Forecast of Energy Consumption of Drying System According to The Environmental Temperature and Humidity on IoT by Arima Algorithm

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***Abstract*— The hot air recirculating drying method has the advantage of handling large output. Moreover, in the drying chamber with a large volume of drying material, factors affecting the drying process such as air flow rate, temperature, drying agent humidity, and surface area of the drying product are always concerned. Because this is the deciding factor for the drying time as well as the quality of the drying product. However, the drying time is closely related to the energy consumed in the drying system. In particular, the temperature and humidity of the environment have a great influence on energy consumption. This paper has built a general mathematical model, using ARIMA algorithm to predict energy consumption for the industrial drying system and applying the mathematical model to actually survey the drying system with a capacity of 1000 kg /batch, 03 drying chambers are designed with a size of 3000mm. x 3000mm x 2500 (length x width x height), total drying tray area 192 m2. Energy sources use thermal oil furnace technology or resistive furnaces. The collected temperature and humidity data is based on the IoT platform. The simulation results forecast the temperature accurately to 99.09%, the humidity is accurate to 98.24% and the energy consumption reaches 96.31%.**

Keywords—Hot air drying; Internet of Things; drying chamber; Arima's algorithm

I. INTRODUCTION

The convection drying method is widely used for drying agricultural products as it is relatively more suited to the diverse nature of types of agricultural products: granular form, the loosely layered granular form, leafy tree form, sliced form [1]. The drying agent in the convection method is usually hot air.

The moisture will be taken out by the exhaust gas stream [2,3] so in the factors that affect the time and quality of the drying product such as: Airflow speed, temperature, the moisture content of the drying agent, the surface area of the drying product, temperature, and humidity need to be paid more attention [4,5,6] because this factor is significantly influenced by the environment. Especially, in areas where the drying system is installed, temperature and humidity change markedly with the seasons [7]. Accurate energy consumption prediction helps users to actively source fuel, the energy required in the production [8,9].

IoT applications (Internet of Things) [10,11] in system control and monitoring is an advantage and is consistent with the trend of the industrial age 4.0. In [12,13,14], the author recommends using IoT technology in environmental monitoring by collecting the temperature and humidity data of the environment through a wireless sensor system. All data are stored and retrieved on Cloud.

Based on this result, the author has developed an application to manage devices that consume power in an economical way through applications on computers and smartphones, for convenient management, help cut down on power consumption. In [15], the authors reviewed the adoption of IoT-based signal processing techniques and used the ARIMA model to predict temperature and energy consumption. Simulation results in the case of predicted temperature and load consumption are more than 98.15% and 99.51% respectively. In this paper, the author has built a general mathematical model and used the Arima algorithm to predict temperature and humidity based on previous data.

Thereby calculating and forecasting the energy consumption of the drying system to recommend that users proactively prepare the fuel source for the drying system to improve the reliability, saving fuel costs of burning. The mathematical model and function blocks of the system are presented in Part 2. The proposed method and simulation results will be presented in parts 3 and 4 respectively.

II. HARDWARE STRUCTURE AND MATH MODEL

A. Hardware structure

Control and monitor the drying mode of the system based on the IoT platform which is responsible for monitoring parameters, hosting add-ons and graphs in the webserver.

In addition to data collection, the system also provides utilities to set alarm controls and control off/on devices to suit the drying mode. The system also allows the user to download batch information in excel format, easy management.

The temperature and humidity sensors are wirelessly connected via the controller modul and bring all data to the Cloud. Data collection is set every 1 hour. The connection diagram is shown in Fig. 1.

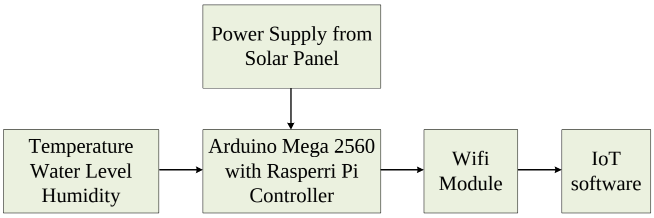

Fig.1. Overall Block Diagram [16]

B. *Mathematical models forecasting energy consumption*

The heat required for the drying process is calculated using the following formulas:

$$Q = Q1 + Q2 + Qtt \quad (1)$$

Which:

Q: the total amount of heat for the drying process

Q1: the heat required for the water in the drying material to evaporate completely to the required moisture content. Calculated based on the equation:

$$q = l.(0{,}24 + 0{,}00047X0).(t1 - t0) \quad (2)$$

Which:

q: the heat used to provide 1 kg of evaporation moisture

X0: the initial moisture content of the air before entering the heater (calorife) [g/kg KKK].

t0 (oC): the initial temperature of the air

t1(oC): the temperature of the air entering the dryer

l [kg KKK/ kg of moisture evaporated]: amount of air required as a drying agent.

