A Systematic Literature Review: Internet of Things on Smart Greenhouse

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***Abstract*—The Increasing food needs and climate instability require researchers to innovate agriculture using smart greenhouses that are integrated with the Internet of Things (IoT). The Systematic Literature Review (SLR) begins with determining the topic keywords followed by searching the publisher link. It obtains 301 publications to be reviewed, 58 of which address the research questions posed. This study aims to collect and analyze in depth various knowledge about the Internet of Things Smart Greenhouse regarding sensors, methods used and publishers who publish the most related topics and the possibility of a research gap. The findings are as many as 12 publications that use temperature and humidity sensors and use the research and development methods integrated with Artificial intelligence methods, of which 62.1% do not use the datasets and 37.9% use the datasets. It obtains two possibilities of a research gap, namely improvising the algorithm and the dataset used and placing full control on the microcontroller development board and making IoT a supporting tool.**

Keywords—IoT; SLR; Smart greenhouse; agriculture; research gap

I. Introduction

As the world's population grows and the need for food continues to increase and the decrease in agricultural land that is used as land for residence requires us to continue to innovate to meet these needs. Not only that climate change, which is increasingly erratic, make the planting period of food crops unstable. One of the innovations that can be done is to use a greenhouse in the agricultural process, by using a greenhouse the planting process can be carried out continuously regardless of the current climatic conditions. The placement of a greenhouse can also be done in places with a limited area such as the rooftop of a building. However, the greenhouse is just a place to grow crops, there needs to be innovation which will later be known as the Internet of Things Smart Greenhouse (IoTSG). These technological innovations include automation, artificial intelligence and the internet of things. The integration of these innovations is proven to have a good impact on agricultural processes and results in greenhouses as described below. This study dissected and dag deeper into various IoTSG literature regarding the sensors used, the methods applied, publisher statistics and the possibility of research gaps that were obtained so that improvisation of the IoTSG could be done.

More specifically about smart green houses, by using smart greenhouses, pest control of food crops can be done easily. As has been done by [1], the robot sprays pesticides around the plants for pest control. Preventive measures by predicting plant diseases in greenhouses can also be carried out as done by [2], [3] on cucumber and vegetable crops.

Preventive measures not only in controlling plant pest diseases, the harvesting process of mushroom plants can also be carried out by robots in a greenhouse environment [4], [5]. Irrigation management in greenhouses and large-scale planting areas can be done easily with the integration of IoT technology and remote sensing [6], [7]. Using the water more effectively and efficiently is an important aspect and needs to be taken seriously. Adequacy of water sources can be monitored and controlled properly by farmers, maintainers and administrators using mobile apps.

Various mobile apps based on the IoT platform can be used as part of an agriculture information system, such as in the FIWARE case [8], [9], this system allows every mobile app holder to convey information models sent to the cloud such as planting, harvesting, product packing, transportation and distribution of agricultural products. All the information is stored properly in the cloud database.

The development of smart greenhouses equipped with sensors, actuators and cloud connections as well as artificial intelligence algorithms has also been carried out, but the IoT platform system is still suspended [10]. The system that is built is called an automated hybrid, some systems work automatically and some are controlled manually.

In sensor data acquisition, the measurement accuracy of the measuring instrument is very important so that the resulting decision will be very accurate. What needs to be done is the calibration of measuring instruments made by comparison with standard measuring instruments. Not only on measuring instruments or IoT sensor systems, calibration is also carried out on measuring instruments or geomagnetic sensor systems and soil temperature sensors that produce the MAG3119 standard deviation sensor for x coordinates of 8.5, y coordinates of 2.66 and z coordinates of 1.9 and standard deviation of the DHT11 sensor of 0.1161 [11].

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II. Research Methodology

This SLR was carried out with the ultimate goal of knowing the main information about the IoTSG that was documented. The SLR that was carried out was different from Traditional Literature Review (TLR), the SLR was carried out methodically and systematically. A good review is a review that can be imitated by other researchers and produces a better scientific value. In addition, it can also evaluate all existing evidence on a validated research topic. The SLR process that has been carried out can be seen in Fig. 1.

