66044: Flexible Automation
Agriculture in controlled environments

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Abstract

The goal of this article is to present a few of implemented technologies that deal with agriculture in controlled environments and propose a new approach, as a part of a holistic system that deals with the problem of food production and distribution on a mass scale. The main tool in solving this problem is flexible automation. The report discusses different techniques of agriculture in context of controlled environment, followed by several examples of implemented applications. Lastly a project is presented as part of a holistic approach to the stated problem.

Introduction

According to United Nations Development Programme (UNDP) humanity is facing several challenges on a global scale in the 21th century and has therefore set Sustainable Development Goals (SDGs), which include:

1. No poverty
2. Zero hunger
3. Good Health and Well-being
6. Clean water and sanitation
7. Affordable and clean energy
11. Sustainable cities and communities
12. Responsible consumption and production

Those goals are strongly related to Millennium Development Goals also set by the UNDP. Several projections published in the year 2015 by the United Nations, Department of Economic and Social Affairs, Population Division on the global population suggest a high probability of having approximately 10 billion people by the end of the 21st century.

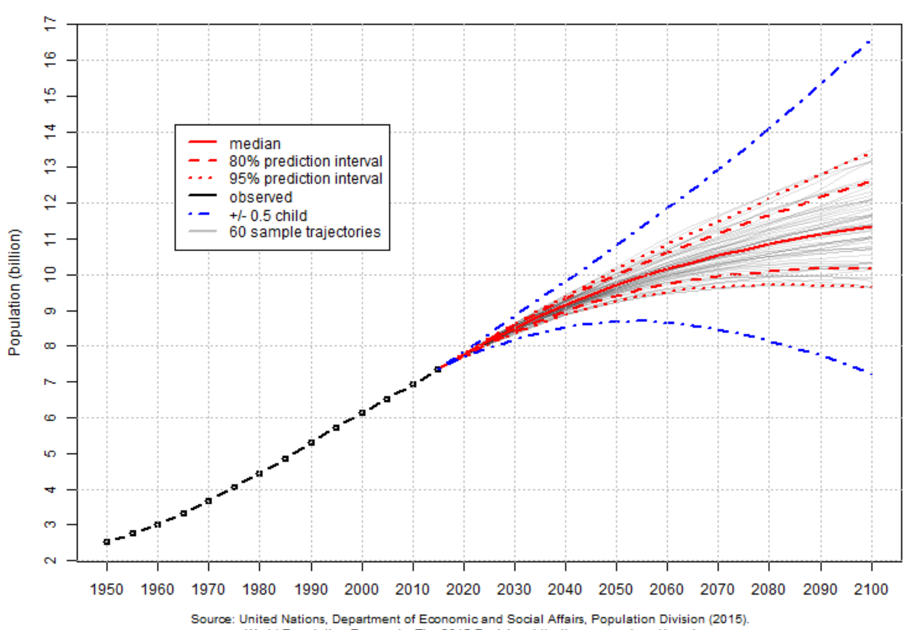

Figure 1: Projections of the total world population by the DoEaSA of the UN.

Considering the above, the engineers of today and tomorrow have to solve the problem of production, distribution and conservation of food and water on a global scale in a sustainable way. The space agencies and private sector of the space industry face similar challenges with their goals of establishing bases on the Moon, Mars and other spatial bodies. Those problems can be solved using agriculture in controlled environments.

Definitions and characteristics

Flexible automation

Flexible automation is the ability for a robot or system to be quickly and easily re-tasked to change product design for both low and high mix manufacturing. When properly utilized, a flexible automation cell can evolve with process and demand, reduce costs and reaction time to engineering changes, improve quality, and eliminate health and safety issues. In other words flexible automation is a more efficient approach in automation of processes.

A very important characteristic of the flexible automation is that it keeps the production cost flat by eliminating the need for custom tooling and fixturing on future products. By being able to adapt and re-task on the fly, production cost can be fixed whether for manufacturing a small batch of parts or a large run of parts. This also means that less resources are being used for a much broader application range.

Flexible automation systems mainly comprise of three components:

1. Sensing: Gather relevant information about surroundings and processes from sensors through vision systems, force sensors, lasers
2. Thinking: Utilization of sensory information by software or hardware like PLCs, microprocessors and neural networks
3. Action: Complete task by guiding robots and machinery using gantries, grippers and other actuators

Controlled environment agriculture

Controlled Environment Agriculture (CEA) is defined as a combination of engineering, plant science and computer managed greenhouse control technologies used to optimize plant growing systems, plant quality, and production efficiency, mainly by manipulating the environment to the desired conditions. Controlled variables include temperature, humidity, acidity or alkalinity (pH), electrical conductivity, carbon dioxide (CO2) and nutrient analysis.

