Robotics for Growing Life

Henrik Hautop Lund

[1] *Technical University of Denmark, 2800 Kgs. Lyngby, Denmark*
[2] *University College Copenhagen (KP), 1799 Copenhagen V, Denmark*
E-mail: hhl@playware.dtu.dk

Abstract

We present a direction of artificial life robotics in which we use robotics to control the growth of real, natural life. The concept of using robotics to grow life presents itself as a proposal for a potential sustainable solution for food production, allowing an optimization of food quality and outcome. The design of these artificial life robotic systems allow for urban farming where food production happens in the close vicinity to the consumer, avoiding the long transportation of food to the consumer. We illustrate this concept with our development of the GrowBot, which is a tabletop size robotic green house for growing edible food plant. The GrowBots use sensors such as humidity, CO_2, temperature, water level and camera sensors, and actuators such as full spectrum LEDs, IR LEDs, UV LEDs, fertilizer and water pumps, air change and air circulation fan. The software acts as recipes for the plant growth in the robotic greenhouse adjusting the environmental condition for the growth of the living plants such as salad, parsley and basil. Changing the recipes, one may experiment and investigate easily to search for optimization for volume production, taste, etc. We illustrate this concept and implementation of artificial life robotics with the growth of Italian basil, *Ocimum basilicum*.

Keywords: Artificial Life, Robotics, Biology, Urban Farming.

1. Introduction

Artificial life is defined as life-as-it-could-be, as compared to life-as-we-know-it [1]. Within artificial life, computer simulations are used to study the development of life in many different forms. In order to study such development in the real, physical world, artificial life robotics developed as a field in which the simulated artificial life organisms were transferred to the physical robots. Artificial life robotics includes biomimetic robotics, in which biology is used as inspiration for creating robots, which in turn can be used as experimental tools to verify biological hypotheses. For example, Lund et al. [2] recorded male cricket *Gryllus bimaculatus* calling song, built a robot with the hypothesised control mechanism for phonotaxis behaviour and verified that it could account for the behaviour by observing the robot doing phonotaxis to the real cricket song. The robot model was implemented as a simple spiking neural network that is less complex than the controllers traditionally hypothesized for cricket phonotaxis and syllable rate preference [3]. Thereby, the robot experiment could be used as an existence proof that such a simple neural network model is enough to account for the complex cricket behavior. The interaction was done between the robot and the live animals, i.e. live crickets / recorded live cricket songs. Also, artificial life robotics is used to study life development in terms of ontogenetic and phylogenetic development, i.e. development attributed to individual life-time experiences with the environment (ontogenesis) and the development attributed to evolutionary process of species over generations (phylogenesis). Ontogenesis is studied with different robot learning methods, and phylogenesis is studied with evolutionary robotics.

In this way, artificial life robotics is used to study the development of life. With the present work, we want to open a direction of artificial life robotics in which artificial life robotics is used not only to study the development of life, but also as a tool to directly grow life. It is not a simulated or virtual representation of life which develops, but it is the actual real life which develops. This allows for new studies and insight into the growth of life and the environmental influence on the growth of life. The robotic system can be used to control environmental conditions, which influence the growth of life. In this way, one can parameterize the growth conditions and with the robotic system investigate how to optimize this parameterization.

The optimization can, for instance, be for height of living plants, canopy size of living plants, taste of harvested leaves and fruits, nutritious value of living plants and insects, energy expense, etc. Applications of this may lead towards an optimization of green food production, towards food production near the consumer in urban areas, and towards food production in otherwise environmental hostile locations for food production (polluted areas, deserts, arctic, etc.)

In this work, we will present an example of robotics for growing life with the development of the GrowBot, which is a tabletop robotic greenhouse aimed for educational use in schools.

