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EFFECTIVENESS OF IOT BASED AUTOMATION SYSTEM FOR SALAD CUCUMBER (*Cucumis sativus*) CULTIVATION IN PROTECTED HOUSE UNDER SRI LANKAN CONDITIONS

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ABSTRACT

Protected house cultivation is one of the best solutions to address food security and overcome the scarcity of land and other resources in the future. An automation system with the Internet of Things (IoT) will be the most effective way to maintain a protected house with minimum labours. This research was mainly focused to determine the effectiveness of IoT based automation system for protected house cultivation of salad cucumber in Sri Lanka and validation of temperature and relative humidity sensors used in this system. The study was carried out in two protected houses with the same crop management practices. An IoT-based automation system was designed to control temperature and relative humidity inside the protected house. Fertigation was done several times a day by an automation system for the automated protected house to control electrical conductivity in grow bags. Temperature, RH, EC, and light intensity were recorded by using sensors and standard methods in different periods. Temperature and RH values measured from sensors and standard methods were not significantly different during the experimental period. Therefore, used temperature and RH sensors were valid for this system. Temperature, RH, and EC values were significantly different in two protected houses and the automated protected house was maintaining those conditions near to the desired levels for salad cucumber. There was a 40% yield increment in the automated protected house than the conventional protected house. Based on the findings, IoT based automation system is effective to use with protected house cultivation of salad cucumber in the southern province of Sri Lanka.

Keywords: Automation, *Cucumis sativus*, Internet of Things, Protected house, Sensors

INTRODUCTION

World Food and Agriculture Organization (FAO), reported that the world population is estimated to be increased by more than 10 billion by 2050 and 90 % of this increment is represented by developing countries (FAO 2017). This will boost up agriculture demand by 50% to feed the rapidly growing world population while at the same time ensuring the best possible conservation of scarce natural resources (Soni and Salokhe 2017). Increasing extreme weather conditions such as drought and floods, limited arable land, and changing dietary habits make this task even more demanding in Sri Lanka. Therefore, agriculture needs to face this problem by using innovations like digital solutions, crop protection, and modern breeding methods (Kumara 2017).

Protected agriculture or controlled environment agriculture is a cropping technique where the microclimate adjacent to the plant is controlled fully or partially throughout its growth (Kumar and Tyagi 2017). The protected house uses the greenhouse effect principle for monitoring and maintaining the environment to desired levels. This type of closed cultivation is more beneficial than open-field cultivation due to few reasons such as high production per unit

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area, extended harvest, easy control of pests and diseases, effective water utilization (Isssac *et al*. 2013). But high relative humidity and temperature inside the protected house are serious problems in tropical and sub-tropical regions like Sri Lanka. Therefore, effective temperature and RH controlling are measured as the basic requirement for greenhouse production in those areas.

Monitoring the conditions of plants and surrounding areas and management of large agricultural areas are key problems in agriculture as they are time-consuming and labor-intensive processes. The use of sensors is the best solution for overcoming those problems. A sensor is an automatic data recording and monitoring device that take delivery stimulus and feedback with an electrical signal (Kamelia *et al*. 2015). Due to labor scarcity, the automation system is becoming more popular throughout the world in various sectors. Automation is a technology or a process with minimum human assistance, to control and monitor the production and delivery of various goods and services (Soni and Salokhe, 2017). The concept of automation, controls air temperature, RH, ventilation, light levels, CO_2 levels, irrigation, and fertilization in protected houses. This system typically prefers fewer variables than human workers, resulting in greater production and quality. Furthermore, this type of modern farming technique attracts the new generation towards agriculture (Hassan *et al*. 2015).

The next age of smart computing is thoroughly supported by the Internet of Things (IoT). IoT describes the network of physical objects that are embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the internet (Evans 2011). It is “a global, invisible, immersive, ambient networked computing atmosphere assembled through the continued creation of smart sensors, software, cameras, databases, and huge data centers” (Doknić 2014). IoT is now widely used in consumer, commercial, industry, and infrastructure sectors. Also, agriculture becomes a data-intensive industry for food security, nutrient responsibility, animal welfare, labor welfare, ecological footprint, and marketing purposes. Those purposes can be easily achieved by using IoT with high precision and less effort (Muthupavithran *et al*. 2016).

