# A Dual Sensor System for Determining the Unique Oxygen Production Signature of Plants

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***Abstract*—Low cost sensor technology has made real-time monitoring of oxygen production and consumption from plants practical and affordable in homes. We describe an automated sensor based monitoring system comprising an oxygen sensor, a light sensor, and an automated data logging program that together enable near real-time measurement of oxygen production from common house plants. The results from the using system on common houseplants show that each plant has a very unique pattern of oxygen production during the course of a day. Even though light is critical for photosynthesis, all plants that were tested maximize their oxygen production during early morning hours, much before sunlight reaches its maximum intensity. Further, some plants tested here are net consumers of oxygen during a 24 hour cycle, as they consume more in respiration than they produce in photosynthesis. There are several practical applications from results observed with this monitoring system and interesting areas for future research. These include creating oxygen neutral smart homes, design of enclosed spaces for space travel, and deeper scientific understanding of the role that specific plants play in oxygen production, which has applications for wellness and prevention of diseases.**

***Index Terms*— Sensors, Sensor systems, Biological systems, Open loop control, Sustainable development**

## I. Introduction

Plants are the main source of oxygen on earth, producing oxygen by the process of photosynthesis. During photosynthesis, plants use the sun's energy to convert carbon dioxide and water into glucose and oxygen. The basic equation for photosynthesis [1] is given by:

$$CO_2 + H_2O + \text{light} \xrightarrow{\text{plant}} (CH_2O) + 112\text{kcal} + O_2 \qquad (1)$$

Photosynthesis and respiration processes in plants have been well researched [2]. Oxygen is essential for human life. OSHA standards specify any work environment where the relative concentration of oxygen in enclosed air falls below 19.5% as unsuitable for work. NASA researchers have studied oxygen production from plants in enclosed environments such as space stations [3, 4]. Recent research [6] has even focused on producing oxygen from plants by stimulating photosynthesis. Higher oxygen content in air from plants is generally believed to lead to better quality of health, including reducing chances of cancer and improving air quality for patients with migraine headaches, asthma or lung problems [7]. In addition, role of plants in air purification and reduction of pollution is well known [8].

The measurement and monitoring of oxygen levels in air during human exhalation has been reported in human health diagnosis [9]. More broadly, wireless monitoring of air quality through wireless sensors in buildings has been reported in environmental research [10]. However, very little of the recent work has focused on reporting oxygen levels from plant respiration processes which can enable better quantification of health benefits from plants or oxygen monitoring inside homes. The advent of low cost sensors now make it possible for anyone with an interest in basic science and basic sensor technology, to measure and understand the impact of fundamental plant photosynthesis and respiration processes suggested in [1] in their homes, without need for a university or industry laboratory. Such results can help quantify impact of different house plants through their unique oxygen production signature to the health benefits described in [3,7] We describe, in this paper, a low-cost dual sensor home oxygen monitoring system that uses an oxygen sensor, a light sensor and data logging software to measure detailed patterns of oxygen production and consumption from houseplants. We believe this system has significant practical applications in designing oxygen neutral environments in homes or enclosed spaces (e.g. submarines, space stations) or further understanding role of plants within homes or hospitals in human health.

## II. Sensor based measurement system

### A. *Dual sensors and their usage*

An oxygen sensor [11] is a sensor that measures the change in concentration of oxygen in the air. When attached to a plant, it measures oxygen production or depletion over time, as plants undergo both photosynthesis and cellular respiration.

Since light intensity, and therefore the amount of energy available for photosynthesis, varies by time of day, a light sensor [12] used in conjunction with the oxygen sensor can measure the light intensity at the same points in time when oxygen was being measured.

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The duration of the experiment affects both the amount of sunlight and cumulative oxygen produced by plant. A software program was developed by the author to enable both oxygen and light sensor readings to be recorded at a specific frequency (e.g. once a minute) over the duration of the experiment.

### *B. Bill of materials for a dual sensor monitoring system*

We used a combination of commercially available consumer products to build up a sensor based monitoring system that could be attached to a houseplant in an enclosed environment. These included a Lego® Mindstorms® light sensor [12] and a Vernier® oxygen sensor [11]. In addition, an Lego® NXT® programmable controller [12] was used to record the sensor readings at a specific frequency. The oxygen sensor, the light sensor, the houseplant measured and the controller were all enclosed in an airtight plastic container to provide the measurement environment. A Lego® Vernier® Sensor Adapter was used to convert the oxygen sensor readings to an NXT readable format. The author developed a custom data logging software program to log the sensor measurements into a text file for data analysis.