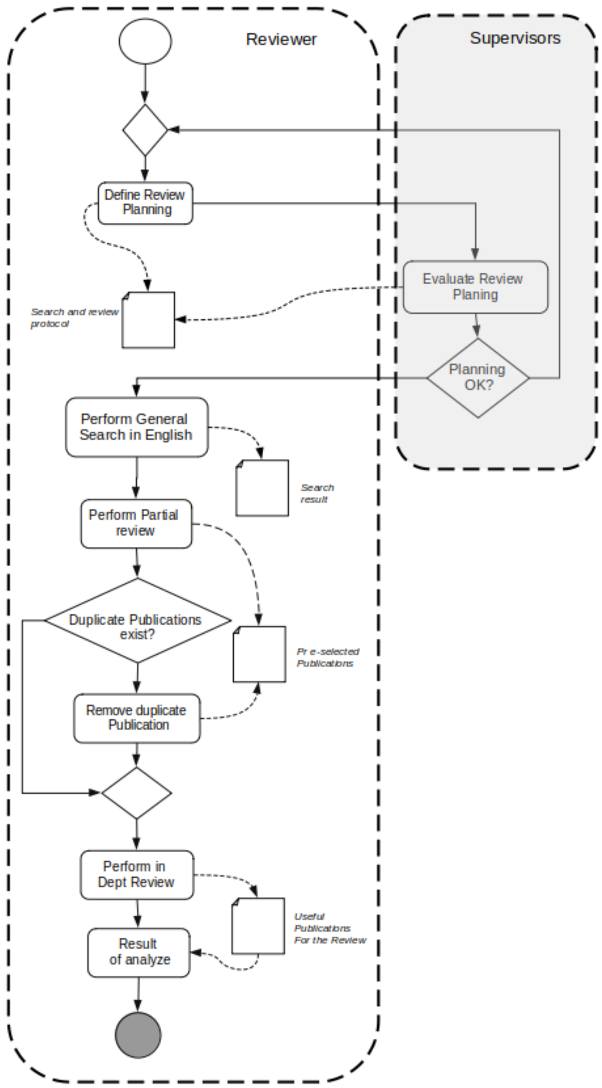

Fig. 1. SLR process [12].

The first thing to do in this SLR is planning a literature review by considering the needs of future research and defining a literature search protocol. Next, the supervisor analyzes and assesses its adequacy. Literature searches were carried out on various sources such as Sciencedirect and IEEE. This search was conducted using only English keywords. Next, conduct an initial review of the search results that have been obtained to optimize publications that are very useful. To delete duplicate publications and the rest of the results of this initial review, an in-depth analysis is carried out. The planning and realization stages of the SLR are described next, while the analysis of the results is presented in Section 4.

A. SLR Planning

To achieve the objectives as described above, Research Questions (RQ) are prepared to define research needs in more detail.

RQ1: What are the sensors used

RQ2: What are the methods used

RQ3: What publishers most related topics

RQ4: What are the research gap possibility

Literature search links include: Science Direct (https://www.sciencedirect.com/), IEEE (https://ieeexplore.ieee.org/Xplore/home.jsp) and MDPI publisher (https://www.mdpi.com/).

B. Search String

The search string uses keywords from the pre-planned research topic. There are four keywords used in this search, namely: IoT, farming, agriculture and greenhouse. The combination of four keywords above for literature searches on each search link is as follows:

C. IoT and Farming and Agriculture and Greenhouse

The search year is limited to 2017 to 2022. Search results are entered into the Zotero reference manager (https://www.zotero.org/) by forming a folder with the name of each folder, including: Sciencedirect and IEEE.

III. Result and Discussion

A. Search String Review

At this stage, a partial review of literature obtained was carried out to obtain the most potential literature in this study. This partial review was carried out on the title and abstract, but in certain specifications a review was carried out on the introduction and conclusion. Definitions related to RQ were included and potentially useful literature was obtained. The realization of this SLR was only done with one search string. The total articles obtained were 301 articles as shown in Fig. 2.

The results were generally displayed at the beginning and the answer for each RQ was placed after it. From each reviewed paper, on average, each paper uses more than one sensor. The general number of sensors used were 26 sensors as shown in Fig. 3. The most widely used sensors in IoTSG were temperature and humidity sensors as many as 12 and the second most sensors are soil moisture sensors with 10.