Salad cucumber (*Cucumis sativus*) is considered a high-priced vegetable in the Sri Lankan market and export market. It has three different uses as a fresh whole, fresh sliced, and pickle. Thus, salad cucumber is an ideal crop for protected house cultivation (Gruda *et al*. 2017). But this is highly sensitive to surrounding environmental conditions such as temperature, RH, light, CO_2, and moisture conditions. Higher changes in these conditions will cause a bitter taste, misshapen and small fruits, and ultimately end up with low profit (Vandre 2010).

Even though the quality and quantity of the harvest of a salad cucumber, highly depend on controlling the inside condition of the protected house, no proper research has been conducted to find out the effectiveness of the IoT-based automation system for protected house salad cucumber cultivation in Sri Lanka. Though there are many types of sensors with different prices, low cost and best quality sensors must be used for the reduction of cost of a system. Therefore, the objectives of the study were, to determine the effectiveness of IoT based automation system for controlling temperature and relative humidity inside the protected house, To determine the effectiveness of IoT based automation system for controlling electrical conductivity in grow bags, To determine the effect of automation system on growth and yield parameters of salad cucumber, and to validate the DHT22 temperature and relative humidity sensors for IoT based automation system.

Figure 1: Long axil view of used protected houses

MATERIALS AND METHODS

Location of study and Preparation of Protected Houses for Crop Establishment

The study was carried out in two protected houses under the same outside environmental conditions at the Faculty of Agriculture, University of Ruhuna which is situated in the Low Country Wet Zone (WL2) from September to December 2018. During the period of research conducted, average rainfall was recorded as 2000 mm by second inter-monsoon rainfall, the average temperature was 28 °C according to meteorological reports. 1000 ft^2 size two protected houses were used with the same direction of the long axis (fig. 1). They were freestanding even-span-type protected houses with sidewalls, end walls, and modified roofs. Two hundred µm poly films with 1,000 gauges were used for the roof and 40 x 25 sq./$inch^2$ insect screening nets were used for the walls of protected houses. The floor was covered with black polythene as the bottom layer and white color polythene as the top layer in both protected houses to reduce the heat generation inside the protected house.

Drip lines were established as one main drip line and six laterals in 90 cm distance. Growing bags were placed along the laterals at drip emitting points with 60 cm x 30 cm center to center spacing. Before two days of nursery establishment, disinfection was done using Abamactin insecticide and Topsin fungicide.

Sensors and actuators placement in two protected houses

DHT22 temperature and relative humidity sensors and MEC10 soil moisture and electrical conductivity sensors were used for this experiment (Fig. 3). Five temperature sensors, five relative humidity sensors, five-light intensity sensors, one electrical conductivity sensor, and nine moisture sensors were placed in each protected house. These temperatures, RH, and lux sensors were placed in three different heights as 4 ft., 7 ft., and 9 ft. Also, two temperature sensors, two RH sensors, and two light intensity sensors were placed outside the protected house to detect outside conditions (Fig. 2). Three turbojet electrical exhaust fans were established on top of the roof of the automated protected house to control relative humidity and temperature inside the protected house. Fans have a 300 mm sweep with 1400 rpm speed. Fans were placed with the same spacing between each fan and end walls to provide even conditions for the whole protected house. Mid pressure, cross misting four-way foggers were used in the automated protected house at 8 ft. height. Three fogger lines were established with six foggers per line to control relative humidity and temperature inside the automated protected house. 0.5 hp centrifugal pump was used for

