automatic harvesting purposes, the re-engineering of Precision Habitat PRO (see Section 3.2 to have modularized boards that can be used in other applications, the development of new features for the FMS (see Section 3.3), the improvement of IOTA Streams API to support multibranching (see Section 4.2), the addition of IOTA Smart Contracts for Tasks Automation (see Section 3.3), and the use of ML to evaluate the impact of growing condition adjustments in the cultivation process. The collected data will be used to train regression models that would predict the resulting yield for each type of crop. Thus, our explanation variables consist of time series for each measured variable while the response variable corresponds to the resulting yield. The structure of the given problem is suitable for the use of sequential models such as long-short term memory modules (LSTMs).

Moreover, in the next iteration, IOTA 2.0, the Tangle is evolving into a new solution that incorporates Sharding and Multiverse [42], [43], [44]; in an off-planet situation, considering communication constraints imposed by planet distance, both Sharding and Multiverse would be characteristics desirable for any DLT.

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