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CONTROL SYSTEM ARCHITECTURE FOR NOVEL EXPERIMENTAL MICROALGAE PHOTOBIOREACTOR SIMBIOS

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Abstract: *Photo-bioreactors for growing biomass based on various microalgae cultures gains interests nowadays due to have possible positive impact to society because of the potential to serve as an atmospheric carbon dioxide removal (CDR) device, produce food or fuel. We present an overall architecture of a control system designed with focus to keep the photo-bioreactor alive for long term continuous operation without any human supervision needed. To test overall control system stability we design a custom build spiral photo-bioreactor (PBR) with novel hyperbolic shaped illuminated part. The shape of the illuminated part was design with the goal to increase the ratio of spiral part to volume due to the fact that the light is crucial for microalgae to grow. The control system was created from scratch while adopting reliable IoT sensors combined with highly reliable custom build embedded control system including a cloud data processing and storage. As a result we have scalable and reliable solution which is suitable for photo-bioreactors of various shapes and sizes to operate in fully autonomous mode without any human supervision needed.*

Keywords: Photobioreactor, IoT sensors, Control system, Autonomous operation.

1. Introduction

Continuous operation of any industrial device brings increased demands to reliability of control system in the manner of error handling (Vechet and Krejsa, 2019), reaction to unknown circumstances or missing human operator in case of remote control (Vechet et al., 2016). Photobioreactors (PBR) for microalgae biomass cultivation are no exception. Sun illuminated PBR are sensitive to sun light condition during various seasons of the year, which can increase/decrease the temperature of the cultivation medium a thus have direct influence to biomass yield (Zijffers, 2010). Cultivated microalgae needs to grow in water mixed with atmospheric CO2 while providing sufficient nutrients. There are various kinds of photobioreactors (e.g. spiral, tubular, panel) see (Sukacova, 2021). During initial phase of the continuous control system development we also developed a novel kind of spiral PBR with the sun illuminated part in the shape of hyperboloid called Simbios, see Fig.1. The hyperboloid shape shows promising results regarding the illuminated area to volume ratio.

Presented paper describes the overall architecture of the Simbios photobioreactor with complete process flow diagram with focus on long term continuous measurements.

The paper is organized in three main chapters: an system overview to describe used hardware, photobioreactor construction details and used sensor and measured equipment, details of raw measurement on all sensors applied to the photo-bioreactor and last chapter describes the results and future plans for presented project.

Initial stock culture of microalgae Chlorella was kindly provided by Dr. Katerina Sukacova (Czech Globe, Drasov, Czechia) and various laboratory equipment to perform laboratory reference measurements was kindly provided by Dr. Martin Nad (Dept. of Process Engineering at Brno University of Technology).

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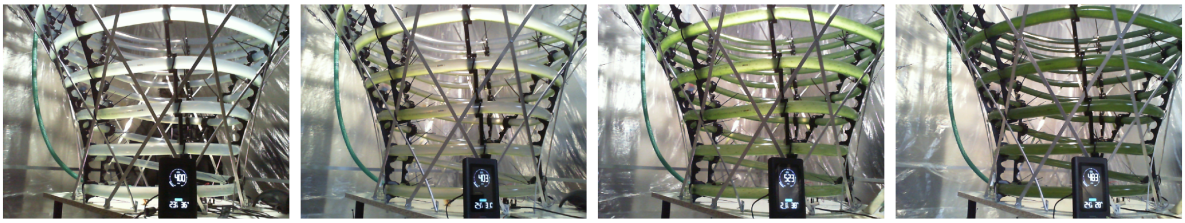

Fig. 1: Experimental photo-bioreactor Simbios during various stages of microalgae growing, images taken sequentially from left to right during initial phases of device running.

2. System overview

The novel photobioreactor was build in laboratories of Institute of Solid Mechanics, Mechatronics and Biomechanics at Brno University of Technology. For the purpose of control system verification it is situated indoor in closed chamber so the ambient environment conditions (CO2 level, light, air flow, temperature, humidity) can be directly observed, measured and quantified. For the purpose of control system verification the main idea of operation is fully automatic regime with no human operator/supervision required.