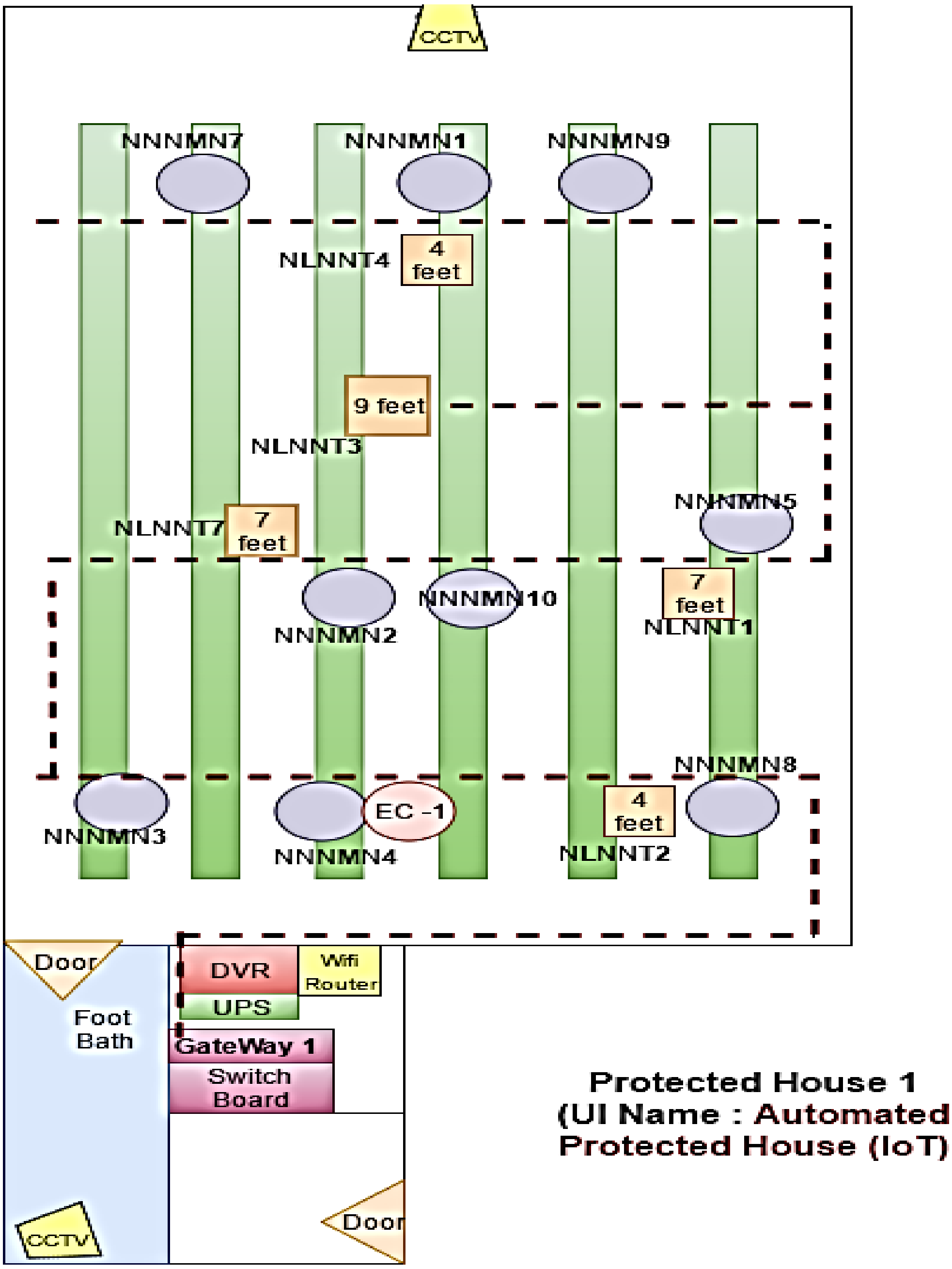

Figure 2: Placement of different sensors in automated protected houses

these fogger lines which is driven by 220 - 240 V and 2 A.

Working principle of automatic temperature and relative humidity controlling inside the protected house and Developed system for automation

Temperature sensors sense the temperature inside the protected house and compare it with a user-specified temperature range. If the internal temperature higher than the threshold value, the automation system refers to the RH values. If the current RH is higher than the threshold RH value foggers on for “t” time until internal temperature drops down to desired value. Also if the current RH is not higher than the threshold value, exhaust fans are on for “t” time until the temperature drops down to the desired value (fig. 4). 32 °C was decided as the threshold temperature throughout the vegetative and reproductive stage according to the previous literature.

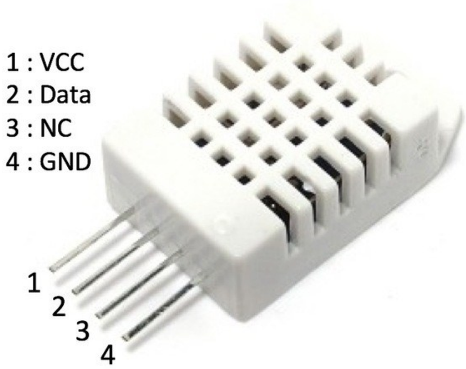

Figure 3: DH22 temperature, RH, and Lux sensor

Relative humidity sensors sense the relative humidity inside the protected house and compare it with the user-specified RH range. If the current RH is lower than the lowest threshold value, foggers on for t time until RH increases to the desired level. Also, if the current RH is higher than the highest threshold value, exhaust fan actuators are on for t time until RH drops down to the desired value (fig. 5). 80 % and 90 % were kept as lowest and highest threshold values respectively in the nursery stage and 55 % and 65 % were kept as lowest and highest threshold values in vegetative and reproductive stages according to the previous literature.

