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LabVIEW Based Fuzzy Controller Designed for a Microwave Oven

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Abstract

This paper presents a new design for controlling microwave oven (MWO) device which has become used daily in last few years. The aim of this work is to develop the operation of the recent MWOs, where three new features have been proposed to be supplemented to the new design, the first one is adding a load cell under a turntable specified for MWO to measure the weight of the processed food instead of setting it manually. The second feature is incorporating the fuzzy techniques with the design of MWO by designing a fuzzy controller capable to decide the suitable power level and total heating time automatically according to the measured weight. While in the third feature a steam sensor has been suggested to be added in the upper cavity of the MWO, so the controller will be able to decide the remaining time to finish once the presence of a steam is detected. Finally the output results of the controller have been tested practically on some kinds of food using the available MWO. The results proved the efficiency of using this design by finding the suitable parameters to process food without dependence on the repeated estimation by the user.

Keywords: Microwave oven, LabVIEW, Fuzzy controller, Weight.

مسيطر مضبب على عمل فرن المايكروويف بالاعتماد على بيئة الآلات الافتراضية

الخلاصة

يقدم هذا البحث تصميما جديدا للسيطرة على عمل فرن المايكروويف الذي أصبح استخدامه بشكل يومي في السنوات القليلة الماضية. إن الهدف من هذا العمل هو تطوير عمل أفران المايكروويف الحالية باقتراح ثلاث خصائص جديدة تضاف إلى التصميم الجديد. الخاصية الأولى هي وضع خلية حمل تحت الصحن الدوار الخاص بالجهاز وذلك لقياس وزن الطعام المراد تسخينه او طبخه عوضا عن إدخاله يدويا من قبل المستخدم. الخاصية الثانية هي دمج التقنيات المضببة في تصميم فرن المايكروويف وذلك بتصميم مسيطر مضبب قادر على إيجاد مستوى القدرة و زمن التسخين الكلي المناسبين أوتوماتيكيا بالاعتماد على الوزن المقاس. أما الخاصية الثالثة فتتلخص بإضافة متحسس للرطوبة في التجويف العلوي للفرن وذلك ليتمكن المسيطر من تحديد الوقت المتبقي لانتهاء عملية التسخين عند تحسسه لوجود البخار. أخيرا تم اختبار نتائج إخراج المسيطر عمليا على بعض أنواع الأغذية وذلك يدوياً باستخدام فرن مايكروويف نوع AM820AGX. أثبتت النتائج كفاءة استخدام هذا التصميم لإيجاده المعاملات المناسبة لمعالجة الغذاء دون الاعتماد على التخمين المتكرر من قبل المستخدم.

الكلمات الدالة: فرن المايكروويف، لابفيو، المسيطر المضبب، الوزن.

Introduction

Microwave ovens (MWOs) have become more popular over the last years and can be used daily not only in home kitchens, but also it can be used in industry applications for food treatment or drying products as macaroni. Use of MWOs in food preparation may be an easier, fast and safer task to teach than traditional cooking skills that involve more direct contact with potentially dangerous appliance, therefore there has been an increasing interest in MWOs which can overcome certain limitations of conventional thermal food treatment [1]. But over the developed technology, MWOs are not as automatic as they could be where the parameters of this device are still being set manually by the household or the user and they must estimate the values of these parameters and repeat setting them by experimentation with try and error procedure. These parameters included: the entire heating time and the power level which must be predictive by the user before each starting operation.

It is evident that this process needs human intuition, so more intelligent control strategies are needed. In current work the fuzzy techniques are used because fuzzy logic incorporates the natural human way of thinking in a control system, making possible the implementation of a controller with a performance like a human operator [2]. This fuzzy controller for a MWO device can give the correct heating time and the suitable power level even though a precise model of the input/output relationship is not available.