The method used in each paper was a research and development method integrated with various other methods such as the addition of artificial intelligence as decision support such as recurrent neural networks, artificial neural networks, fuzzy logic, decision trees and so on.

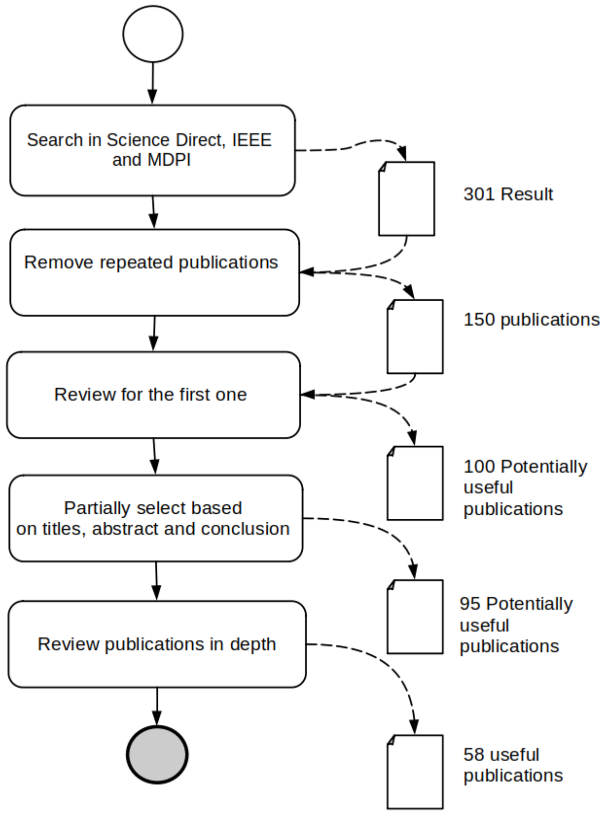

Fig. 2. SLR Step.

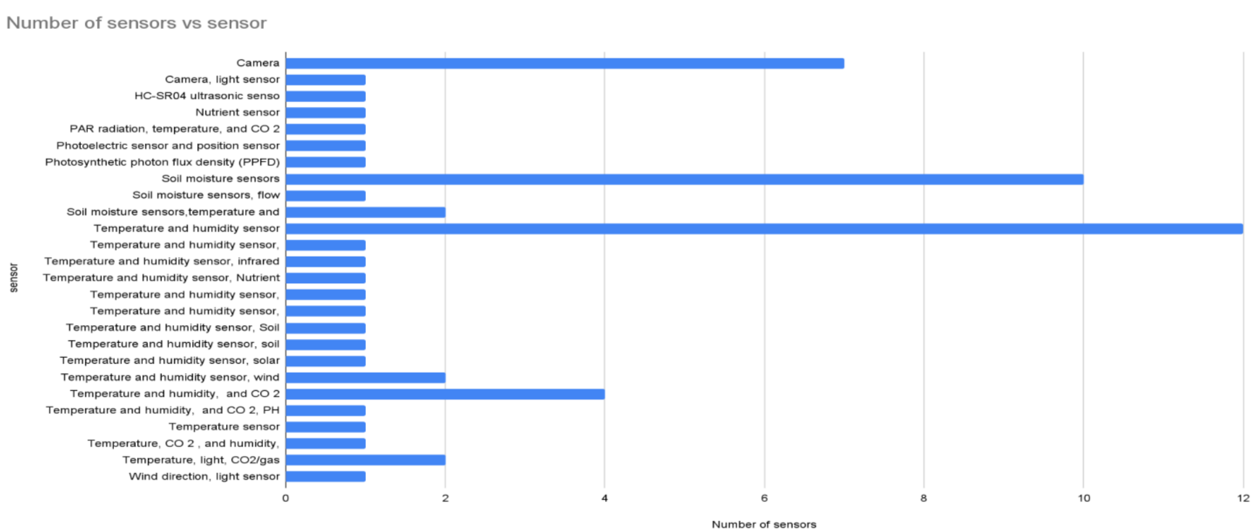

Fig. 3. Sensors used

Development of a meteorological information system using the KOSEN Weather Station (KWS) [13], the Google web toolkit implementing the inter-browser communication method of remote method calls [14], sharing and linking data using partnerships for data innovation that provide the information needs of farmers [15]. The system can help farmers with weather forecasts that are stored in the cloud and information can be viewed via a web that is easy for farmers to understand. To compare the level of accuracy of KWS, the same data was also built using the WXT520 sensor and it was proven that KWS was more accurate.