The sensor kit senses the inside conditions and that information pass to the control unit. Actuators of the automation system are switched on by relays of the control unit after referring to the threshold values. Also, all information is sent to the dialog IoT platform via the gateway. The software application was developed for better communication between the computer and electronic circuit. The user interface was shown all conditions inside the protected house at any time and it was used to manage threshold conditions of the automation system. Internet of things (IoT) was helped to control this system with the smartphone or computer in any location using this interface.

Crop Management Practices

One of the Cucurbitaceae family members of Salad cucumber (*Cucumis sativus*) was used as an experimental crop and a hybrid variety of 'Efdal' was selected (fig.6). Separate nurseries were maintained in two protected houses using nursery trays with 60 holes fill with disinfected coir media and one seed was kept in one hole of tray. In each protected house, 240 seeds were kept in four trays. Daily watering was done in small amounts. Seed germination was started 4 days after nursery establishment and healthy seedlings were transplanted into bags 10 days after nursery establishment. When transplanting, the top layer of the root ball was level with the top layer of media. Training and pruning practices were done in both protected houses using the same methods. Before transplanting, wires were laid parallel to the planting rows and 8ft above the ground level. Five days after transplanting, pruning was started continued daily. All tendrils, lateral branches, and damaged and diseased leaves were removed from the vine. Also, unwanted and aborted fruits were removed after flower initiation. Wine training was started eight days after the transplanting. Strong treads were stretched from wires to bag and vine was rolled clockwise along with the tread. This technique was done until the vine is grown up to the level of wire and then vine lowering was started. Vines were lowered at the bottom with a loop while removing few leaves from the bottom layer.

Irrigation and fertigation were done using a drip irrigation system. Two separate fertigation tanks, pumps, and drip line systems were used to fertigate each protected house. 0.5 hp centrifugal pumps were used which is driven by 220 - 240 V and 2.2 A. An average of 60 ml was discharged from one emitting point in drip lines. The Fertigation system of the conventional protected house was operated manually. From 6.00 to 7.00, the drip system was switched on for conventional protected houses until leaching out the water, and then

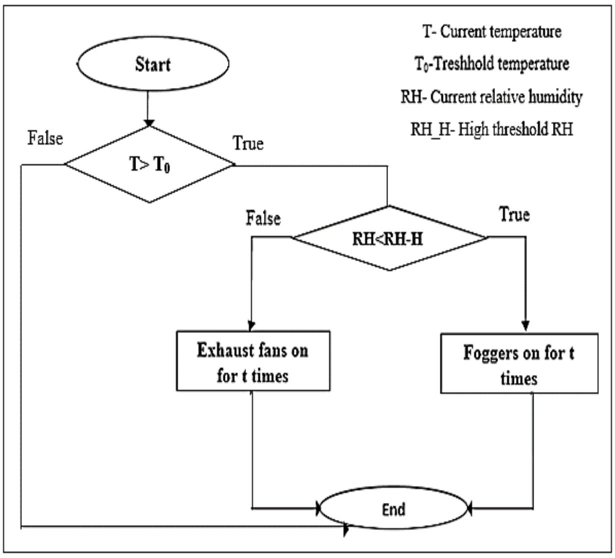

Figure 4: Flow diagram of automatic temperature controlling

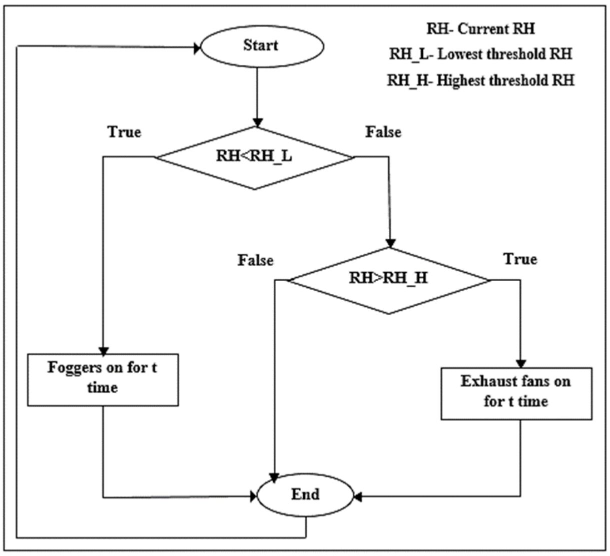

Figure: 5 Flow diagram of automatic relative humidity controlling

during 9.00 to 10.00, fertigation was done through drip lines. In automated protected house fertigation was done automatically from 6.00 to 18.00 by dividing it into 36 times. The same volume of water and the same amount of fertilizer was used for both protected houses. Recommended amounts of Albert fertilizer were used in different growth stages as shown in table 1.