The work presented in this paper covers full design of a fuzzy logic controller (FLC) for MWO in LabVIEW environment version 2009. LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a powerful and versatile graphical programming environment that was developed to facilitate instrumentation control and analysis which can be used with a wide range of applications especially in control field [3]. LabVIEW has a Fuzzy Logic Toolkit that enables users to integrate fuzzy logic control into virtual instruments (VI), this toolkit is utilized in current work to design and implement rule-based fuzzy logic system for expert decision making.

Literature Review

At present, many researches utilized the fuzzy techniques for different applications like air condition system, auto focus camera, washing machine ... etc, but there isn't an attention or researches to develop the MWO design. The recent researches that concerned with this device are for drying single kind of food with constant ON-OFF power cycle ratio within a predefined time interval manually, so nowadays the parameters of the MWO are still left uncontrolled and could only be estimated by experimentation.

Liang *et al*. [4] dried flowers with microwaves which offered a number of advantages over conventional methods, including faster heating, more uniform drying, and little variation in colour values. They concluded that a "10 sec ON: 45 sec OFF" cycle was suitable for rose flower drying.

Changrue *et al*. [5] recommended that, to achieve an efficient drying process, carrot cubes should be dried under a fixed power density of 1 W/g with 70°C hot air. The power to the magnetron was manually controlled with an initial pattern of "55 sec ON: 5 sec OFF" followed by a pattern of "30 sec ON: 30 sec OFF" when the moisture content of the carrot cubes dropped below 30% (wet basis).

Wang Gui-juan *et al.* [6] combined neural network with fuzzy technique to design a washing machine controller. They considered that the main factors which influence the washing time are turbidity level and the change rate of turbidity level. So, the turbidity and change rate of turbidity was used as the input parameter of control system, and washing time was used as control variable of control system, that is, the output of the system.

Microwaves and MWO Technology

In the middle of 1950s, a microwave heating becomes the custom with microwave ovens, and later it was used in food industry for drying [7]. MWO are the high voltage system that generate microwave energy which heats or cooks food by radiation without applying any external heat.

Microwave radiation

Microwaves are a part of the electromagnetic radiation spectrum between common radio and infrared frequencies, this radiation are extremely high frequency radio waves 0.3-300 GHz [1]. Microwaves absorption and reflectivity are functions of the matter subjected to them. Hence, electrically non-conductive materials like glass, paper, plastic and ceramic allow microwave to pass through them with very little absorption and all other materials that fall between metals and electrical isolators absorb microwave at different rates. So materials that containing moisture (such as food and even people), absorb microwave energy in a process called dielectric heating. If this energy is absorbed at a rate greater than the rate at which the material loses energy (rate of cooling) its temperature increases [8].

MWO Technology

A microwave oven is a metal box, furnished with a glass door that is covered by a net of metal, which attenuate the leakage of microwave radiations [8]. The heart of this system is the magnetron which is specialized vacuum tube, in which electrical energy converted to oscillating electromagnetic fields of 2,450 GHz frequency (a Wavelength of 12.24 centimeters (4.82 in)) which is transmitted into the enclosed metal oven cavity. In the cavity, they are reflected by the oven walls and absorbed in food or drink placed in the oven as described in the previous section. To produce these very high frequency waves, a magnetron requires a very high voltage supply (4Kv for commercial MWOs), so the line power 220 volt (in Iraq) is converted by a high voltage transformer and supplied to the magnetron, which generates the microwaves [9].

In fact, these waves are not heating in themselves but microwave-generated alternating electric fields are a form of energy, converted to heat through their interaction with charged particles and polar molecules [10].

All food molecules have positive and negative particles which attract and repel each other like magnets. The alternating electric field forces the polar molecules in the food to rotate back and forth, by continuously reversing the polarity of the food molecules a tremendous number of times (2,450,000,000 times per second), This causes molecular agitation and thus agitation causes friction between the molecules which produces a rapid rise in temperature to develop heat. Once the microwaves stop, this friction action continues by itself, eventually returning to normal molecular action [11]. The oven walls are not directly heated by microwaves, as they do not absorb microwave energy, but the inside of the oven may feel warm due to the presence of the hot food and the heat generated by the electrical circuits.

