BIO-ENERGY MANAGEMENT FROM MICRO-ALGAE BIO-COMPUTATIONAL BASED REACTOR

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Abstract. Microalgae are a sustainable source of unique properties with potential for various applications. Biofuel production has led to the use of them as bioreactors on an architectural scale. Most of these efforts cannot manage the output due to the lack of intelligent control and monitoring over environmental micro-scale growth. This research presents the possibility of control and monitoring over the bio-energy retrieved through micro-organisms in bio-reactors, specifically the growth environment's computation. To achieve monitoring, three dimensions of the medium culture captured by cameras, and with the advantage of image processing, the picture frames pixel values measured. In this process, we use the Python OpenCV Library as an image processing reference. Finally, a specifically developed algorithm analyses the calculated 3d-matrix. By changing the environmental parameters, control happens by directly recognizing changes in density and outputs. This research's computational process has proposed a novel approach for controlling particle-based environments to reach the desired functions of microorganisms, This approach can use in a wide range of cases as a method.

Keywords. Bio-Computation; Monitoring; Image Processing; Pattern Recognition; Multi-Functional Bio-Materials.

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1. Introduction

Microalgae are photosynthetic microorganisms that live in the aquatic medium culture and can tolerate environmental conditions changes. They can be growth in the medium culture as a group or individually, which changes their unique properties during the growth steps. Microalgae are an essential source of carbon dioxide and various biological products widely used to produce biofuels, food industry, pharmaceuticals, and wastewater treatment (Barsanti et al.2008;Das et al.2011;Brennan and Owende .2010). This materials can be used for a wide range of applications, such as Architectural Component, the use of bio-materials for large scale architectural and engineering applications is still underdeveloped (Benyus 1997; Vincent 2012). In recent years, micro-algae has received much attention as a bioreactor to be embedded into buildings to produce renewable energy (Pasquero and Poletto,2020). In most of these efforts, two main and fixed methods use to cultivate algae: Raceway pond systems and photobioreactors (PBRs). "A typical raceway pond comprises a closed loop oval channel, w0.25e0.4m deep, open to the air, and mixed with a paddle wheel to circulate the water and prevent sedimentation (Ponds are kept shallow as optical absorption and self-shading by the algal cells limits light penetration through the algal broth). In PBRs the culture medium is enclosed in a transparent array of tubes or plates and the micro-algal broth is circulated from a central reservoir. PBR systems allow for better control of the algae culture environment but tend to be more expensive than raceway ponds "(Slade and Bauen 2013). These methods apply for biological fuel production and air purification with limited architectural scale forms. Energy generation through micro-algae is divided into two main phases. In the first step, the biomass that is created by them will collect. In a second step, the biomass is converted into renewable energies through multiple-stages processes such as thermochemical or bio-chemical, which are utilizing expensive equipment with low efficiency (Singh and Sharma,2012). In these processes and methods, parameters such as oxygen and light use to control the growth and outputs efficiency, which is controlled by the timing of oxygen injection or the quantity of light in laboratory environments with limited computing infrastructure. At the architectural scale, due to the reality of various forms and structures and different environmental conditions, the parameters affecting growth perform a more critical role that cannot be calculated with limited laboratory infrastructures. To use personalized bioreactors on the architectural scale, industrialization and, mass customized production, we need to use methods beyond the individual controlling parameters (Haidari et al.2017;Heidari et al.2018;Bitaab et al.2018). That can adapt to different environmental conditions, and in an intelligent interface, it can compute changes with a multitude of parameters. On the other hand, the use of multi-stage energy production methods at the architectural scale, due to various forms, limit the use of this type of sustainable mechanisms in mass production and slow down its development process. When living materials is used in a structure, there are various ways to guide those to the designer's specific goals. In addition, to direct control by DNA and determining their behavior, this control can be done by controlling environmental parameters. Due to various forms on the architectural scale, environmental parameters are set in different