Controlled environment agriculture provides separate control of the root-zone environment as well as secure, healthy, and cost effective year-round production of many premium edible, ornamental, and high value plant species. It introduces more flexibility and stability in food production, since most controlled environments are independent of their surroundings and can be adjusted to completely different conditions if necessary.

CEA technologies include geoponics, hydroponics, aquaponics and aeroponics.

Farming techniques

- Geoponics

  It is the conventional cultivation of crops in soil. Different techniques involving geoponics include polyculture, crop rotation, companion planting and use of fertilizers and pesticides.

  Hugelkultur is one of possible improvements of geoponics. It involves burying large woody material to create a raised garden bed. This technique uses up rotting wood, twigs, branches and even whole trees that would otherwise go to the dump or be burned.The layers decompose slowly, creating rich humus over four or five years and resulting in very fertile soil. The wood in the bed also holds water and prevents nutrients excess from passing in the ground water. This makes hugelkultur very suitable for growing garden crops in the desert with no irrigation.

  Another possible improvement of geoponics is agroforestry. This is the intentional integration of trees and shrubs into crop and animal farming systems. This land management system combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy, and sustainable land-use systems. Merging forestry with crops cultivation offers protection against strong winds and higher total output per unit area of tree/ crop/livestock combinations as compared to single component alone. There are five popular categories of agroforestry: silvopasture, alley cropping, forest farming, windbreaks and riparian forest buffers.

Those improvements require robotic solutions that adapt quickly to new circumstances, which is the main characteristic of flexible automation. Mobile robots equipped with sufficient sensors and adaptive algorithms should be able to complete necessary tasks in those environments, even if the areas would not be fully controlled.

- Hydroponics

  Hydroponics can be simply defined as the technique of growing plants without soil. The plants are provided the necessary elements and nutrients but using mineral nutrient solution or an inert medium. Soil has played its role in agriculture as holder of nutrients and base support for the plants. Taking soil out of the agriculture, gives the advantage of eliminating soil borne diseases and weeds, and reduced the consumption of water. Moreover, it provides precise control over the plant's nutritional requirements.

  Hydroponic crops are currently grown on more than 40,000 acres all over the world with U.S. accounting for more than 1000 acres alone. They are widely popular in producing certain crops such as tomatoes, lettuce, cucumbers, bell peppers, herbs, foliage plants, and flowers.

  Most popularly used materials for Hydroponics include:

  - Perilite
  - Rockwool
  - Expanded Clay Pebbles

  Two primary growing techniques are:

  1. Drip (also known as Substrate) System
  2. Nutrient Film Technique (NFT) System

  Large scale hydroponics systems usually require a complex automation system that reliably delivers and monitors the nutrients and plants themselves. Since those systems are in most cases expanded with time or the demand for food type changes, flexible automation solutions would be preferred with this technique also.

- Aquaponics

  A technique similar to hydroponics, however additional living systems are introduced to improve efficiency of the overall system by providing necessary filtration and utilization of waste products and at the same time converting those into useful side products. In aquaponics, aquaculture (fish farming) is combined with hydroponic production. The nutrient-rich waste water from the fish tank is pumped through plant beds. Although not as precise as a hydroponic fertilizer mix, the effluent from a fish tank is high in nitrogen and many other elements and most plants do quite well in aquaponics, through this integrated system approach. The key to aquaponics is the establishment of a healthy bacteria population.

  Since aquaponics is dealing with living organisms that are big enough to influence the system in a significant manner, static or conventional automation solutions might not be sufficient or cost effective.

- Aeroponics

  Aeroponics is quite similar to hydroponics with the difference that aeroponics has no growing medium while hydroponics uses water as growing medium. Under aeroponics, plants are suspended in a closed or semi-closed environment and their roots and lower stems are sprayed with fine drops in form of a mist or aerosol of nutrient solution. The roots of the plant are separated by its support structure. This technique reduces water usage by 98 percent, fertilizer usage by 60 percent and eliminates pesticides usage altogether.

A major advantage of aeroponics is that it can limit disease transmission since plant-to-plant contact is reduced and each spray pulse can be sterilized. Even if a particular plant does get diseased, it can be quickly removed from the plant support structure without disrupting or affecting other plants if the supporting structure is designed properly.