Recent and Proposed MWO

In order to develop the commercial MWOs operation, the automatic control and especially intelligent fuzzy techniques are utilized in this design. In recent MWO the user must set the power level besides either setting the temperature duration time or in some new MWOs the user can set the weight of the processed food instead, this type is listed as auto reheat term, but in this case the setting value of this weight will be approximated or the user need to weigh the food before processing it, however, according to this set weight value the program delimits the total needed duration time with a linear relationship as shown in Table 1, these values are taken from the available MWO model AM820AGX by Délonphy Company.

Table.1 The linear relationship between weight and time

Weight (g)	Total processing time (min.)
100	1.16
200	2.32
300	3.48
400	4.64
:	:
2000	23.2

Hence the ideas of the proposed design are concluded firstly by designing a fuzzy controller that decides the duration time and the ON interval time automatically according to the weight of the processed food. Secondly instead of setting the weight of food manually, a load cell can be used and located under the turntable dish to measure the weight of food before starting the operation and this information is used as an input to the fuzzy controller to control the program by deciding the suitable required time instead of calculating it by linear relationship in conventional MWO design. The advantage of this technique that would, to a large extent, makes the operation easier for users by automating the MWO system design, thus the cost of these weighing scales is presently not high in price, so this modification on the recent design don’t cost as compared to its benefits and this feature may be incorporated easily in domestic microwave ovens.

Implementing the MWO Design as FLC

The Proposed Design

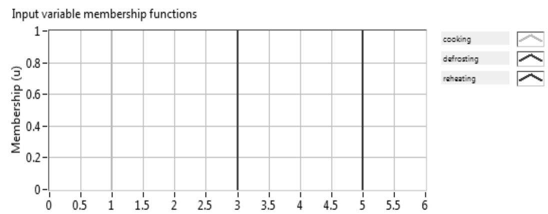
The fuzzy controller is designed with dual inputs and dual outputs, the first input variable is the weight which represents the amount of food outcome from the load cell, the second input variable is the classification for the type of process that the user want to do, these processes are classified as: defrost, reheat and cook. On the other hand the FLC is designed with two outputs, one of them to set and control the entire duration time (T_1) needed to complete the required process, another important controlling parameter is the ON power time interval (t_{on}) which set the power level. There is no doubt that the power supplied as a constant value for each device and it is not an adjustable value, but in MWOs or even conventional ovens the different power levels setting is done as a simple ON-OFF operation to change the mean power delivered to load, where the oven is turned ON at full power for some time (t_{on}) during the cycle and switched off during the rest of the cycle, the time fraction of ON-OFF operation represents the duty cycle defined as

duty cycle= t_{on} / (t_{on} + t_{off})………...….(1)

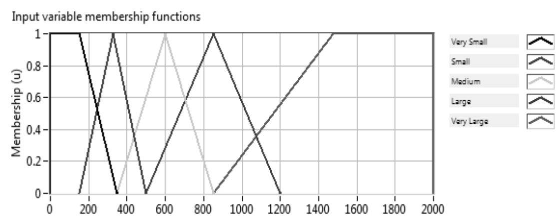
duration time (t) = t_{on} + t_{off}……………...(2)

Actually the *power level* term is used as a GUI term that represents the percent ratio of the duty cycle, in the proposed design this parameter would be set automatically for each classification, in addition to possibility of setting it manually as another option for the user. According to Equation (1) duty cycle represents the ratio between t_{on} and t, therefore in the proposed design the t_{on} value is considered as a second output parameter for this controller, so by this on-off fuzzy control the FLC sets all unknown parameters required to produce the supplied electric power to magnetron. By this procedure the fuzzy controller designed got rid of setting these parameters manually by the user.