situations and typologies relative to microorganisms. These multiple behaviors with computations in the ideal environment by the handy tools have significant gaps, such as determining microorganism's real-time behavior relative to input parameters and their output efficiency. The lack of integrated biocomputational infrastructure in architecture has led to the lack of development of microorganisms in this area to achieve the goals defined by the architects and designers. These constraints have made bioreactors on an architectural scale limited to specific forms and positions and added to the buildings as separate components. They can additionally identify as building and Form. These restrictions will lead to the lack of development of creative approaches in this field and the death of ideas at the scale of biology and architecture laboratories due to the inability to develop them industrially. To fill these gaps, we need to monitor and control the medium culture designed as a bioreactor to directly change the medium culture growth environment by changing the environmental parameters. These analyses provide the ability to controlling outputs and recognizing, including biological energy, particle movement detection, density, and diffusion.

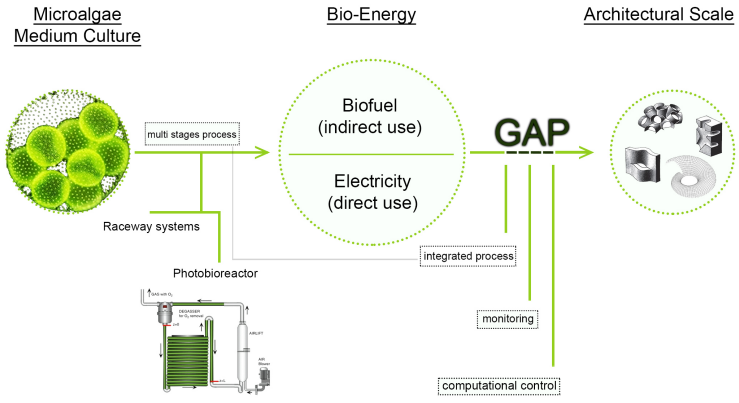

Figure 1. The Gap between biological functions in laboratory and mass customization in architecture.

2. Research Structure

The Western tradition of prioritizing mind over matter, along with the long time governed architectural discourse, developed in the sixteenth century by Leon Battista Alberti, draws a clear distinction between the responsibilities of the architect and those of the builder, separating the mental labor of design from the physical labor involved in materials and construction. (Cardoso Llach,2015). It is important to define the difference between bio-inspired and bio-integrated design.

Biomimicry is defined as imitating or taking inspiration from nature's forms and processes to solve human problems (Benyus, 1997). To use bioreactors as an architectural component, there is a need to design them in various forms, with the ability to control and detect micro-scale particles in them and eliminate the multiple-stages of energy production. In most past efforts, the medium culture's control done through various detection modules, including ultrasonic, thermal modules, or lighting. Due to the real-time changes in the density and diffusion of microorganisms in the growth medium, this sensors and modules methods have computational faults and cannot evaluate at the micro-scale and cover a large diffusion volume. On the other hand, libraries of these modules limit to specific commands that will not support various environmental conditions on an architectural scale. This research's primary focus is on controlling and monitoring the medium culture and their output, which implement the growth process of the specific type of micro-algae called "Spirulina." The multi-stages energy production process is eliminated and performed directly by the electrodes from the medium culture to produce energy connected with microorganisms' growth. Three cameras are placed in three dimensions to implement the monitoring through image processing (top, left, right) to capture the medium culture. The medium culture was captured for four days, with an interval of 15 minutes. To control the growth environment, oxygen used as a critical parameter, If we assume that the flow of oxygen injected into the medium culture on the first day is 1 liter per minute, 1 liter per minute is added to its flow rate daily, and finally, on the fourth day of capturing, it reaches 4 liters per minute, so that the effect of this process changes in output growth and energy. The medium culture's nutrient, including light, temperature, humidity, and the cameras' distance from the medium culture, is fixed and does not change during the capturing days.