The material used for the spiral part of the photobioreactor is 25 meter long PVC clear pipe with internal diameter 1", the total height of the spiral part is 1m with the bottom spiral diameter 0.5 m and the top diameter 1.5 m, the used water volume including water reservoir is 20 liters. The process flow diagram for photobioreactor Simbios is shown on Fig. 2. Various internal streams are marked with numbers from 1 to 6, where each stream is described as:

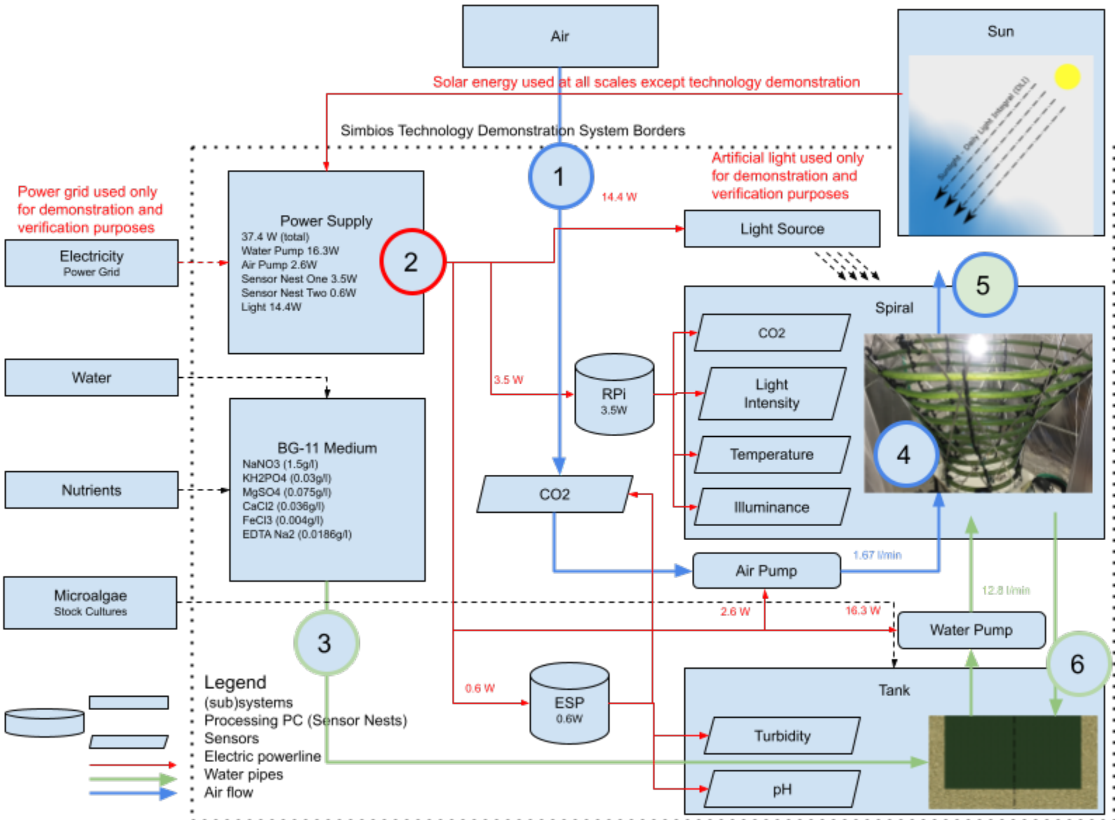

Fig. 2: Process flow diagram of the novel photo-bioreactor Simbios including all sensors used.

– Stream 1: Air Input. Ambient atmospheric air with typical 400ppm of CO2 further used to mix with water to grow microalgae.