The Fuzzy System Designer toolkit in LabVIEW environment is used to design the controller, where the weight input variable is set with a universe of discourse UOD from 0g to 2000g and with five fuzzy sets (very small, small, medium, Large and very Large), whereas the second input (classification) is considered as a crisp input with singleton membership functions MFs, because there is no middle state between its terms (reheat, cook and defrost) this input variable is added instead of designing three FLC for each process. Figure (1-a) and Figure (1-b) show the MFs of these two inputs. Figure (2-a) and Figure (2-b) show the MFs of the outputs variables: T_1 and t_{on} of the proposed controller whereas T_1 variable is designed with a UOD range from 0 to 20 minutes and t_{on} from 0 to 2 minutes. These UOD ranges are set by trial and error procedure.

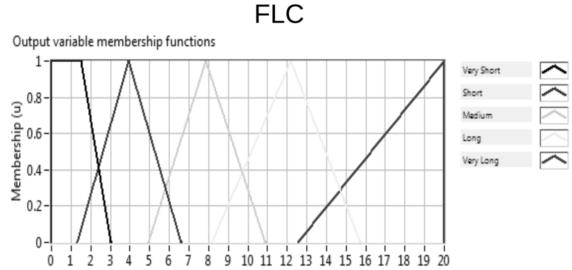


(a) Classification

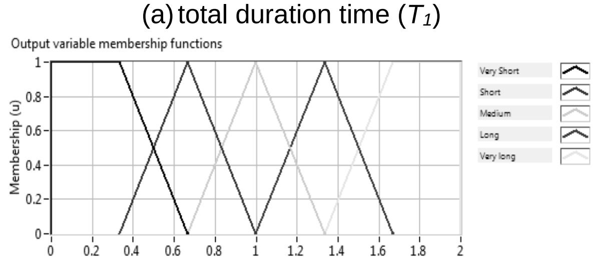


(b) Weight

Fig. 1. Input variable MFs for the designed FLC



(a) total duration time (T_1)



(b) t_{on} duration time

Fig. 2. Output variables MFs for the designed FLC

The decisions which are made by the FLC are basically based on if–then rules, these fuzzy rules are obtained and created by many repeated experiences on the MWO and by depending on the human intuition derived from common sense for typical home usage, where for defrosting mode the duty cycle must be extremely less than the other two modes because the frozen food needs a discontinuous heat for deliquescence it, as well as to avoid cooking the food under the continuous heat since the defrosting mode is for deliquescence food only. On the other hand the cooking mode requires full power level to cook the food besides the operation of a grill heater this type of cooking is called a convection cooking so in this case there is no need to calculate the t_{on} parameter in the fuzzy rules, also the output duration times of the FLC are multiplied by a scalar factor to expand the output UOD for output variables. The number of these rules is five for each mode or classification, so the total number of rules is 15 rules as listed below:

1. If '*classification'* is '*defrosting*' and '*weight*' is *'Very Small* ' then *'* T_1 ' is *'Very Short'* also ' *ton* ' is *'Very Short* '.
2. If '*classification'* is '*defrosting*' and '*weight*' is *'Small*' then *'* T_1 ' is *'Short*' also '*ton*' is *'Short* '.
3. If '*classification'* is '*defrosting*' and '*weight*' is *'Medium'* then *'* T_1 ' is *'Medium*' also '*ton*' is *'Medium* '.
4. If '*classification'* is '*defrosting*' and '*weight*' is *'Large*' then *'* T_1 ' is *'Long*' also '*ton*' is *'Long*'.
5. If '*classification'* is '*defrosting* ' and '*weight* ' is *' Very large* ' then *'* T_1 ' is *' Very Long* ' also '*ton*' is *' Very Long* '.
6. If '*classification'* is '*reheating*' and '*weight*' is *'Very Small*' then *'* T_1 ' is *'Very Short* ' also '*ton* ' is *'Very Short* '.
7. If ' *classification '* is '*reheating*' and '*weight* ' is *' Small* ' then *'* T_1 ' is *'Very Short*' also '*ton*' is *' Short* '.
8. If '*classification'* is '*reheating*' and '*weight*' is *' Medium*' then *'* T_1 ' is *' Short '* also '*ton*' is *'Medium '.*
9. If '*classification'* is '*reheating*' and '*weight*' is *' Large*' then *'* T_1 ' is *' Medium* ' also '*ton*' is *'Long* '.
10. If '*classification'* is '*reheating*' and '*weight* ' is *' Very Large* ' then *'* T_1 ' is *' Long* ' also '*ton*' is *'Very Long* '.
11. If '*classification'* is '*cooking*' and '*weight*' is *' Very small* ' then *'* T_1 ' is *' Short* '.
12. If '*classification'* is ' *cooking* ' and '*weight*' is *' Small* ' then *'* T_1 ' is *'Medium* '.
13. If '*classification'* is ' *cooking* ' and '*weight*' is *'Medium* ' then *'* T_1 ' is *' Long* '.
14. If '*classification'* is ' *cooking* ' and '*weight*' is *' Large* ' then *'* T_1 ' is *' Very long* '.
15. If '*classification'* is '*cooking*' and '*weight*' is *' Very Large* ' then *'* T_1 ' is *Very Long'* .