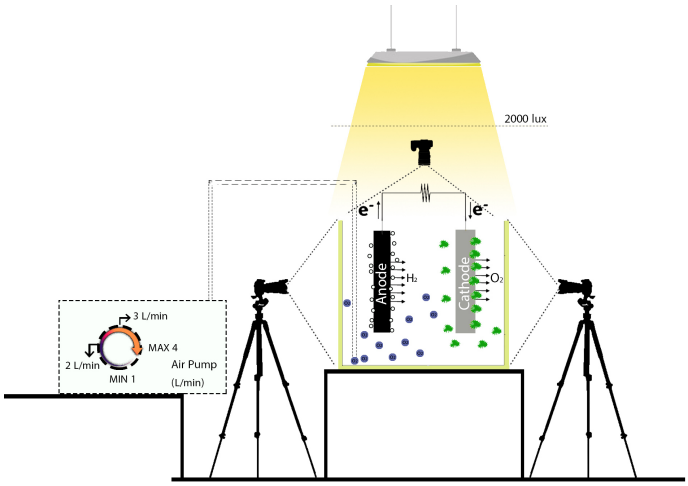

Figure 2. Overview of Project.

3. Material and Methods

3.1. IMAGE PROCESSING

When we talk about image processing, we want to analyze an image's numerical matrix. Matrices in images are the same pixels that make them up, this reason, the capturing resolution of our different dimensions determines the number of pixels and, finally, our matrices' formation. In a two-dimensional image, the pixels are positioned in the x and y directions, each with a numeric value determined by RGB. This value in each image is directly related to the camera settings, which must also be set to RGB. After completing the Image processing in different dimensions, we have a set of medium culture images in triplicate at certain times, which generally determines our microorganism's growth graph at specific intervals. We use the Thresholding method to binary these images and convert them into two colors in black and white. In general, with this method, the images are remapped to the numeric range 0 and 1.

3.1.1. Pre-Processing

Before this round, we need a pre-process to remove the noises from the images. In this project, three steps define to reach this goal. Due to the presence of micro-algae microorganisms in the medium culture, its color composition is in the green range; in the first step, we filter the green color in binary images. After this stage, the image contrast increases, and microorganisms appear in the medium culture. This process changes the triple numeric arrays between the initial 0 to 255 of the images to our regular range, and these high-contrast images can measure by Thresholding.

Noises are pixels with specific numerical values whose value of RGB is unbalanced with the Context RGB value. After increasing the contrast of the images, noises appear in it, and due to the microorganisms' micro-scale, they are known as noise. We use the "Gaussian Function" to remove noises. "Gaussian Function" averages each pixel's numerical values with the surrounding pixels in a two-dimensional range and normalizes them in a specific command. Because of the very small scale of microorganisms, they themselves are also known as noise. We must prevent them from being removed during the Gaussian process. To prevent the removal of microorganisms from images, we use the dispatcher or exclude function. To perform this process, we write a function that, when filtering, Separate pixels whose RGB value is close to the RGB of our particles and put them in those categories, and finally executes the "Gaussian Function" for the unused pixels.

3.1.2. Thresholding

After performing the Gaussian Function and removing the noise, our images are placed close to each other in a specific numerical matrix and ready for the main Thresholding process. In this section, like the Gaussian process, we use the OpenCV library. Before starting the main Thresholding process, the image needs to be Gray style and form the main color handle with values 0 and 1 in the images. Because Thresholding analyzes based on white and black colors, by

doing Gray style, we have helped this process one step to increase its accuracy. Finally, black-and-white images and quantification fall into two general areas of context and particles, the black parts being the same medium culture and the white parts being the same microorganisms. A set of matrix shapes of numbers 0 and 1 shows the density of white parts in black, which is the same as the growth of microorganisms in different time intervals. Furthermore, it shows the growth trend in terms of density. Total density (WS) at time T is the total of two-dimensional densities in three dimensions divided by 3.