2. GrowBot Hardware and Software

The first iterations of our development were inspired by the MIT Media Lab OpenAg food computer [4, 5], before we made extensive changes. The OpenAg met criticism that it was difficult to make the food computer work, to make plants grow, to achieve robustness, and to make the food computers work in school settings [6], and the project was shut down in 2020. In order to address these inadequacies, we used a comprehensive system design method from the area of playware [7] to develop the GrowBots to bring the smart farming approach into use in the educational sector.

The GrowBot is designed as a small, robotized greenhouse for hydroponic farming. The GrowBot measures 450mm x 450mm x 600mm, and consists of a 150mm top part, which holds the electronics – see Table 1 – and the growth-chamber. There is a water tray at the bottom of the chamber. It has a lid with 4 x 4 holes, in which the plants can grow. On the top, there is a 5” touchscreen display and a connector for a micro:bit [8]. See Table 1 for the technical specifications.

Table 1. Main components of the GrowBot.

Description	**Specification**
Processor	Raspberry Pi 4 Model B 2GB
I/O interface processor	16Mhz Arduino NANO V3.0 Atmega328 UNO IO Shield
Wireless communication	Raspberry Pi 4G/LTE with base HAT and antenna on the Quectel EC25 Mini PCle 4G/LTE Module
Display	5" Raspberry Pi LCD touchscreen with 800*480 resolution and 108×64.8mm display area (SKU DFR0550)
Power	12 V Power supply and a 3.3V linear regulator (ADP3338)
PWM controller	PCA9685PW PWM Controller
Air circulation fans	405FH DC Axial fans 9m3/h
LED drivers	LDH45 LED driver
Full spectrum light	LM301B white LEDs
IR light	XLamp XP-E2 IR 730nm
UV light	XLamp XP-E UV 458nm
Heater	Ceramic (PTC) air heating element
PWM Controller	PCA9685PW, PWM Controller
Pumps	DC 12V Air Diaphragm Pump 1.5-2 L/Min
Aeration	Oxygen disk
Humidity and temperature sensor	DHT 22 relative humidity and temperature sensor
CO_2 sensor	MHZ16 infrared CO_2 sensor
Water level sensor	DFROBOT SEN0193 capacity soil moisture sensor
Camera	Raspberry Pi 4 camera 150 degree wide angle 5 megapixels (OV5647 sensor)
micro:bit	BBC micro:bit board

Sensors in the GrowBot include humidity sensor, CO_2 sensor, temperature sensor, water level sensor, and RGB camera. Actuators include full spectrum lights, IR lights, and UV lights, fertilizer pump, water pump, air pump to pump air to the oxygen disk placed in the water tray, air change pump, and air circulation fan.

Fig. 1. The GrowBot

We have designed the GrowBot so that it can be programmed easily with simple graphical block programming. This can happen (i) programming a micro:bit, (ii) programming on the GrowBot display, or (iii) programming on a remote web-interface. With the simple graphical block programming, one can program the GrowBot to control the different environmental conditions, which may influence the growth of the plants, such as daily light cycle, light color, temperature, nutrient level, etc. A web-interface allows remote monitoring of sensory values and camera images.

With the programming of the GrowBot for the experimentation with growth of edible plants such as parsley, salad, and basil, the students can work on optimizing the environmental conditions in the GrowBot for the growth of the plants, e.g. in terms of plant height, leaf size, health of the plants, nutritional value, etc. Their programs can be viewed as recipes for the growth of specific plant species, and the students can exchange these recipes with each other.

3. Experimentation

We performed a number of experiments with the GrowBots to validate the functioning before bringing the GrowBots to schools. In one experiment, we planted seeds for parsley, basil, red lettuce and green lettuce in nine GrowBots, and ran the experiment of 43 days. All GrowBots had a light cycle of 18 hours of light and 6 hours of no light during each 24 hour period. They were programmed to different colored light. Figure 2 shows the reading of the sensory values over a 2-day period from the web-interface. It can be observed that during the night when lights are turned off, the temperature falls, while the humidity and CO_2 rises.

