Development of Extraterrestrial Food Production Systems: an Application of Mechatronics and the Internet of Things

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Economic Development, Jobs, Transport and Resources

Image Source: NASA – JPL

Adaptation from Simulation of Hubble Telescope Image

Outline

- Controlled-Environment Agriculture (CEA)
 - Terrestrial CEA
 - Extraterrestrial CEA
- Internet of Things (IoT)
- Mechatronics
- Application of IoT & Mechatronics to CEA
 - Research challenges
 - Pilot project in progress
 - Future plans
- Conclusions

Controlled-Environment Agriculture (CEA)

Terrestrial CEA concept





Terrestrial CEA – Yield Multipliers

- Simulation Parameters:
- Sampling: Latin Hypercube
- Random Number Generator: Mersenne Twister
- No. of Trials: 5000



Multipliers: more harvests , higher planting density, no cost for transportation, longer shelf life, 10-shelf growth chamber

Glasshouse vegetables: kale, spinach and lettuce



Yield Improvement by CEA = 78 x Field Agriculture

Source: Benke and Hale, 2018

Extraterrestrial CEA

Mars food production concept



Source: CNBC

Extraterrestrial CEA

In the case of Mars there are five primary problems:

- (1) Low temperature
- (2) Low atmospheric pressure
- (3) Low gravity
- (4) Low photosynthetically active radiation (PAR)
- (5) Unknown nutrient supply and cycling capacity

These problems are amenable to engineering and plant genetic solutions. A multidisciplinary approach is needed to address questions relating to systems functionality and sustainability.

Source: O'Leary and Benke, 2018

Internet of Things

- Many sensors and actuators communicate over wireless networks
- Many application domains including agriculture vertical market
- Domain independent services horizontal market



Source: Al-Fuqaha et al, 2015

Mechatronics

- A combination of mechanical and electronic devices
- Includes sensors, actuators and processors forming control systems
- Many application areas including aerospace and biosystems engineering



Source: Marquette University

Application of IoT & Mechatronics to CEA - Research Challenges

- Harsh extraterrestrial environment
 - high solar radiation
 - extreme temperatures
 - vibrations
 - low power consumption/power harvesting needed
 - communication delays with Earth
- Need for fail-safe hardware & software
 - limited availability of spare parts
 - limited human skills robots needed
- Security challenges for terrestrial CEA
 - authentication
 - confidentiality
 - access control

Source: Tzounis et al, 2017

Application of IoT & Mechatronics to CEA - Research Challenges

A need for Big Data Analysis and Machine Learning



Machine Learning Approaches Artificial Neural Network (ANN) Random Forest (RF) Generalised Linear Mixed Model (GLMM) Support Vector Machine (SVM) Classification and Regression Tree (CART)

risk assessment and uncertainty analysis

Source: Mahdavinejad et al, 2018

CEA-IoT Pilot Project in Progress

Hardware Components used to date

Evaluation of sensors, wireless communication & data analysis in experimental greenhouse



Wireless Sensor Network

Sensors can monitor temperature, humidity, light exposure, soil moisture, biological parameters, etc

So far we have built a basic WSN sending data from a few sensors to an internet gateway using Zigbee protocol, storing in a local database and serving data over the internet



Zigbee Based Wireless Sensor Network

Website prototype for CEA Sensor Readings Database

- Display of sensor readings on local database
- Accessible over internet
- Time series analysis
- Visualisation
- Algorithmic analysis
- Machine learning

🗅 Richard's IoT/agtech Website 🗙 🕂

← → C ① Not secure | 192.168.1.107/CEA_Database.php



This database uses SQLite on an Nginx web server, hosted on a Raspberry Pi ${\rm 3B}$ Microprocessor

For online documentation please refer to: nginx.org, sqlite.org

Public URL: http://194.223.17.121/CEA_Database.php

This URL is set by DHCP, so changes from time to time

Sensor Value Date/Time

(LDR:Light Dependent Resistor, TEMP:Temperature, HUM:Humidity) {"new_field":"LDR","value":"","date":"2018-11-1907:26:10"} {"new_field":"LDR","value":17,"date":"2018-11-1907:26:10"} {"new_field":"LDR","value":"","date":"2018-11-1907:26:10"} {"new field":"LDR","value":855,"date":"2018-11-1907:26:11"} {"new_field":"TEMP","value":22,"date":"2018-11-1907:26:11"] {"new_field":"HUM","value":17,"date":"2018-11-1907:26:12"} {"new_field":"LDR","value":864,"date":"2018-11-1907:26:22"} {"new_field":"TEMP","value":22,"date":"2018-11-1907:26:22" {"new field":"HUM"."value":17."date":"2018-11-1907:26:22"} {"new field":"LDR","value":860,"date":"2018-11-1907:26:32"} {"new field":"TEMP","value":22,"date":"2018-11-1907:26:33"} {"new field":"HUM","value":17,"date":"2018-11-1907:26:33"} {"new field":"LDR","value":863,"date":"2018-11-1907:26:43"} {"new field":"TEMP","value":22,"date":"2018-11-1907:26:43" {"new_field":"HUM","value":17,"date":"2018-11-1907:26:43"} {"new_field":"LDR","value":864,"date":"2018-11-1907:26:54"} {"new field":"TEMP","value":22,"date":"2018-11-1907:26:54"] {"new_field":"HUM","value":17,"date":"2018-11-1907:26:54"} {"new field":"LDR","value":863,"date":"2018-11-1907:27:04"} {"new_field":"TEMP","value":22,"date":"2018-11-1907:27:05"}

Mechatronics & IoT applied to CEA – Pilot Project in Progress

Experience of Team Members

Technology	Hardware, software, firmware
Embedded Computing	Arduino MCU, ESP8266 MCU with wifi, Raspberry Pi (R Pi) MP with wifi, Raspbian operating system
Wireless Communication	XBee wireless module, XCTU software for Windows, Zigbee protocol, Wifi protocol, MQTT protocol
Sensors	Temperature/humidity (DHT11), Luminosity (LDR), Photosynthetically active radiation (PAR), Atmospheric pressure
Local Databases	SQLite for R Pi
Web Servers	Nginx for Raspbian, Mosquitto MQTT broker for Windows & Raspbian
Programming Languages	C, C++, Java, Python, SQL
Cloud Computing	Amazon Web Services (AWS)
Big Data Analytics	Predictive Analytics, Data Mining, Data Visualisation

Requirements for Research and Development

- Research Platform on Earth: Controlled-Environment Agriculture (CEA)
- **Specialist Team:** Training in Agronomy, Computer Science, Horticulture, Mathematics, Operations Research, Physics and Engineering.
- **Experience:** Hardware Integration, Software Development, Modelling and Simulation.
- **Tools:** Data Analytics, Statistics, Simulation, Hydroponics, Plant Science.
- **Research Translation:** Advanced sustainable food production on Earth.

Future Plans

Extend current project development

- Larger wireless network
- Store data on cloud (protocols etc)
- Sensors needed for extraterrestrial CEA
- Biosensors for food production & waste disposal
- Intelligent signal processing
- Big Data analytics (data mining, data visualisation, predictions)
- Experimental greenhouse
- System optimisation

Conclusions

- Controlled-environment agriculture (CEA) future potential for food
 production on Earth and for extraterrestrial exploration
- Extraterrestrial CEA much more research needed for Mars mission
- Internet of Things & Mechatronics enabling technologies for CEA
- Multidisciplinary research needed in CEA Our research team has started work on a pilot project applying IoT technology to CEA
- Collaboration and Research Funding needed for programme expansion