In greenhouses, there is a way to maximize plant growth by adding lighting using LEDs [16]. The method used was research and development to build an automatic control system for adding lighting using three LEDs among others: red LED, blue LED and a combination of both. Plant growth was observed using IoT, the results obtained from the addition of lighting were better seen from the leaf area index, leaf area rate index and leaf weight rate, besides that the photosynthetic activity of plants was the highest if green light was added in terms of redistribution of quanta absorbed by the plant the entire leaf thickness [17].

By utilizing the application of IoT technology in agriculture, it is proven to increase productivity and production, harvest quality and resource efficiency. This research and development has been carried out using case studies and models as a service approach [18]–[21] real time and historical data and predictive models can be accessed via the web [22]. Firebase servers [23], one of the protocols used is LoRa which is considered sufficient to transmit small data from sensors to the cloud [24]–[26]. The system helps farmers because it produces a Decision Support System (DSS).

To improve the sustainability of agricultural cultivation, research and development methods are used integrated with deep learning, maps of planting sustainability forecasts can be obtained in real time using IoT networks [27].

Energy use in agricultural IoT systems is very important, it is necessary to pay attention and take into account the peak times and prediction models of energy use in IoT-based greenhouses have been made. Various algorithms have been used with research and development integrated with machine learning algorithms such as artificial neural networks, support vector machines, extreme gradient boost and random forest, in research [28] it was found that random forest produces predictions with the highest accuracy compared to other algorithms of 92 %. Integrate the Multi agent System to build greenhouse energy management to optimize energy use for two seasons in one year [29]. The original genetic algorithm was also used for predictive lighting for lighting control in the greenhouse, from the result of measurements that was carried out on growth there was no difference between greenhouses with lighting control and those without lighting control, but there was an efficient use of electrical energy from greenhouses that used lighting control [30].

Various algorithms have been developed for smart agriculture in greenhouses for various estimates that produce contributions, one of which is the algorithm that has been developed is a Repetitive Neural Network (RNN) which can estimate plant growth rates in greenhouses from 0.75 to 0.81 in all growth periods [31].

To obtain data from physical dynamics, a greenhouse requires sensors that are integrated in a wide range. A sensor network was built in a wireless sensor network (WSN) using a wireless Zigbee module with a mesh topology to sense air temperature, CO_2 levels [32]. In addition to the Zigbee module, you can also use the SL900A module in the UHF band [33]. The measurement of wave attenuation for the 2.4 GHz frequency band that penetrated the greenhouse was also measured to determine the effect of the waves on plants [34]. The data loss rate between data acquisition units in WSN was also measured, where data loss at the gateway was 1.52%, between gateways and server was 0.4% [35].

Not only in terms of sensor networks in greenhouses, the development of robot agriculture with a three-device system (3DS) for growth plant monitoring and pest management used the main features of spectroscopy in Automated Guided Vehicles (AGV) [36]. In addition, by utilizing image analysis, image processing technology based on IoT cameras on tomato cultivation in greenhouses was able to estimate the number of blooming flowers, ripe fruit and harvest date with an error of approximately 2.03 days which can support plant growth management [37]. Sending the water level measurement value from the HC-SR04 sensor using a short message service shows good results and efficient [38] , in maximum water level is 3.182m have resolution about 19.2 mm [39] and using MW22B multi turn Potentiometer have obtained vertical resolution about 0.03 m and error is 1.11% [40]. Detection of whole tomatoes used research and development methods by integrating Convolutional Neural Network (R-CNN) with an accuracy of 87.83% [41]. While using deep learning based classification and detection, the accuracy rate reached 99% [42], this method showed that the method used had great potential for predicting tomato ripeness and yield. A genetic algorithm was used to predict tomato growth using data on air temperature, PAR radiation and CO2 concentration [43].