Q2: the heat of the drying material

$$Q2 = m.Crn.(t1 - t0) \quad [kJ] \quad (3)$$

Cm: Specific heat capacity of the drying material (kJ/kg.K)

m: Mass of drying material [kg]

Because the system has insulation on the pipe, insulation in the drying chamber should be selected

$$Qtt = 0.06Q1 \quad (4)$$

From there, we see that the amount of heat needed to supply the drying system depends on the temperature and humidity of the environment.

Therefore, forecast energy consumption of the drying system according to weather conditions (temperature, humidity) is very important. The energy forecasting model is performed similarly to the forecasting of temperature and humidity model, but in a day, I work 3 shifts (8 hours/1 shift) then the mathematical model of the calorific value Q(t) is shown by the following equation:

$$Q(t) - \hat{Q}(t) = e(t) \quad (5)$$

$$G(t) = (1 - B)(1 - B^3)Q(t) \quad (6)$$

In that G(t) is the stationary signal, Q(t) is a non-stationary signal (heat at time t), $\hat{Q}(t)$ is the projected calorific value at time t, e(t) is the error between the actual heat and the predicted heat. Based on ARIMA theory, we have equation (5) as follows:

$$(1 + \phi_1 B^1)G(t) = (1 + \theta_1 B^1)e(t) \quad (7)$$

Replace equation (6) with equation (7), we get

$$(1 + \phi_1 B^1)(1 - B)(1 - B^3)Q(t) = (1 + \theta_1 B^1)e(t) \quad (8)$$

Multiply all terms of the equation (8), we have the prediction equation:

$$\begin{aligned} Q(t) &= \phi_1 Q(t-1) + \phi_2 Q(t-2) + \phi_3 Q(t-3) + \phi_4 Q(t-4) + \\ &\phi_5 Q(t-5) + e(t) + \theta_1 e(t-1) \end{aligned} \quad (9)$$

From equations (5) and (9), heat $\hat{Q}(t)$ can be rewritten as follows:

$$\begin{aligned} \hat{Q}(t) &= \phi_1 Q(t-1) + \phi_2 Q(t-2) + \phi_3 Q(t-3) + \\ &\phi_4 Q(t-4) + \phi_5 Q(t-5) + \theta_1 e(t-1) \end{aligned} \quad (10)$$

Equation (10) shows that the forecast data $\hat{Q}(t)$ is greatly influenced by historical data in Q(t-1), Q(t-2), Q(t-3), Q(t-4) , Q(t-5) and error e(t-1).

Parameters in the equation (19) can be estimated using linear regression and in Matlab, the equation has the form:

$$parameter = pinv(\hat{Q}(t))Q^T \quad (11)$$

$$parameter = \begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \\ \phi_5 \\ \theta_1 \end{bmatrix} \qquad Q = \begin{bmatrix} Q(t-1) \\ Q(t-2) \\ Q(t-3) \\ Q(t-4) \\ Q(t-5) \\ e(t-1) \end{bmatrix} \quad (12)$$

The error between the real data and the forecast data is calculated as follows:

$$\varepsilon = \frac{|Q(t) - \hat{Q}(t)|}{Q(t)} \times 100\% \quad (13)$$

III. TEMPERATURE PREDICTION ALGORITHM, HUMIDITY AND ENERGY CONSUMPTION OF THE DRYING SYSTEM

Building ARIMA model based on historical data of temperature and humidity collected as Fig. 2 ARIMA algorithm is depicted in Fig. 3.