The reduction in water required for plant growth and complete elimination of soil offers great reduction in weight. Since reduced payload weight in a spacecraft decreases launch cost and vacates space for other cargo, aeroponics is a very favourable technique for cultivation of crops during long term missions in space. In addition, Aeroponic crops not only offer food but are also a potential source of fresh oxygen and clean drinking water.

Flexible automation should be of interest to almost every aeroponics system, since the requirements can be very strict and different tasks might be needed to be performed quickly.

Overall, automation in the presented agriculture techniques can be implemented in the conventional static approach and in the flexible way. Depending on the application and system, as it is the case in other parts of industry, flexible automation should be more efficient in the long run, even though the initial cost, be it from the economic or resource perspective, is higher, so is the profit and the cost is reduced with new modifications to the system. Out of the presented techniques aeroponics has been claimed by HydroShow.tv and others to be the most efficient one, when it comes to speed and growth.

Urban Agriculture

- Vertical Farming

  The usage of multi level cultivation areas with a smaller base footprint compared to the conventional approach is the definition of vertical farming. Since most cities have a rising population and area constraints, vertical farming could improve the rate of local and regional production, and provide local distribution solutions at the same time. Because of size and mobility constrains, and great demand for food in high density populated areas, high speed flexible solutions are optimal for vertical farming.

- Permaculture

  Permaculture is a scientific approach to ecological design, ecological engineering, environmental design and resources management that results in a sustainable architecture for food production based on multiple social and ethical aspects. Even though after the design phase, the layout of the permaculture area changes slowly over several years, the terrain is usually not uniform. If applied on a larger scale, a flexible solution would be preferable to be used with permaculture.

Implemented applications

Several subsystems of agriculture in controlled environments have been already developed. Most of them however are either still in the testing or prototype phase, or could be considered standalone narrow scope solutions. One should note, that with the current scientific understanding only a global approach to such aspects as food production on a mass scale would be efficient as a long term solution. This also applies to other branches of industry and social life however, and is beyond the scope of this work.

Outer space projects

In order to support life and facilitate successful long-term missions into deep space, it is imperative for the crews to take and grow their own crops. Plants were first taken into Earth's orbit in 1960 on two separate missions Sputnik 4 and Discover 17. As discussed previously, aeroponics is a very efficient way to grow plants, also in outer space.

NASA started investing in aeroponics plant growth experiments in late 1990s. In 1997, NASA-sponsored studies aboard the Mir space station studied adzuki bean seeds and seedlings. While the beans were growing in space zero gravity, similar experiments were performed on earth in parallel. Both sets of plants were treated with similar liquids. It was observed in the end that those aboard Mir space station grew more than those on Earth.

In a recent study, an experiment designed and built by BioServe flew to the Internation Spacec Station (ISS) aboard the NASA Space Shuttle Endeavour on STS-118, in August 2007. One of the challenges was to transport seeds safely to ISS and ensure that they were unable to germinate before the start of the experiment. The AeroGrow Seed Pod, developed by AeroGrow International Inc., was found very suitable for this task.

Almost all space agencies are currently working on technologies to grow food in controlled environments for space missions that will incorporate colonization. Flexible automation is crucial in those programmes, since there are many restraints involved, for example the physical size and weight of the equipment that can be carried on the mission. Universal robots that can readjust to complete different known tasks and new tasks, that neither the crew nor the ground design team anticipated, are imperative. This includes systems that enable to quickly change end-effectors of the manipulators, similar to those offered by ATI Industrial Automation as well as TDM SA and are able to re-adapt on the fly. As one of the more efficient approaches to space exploration

Omega Garden

The Omega Garden Cylindrical Hydroponics Design is a cylindrical turning wheel that can hold and rotate plants around a light positioned in the rotation axis of the structure. It is designed to work with hydroponic technique of cultivation, however other techniques could also be implemented. The continuous rotation mechanism introduces forces acting on the plants that could correspond to strong winds in the natural environment. According to the manufacturer those forces stimulate growth and result in overall more energy carrying plants, which is desirable.

Biosphere 2

The research facility located in Oracle, Arizona in United States of America called Biosphere 2 is to this date the largest closed system ever build. The facility is currently owned and operated by the University of Arizona with main goal in researching the interdependency of ecological systems. One possible result of this research is the development of a model of the ecological mechanisms on our planet. Only two long term missions have been conducted at the site and both faced several challenges like a dropping oxygen level. The human factor did not contribute in obtaining objective data from both long term operations. Structure of the buildings on the site was influenced by the designs proposed by Buckminster Fuller. The main automation aspect consisted in gathering all of the relevant data and making projections based upon those.

