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Open Phytotron: A New IoT Device for Home Gardening

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***Abstract*—Phytotrons are culture chambers used by researchers in which ambient parameters such as temperature, humidity, irrigation, electrical conductivity of the nutrient solution, pH, lighting and CO_2 are finely controlled. In addition, these installations make it possible on the one hand to measure the impact of environmental changes, and on the other hand to optimize the growth of plants in artificial growing conditions. Thanks to the democratization of hardware, cloud computing and the new possibilities offered by the Internet of Things (IoT), it is now possible to build a personal phytotron at an affordable cost. In this article, we propose to use connected objects to develop a personal growth chamber in order to produce fresh vegetables in an urban context.**

***Index Terms*—phytotron, growth chamber, smart home, smart agriculture, cloud computing, Internet of Things, Home Assistant, openHAB, Node-Red**

I. INTRODUCTION

With the global population growth, the need for crop production and raw fiber also increases. Indeed, the Food and Agricultural Organization of the United Nation (FAO) predicts that the global population will reach 8 billions peoples by 2025 and 9.6 billions peoples by 2050. This practically means that an increase of 70% in food production must be achieved by 2050 worldwide. The great increase in global population and the increasing in demand for high-quality products creates the need for the modernization and intensification of agricultural practices. At the same time, the need for high efficiency in the use of water and other resources is also mandatory. Plant-derived products are among the most important challenges we face in our daily lives and industrial processes, because of the high requirements and demands of food, feed and raw materials. Transverse approaches from the molecular scale to field applications are also crucial to develop sustainable high yield production while using a minimum of resources. Phytrotron presents a research installation used by scientists to test new variety of performances in controlled conditions, measure impact of environmental changes, and develop culture recipe to improve crop performances.

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II. LITERATURE REVIEW

The main challenges in the elaboration of a phytotron is on one hand to choose an adapted material able to measure finely and correctly environmental conditions, and on the other hand automated actuator allowing to ensure the growth of plants in optimal conditions. The following paragraph focuses on these aspects and on reviewing existing works dedicated to this field in the literature.

A. Background

a) At Local Level: In our previous works [1], we have carried out a comparative study of IoT interoperability architectures. In this study, we described the need of interoperability in IoT architectures. We have then presented the different kinds of architectures used in the field of IoT. The article end up with an analysis of various recent researches proposed to guarantee interoperability between connected objects and their architectures, and a critical study which determine the limits of these architectures. Finally, we concluded that, despite the diversity and usefulness of the proposed architectures, they showed certain crucial limitations and weaknesses. Indeed, most of these architectures do not meet the requirements for mobility, functionality, efficiency and cost optimization. The vast majority of these architectures are limited to a specific field of application; also, these architectural proposals are generally limited to the level of energy consumption; Most of them do not offer the possibility of providing platforms which interact with one or more specified systems. However, none of these architectures presents a generic model taking into account all the protocols and technologies and their use cases.

In [2], we have proposed a prototype of IoTs interoperability models which allows to define all the concepts as well as the relationships between them, in order to define interoperability in the context of Internet of Things.

The work presented in [3] described our generic IoT interoperability architecture allowing to generate other specific physical architectures which perfectly meet the need of best practices for IoT applications. These practices consists of : (1) achieving interoperability between IoT platforms thanks to the automatic generation of specific models and the use of MDA (Model Driven Architecture), especially the bridge element of the architecture. We can therefore benefit from interoperability even between the specific architectures generated, which ensures better interoperability between IoT architecture and platforms.

Another good practice is (2) technical transparency guaranteed by the use of our generic IoT architecture of interoperability. Hence, project leaders can generate their physical architecture proposals specific to their needs, and then estimate materials and implementation costs in advance, and maximize productivity, [1]. Two other good practices are: (3) defining an interoperability meta-model [4] and (4) the study of a new quality model of interoperability for connected objects [5].

b) At Cloud Level: In our previous works, we have also proposed an architecture which has been progressively developed through different use cases such as cattle behavior [6], [7], [8], Farm animals' behavior [9], the health of beehives [10], connected pivot-center irrigation [11], landslides monitoring [12], elderly and patient monitoring [13], urban gardening [14], smart poultry [15], smart home [16], smart building [17], smart cities [18], and digital phenotyping [19] [20]. In all these use cases, Lambda architectures were used to ingest streaming time series data from IoT devices. Cattle, farm animals' behavior and the health of beehives behavior consumes relevant data from Inertial Measurement Unit (IMU). These data are transmitted by using the LoRaWan protocol or locally stored on the device. They are discharged offline and then ingested by batch processing of the Lambda Architecture. Pivot-center irrigation and digital phenotyping were integrated into the lambda architecture. In this paper, we adapt previous cloud architecture for personal phytotron using heterogeneous material in various conditions.