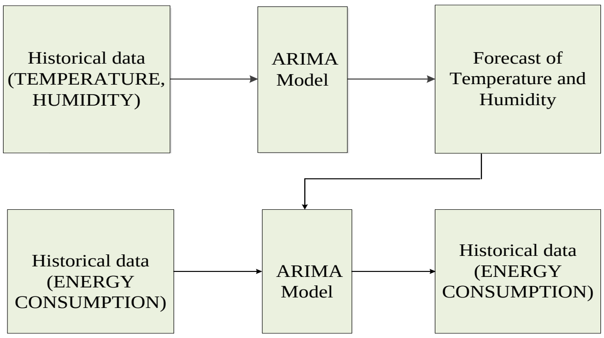

Fig. 2. Block diagram

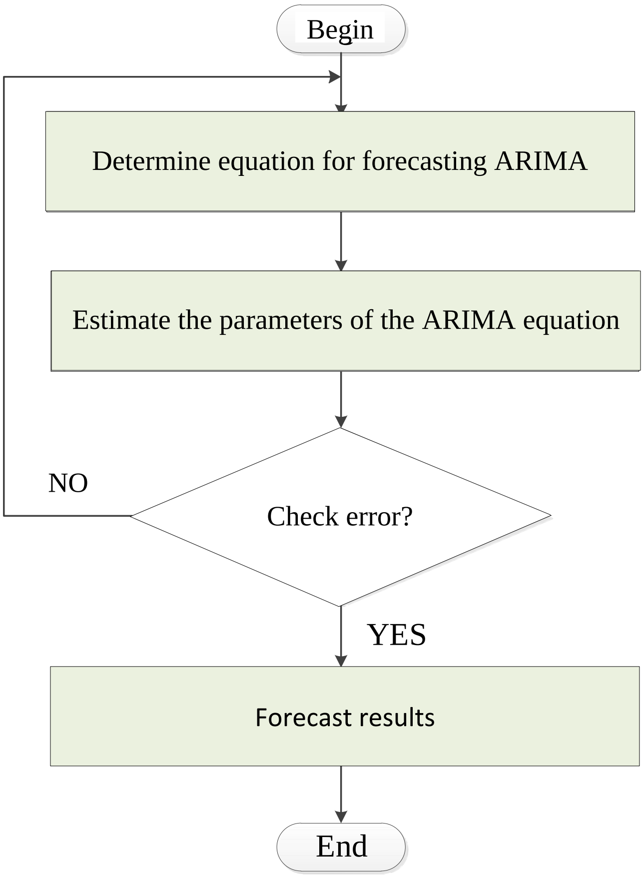

Fig. 3. The ARIMA algorithm

IV. SIMULATION RESULTS

In this study, temperature and humidity data are collected at Nhon Trach, Dong Nai by using smart IoT devices.

The temperature and humidity device's sampling frequency is set to be one hour/sample respectively, respectively.

Historical data is collected for a week. Dimensions of temperature and humidity data are 168x1. Simulation is performed using either the MATLAB or Excel platform.

A. Heat prediction simulation results

The graph of sampling temperature and forecast temperature is shown in Fig. 4. The forecasted temperature for the next week is based on historical data for the previous week simulated by Arima's algorithm that followed the sampling data, the average error is 0.91% so the Arima algorithm is reliable and can be used as an input database for forecasting energy consumption when the ambient temperature changes.

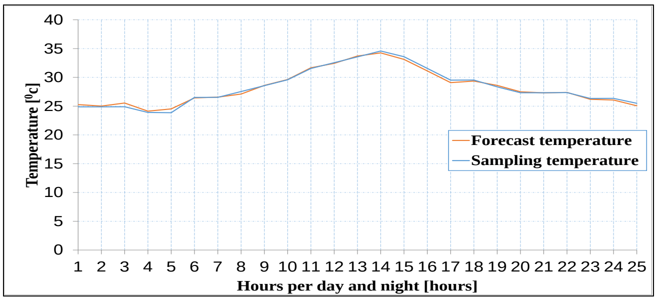

Fig. 4. Sampling temperature and forecast temperature

In Fig. 5 and Table I the forecasted temperature error is from 12 am to 5 am (average of about 1.7%) higher than the time between 6 am and 11 pm (average of about 0.72%), shows when the temperature drops below 250C, Arima algorithm has a higher error.