Figure 2: The Omega Garden Cylindrical Hydroponics Design system seen from the front. Source: http://www.omegagarden.com/

Proposed application

An autonomous automated nutrients and utilities production facility

Proposed is a fully autonomous automated nutrients and utilities production facility. This project incorporates several of presented ideas and techniques. It also provides an open basis for further development not only restricted to the area of agriculture.
The building is made out of modular floors/levels, where each can serve another function and together create a closed and independent unit. Efficient design is a key element of this project.

Building structure

Conventional building techniques involve adding and removing of building and other materials, which usually is highly inefficient. The proposed design is universal and open for further improvement. The main structure is designed in such way, that it allows each floor to be prefabricated, transported and then assembled at the target area. All structurally imperative connections, all connections for the electrical, gas, water and other utilities are also universal, so that depending on the needs they can be adjusted, made quickly and safely with minimum effort. A similar approach has been presented by the BROAD company, where a 30 storey building consisting out of premanufactured components was risen in 360 hours by 200 workers. One aspect is also to provide the capability to use and test other building techniques like three dimensional printing. An additive manufacturing method not only is in most cases more efficient, but also provides more flexibility with choosing the building area, for example a construction site on a slope of a mountain.

The structure of the building consists out three layers: the inner layer, the main layer and the outer layer.

Inner layer

The inner layer is used for transport, all relevant communication infrastructure and emergency access. For maximum efficiency the transport system should be controlled by artificial intelligence. The main function of the AI would be to optimize the usage of the elevators for minimum time and energy consumption based on the demand by the production facility itself and the outside demand. Further the elevator should be able not only to carry the goods but also machinery, for example transport robots from one floor to another. This way in building with less demand on quick food production only a few robot units could take of the whole building.

Main layer

The main layer is used for the specified function, which in most cases is either geoponics, hydroponics, aquaponics or aeroponics cultivation of food in fully controlled environments. Here similar systems to the Omega Garden would be implemented. However the design of the level would be optimised for food production, the presence of humans would not be considered, since it introduces a whole range of inefficient design requirements. Further the arrangement of the cylindrical mechanisms would be optimised further with usage of aeroponics, where one nutrient transport tube could be used for the cylinders. The cylinders would have a quick switch system implemented, that would allow for very time efficient exchange of cultivated crops by using rails that could be loaded and loaded by a robot and then transported to the elevator.

Additional capabilities of the whole project include electrical energy generation, water, gas and fertilizer production. This means that some levels would be used for functions like storage of gravity filtered rain water, that can be then used within the building itself, but also provide pressurised drinking water for the outside. Electrical energy could be converted into heat and stored in isolated water tanks buried several elevations under the ground. For optimal usage of energy, air as a heat energy carrier should be shared among all levels, however additional filtration using high voltage electrostatic systems might be necessary, since especially aeroponics has very high requirements for sterile environment.

Outer layer

The outer layer of the building consists of the windows and structures outside. One such structure would be an array of solar panels that could be adjusted in pitch and yaw for optimal orientation towards sun and therefore most efficient energy transformation. At certain locations in combination with external mirrors following the trajectory of the sun and redirecting sunlight towards the structure the overall efficiency of the solar array could be increased even further. Additionally water gathering systems could be implemented on top of the building and storage rooms in the underground or ground levels for easier access and more efficient energy usage.

Networking

There are two main automation aspects to this project. First consists of continuous monitoring, data acquisition, analysis and based upon those predictions. The second aspect is the planning and execution of different tasks to continue the production and satisfy the outside demand for goods. Both aspects have to be flexible in such sense, that they can undergo changes during the production cycle, for example because of change in the demand or because certain resources are not available any more. A complex network of sensors and individual actuators would be based either upon an already proven industrial networks like CAN or possibly FlexCAN or a custom implementation. The data would have to be abstracted on several levels, so that it is also readable to humans on the highest levels, but can at the same time be used with the data from other buildings, creating a network that should always allow synchronization of tasks, for example for the purpose of meeting a short-time high priority demand. Such a network would also make it possible to coordinate production of nutrients on a virtually global scale, which should be the ultimate goal.