B. Related Works

Sani *et al.* [21] have suggested a web monitoring platform using wireless sensors and an actuator network of a aeroponics grow chamber in which temperature, light intensity, and pH level are transmitted via internet to a server via GSM/GPRS and displayed on a website. However, in case of network unavailability, the system cannot work. To address this issue, we control locally the installation on a low-cost compatibility platform and then export data to the cloud. Fernando *et al.* [22] have designed a fuzzy logic controller based on 12 fuzzy logic rule, to control the temperature, relative humidity and Carbon Dioxide (CO_2) inside a prototype growth chamber. The proposed model automatically adjusts the inside parameters to obtain the optimum plant environment condition and minimize energy consumption. Fuzzy logic rules are difficult to understand for general public; we use a decision tree that is easier to understand. Grindstaff *et al.* [23] have proposed an affordable remote monitoring of plant growth using open source software and combining sensing (temperature, humidity, and light intensity), cloud storage, image capture, and alerts, into a single platform. Our architecture proposition offers a more flexible interoperability and integration with existing IoT platforms.

Cabaccan *et al.* [24] come up with the use of network nodes composed of a Raspberry Pi, temperature, humidity and light sensors, and a real-time clock. Theses nodes communicate wirelessly with the base station. A Graphical User Interface (GUI) developed with Matlab allows to visualize the acquired data. Jagadesh *et al.* [25] have developed a system of sensing and actuating for aeroponics system using Cloud Infrastructure Management Interface (CIMI) which allows interoperability between a consumer and multiple cloud providers that all offer the standard CIMI interface for managing a cloud infrastructure. Ferrer *et al.* [26] have described the OpenAg^{TM} Personal Food Computer (PFC) an open source and open hardware platform coupling a Raspberry Pi 3 and an Arduino Mega 2560. Moreover, the PFC allows its users to create, store, and share the data generated during the growth cycle.

III. Our Proposition

Our proposition is a Phytotron also called culture chamber, or growth chamber actually allows to control artificial environment of growth in order to improve the natural growth of plants. The aim of this article is to design a versatile device that can be used on different types of hardware and can be interfaced with existing systems such as openHAB[1], home-assistant[2], Node-Red[3], etc via MQTT protocol.

A. IoT Interoperability Architecture

As shown Fig. 1, our IoT Interoperability Architecture is organized around 7 layers (from bottom to the top): (1) The infrastructure Layer connects all sensors and actuators; (2) The Information Layer collects data from the Infrastructure Layer; (3) The Communication Layer transmits data according to various communication protocols; (4) Connectivity Layer ensures the interoperability between different protocols of communications; (5) Middelware Layer normalizes data, centralizes them in the cloud before their storage; (6) Service Layer is the decision aim which control and automate the

[1]https://www.openhab.org/
[2]https://www.home-assistant.io/
[3]https://nodered.org/

phytotron; (7) Application Layer exploits the data produce by Service Layer and make it familiar to user.

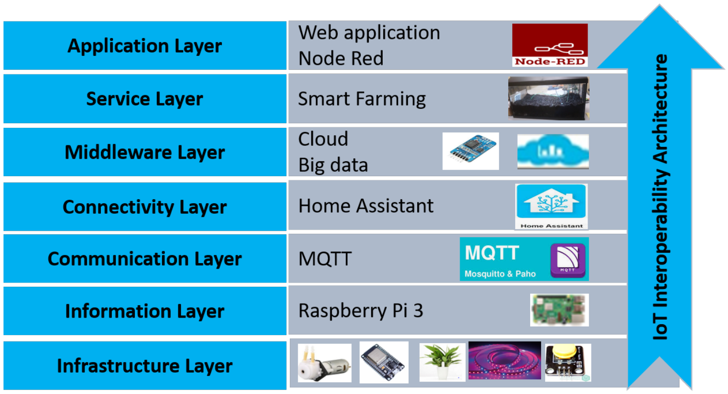

Fig. 1. Proposed Architecture

B. Cloud Architecture

Our Cloud Architecture is located at Middelware Layer level, as shown in Fig. 1. It is composed of a Lambda Architecture built around Apache Kafka. This architecture has been widely described and validated in various use cases in our previous papers such as cattle behavior [6], Farm animals' behavior [9], the health of beehives [10], connected pivot-center irrigation [11], landslides monitoring [12], smart campus [27], bird nesting [28], AI-IoT [29], elderly and patient monitoring [13] and digital phenotyping [19].