### *C. Plants used for measurement*

We used five different plant species, all of which are commonly used as house plants in the United States of America and known to produce oxygen [5]. The five species of plants include:
1) Thuja occidentalis, or Cypress, an evergreen coniferous tree found in the Northern Hemisphere;
2) Yucca Elephantipes, or Yucca, native to Southern Mexico and Central America;
3) Sansevieria trifasciata, or Snake Plant, an evergreen tropical plant native to Africa;
4) Musa, or Banana plant, native to Asia; and
5) Adromischus maculatus, or succulent plant, native to South Africa.

We chose similarly sized plants to reduce any discrepancies based on the size of the plants. All of the plants we used were in six inch containers.

## III. MEASUREMENTS, RESULTS AND DISCUSSION

There are several factors that impact oxygen concentrations around the plant, including atmospheric pressure, temperature and relative humidity of air. To keep these factors constant, all measurements were at the same location and started at the same times during the day. Taking measurements at same times every day also ensured similar starting points for light intensity across all experiments.

### *A. Measurements and error reduction*

Readings that were too frequent caused issues with large volumes of logged data whereas infrequent readings lost the exact pattern of photosynthesis. To optimize the interval between readings, 20-30 initial experiment runs were conducted and a 6-8 hour period was selected with 1 minute between successive readings.

There are 2 types of errors in this system: measurement error in sensors and sampling error due to sampling of enclosed environment when the sensor measures readings. The measurement error of the oxygen sensor was rated as 1 percentage point (i.e. 0.01% oxygen concentration) [11]. Further, given each sample run had 360 readings for each plant in every run, we noticed that the variations in any reading were order of magnitudes smaller than changes reported in oxygen levels in the experiment over the time period.

The second type of error is sampling error. This error stems from the fact that the oxygen levels at sensor may not represent the oxygen levels across the entire enclosed environment. To correct for this, we calculated a diffusion time of 10 minutes for oxygen to diffuse through the air in enclosed environment based on size of container and diffusion rate of emitted oxygen in air [13]. To reduce sampling error and reduce effect of initial conditions, we discarded readings for first 20 minutes (double the calculated time for diffusion).

Using same measurement technique over 10 sample runs and with readings taken every minute over an 8 hour period for same plant in each sample run, we found that the standard deviation of error in any oxygen sensor reading was less than 0.005% in the beginning of the experiment and went to down to less than 0.00001% at the end of the 8 hour experiment.

In all, over 2000 sensor readings were taken for the observations reported below. The maximum time period of 8 hours in each experiment was based on the maximum amount of data that could be stored in the processor’s memory and the battery capacity of the controller to enable continuous monitoring.

### *B. Results and discussion*

Figures 1a, 1b and 1c show the absolute oxygen concentration (%) in the Y-axis vs the time (minutes) in the X-axis for the five different plants. Figure 1a shows the plants oxygen production from 6 am to 12 pm. Figure 1b shows the plants oxygen production from 2 pm to 10 pm. Figure 1c shows the plants oxygen production from 10 pm to 6 am.