Sampling and Data recording methods

Sampling was done for collecting data on growth and yield parameters. Each protected house consisted of a total of 204 plants in six rows and 32 plants were selected as samples by using simple random sampling. Data were collected from both growth and yield parameters and protected house conditions from the beginning of the nursery and end of the crop. Vine length, average days for emerging fifth and fourteenth leaf, number of leaves per vine, and time are taken to first harvest were selected as growth parameters. The fresh weight of the yield was taken as the yield parameter. Daily protected house conditions were recorded by using both sensors and standard methods. Sensor data were automatically recorded into an excel sheet with the relevant date and time. Temperature, RH, and light intensity were recorded using standard methods four times a day from 06.00 to 10.00, from 10.00 to 12.00, from 12.00 to 16.00, and from 16.00 to 20.00. The temperature of two protected houses and outside were recorded by using thermometers and temperature sensors, the relative humidity of two protected houses and outside were recorded by using wet and dry bulb thermometers and RH sensors, the light intensity of two protected houses and outside were recorded by using lux meter, the electrical conductivity of grow bags inside the two protected houses was recorded by using

Figure 6: crop arrangement inside protected houses

Table 1: Amount of Albert solution used per plant per day in different growth stages of salad cucumber

Growth period	Amount
Transplanting – first flowering	0.5g
Frist flowering – fruit setting	0.8g
After fruit setting	1.0g

digital EC meter from 6.00 to 10.00. Data were analyzed by descriptive statistics and a two-sample t-test with the help of Minitab statistical software and Microsoft excel. Analyzed data was presented by using bar charts, line charts, and tables.

RESULTS AND DISCUSSION

Validation of Temperature and Relative Humidity Sensors for IoT Based Automation System Using Standard Methods

The effectiveness of an automation system is directly related to the accuracy and the reliability of data values recorded by sensors (Ashok *et al*. 2013) Even sensors are manufactured very precisely, the accuracy of raw data can be reduced during the period of it used due to some reasons like environmental noises and drifts. Also, this automation system refers to temperature sensors and relative humidity sensor data for its functioning (Ravichandran and Arulappan 2013). From 6.00. to 20.00, variances and means of temperature sensor readings and thermometer readings were not significantly different at 0.05 probability level in the automated protected house throughout the experimental period (fig. 7).

When considering figure 8, during the experimental period from 6.00 to 20.00 means of relative humidity sensor readings and wet and dry bulb thermometer readings were not significantly different at 0.05 probability level. Also, variances of sensor readings and wet and dry bulb thermometer readings were not significantly different at 0.05 probability level in the automated protected house during the experimental period.

Effectiveness of IoT Based Automation System for Protected House Salad Cucumber Cultivation in Sri Lanka

The effectiveness of IoT based automation system was evaluated by considering the results of the effectiveness of automation system for controlling relative humidity, temperature, and electrical conductivity inside protected houses and by considering results of comparison of important growth and yield parameters in automated and conventional protected houses (Kamelia *et al*. 2015).

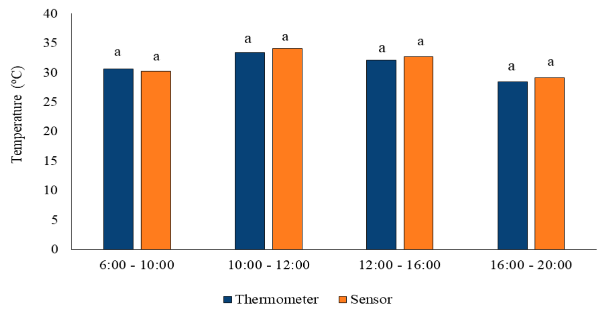

Figure 7: Mean (from 53 data) temperature recorded in thermometer and sensor inside the automated protected house at four different periods.