3.2. BIOLOGICAL-PROCESS

In this research, to eliminate multiple stages of energy production, a new approach has been used to directly generate electrical energy from an electrolyte solution through copper and aluminum electrodes. The oxygen parameter is injected into the medium culture through an air pump with a maximum transfer capacity of 4 liters per minute. To analyze the effect of environmental parameters on growth and the amount of energy output, the oxygen parameter has been selected as a sample. Its effect on growth rate can be seen through our defined computational process. The ambient temperature is 25 to 28 degrees Celsius, and the amount of direct light in the environment is 2000 lux. The culture medium is a cube with dimensions (20cm * 20cm * 30cm) with 12000 liters of solution. Ingredients of the culture medium, general light, distance of cameras to the culture medium are considered. Details of the ingredients of the culture medium can be seen in full in Table 1.

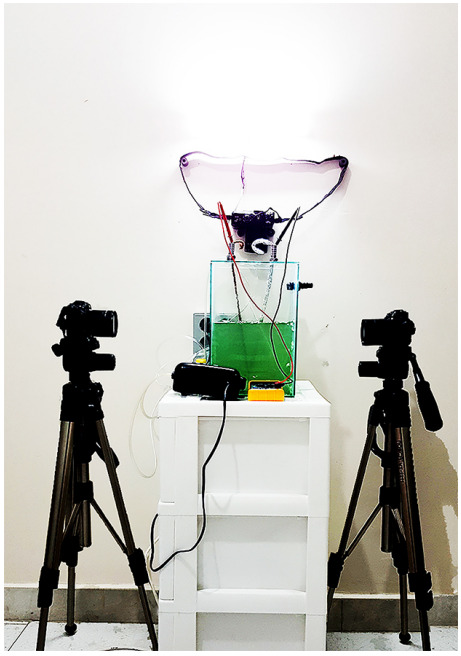

Figure 3. Real-Environment Details.

Table 1. Medium Culture and Environment Condition.

Component	Amount	PH	Temperature	Oxygen Supply	Target Tank Volume	Environmental Light	Microorganism	Medium Culture Amount
Nacl	1g	7	25-28c°	Max: 4 L/min Min: 1 L/min	20*20*30 cm 12000 ml	2000 Lux	Spirulina Algae (6000 ml)	6g
Magnesium sulfate	0.2g	5.5-6.5						1.2g
Sodium bicarbonate	16.8g	8.4						100.8g
Phosphate	0.5g	9.8						3g
Sodium nitrate	2.5g	5.5-8						15g
Potassium sulfate	1g	5.5-7.5						6g
Calcium chlorid	0.04g	5.5						0.24g
Ferrous sulfate	0.01g	2						0.06g
EDTA	0.08g	4-6						0.48g
Solotion A	1ml	7						6ml
Solotion B	1ml	7						6ml

4. Data Analysis

Based on the monitoring process, it is illustrated that as flows increased in a specific time the bacteria density is increased. From the monitoring system, during an independent day, it is achieved that bacteria have a steady growth rate on their own. The bacteria growth ratio is in an increment as the colony density is enhanced and the environment parameters are adjusted to the comfort setting. However, the interesting behavior demonstrated here from the colony is that the growth range will accelerate as the oxygen flows within the vitro. So, the fluctuation of the growth rate is represented here in the graph is because of that. The secret part is that how we can reduce this fluctuation and drive it in a sharp increment way. Thus, we did some controlled periodic flow and trying to set it with the other vitro parameters. The results will be discussed in our future works to use them in analysis phases.

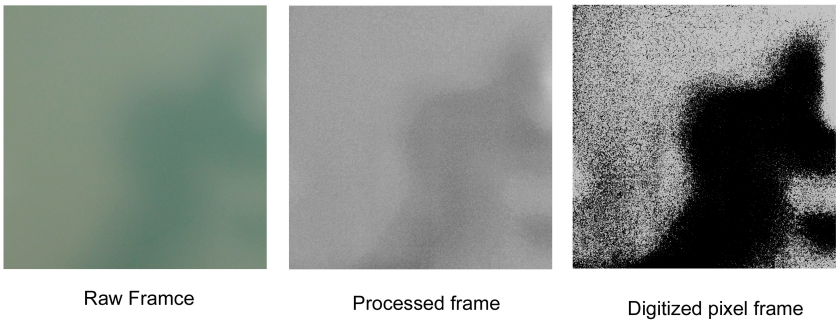

Figure 4. Filtering and Pre-Processing.