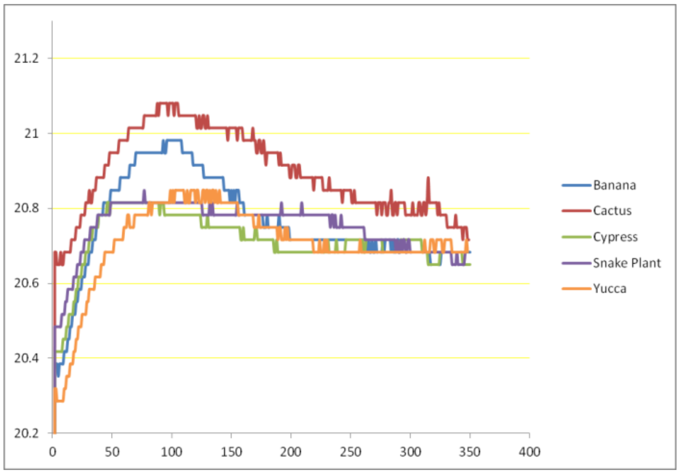


Figure 1a: Plant oxygen production – 6 am to 12 pm

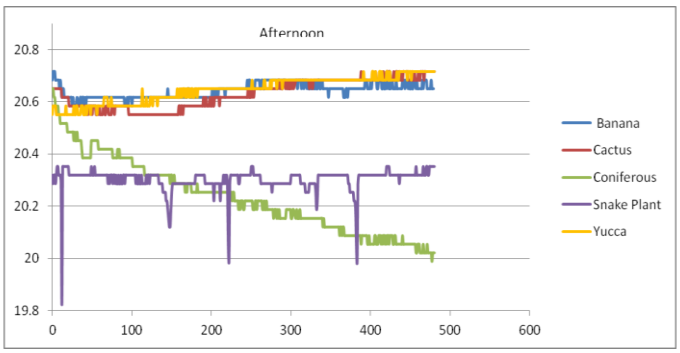


Figure 1b: Plant oxygen production – 2pm to 10pm

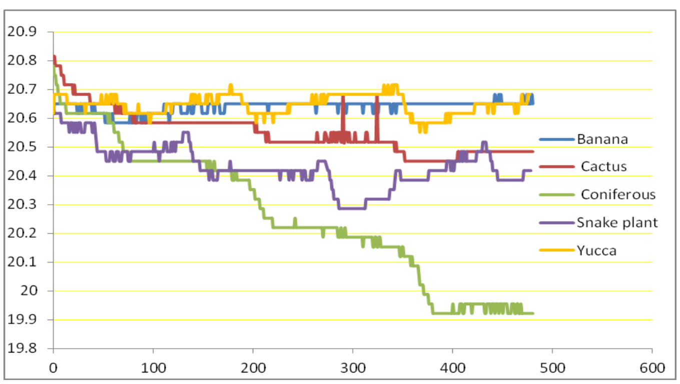


Figure 1c: Plant oxygen production – 10 pm to 6 am

Figures 1a, 1b and 1c show that each plant type has its own unique patterns of oxygen production through the day (an "oxygen fingerprint"). For example, the cactus produced the maximum oxygen concentration level of 21.1%, followed by the banana, yucca, snake plant and cypress. There is a difference in the maximum oxygen concentration of almost 0.3% between the different types of plants tested between 6 am and 12 pm. It is quite interesting to note that despite differences in the plants, the point where oxygen concentration is largest occurs in the early morning. The shape of oxygen concentration curves are similar in early morning readings (Fig 1a), in contrast to the afternoon readings, in which there is a distinct difference in oxygen patterns (Fig 1b), and the night readings (Fig 1c), in which some plants (e.g. cypress) continue to consumer oxygen while others (e.g. cactus) change their patterns to gradually become net producer of oxygen.

Figure 2 shows how the oxygen production changes with light intensity. As seen, higher light intensity leads to more photosynthesis and thus higher oxygen concentrations. However, Figure 2 also shows that shows the best light conditions for producing maximum oxygen concentrations are very different by plant type. For example, oxygen concentration peaks at 80-86% of the maximum light intensity measured for banana, whereas it peaks at 91-94% for yucca. This finding has practical implications on growing indoor plants under artificial light. Results here suggest that each plant type responds quite differently to differing light intensity levels. It can also be seen that the oxygen concentration becomes less dependent on light intensity for higher light intensities. This is evidenced by the spread of data points along vertical line at higher light intensities. Interestingly, this spread is quite different for each plant type.