– Stream 2: Power Supply. Simbios reactor requires 327kWh energy a year which can be, in the future, generated by photovoltaic panels on-site and stored/accumulated for cloudy days.

– Stream 3: Microalgae grow medium. Medium is used as a mix of tap (fresh)water plus minerals added, typicaly based on Nitrate a modified GB-11 medium is used with 0.0382g/l of Nitrate (Sukacova, 2021).

– Stream 4: CO2 capture. CO2 capture in microalgae mass on photosynthesis at rate 1kg of CO2 to 0.48 kg of microalgae see (Zijffers, 2010).

– Stream 5: Output gas flux, Approx 1% of water during year is lost due to partially closed system to depressurize the whole pipe/tank system, also O2 as a product of microalgae growing and minor gaseous product are emitted.

– Stream 6: Microalgae reservoir for further usage or sequestration.

3. Sensor equipment

The Simbios PBR consists of two main hardware groups, first: the biomass cultivation part (spiral pipe, water tank) including water pump and air pump to circulate the water and mix the air with water respectively. Second: the monitoring and control system for continuous data acquisition, cloud storage and advanced data fusion (Krejsa and Vechet, 2018; Vechet et al., 2010) application for identify the required control actions.

The core parts of the photobioreactor for microalgae cultivation are: Spiral pipe to illuminate the water with microalgae by artificial light (this will be replaced by direct sun light during summer); Water tank as an reservoir of microalgae; Water pump NPTP-O 1500, which circulates the water including microalgae troughs the whole pipe system; Air pump APS100 which intakes the ambient air and mix it with water to ensure the atmospheric CO2 is in contact with culture medium as much as possible.

The data acquisition parts are: Light sensors; Turbidity sensor TS-300B; CO2 level sensor with temperature compensation MH-Z19; Temperature sensor integrated in MH-Z19 CO2 level sensor; Humidity sensor; Power input monitor EMOS P5801 Wattmeter; Raspberry Pi 3B microcomputer to onsite data logging; NODE MCU 1.0 12E an ESP based micro-controller to measure turbidity and light conditions and send the data to cloud storage.

As an reference measurement was used three additional information sources from manually taken samples: Luxmeter Testo 540; Laboratory turbidity sensor Vernier TRB-BTA; Laboratory pH sensor Go Direct pH.

Fig. 3: Raw data measured from all input points during the testing period from 21th of Nov 2021 to 5th of Jan 2022. The samples were taken with 15s period. The device is still in operation (during the time of preparation of this paper Feb of 2022).

Complete set of raw data measured during the first two months of photobioreactor Simbios operation is shown in Figure 3. The evaluation period starts 21th of Nov 2021 and ends 5th Jan of 2022, however the photobioreactor is still in operation (in the time of this paper) and all data are continuously collected, for the first system design evaluation were used data measured up to 5th of Jan 2022.

During the evaluation period various kinds of tests were performed including the influence observation of changing the day to night rate via artificial light turning on and off respectively, while in later stages of the project the constant value of light was provided to the photobioreactor. Also the calibration experiment, similar to (Nguyen and Rittmann, 2018), on relatively cheap IoT turbidity sensor TS-300B was performed with relation to more precise laboratory measurement device Vernier TRB-BTA, which will help with further photobioreactors designs and microalgae cultivation environment monitoring.

4. Conclusions

Briefly presented control system architecture for novel photobioreactor is a part of activities taken in the process of adoption of the mechatronics approach into a research area of microalgae cultivation processes which is a popular topics nowadays.

For the purpose of control system design, architecture verification, scalability testing and various sensors evaluation the novel photobioreactor Simbios was designed and operated.

Further research is focused on calibration of simple sensors to achieve the same result as a precise laboratory equipment to address the questionable widespread of photo-bioreactors due to demanding measurement process using the traditional laboratory approach. The idea is to use IoT sensors and with data processing using modern AI methods to create a scalable control system which can be used in photobioreactors of various constructions to control the internal processes fully autonomously without human supervision required.

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