The algorithms used to estimate plant growth in greenhouses can also be used to estimate temperatures in cold greenhouses which cause the greenhouse to freeze, the method used is research and development by integrating Artificial Neural Network (ANN) algorithms and Fuzzy Associative Memory (FAM) with the effectiveness of the results reaching 90% accurate [44] The root mean square error for temperature prediction with a value of 0.2, CO_2 1.29 and humidity 0.14 [45], using a network of long short term memory and Recurrent NN with a root value mean square error of 0.289 [46]. The estimation of soil moisture content or soil moisture as a planting medium in a greenhouse can also use the ARX, ARMX, BJ and State algorithms with values of 91.31%, 91.09%, 91.08% and 90.75% [47]. The development model of Soil Moisture Forecasting (SMF) to activate Constant Moisture Automatic Irrigation (CAIS) using soil moisture data using sensors on planting media soil with different depths with the estimated error values of 0.011 [48], 0.962 [49], 0.014 [50]. The use of capacitive soil moisture sensors in measuring soil moisture is more resistant to rust than resistive soil moisture [51]. While using a model based on long short term memory, the error value is 0.72% [52] and if using a synthesis algorithm and combining it with a triangular affiliation function 0.99% [53]. By controlling soil moisture in the planting medium in the greenhouse automatically the estimation results of the algorithm used can save both, water irrigation and plant nutrients [54]. To overcome the problems of irrigation control due to the weakness of the internet network, an edge of the network was created. All sensor data is stored in the cloud database if there is a network problem it will affect the resulting decision [55].

The application of fuzzy inference engine determines for control and monitoring of hydroponic plants in greenhouses, the defuzzification obtained from sensor network data was used to control irrigation. Plant growth was monitored as input fuzzy parameters [56]. The application of fuzzy logic [57] and Neural Network [58] in this irrigation control can improve water use efficiency. Sensor networks have also been created in several zoning to facilitate obtaining fuzzy parameter input data based on crop area [59]. The water needs of the plants are properly fulfilled and the efficiency of water use is obtained.

Generally, the roofing material for greenhouses is Ultra violet (UV) plastic, but the presence of a transparent photovoltaic solar module that is used as a roof as well as a source of energy for the greenhouse is a distinct advantage [60]. Sunlight as a light source for the photosynthesis process of plants in the greenhouse can enter through transparent photovoltaic which is also a source of electrical energy for the greenhouse.

In addition to the sensor network in the greenhouse which is used as data input in controlling the application of intelligent robots based on the Intelligent Mechatronic System, research has also been carried out. This intelligent robot was tasked with monitoring plant growth conditions in the greenhouse, this robot was used as a substitute for officers in the greenhouse and had an operating efficiency of 95.86% [61]. The use of drones in greenhouses can also help manage greenhouses. Simultaneous visual localization and mapping algorithms and ORB-SLAM utilize the camera as a sensor [62].

The publishers who published the most papers with related topics are MDPI as much as 56.9%, IFAC-Paper Online as much and Information Processing Agriculture as much as 10.3% and the remaining less than 5% as shown in Fig. 4, from this information we can obtain information highest probability of publishers publishing related topics. So that the technical paper that will be produced from this SLR is most likely to be published by the publishers who publish the most related topics.

To find out the quality of publishers at the Quartile level, each paper was analyzed through https://www.scimagojr.com/ by using the ISSN number in each paper as a search keyword. The results of the journal rank analysis can be seen in Fig. 5.

Paper in quartile 1 is 72.4%, quartile 2 is 17.2% and quartile 3 is 10.3%. This shows that the papers on this SLR, which will later become references to technical papers, occupy journal quality in quartiles 1 to 3.

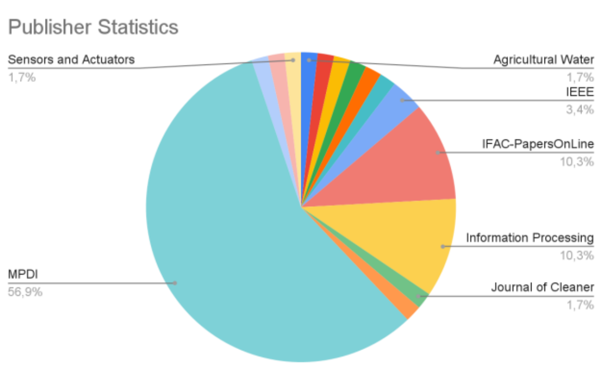

Fig. 4. Publisher statistics.