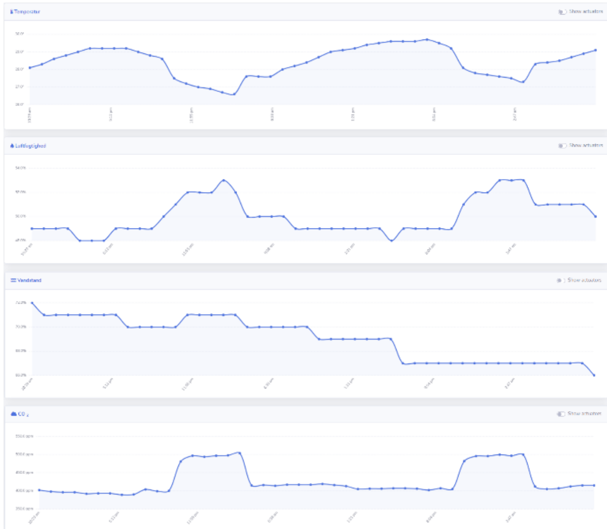

Fig. 2. The web-monitoring of four sensory values over 2 days of experimentation (temperature, humidity, water level, CO_2). It can be noticed that during the night when lights are turned off, the temperature falls, the humidity and CO_2 rises.

Figure 3 shows an example of some of the basil plants harvested at the end of the experiment. Roots were carefully dissected, and the plant weight, height and leaves sizes were measured in the experiment.

Fig. 3. Harvested basil plants from one of the nine Growbots.

With the robotic greenhouse and programming that allows for the careful control of the environmental conditions for growth of life, it is possible to perform numerous experiments that can give us further insight into the growth of life. In the experiment mentioned above, it was found that blue light condition (458nm) gave higher yield than red light condition (720nm) [9].

Figure 4 shows an example from another experiment, in which we investigated the consequences of stress on plant growth with heat stress and nutrient deficiencies. Here, the temperature was set to 29ºC - 35ºC. The nutrient composition was made to lack different chemicals in different experiments, e.g. lack of magnesium (Mg), potassium (K) or nitrogen (N). In the example in figure 4, it is clearly visible how the heat stress and potassium deficient nutrient combination leads to conditions on the leaves such as necrotic spots and chlorosis after merely 6 days [10, 11].

Fig. 4. Heat and potassium stress experiment at day 1 (left) and day 6 (right). Necrotic spots and chlorosis is clearly visible on many leaves after 6 days (right).

4. Discussion and Conclusion

This direction of artificial life robotics uses robotics to control the growth of real, natural life. In the GrowBots, we can for instance control the growth of plants to optimize for food production. The GrowBot robotic system allows us to parameterize life growth conditions for the natural plants through the recipes in terms of temperature, humidity, day light cycle, color of grow light, fertilizing, etc. However, this novel artificial life robotics concept can as well be used to optimize the growth of life in the form of drosophila farms, butterfly farms, and worm farms. Indeed, these can be insect food farms, e.g. for larvae mealworms, crickets, locust, and ants, optimizing the nutritional value and volume outcome by controlling the variables such as temperature, humidity, feed, water sources, and lighting depending on the insect species. Further, the artificial life robotics concept lends itself to studies within synthetic biology and biomedical engineering, e.g. biopharmaceutical production.

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Authors Introduction

Henrik Hautop Lund

Professor, Ph.D. Henrik Hautop Lund, Center for Playware, Technical University of Denmark, is World Champion in RoboCup Humanoids Freestyle 2002, and has more than 200 scientific publications and 5000 citations. He was awarded the Most Outstanding Healthcare Innovator in the World in 2019. Over the last year, he received international awards in Tokyo, Singapore, and London. He has developed shape-shifting modular robots, presented to the emperor of Japan, and has collaborated closely on robotics and AI with companies like LEGO, Kompan, BandaiNamco, Microsoft, Mizuno. He is the inventor of the Moto Tiles (www.moto-tiles.com), which are used by seniors all around the world.