C. Personal Phytotron Prototype

A global schema of our prototype is presented in Fig. 12, at the end of this paragraph. The Fritzing file is available on GitHub, see section supplementary material. Our proposition is built around ESP32 microcontroller, which is low-cost, and support Over-the-air (OTA) programming as well.

In the subsequent paragraphs, we will describe the main components that we used to achieve our phytotron prototype.

1) **Central Control System:** consists in a microcontroller ESP 32 which connected with sensors and actuators, a real-time clock, and a power supply DC 5V.

   the ESP-WROOM-32: is equipped with a Wi-Fi and a Bluetooth interfaces that allows it to communicate with the local gateway configured as Access Point. We use Arduino IDE to program it in the same way as an Arduino UNO. ESP-WROOM-32 contains a Xtensa dual-core 32-bit LX6 microprocessor at 240 MHz, 520 KiB SRAM, 4 MiB Flash Memory. Moreover, it provides 12-bit SAR ADC up to 18 channels, 2 DAC of 8-bit, 10 GPIO, 4 Serial Peripheral Interface (SPI), 2 Inter-IC Sound (I^2S), 2 Inter-integrated Circuit (I^2C) (Fig. 2).

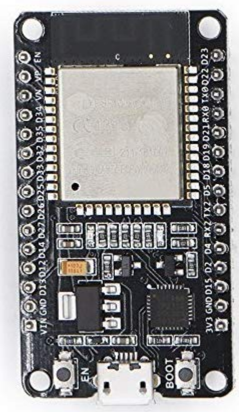

Fig. 2. Microcontroller ESP-WROOM-32

The DS3231 is a low-cost, and extremely accurate I^2C real-time clock (RTC) with an integrated temperature-compensated crystal oscillator (TCXO). The RTC plays a crucial role in the automation of control processes of environmental condition. This RTC is also equipped of a 32Kbits EEPROM allowing to store next step in the plant growing process which guarantees the operation of the installation in the event of a network failure. A DC 3V lithium battery ensures the power to the real-time clock for 10 years (Fig. 3).

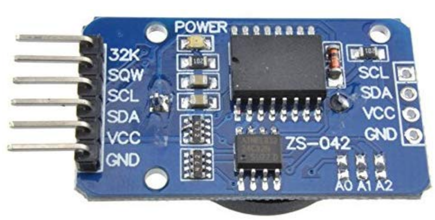

Fig. 3. Real-Time Clock I^2C

2) **Sensors:** acquire air temperature and relative humidity, soil moisture, light intensity data required to evaluate environmental conditions of plants. Table I provides an overview of technical characteristics of sensors used.

   The AM2302 (Aosong) is a I^2C sensor with a pull-up resistor of 5.1 Kohm that allows to measure the Air temperature in Celsius degree and Relative Humidity expressed in percent. The range of measure for the temperature is comprise between -40°C and 80°C with an accuracy of ± 0.5°C while humidity can be measured between 0% to 100% with an accuracy between 2% to 5 % (Fig. 4).

   The resistive soil moisture sensor measures the quantity of water contained in the soil porosity. A resistance

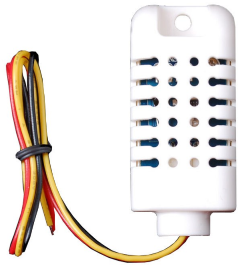

Fig. 4. Temperature and Humidity Digital Sensor

value between 0 to 300 corresponds to a dry soil. Values between 300 and 700 represent a humid soil while values more than 700 are saturated in water soil. The Module also contains a potentiometer which will set the threshold value. This threshold value will be compared by the LM393 comparator. The output LED will light and down up according to this threshold value. (Fig. 5)

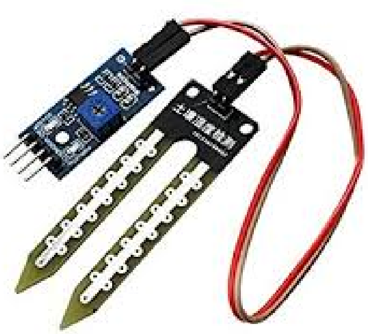

Fig. 5. Resistive Soil Moisture Sensor

The AS7265x (SparkFun Qwiic) is a Triad Spectroscopy Sensor (AS72651, AS72652, and AS72653) which can detect 18 individual light frequencies from 410nm to 940nm each with 20nm with precision down to 28.6 nW/cm2 and accuracy of +/-12%. (Fig. 6).