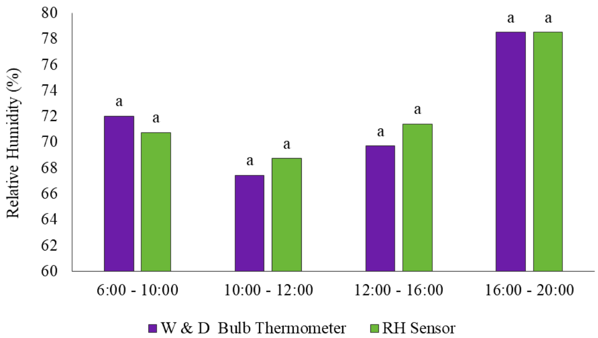

Figure 8: Mean (From 53 data) relative humidity recorded in sensor and wet and dry bulb thermometer inside the automated protected house at four different periods.

Effectiveness of automation system for controlling relative humidity inside the protected house

A protected house is a closed system, so relative humidity always tends to increase than the outside environment. Therefore, humidity can be the most difficult environmental factor to control in the greenhouse (Hirasawa *et al.* 2014). Also following figure 3 shows higher mean relative humidity values inside the automated and conventional protected houses than outside throughout all periods. Variances of relative humidity inside the automated protected house and outside were not significantly different and means of them were significantly different at 0.05 probability level throughout all periods. However, from 6.00. to 16.00 variances and means of relative humidity were significantly different inside the conventional protected house and outside. But variances and means of them were not significantly different from 16.00 to 20.00 at 0.05 probability level.

As summarized in figure 9, from 6.00 to 16.00, variances of relative humidity were not significantly different in two protected houses and means were significantly different at 0.05 probability level. Further, the automated protected house showed a lower mean relative humidity than the conventional protected

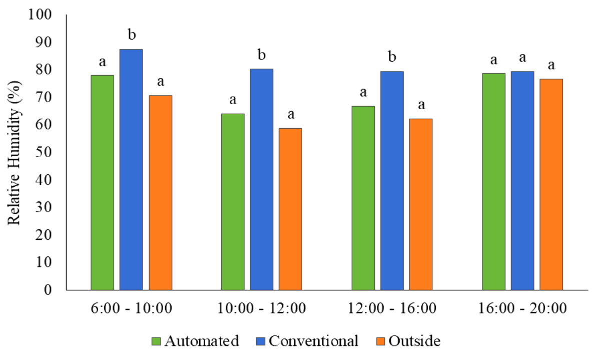

Figure 9: Mean (From 53 data) relative humidity recorded inside two protected houses and outside at four different periods.

house. The automated protected house was maintained its mean relative humidity values near to the expected relative humidity conditions (55% – 65%) of salad cucumber during all these periods (Gruda *et al.* 2017). However, from 16.00 to 20.00, two variances and two means are not significantly different at 0.05 probability level and the automated protected house was unable to maintain its mean RH value near to the expected humidity conditions of salad cucumber.

If higher the relative humidity in the surrounding environment of plants, evapotranspiration will be decreased, and meanwhile, plants will have some nutrient deficiencies due to low nutrient uptake. On the other hand, higher humidity causes the closing of stomata and decreased the photosynthesis rate. Higher relative humidity encourages some fungal and bacterial diseases. Finally, higher humidity conditions reduced the crop yield. When considering the results of this experiment, the automated protected house was able to maintain lower humidity values than the conventional protected house. (Harel *et al*. 2014)

Effectiveness of automation system for temperature control inside the protected house

Due to the greenhouse effect, temperature always tends to increase inside a protected house (Ghattas 2014). According to figure 10, this experiment also showed higher temperatures inside both automated and conventional protected houses than the temperature of the outside environment. During all the periods, variances of the temperature inside the automated protected house and outside were not significantly different and means of the temperature inside the automated protected house and outside were significantly different at 0.05 probability level. Also, variances of the temperature inside the conventional protected house and outside were not significantly different while the mean of them was significantly different at 0.05 probability level throughout the day. As shown in figure 4, during the experimental period, from 6.00 – 12.00, and 16.00 – 20.00 variances of the temperature inside automated protected houses and conventional protected houses were not significantly different at 0.05 probability level. From 6.00 to 10.00 mean of temperature in the two protected houses was not significantly different and from 10.00 to 20.00 means of the temperature inside the two protected houses were significantly different at 0.05 probability level. And also, the automated protected house was able to maintain its temperature near to the expected temperature conditions (30 ºC – 32 ºC) of salad cucumber throughout the day.