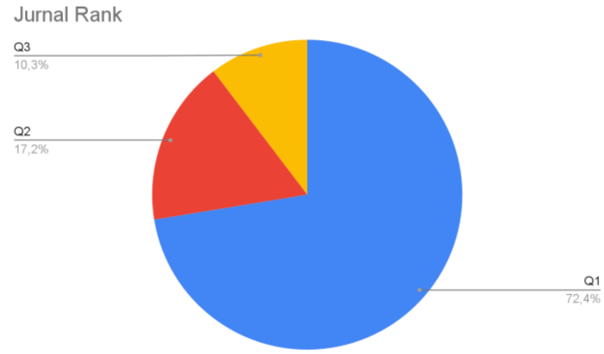

Fig. 5. Rank journal.

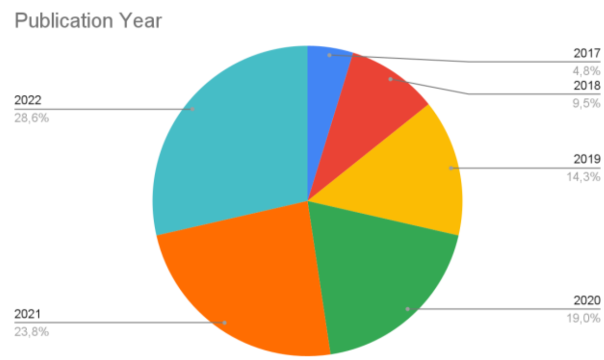

Fig. 6. Publication year.

To find out the research position of related topics, an analysis of the year of publication of each paper, the results are as shown in Fig. 6 above with the number of papers published in 2022 of 28.6% (until August 2022), 23.8% in 2021, 19.0% in 2020, 14.3% in 2019, 9.5% in 2018 and 4.8% in 2017. Judging from the increase in the number of related topics from year to year, it shows that related topics are still good topics for research.

Answering RQ4 to obtain a research gap, one of the analysis carried out was to group paper papers into two groups, namely groups of papers that use datasets and those that do not. The result obtained was 62.1% not using a dataset and 37.9% using a dataset as shown in Fig. 7 using a dataset.

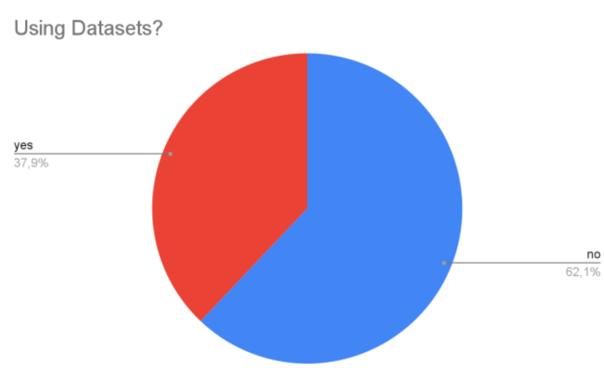

Fig. 7. Dataset.

B. The Possibility of a Research Gap 1

To obtain the possibility of a research gap, a more in-depth analysis was carried out, both on papers that used datasets or not. Papers that used datasets were papers whose research used artificial intelligence such as machine learning using artificial neural network algorithms, decision trees, and so on. The dataset used was a private dataset built by collecting data for some time, then the dataset obtained was used to train the algorithm created. Prediction accuracy and speed as well as memory usage was recorded as a result of the study. To improvise the algorithms and datasets that were created, we corresponded to researchers using the correspondence email contained in each paper. We asked for the source code and dataset, then compiled and tested it on another microprocessor, after obtaining the accuracy and predictive speed and using the same memory, we tried to improve and produced a research gap or novelty, and the results were presented in another technical paper. For example, an algorithm used to create a greenhouse temperature model using the Light Gradient Boosting Machine algorithm (LGBM) [63] median error /^{o}C -0.027, mean error/^{o}C -0.058 and Root Mean Square Error /^{o}C 0.645, it is hoped that after improvement the algorithm (call the x algorithm) a smaller predictive error value is obtained as shown in Fig. 8.