Universal robot

The second aspect would be based upon a universal robot. That manipulator should be robust, efficiently designed when it comes to resources and using reliable and easily maintained technology. One possible model could be based upon servomechanisms with inductive motors, with a low enough transmission, so that necessary precision without compromising the speed could be achieved. Inductive motors are in less expensive and have a less demanding production process than direct current or synchronous motors. Since they are also simpler in construction, the overall tendency is to have less risk in defects during operation and easier maintenance. One of the design aspects of such a robot should include and fast plug'n'play vital component replacement system, so that the downtime could be reduced to a minimum. The robot would most likely be hanging from the ceiling, so that its mobility would not interfere with goods and at the same time provide accessibility to all areas across all levels independent of the function for the given level. The transportation of the robot would also allow for easier maintenance for human workers, since the building itself would not be designed for human inhabitants.

Mid-term goals

All of the project systems and subsystem would be designed and operated by open and freely available software and hardware solutions to the largest possible extent, so that sharing of ideas and further improvement would be as easy as possible. The main goal of the project is not to make profit, but to solve the problem of food production and distribution. The described design ideas would provide enough autonomous capability for the building, so that it could operate on its own, without the need to access the infrastructure, since one of the main goals would be to surpass self-sufficiency and provide a surplus of resources, in form of electrical energy for example. This would at the same time use the proposed project as a basis for future building infrastructure and solve the problem of distribution of nutrients, especially in difficult to reach areas.

Conclusions

The described solutions address one of the most important challenges humanity is facing during the 21st century, namely how to feed the world. There are multiple social and economic aspects involved that have been omitted, but are of vital importance to the overall progress. Described systems have so far been used as isolated solutions, there have been very few ideas proposed by single individuals that deal with a holistic approach to the food production problem however. Some of those ideas were proposed by Buckminster Fuller, who is also known for his sophisticated geometric designs. Jacque Fresco proposes a Resource Based Economy (RBE) as a sustainable global socio-economic post-scarcity model for humanity. The presented project of an autonomous automated nutrients and utilities production facility could be one of the elements of such a global system and it would be especially vital during the transition phase.

Considering the work several space agencies have done, it is of utmost importance to start seeing planet Earth as another isolated system with finite resources and specific mechanisms in place that are complex, but can be modelled. The Biosphere 2 project did emphasise how little experts from different scientific areas know about the interdependency of ecological systems. The space exploration and colonization programmes focus on the same problems humanity is facing on Earth, but there is no room for those abstract errors that the current socio-economic system introduces in outer space and the effects of those errors are seen without any delay. Exactly the same level of precision and discipline needs to be implemented on a regular basis in global systems, and one of the most important tools to master these challenges is flexible automation. It enables possibilities for high capacity, high speed complex task processing within very limited and restricted environments.

References

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1. http://www.undp.org/content/undp/en/home/mdgoverview/post-2015-development-agenda.html
2. https://www.un.org/development/desa/en/
3. http://cross-automation.com/blog/what-flexible-automation
4. http://www.mwes.com/blog/flexible-automation-what-is-it-and-why-should-manufacturers-consider-it
5. http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=agroforestry.html
6. http://www.appropedia.org/Hugelkultur
7. http://www.richsoil.com/hugelkultur/
8. https://en.wikipedia.org/wiki/Permaculture/Common_practices
9. https://spinoff.nasa.gov/Spinoff2008/ch_3.html
10. https://en.wikipedia.org/wiki/Biosphere_2
11. http://www.nasa.gov/vision/earth/technologies/aeroponic_plants.html
12. http://www.omegagarden.com/index.php?content_id=1500
13. Sheikh, B.A. 2006. Hydroponics: Key to sustain agriculture in water stresses and urban environment, Sindh Agriculture University, Tandojam, Pakistan
14. Sengupta, A. and Banerjee,H. 2012. Soil-less culture in modern agriculture. Bidhan Chandra Krishi Viswavidyalaya, Department of Agronomy, West Bengal, India.
15. http://en.broad.com/video.html?3
16. http://www.news.com.au/travel/travel-updates/chinas-pre-fabricated-future-green-buildings-built-in-the-blink-of-a-eye/story-e6frfq80-1226242302692
17. https://en.wikipedia.org/wiki/Buckminster_Fuller
18. https://en.wikipedia.org/wiki/Jacque_Fresco
19. https://www.thevenusproject.com/en/about/resource-based-economy
20. http://hydroshow.tv/
21. http://tdmspindles.com/multi_product.asp