The rate of respiration increases with the rise of temperature up to a certain level. In conventional protected house temperature increased more than required levels. This higher respiration rate affects the photosynthesis rate negatively. Extreme temperature creates wilting problems in the vine and also causes fruit abortion (Rasul *et al*. 2002). A higher number of aborted fruits were reported in the conventional protected house than the automated protected house because of this temperature increment. Some pest and disease attacks like mike attacks can be severe with temperature increment. When considering the above results automated protected house was able to maintain a lower temperature than the conventional protected house.

Variation of light intensity inside two protected houses and outside

The plant growth process involves the use of light, CO_2, and water to manufacture food for plants. Light intensity is directly associated with temperature. So, checking the variation of light intensity inside two protected houses is important to make more precise conclusions about the effectiveness of automation systems for temperature controlling (Brown 2015). Even figure 11 shows somewhat high lux values in automated protected houses, light intensity values inside two protected houses were not significantly different at 0.05 probability level throughout the day. But in daytime outside were shown somewhat higher lux values than two protected houses.

Effectiveness of automation system for EC controlling

Electrical conductivity is the soluble salt in the substrate. EC that too high can result in excessive top growth or damage to root tips and physiological drought which restrict root water uptake by the plants, even when the substrate is moist. EC that too low indicates insufficient nutrition for the plant. This may cause some nutrient deficiencies and slow down plant growth (Samarakoon et al. 2014).

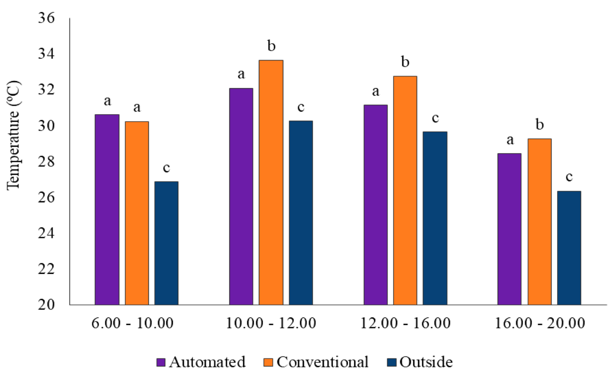

Figure 10: Mean (From 53 data) temperature in automated and conventional protected houses and outside environment at four time periods.

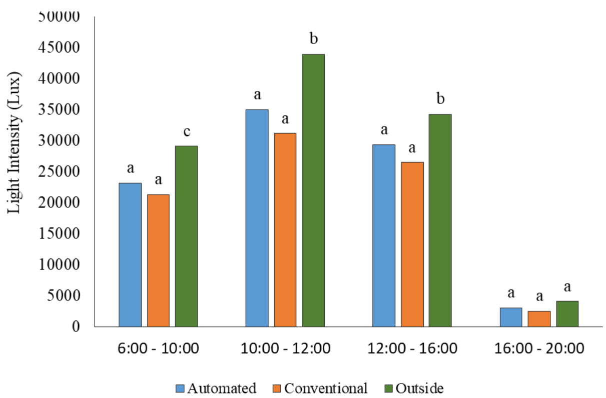

Figure 11: mean (From 53 data) light intensity variation inside two protected houses and outside at four time periods.

For best cucumber production, 1190-1750 µS/cm is recommended. EC values of the automated protected house vary between 900-1200 µS/cm while EC values of the conventional protected house vary between 600-800 µs/cm. Also, there was a significant difference between mean EC values at the 0.05 probability level.

Comparison of important growth and yield parameters in automated and conventional protected houses

Vines with higher length are difficult to train and maintained. So, maintaining a shorter vine length is more beneficial in salad cucumber cultivation. With the higher temperature and lower light intensity plants produce higher internodal lengths other than producing more leaves and flowers (Barangay et al. 2015). From the first week to six-week vine lengths in two protected houses were shown significantly different values at 0.05 probability level. When looking at figure 12, the conventional protected house was shown higher vine length than the automated protected house.

The number of leaves is an important factor for increasing the yield of salad cucumber. Because one or few numbers of fruits are bearing at every point of leaf petiole of salad cucumber. Also when the number of leaves increased, photosynthesis is increasing. At last, it will directly increase the crop yield (Adeoye and Balogun 2016). As shown in figure 13, when comparing the number of leaves per vine during the experimental period, from the first week to the fourth-week number of leaves in the automated and conventional protected house were not significantly different. But after the fifth week, it was shown a significant difference in the number of leaves per vine at a 0.05 probability level. Also, an average of 10 days was taken to emerge fifth leaf and an average of 19 days for emerging fourteenth leaf in both automated and conventional protected houses.