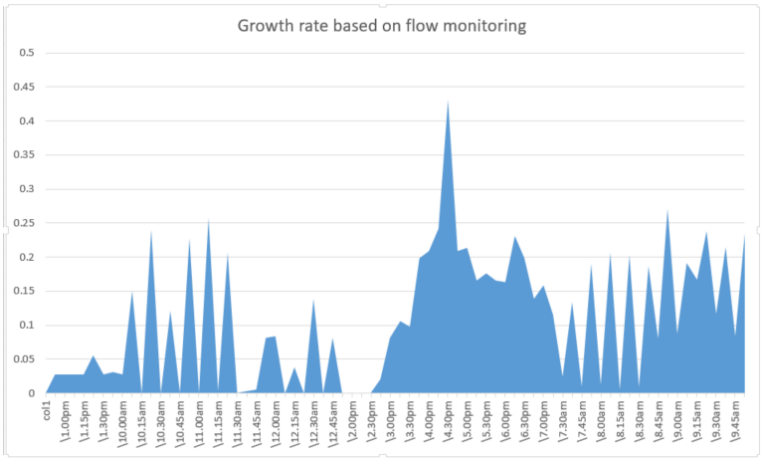

Figure 5. Sample of Growth Rate-December 9th.

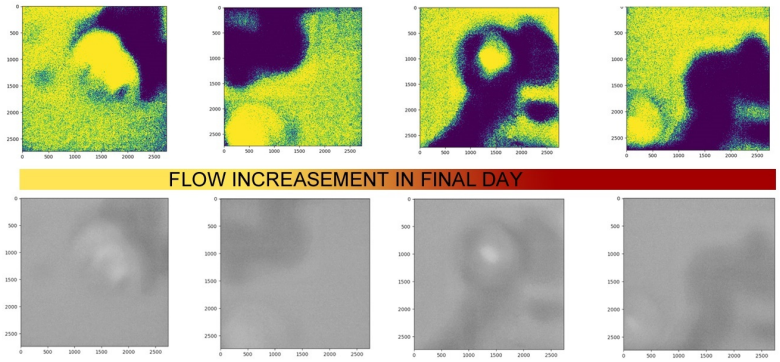

Figure 6. The effect of Oxygen flow during 4 days - An analysis of the maximum density at the end of each day.

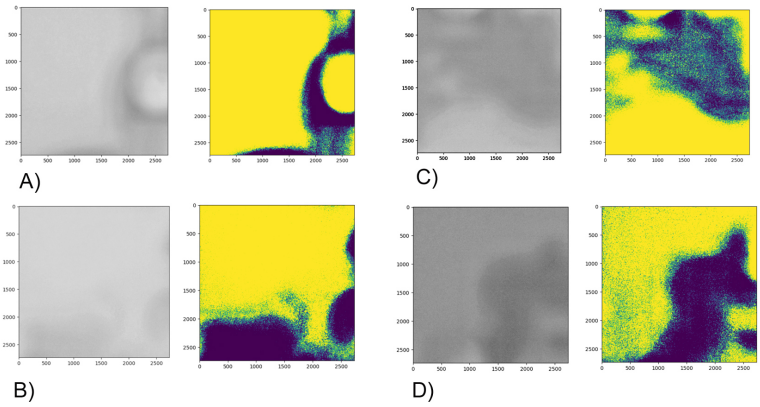

Figure 7. sample of different diffusion of microorganisms at the medium culture.

5. Conclusion

The main purpose of this study is to create a new approach to monitoring and controlling the medium culture of microorganisms with the aim of using different functions of them in the architectural scale, which has been done using image processing tools. The process defined in the computational part of this project is a method of controlling and monitoring the function to use them in the architectural scale. In the example of this project Spirulina microalgae and its biological energy have been applied as an output function on the medium culture. By using this process in monitoring the growth of microorganisms daily and in general over 4 days Recorded at any time, which grows over a period of time and shows the behavior of microorganisms with changes in environmental parameters. These behaviors allow us to observe the effect of the type of inputs and their amount on growth and ultimately its effect on output performance and achieve the desired output by changing the inputs relative to the microorganism's behavior. In this study, oxygen was considered the determining input parameter. By changing the amount of injection on different days, its effect on growth and diffusion, and finally, the biological energy of the output was investigated, both of which had an upward trend towards increasing oxygen injection Generally.