The HC-SR04 is an ultrasonic sensor able to measure distance between 2 and 400 cm with an accuracy of 3 mm in optimal condition. The sensor emits a sonar wave composed of 8 pulses at 40 kHz. We use it to measure the water level in the tank (Fig. 7).

3) **Actuators:** are used to control environmental variables impacting growth plant such as lightning, soil moisture, air temperature, and air humidity.

A 5V 4 Channel Relay interface board equipped with high-current relay with a maximum load of AC250V

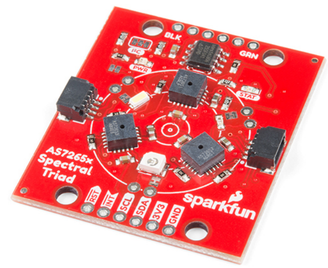

Fig. 6. Triple micro spectrophotometer

Fig. 7. Ultrasonic Sensor

10A or DC30V 10A. Relays isolate by optocoupler operate at DC5V with a trigger current of 5 mA (Fig. 8).

Fig. 8. 4 relays card isolate by optocoupler

A DC12V dosing pump is a peristaltic pump able to deliver a flow range between 0 and 100 ml / min. It distributes water and nutriments in the growth chamber. The flow must be calibrated in operating conditions and then the activation time is calculated in from water volume to transfer (Fig. 9).

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LED Grow Lights Strip is used to increase significantly the natural speed of grow of plants. Ribbon of leds mix red leds with blue leds with a ration 3:1 to 5:1; red leds promote the growth while blue leds stimulate the flowering (Fig. 10).

Air Flow Fan 12 VDC allows to extract excessive

TABLE I
POWER CONSUMPTION ACCORDING TO MANUFACTURER'S DATA AND INTERFACE OF CONNECTION

Component	Interface	Operation mode	Supply Current (Max)	Voltage
Liquid Crystal Display (LCD 2004)	I^2C	Current	200 mA (Backlight 180 mA)	5V
Real-time Clock (DS3231)	I^2C	Active / Stand-by / Conversion	300 μA / 170 μA / 650 μA	5V
Triple micro spectrophotometer (AS7265x)	I^2C	Active	112 mA	2.6 to 3.6V
Temperature & Relative humidity (AM2302)	Digital	Stand-by / Measuring / Converting	50μA / 1.5 mA / 2.5 mA	3 to 5V
Moisture Sensor	Analogical	Current	35 mA	3.3 to 5V
Ultrasonic sensor	Digital	Sleep / Normal	2.5 mA / 20 mA	4.5 to 5.5V

Fig. 9. Irrigation peristaltic pump

Fig. 10. Grow Led Strip

humidity or lower the air temperature when it is too high (Fig. 11).

Fig. 11. Air Flow Extraction

4) **Home assistant / MQTT Server:** A Raspberry Pi 4B runs on last release of Hassio and hosts the last release of Apache and Eclipse Mosquitto^{TM} which are respectively a web server and a MQTT server supporting the MQTT protocol versions 3.1 and 3.1.1. MQTT is an extremely lightweight publish-subscribe machine-to-machine protocol where published data is automatically sent to all subscribers.

IV. RESULTS

Our prototype system is built with a 60 liters aquarium. This tiny phytotron allows us to grow Moroccan mint with a growth rate of 3 to 4 times faster than the natural growth (Fig. 13).

The ESP32 microcontroller of our prototype publishes values of sensors and status of actuators on the mosquito MQTT server installed with the Home Assistant. The ESP32 subscribes also to other topics of MQTT Server to provide us with the opportunity to actuate manually the pump, the fan and lights. Home assistant is used to visualize data sent on MQTT topics and proposes also a User Interface (UI) with switch to turn on/off actuators. Our prototype has also been tested with OpenHAB and Node-Red which can connect to MQTT Server and publish / subscribe to topics (Fig. 14).

Each installation is described by means of a semantic description that is a JSON file containing a unique identification, the owner of the installation and a description of the system, sensors and actuators (Fig. 15).