This FLC is integrated with a complete design in LabVIEW that creates the ON- OFF power fuzzy control system. This controls the very high voltage 4Kv after it is transformed from the voltage supply 220v to change the power output of the magnetron in an on-off mode (duty cycle control). Figure (3) and Figure (4) show the block diagram and the front panel for this design.

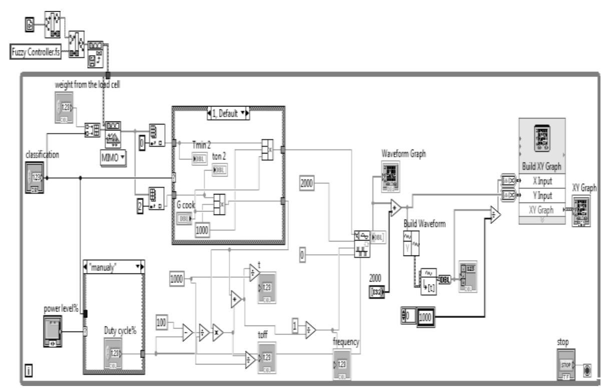


Fig. 3. The block diagram of the designed MWO

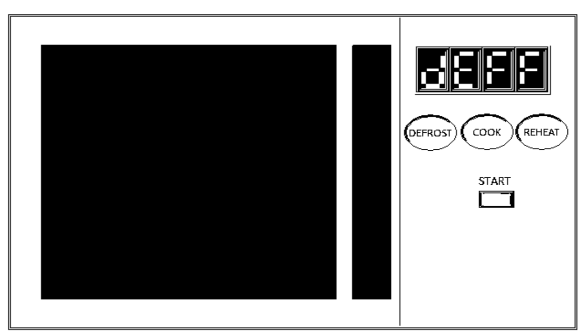


Fig. 4. The front panel of the designed MWO in LabVIEW

The Modified Proposed Design

To improve the previous design, in this section another modification is added to it, where the state of the processed food could be returned to the controller to adapt its outputs, i.e. a feedback control system has been accomplished in this design. Clearly it is difficult to set a temperature sensor inside the food during microwave operation, and this needs a certain type of contact sensors as well as for a frozen food it is impractical to fix any sensor inside that food. So another technique is considered.

During processing food in MWO, a certain amount of steam is produced eventually, therefore a humidity sensor is utilized and placed at a point where the steam leaves the cavity and collect at the end of a certain duct. This sensor detects the presence of steam emitting by the food being processed, and then measures the moisture content of the rising gasses from the food. The percent value of the measured humidity is send to a fuzzy controller in addition to the measured weight from the load cell as in preceding design, according to this information the fuzzy inference decides the second duration time T_2 and stop the first duration time T_1.