6. Outlook

This research can be performed as a method on other microorganism samples to achieve the desired functions. By eliminating the problem of monitoring and precise control of microorganism's growth environments, a platform has been provided for their use with different applications in architecture. Due to this process's micron accuracy, and behavior in the growth environment for changes in environmental parameters can be identified. On the other hand, if we want to change the genetics of microorganisms to create a function in architecture, with the method proposed in this research, the subsequent behaviors of genetic changes can

be controlled, and a step further, it will also optimize its behavior. On a small scale, by creating a platform for dynamic imaging in different parts of the building, this process will be able to be implemented simultaneously in the form of an intelligent central core in the building. This method has removed the limitation in using different forms with desired functions on an architectural scale by monitoring and controlling the microorganism's growth environment.

References

Barsanti, L., Coltelli, P., Evangelista, V., Frassanito, A.M., Passarelli, V. and Gualtieri, P.: 2008, Oddities and curiosities in the algal world., *Algal toxins: nature*, **-**, 91-353.

Benyus, J.M.: 1997, *Biomimicry: Innovation Inspired by Nature*, Quill, New York.

Bitaab, N., Heidari, F. and Khadivi Golestani, N.: 2018, Investigating Strategies for Creating Healthy Cities with Sustainable Development Approach, *European Journal of Research*, **1**, 34-44.

Brennan, L. and Owende, P.: 2010, Biofuels from microalgae- a review of technologies for production, processing, and extractions of biofuels and co-products, *Renewable sustainable energy*, **14**, 77-557.

Cardoso, L. and lach, D.: 2015, *Builders of the vision□: software and the imagination of design*, Routledge, New York.

Das, P., Aziz, s.s. and Obbard, J.P.: 2011, Two phase microalgae growth in the open system for enhanced lipid productivity, *Renewable energy*, **36**, 8-2254.

Gajda, I., Greenman, J., Melhuish, C. and Ieropoulos, I.: 2015, Self-Sustainable Electricity production from algae grown in a Microbial Fuel cell System, *Bio-mass and Bio-Energy*, **82**, 87-93.

Heidari, F. and Mahdavinejad, M.: 2017, High-performance Sonitopia (Sonic Utopia): Hyper intelligent Material-based Architectural Systems for Acoustic Energy Harvesting, . *Proceedings of the 2nd International Conference on Green Energy Technology*.

Heidari, F., Mahdavinejad, M. and Sotodeh, S.H.: 2018, Renewable energy and smart hybrid strategies for high-performance architecture and planning in case of Tehran Iran, *Proceedings of the 4th International Conference on Environment and Renewable Energy*.

Pasquero, C. and Poletto, M.: 2016, *Cities as biological computers*, Cambridge University Press, Cambridge .

Pasquero, C. and Poletto, M.: 2020, Bio-digital aesthetics as value system of post-Anthropocene architecture, *International Journal of Architectural Computing*, **18**, 120-140.

Singh, R. and Sharma, S.: 2012, Development of suitable photobioreactor for algae production–A review, *Renewable and Sustainable Energy Reviews*, **16**, 2347-2353.

Slade, R. and Bauen, A.: 2013, Micro-algae cultivation for biofuels: Cost, energy balance, environmental impacts and future prospects, *Journal of Biomass and Bio-Energy*, **53**, 29-39.

Vincent, J.: 2012, *Structural Biomaterials*, Princeton University Press, Princeton.

De Wilde, P.: 2014, 'The gap between predicted and measured energy performance of buildings: A framework for investigation, *Automation in Construction*, **41**, 40-49.