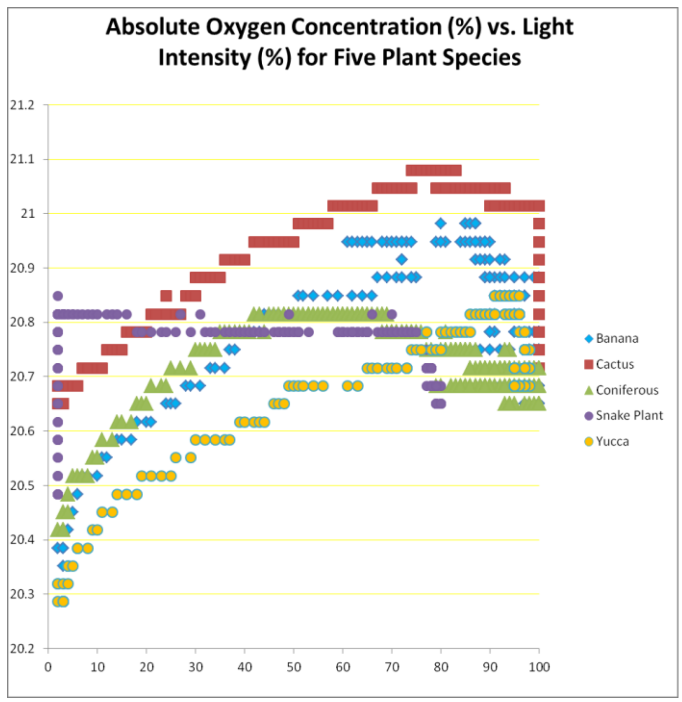


Figure 2: Oxygen concentration vs. light intensity

Figures 3a, 3b and 3c show the absolute oxygen concentration (%) on the Y-axis vs the time (in minutes from the start) on the X-axis for two of the best oxygen producing plants: banana and yucca. Fig 3a shows the oxygen concentration increasing rapidly from 6 am to 8 am. It then descreases from 8 am to 10 am before stabilizing. Fig 3b shows the oxygen concentration slowly increasing from 2 pm to 10 pm. Fig 3c shows the oxygen concentration nearly constant from 10 pm to 6 am.

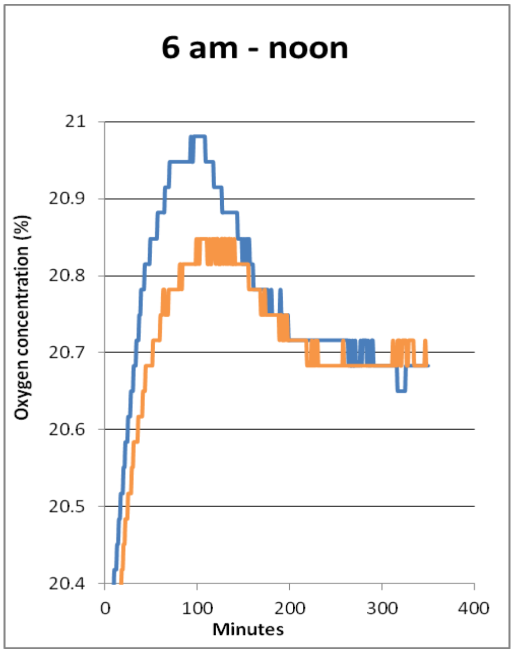


Figure 3a: Oxygen concentration – 6 am to 12 pm

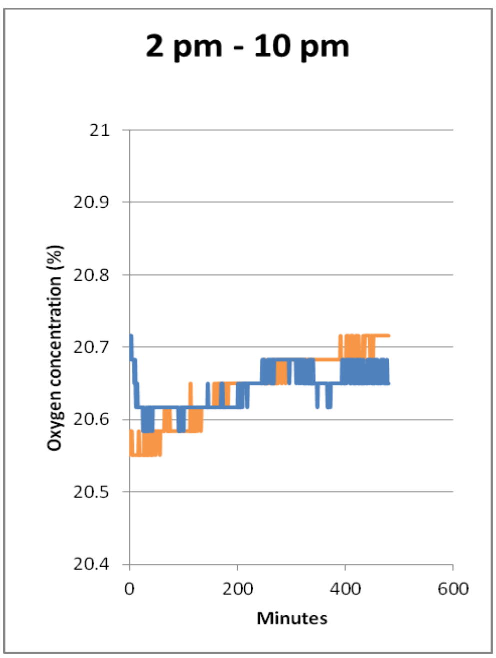


Figure 3b: Oxygen concentration – 2 pm to 10 pm

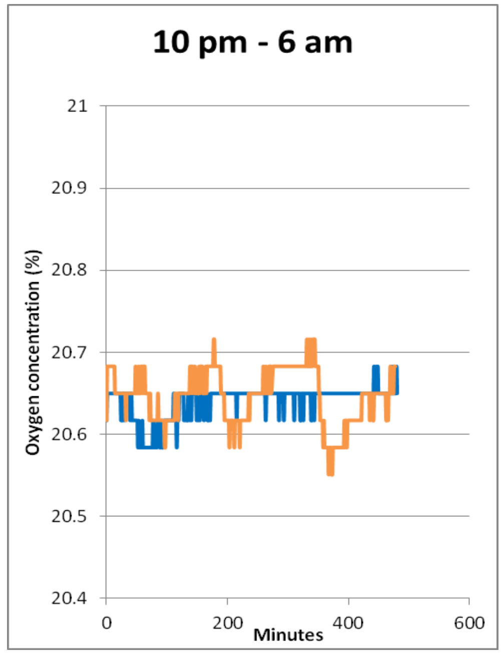


Figure 3c: Oxygen concentration – 10 pm to 6 am

Table 1 shows the oxygen produced per 100 liters of air by different time species over the course of the day. It is very interesting to note again that each plant type has its own signature in terms of specific pattern and amount of oxygen production. The 6 am – 12 pm period, however, is the one where all species produce the maximum oxygen. The cycles of oxygen production are also different among plant types. For example, the banana plant is a net producer of oxygen for most of the time periods measured. In contrast, the cypress plant is a net consumer of oxygen in the afternoon and night sessions and is an oxygen producer only in the morning session. This opens up an interesting research question in using specific plants as an oxygen source for health improvement, particularly if people have plants in their bedroom, since some plants end up being net consumers of oxygen at night.