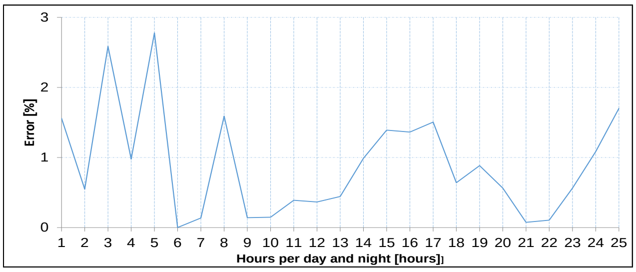

Fig. 5. The error between the sampling temperature and the predicted temperature

TABLE I. TEMPERATURE ERROR

Hour/day	Sample temperature	Forecast temperature	Error
9	28.5644	28.6048	0.1413
10	29.5826	29.6264	0.1480
11	31.5468	31.6696	0.3894
12	32.5507	32.4320	0.3647
13	33.5638	33.7128	0.4438
14	34.5867	34.2448	0.9886
15	33.5858	33.1188	1.3904
16	31.5641	31.1339	1.3628
17	29.5228	29.0783	1.5057
18	29.5371	29.3480	0.6402
19	28.3541	28.6048	0.8842
20	27.3319	27.4860	0.5639
21	27.3273	27.3069	0.0743
22	27.3599	27.3888	0.1057
23	26.3353	26.1872	0.5622
24	26.3562	26.0702	1.0851
25	25.5014	25.0675	1.7013

Hour/day	Sample temperature	Forecast temperature	Error
1	24.8818	25.2700	1.5601
2	24.8816	25.0180	0.5484
3	24.8959	25.5400	2.5870
4	23.8962	24.1296	0.9766
5	23.8556	24.5184	2.7783
6	26.5237	26.4320	0.3457
7	26.5255	26.5616	0.1362
8	27.5353	27.0972	1.5910

B. Humidity prediction simulation results

Fig. 6 and Fig. 7 show that when the humidity decreases, the predicted humidity has a large error, specifically, between 11 am and 18 pm and the humidity is less than 62%, the average error is about 2.68%. Whereas, other hours have a specific lower error:

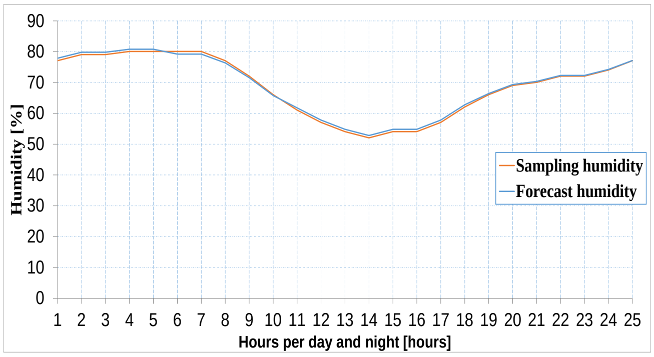

Fig. 6. Sampling humidity and forecast humidity

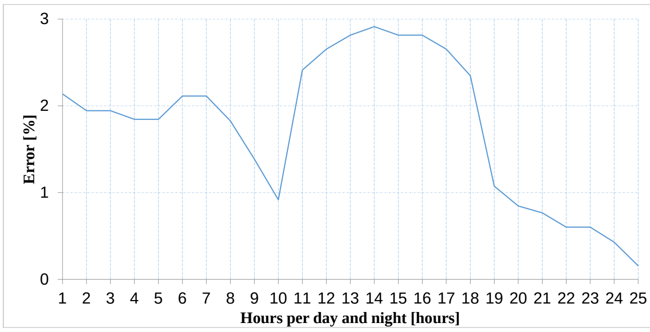

Fig. 7. The error between the sampling humidity and the forecast humidity

From 24 pm to 10 am, the average error of the forecast humidity is about 1.8% compared to the measured data, from 19 pm to 23 pm, the average error is about 0.64%

According to Table II, the average error is about 1.76%. This proves that the Arima model used to predict future data based on previous historical data is reliable and we can use this result to calculate and predict the thermal energy consumption of the system-specific drying system.