Users have the possibility to edit and share their growth recipes. An extract of a recipe for Moroccan mint (Mentha spicata 'Nanah') is illustrated in Fig. 16.

V. CONCLUSION AND FUTURE WORKS

In this paper, we propose a low-cost home phytotron built with on open source and an open hardware using IoT Compatibility Architecture to manage and interoperate various protocols of communication. The community has also the possibility to exchange recipe of growth and contribute to improve the project. Thanks to the proposed architecture, we are able to employ any installation using MQTT protocol and integrate it in existing home system such as Home Assistant, OpenHAB, etc.

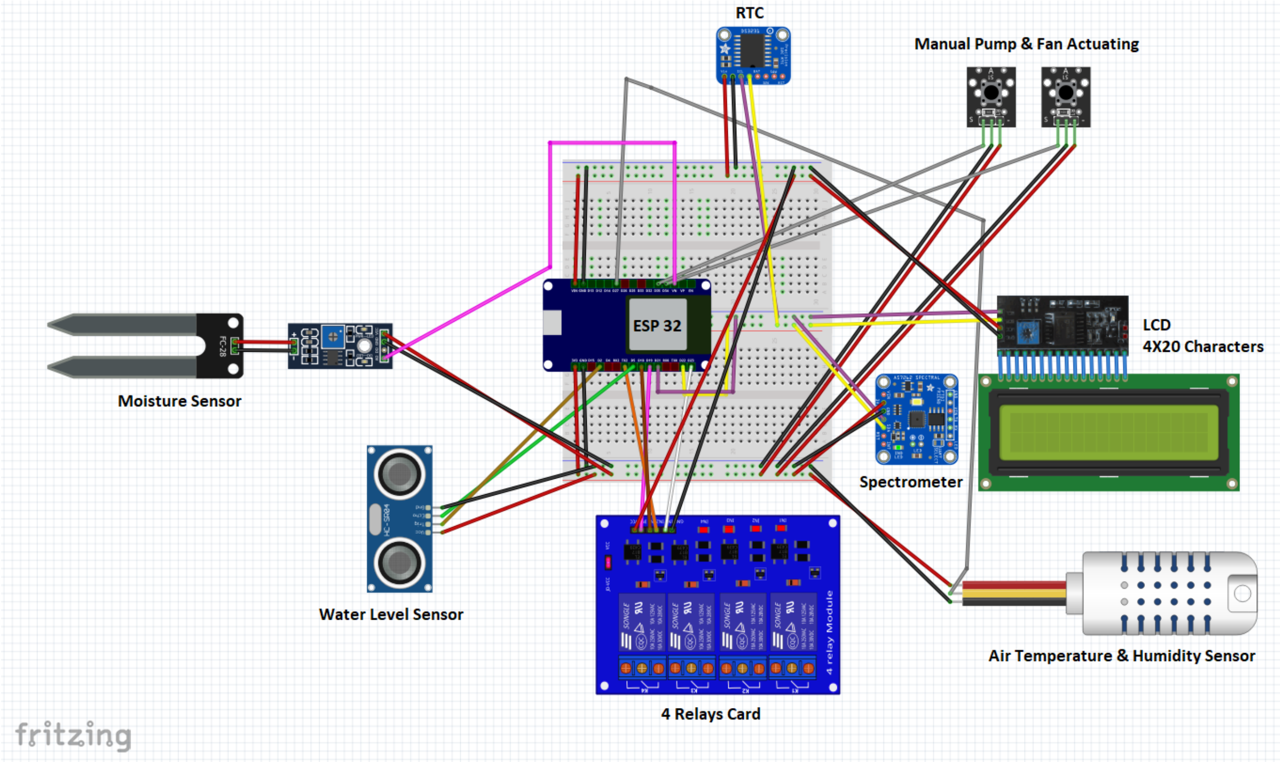

Fig. 12. Schema of the prototype

Fig. 13. Our prototype of phytotron

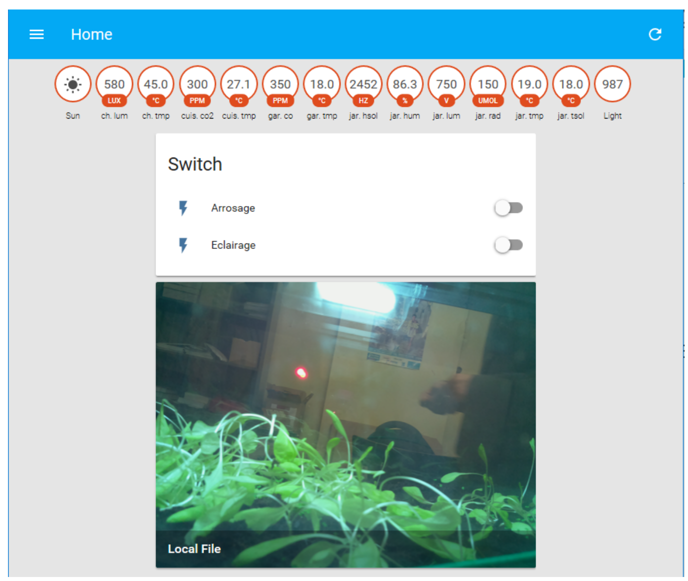

Fig. 14. Our Prototype integrated in Home assistant

In our future works we will evaluate the possibility to replace the resistive soil moisture sensor and the light sensors by a Xiaomi Mi Flora which contains temperature, soil moisture, light sensors also a soil conductivity monitoring. This sensor communicates with ESP32 with BLE protocol. ESP32 should be connected with a network of Mi Flora to manage a more important volume personal phytotron. Moreover, the use of several sensors improve the reliability of the phytotron. Afterwards, developed concepts in this paper, will be applied to aeroponic, hydroponic and aquaponic installations.

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```
{"_id":"84deb264f70e8f957fcf8f7b050015b7ee656396",
"owner":"WeboT",
"system":[
    {"type":"microcontroller","model":"ESP32","manufactory":"Expressif","voltage":5,"voltage_type":"DC"},
    {"type":"rtc","model":"DS2331","manufactory":"?","input":"I2C","voltage":12,"voltage_type":"DC"}],
"sensors":[
    {"type":"light","model":"TSL2591","manufactory":"Adafruit","input":"I2C","min":0.000118,"max":88000,"precision":1,"unit":"lux"},