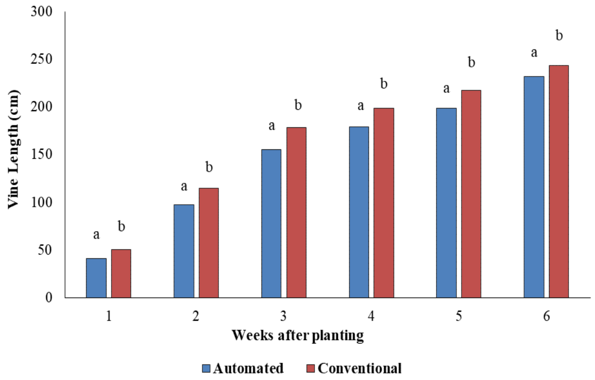

Figure 12: Average vine length during six weeks of harvested in automated and conventional protected house.

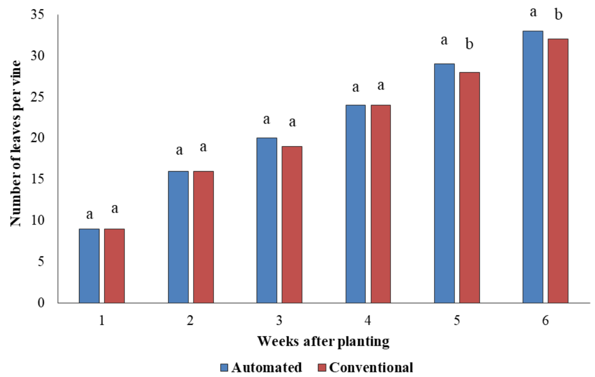

Figure 13: Number of leaves per vine during first six weeks in automated and conventional protected houses.

Figure 14 shows high yield in the automated protected house than the conventional protected house through every week of harvesting. Also, those yield values were significantly different at 0.05 probability level in every week other than the first week. The total yield increment was calculated as 40% in the automated protected house than the conventional protected house. For the first harvest, automated protected house vines were taken an average of 31 days while conventional protected house vines were taken an average of 34 days. In commercial production, the yield is the most important parameter to get more profit. the yield of cucumbers mainly depends on variety, the nutrient in media, environmental condition,

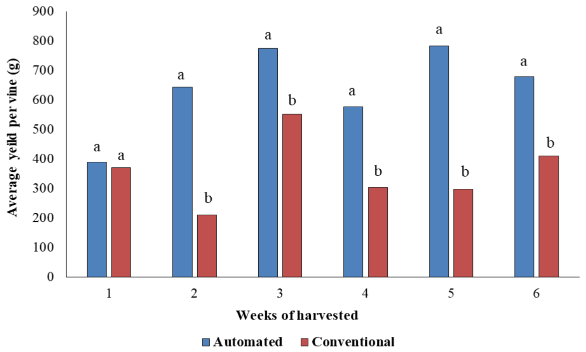

Figure 14: Average yield per vine during six weeks of harvested in automated and conventional protected house.

and pest and disease damages (Vandre 2010). In this experiment, the high-yielding variety was selected and all required management practices were done at the correct time for both protected houses. Therefore, this yield increment must be due to the nutrient management and humidity, and temperature control inside the automated protected house.

CONCLUSION

Used DHT22 temperature and relative humidity sensors are valid for this IoT-based automation system of salad cucumber under local conditions. Also, this IoT-based automation system is suitable for controlling relative humidity inside the protected house. By considering all temperature and light intensity variations inside the protected house and outside, this IoT-based automation system is suitable for control temperature inside the protected house. Automated fertigation can maintain the EC level of grow bags near to the optimal range of EC for salad cucumber than manual fertigation. This system was increased the total yield by 40 %. Therefore, this IoT-based automation system is effective to use with salad cucumber in Sri Lanka.

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Author Contribution

SNAJ, KKLBA and HKMSK conceptualized and designed the study. SNAJ performed the experiments. SNAJ and HKMSK analyzed and interpret the data. SNAJ drafted the manuscript. KKLBA and HKMSK critically commented and revised the manuscript.