| | Yucca | Banana | Snake Plant | Cactus | Cypress |
|---|---|---|---|---|---|
| **6am-12pm** | 0.36 | 0.30 | 0.20 | 0.03 | 0.23 |
| **2pm-10pm** | 0.16 | 0.00 | 0.03 | 0.13 | -0.70 |
| **10pm-6am** | 0.07 | 0.03 | -0.30 | -0.40 | -0.86 |
| **Total** | 0.60 | 0.33 | -0.07 | -0.23 | -1.33 |

Table 1: Net Oxygen Production/100 L of Air: Variation During 24 Hours Across Plant Species

It is interesting to note that the results show that there is a significant difference in oxygen produced in a 24 hour period between plant types. Yucca and banana are net producers of oxygen. Others (like snake plant) are net neutral over a daily cycle. Some other plants like cypress and cactus consume more oxygen in respiration than what they produce in photosynthesis and thus are net consumers of oxygen.

## IV. Conclusions and Further Research

We have shown a multi-sensor measurement system that allows us to measure real-time oxygen production signatures for different plant types. The oxygen production patterns reveal useful insights. For example, we can verify that each plant species has its own *unique oxygen production signature*. Different plants maximize oxygen production at different levels of light. Cypress plants (native to northern latitudes) maximize oxygen production at lower light levels (50-60% light) than cacti (native to deserts) which maximize oxygen production at higher light levels (60-80% light). This result also suggests using different light intensities to induce photosynthesis in plants grown indoors.

Most plants produce the highest concentration of oxygen between 7am and 9am (50-80% of the total light intensity measured), suggesting applications to health (e.g. benefits of exercising early mornings).

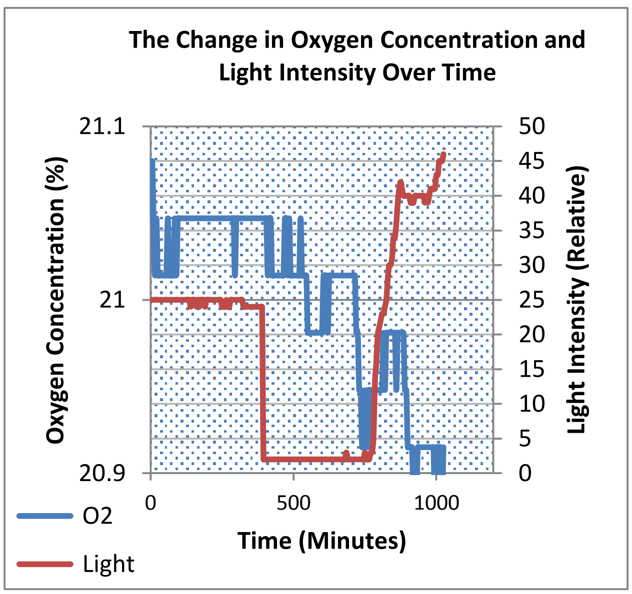


Figure 4: Snake plant oxygen production pattern

Figure 4 shows oxygen concentrations and corresponding light intensities for the snake plant These measurements were over the course of ≈17 hours (the x-axis shows minutes since 6:00am) and reveal another interesting insight: oxygen concentrations started to change before the light intensity starts increasing, showing that plants may have an ability to predict the pattern of light intensity changes and change their behavior in anticipation.

There are several other interesting research questions that come out of this multi-sensor measurement system and ability to measure unique oxygen production patterns:

i) Can specific plants, due to their unique oxygen production signatures be more beneficial in health?
ii) Do the specific oxygen production signatures vary across seasons or in specific suburban environments (e.g. cities vs. villages, space station vs submerged space)?
iii) Can a combination of houseplants and air quality sensors be used to create an sustained dynamically healthy home or office or hospital design?

We believe the system described here is hugely relevant for research into designing oxygen re-generating enclosed spaces and understanding role of specific plants in improving human health.

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