For this modified design, Figure (5), another fuzzy controller has been added to the first one, where the first controller decides the initial interval time T_1 and the second controller determine the remaining time or which is called the balance time T_2 with a small range from 0 sec to 2 min., where this time interrupts the T_1 period when steam is detected and the design automatically jumps to a second period T_2 and this value appears in the display LED window.

The second added controller has been designed with two inputs (the T_1 value and the classification type) and single output T_2 remaining time. The rules of this controller are set according to human intuition and usage of this device. It is evident that for defrost classification type the steam sensor is not useful because the defrosting process do not produce steam, therefore the controller operates only for cooking and reheating mode. The time T_2 for cooking must be longer compared with reheating, and the later must be very small because at moment the steam is escaped from the food, it will be hot. For cooking mode when T_1 time is long i.e. the weight is big, the controller decides that the T_2 value must be long and vice versa if T_1 is short time, T_2 must be short too and so on. Figure (6) shows the output variable MFs.

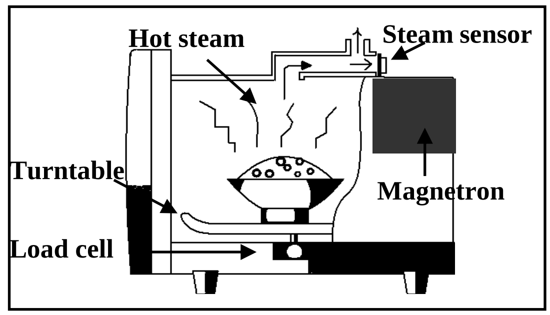


Fig. 5. The modified design for MWO

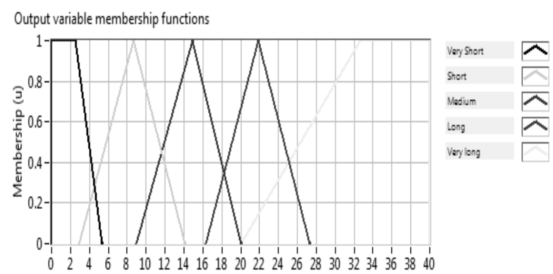


Fig. 6. Output MFs for (T2) variable in the modified FLC

The fuzzy rules for this controller are listed below:

1. If '*classification'* is *'reheating*' and '*T_1*' is *'very short*' then *' T_2 '* is *'very short*'.
2. If '*classification'* is *'reheating*' and '*T_1*' is *'short*' then *' T_2 '* is *'very short '*.
3. If '*classification'* is *'reheating*' and '*T_1*' is *'medium*' then *' T_2 '* is *'short*'.
4. If '*classification'* is *'reheating*' and '*T_1*' is *'long*' then *' T_2 '* is *'medium*'.
5. If '*classification'* is *'reheating'* and '*T_1*' is *'very long*' then *' T_2 '* is *'long*'.
6. If '*classification'* is *'cooking'* and '*T_1*' is *'very short*' then *' T_2 '* is *'medium*'.
7. If '*classification'* is *'cooking'* and '*T_1*' is *'short*' then *' T_2 '* is *' medium'*.
8. If '*classification'* is *'cooking'* and '*T_1*' is *'medium*' then *' T_2 '* is *'long*'.

9. If '*classification'* is *'cooking'* and 'T_1' is *'long*' then *'* T_2 ' is *'very long*'.
10. If '*classification'* is *'cooking'* and 'T_1' is *'very long*' then *'* T_2 ' is *'very long*'.

Experimental Results

As the LabVIEW environment has been designed specifically for test, measurement, and control, the output times of the designed FLC is firstly tested using this software then it is applied on a domestic MWO (model AM820AGX 800 watt) to test the efficiency of this design practically. Different weights of food are used, so the output times of the first proposed controller is summarized in Table (2). The consequential on-off power signal for ch mode selection is shown in figures low, where the Figures (7) and (8) show the on-off power signal for the defrosting mode with 100g and 500g respectively and the power level is set to (auto power) for all these measurements. For reheating mode Figure (9) show the on-off signal for 1000g and Figure (10) shows the signal of cooking mode for 700g of food.