TABLE II. HUMIDITY AND ERROR WHEN FORECASTING BY ARIMA ALGORITHM

Hour/day	Sample moisture	Forecast humidity	Error (%)
1	77.0693	77.8929	2.1374
2	79.0711	79.8398	1.9443
3	79.0711	79.8398	1.9443
4	80.0720	80.8106	1.8449
5	80.0720	80.8106	1.8449
6	80.0720	79.2261	2.1128
7	80.0720	79.2261	2.1128
8	77.0693	76.3656	1.8261
9	72.0648	71.5657	1.3852
10	66.0594	65.7564	0.9175
11	61.0549	61.7914	2.4127
12	57.0513	57.8083	2.6539
13	54.0486	54.8093	2.8150
14	52.0468	52.8049	2.9130
15	54.0486	54.8093	2.8150
16	54.0486	54.8093	2.8150
17	57.0513	57.8083	2.6539
18	62.0558	62.7842	2.3476
19	66.0594	66.4139	1.0734
20	69.0621	69.3541	0.8456
21	70.0630	70.3313	0.7659
22	72.0648	72.2813	0.6009
23	72.0648	72.2813	0.6009
24	74.0666	74.2253	0.4284
25	77.0693	77.1293	0.1557

C. The results of the forecast of energy consumption of the drying system

The real energy forecasting model is based on an actual drying system, installed in Dong Nai with a capacity of 1000 kg/batch. Drying chamber: (Length x Width x Height) is 3000 mm x 3000 mm x 2500 mm

Drying tray: 36 vehicles x 11 trays = 396 trays, area of 0.48m2/tray. Thermal oil furnace: 100,000 kcal/h is equivalent to 120 kW. 3-shift working day (8 hours/1 shift) are divided as in tables 1 & 2, with the sample size of humidity and temperature being 168x1, the sample size of the forecasted energy consumption in 1 week (7 days) is 21 x 1.

The forecast results of energy consumption for a resistive furnace and the amount of firewood burned for a thermal oil furnace are shown in Fig. 8 and Fig. 9.

From those two figures, the energy consumed and the burning fuel depend on the temperature and humidity of the environment very much. Specifically, when drying in the period from 24 am to 8 am with low temperature and high humidity, the energy consumption is about 20% higher than the drying time from 9 am to 4 pm.

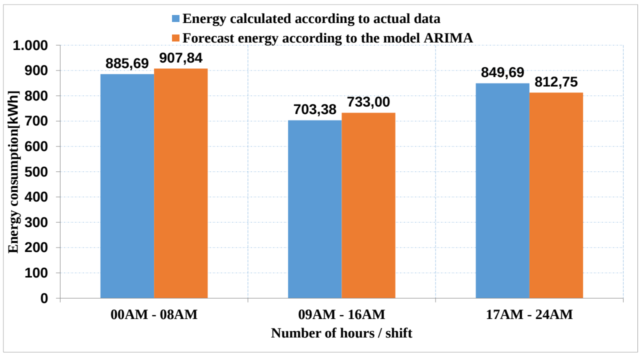

Fig. 8. The energy consumption of the resistive furnace is based on real data and forecasted by the ARIMA model.

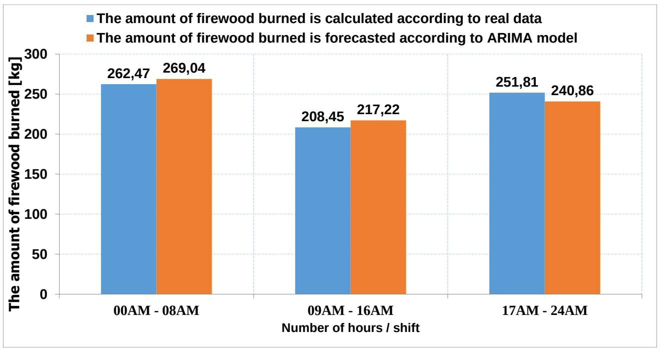

Fig. 9. The amount of firewood burned in the kiln using thermal oil furnace technology is based on real data and forecast according to the ARIMA model.

V. Conclusion

In this paper, we looked at the adoption of IoT-based signal processing techniques to manage systems and collect environmental temperature and humidity data. The simulation results show that when the temperature is low and the humidity is high, the energy is consumed much. Therefore, factories need to choose the drying time of day accordingly. The best time which we choose from 9 o'clock to 16 o'clock. Forecast results based on the ARIMA model for temperature is 99.09%, humidity is 98.24% and the energy consumption is 96.31%. This is the basis to apply the forecast of energy demand for the next weeks of the drying system so that the producers can actively source fuel and energy. In particular, the forecasting model is very useful when the drying system is installed in the regions where the temperature and humidity are much different according to the seasons of the year.

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