    {"type":"temperature","model":"AM2302","manufactory":"Adafruit","input":"digital","min":-40,"max":80,"precision":0.5,"unit":"degree celsius"},
    {"type":"humidity","model":"AM2302","manufactory":"Adafruit","input":"digital","min":0,"max":100,"precision":"3%","unit":"%"},
    {"type":"moisture","model":"?","manufactory":"?","input":"analog","min":0,"max":4095,"precison":1,"unit":"-"}
],
"actuators":[
    {"type":"relay","model":"4 Relay card","manufactory":"?","number":4,
        "link":[
            {"type":"light","model":"growth led strip","manufactory":"?","value":"3:1","voltage":12,"voltage_type":"DC"},
            {"type":"light","model":"growth led strip 5:1","manufactory":"?","value":"5:1","voltage":12,"voltage_type":"DC"},
            {"type":"pump","model":"peristaltic pump","manufactory":"?","value":"0-100ml\/min","voltage":12,"voltage_type":"DC"},
            {"type":"fan","model":"fan 40x40 mm","manufactory":"Sunon","value":"340m\u00b3\/h","voltage":12,"voltage_type":"DC"}],
        "input":"digital","voltage":5,"voltage_type":"DC"},
    {"type":"display","model":"LCD 2004","manufactory":"?","input":"I2C","voltage":5,"voltage_type":"DC"}]
}
```


Fig. 15. Phytotron Semantic Description


```
{"_id":"e717a45650f6a129deddd1c7cb7e8dc7a724469b",
"Source:84deb264f70e8f957fcf8f7b050015b7ee656396",
"author":"WeboT",
"version":"1.03",
"trigger": [
    ["moisture": 450]
]
"operations": [
    [0, "air_temperature", 25],
    [0, "air_humidity", 25],
    [0, "light1", ON],
    [0, "light2", OFF],
    [5400, "light1, OFF"],
    [5400, "air_temperature", 20],
    [5400, "air_humidity", 25],
    [10800, "air_temperature", 25],
    [10800, "air_humidity", 25],
    [10800, "light1", OFF],
    [10800, "light2", ON],

    ...
]
}
```


Fig. 16. Extract of a recipe example

Supplementary Material

All script source codes for installing, setting up our prototype and Fritzing schema are publish under MIT license on Github at url: https://github.com/Smartappli/IoTDemonstrators /tree/master/Phytotron.

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