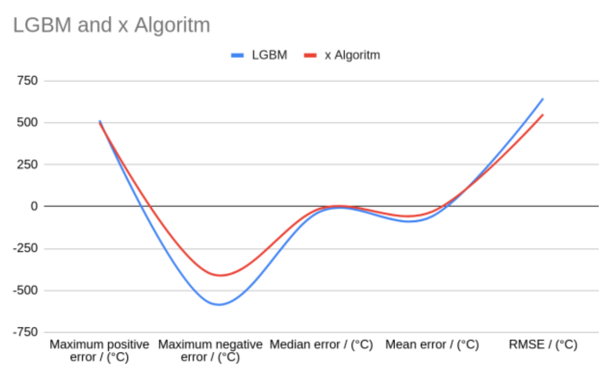

Fig. 8. x algorithm.

Not only did the predictive error value improve, the time training x algorithm also improved as shown in Fig. 9.

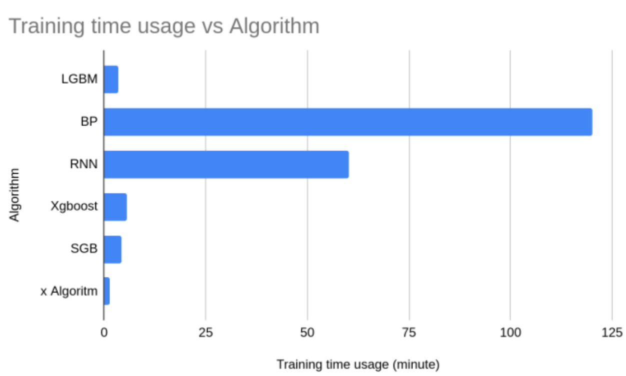

Fig. 9. Time training algorithm.

For papers that did not use datasets in their research, they only built systems for control and monitoring in greenhouses. In general, the system built in each paper can be seen in Fig. 10 as follows.

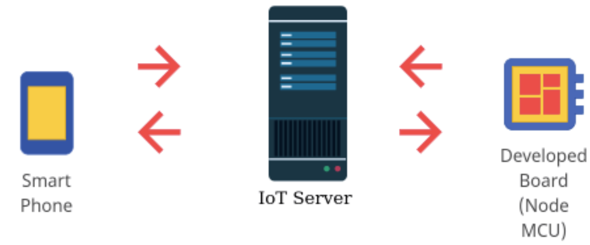

Fig. 10. General IoT system.

The IoTSG system that was created for both control and monitoring was completely on the server or on smart phone mobile apps. The developed board or nodeMCU is only a transmitter and receiver of the sensors and actuators in the greenhouse. The system is very dependent on internet connection, if the internet connection is good then monitoring greenhouse conditions such as temperature, humidity, soil moisture and soil nutrient levels were monitored properly as well as controlling actuators for the process of watering plants and fertilizing can be done properly too. If the internet connection is not good or disconnected, the system will die, monitoring and controlling cannot be done, which can be fatal to plants.

C. The Possibility of a Research Gap 2

To overcome the weaknesses of the IoT system, as stated above, it is necessary to add a developed board that is connected to sensors and actuators in the greenhouse to carry out real time control and monitoring and to compose the IoT system as supporting tools instead of full monitoring and control. In addition, artificial intelligence algorithms can be written on this developed board, for the results of this second novelty will be presented in the next technical paper.

IV. Conclusion and Future Work

The results of the SLR confirmed that The Internet of Things research on Smart greenhouses was still a trend, as seen from the increasing number of related topics from year to year in quartile 1 to 3 journals. The most widely used sensors were temperature and humidity sensors with research and development methods that were integrated with other algorithms as a decision support system. The decision obtained was used to control the actuators in controlling conditions in the greenhouse such as temperature conditions, air humidity, soil moisture, robot control, nutrient levels of both soil and water planting media.

From the publisher statistics, information was obtained that published the most related topics so that we can choose where to publish the next technical paper; this increased the probability of an accepted paper.

For future work, we will conduct research with topics obtained from two possibilities of a research gap, the first future work: the improving algorithm to obtain better prediction and error values than before. The second future work: the addition of a developed board like developed board which is connected to sensors and actuators in the greenhouse to carry out real time control and monitoring. The developed board communicates serially with the cloud-connected Nodemcu.

V. Declaration and Competing Interest

The researchers declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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