Table 2. Time produced according to the FLC

Weight (g)	**Defrosting mode**		**reheating mode**		**Cooking mode**	
	T	**t_{on}**	**T**	**t_{on}**	**T**	**t_{on}**
100	1.508	0.333	1.508	0.333	7.882	7.882
300	3.557	0.605	1.561	0.513	14.426	14.426
500	7.897	0.999	3.939	0.743	19.189	19.189
700	10.222	0.986	6.012	1.162	23.989	23.989
1000	13.506	1.322	9.502	1.437	27.011	27.011
2000	17.517	1.766	12.012	1.666	36.833	36.833

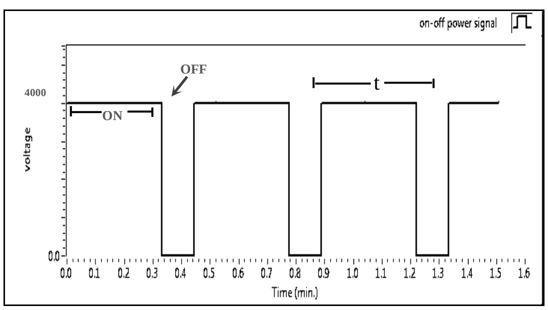


Fig. 7. The corresponding ON-OFF time (T_1) for defrosting mode, the weight is 100g

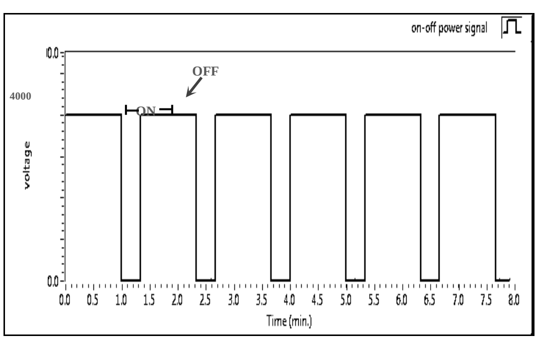


Fig. 8. The corresponding ON-OFF time (T_1) for defrosting mode, the weight is 500g

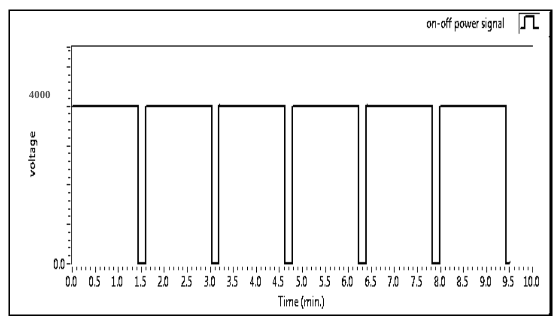


Fig. 9. The corresponding ON-OFF time (T_1) for reheating mode, the weight is 1000g

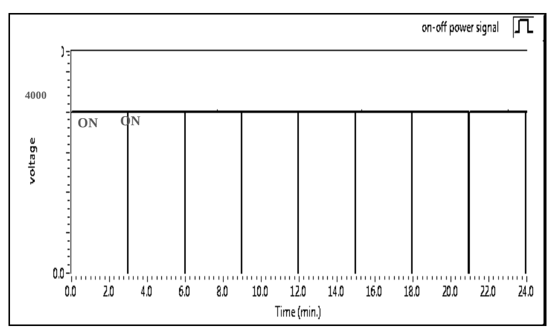


Fig. 10. The corresponding ON-OFF time (T_1) for cooking mode, the weight is 700g

The next experimental measurements is carried out practically using MWO, where three kinds of food are utilized since the proposed design has three classification modes, these kinds is considered the most frequently used kinds in the home MWO applications in the kitchen. Each one with different weights are specified for each mode, for reheating mode the precooking rice are used and the frozen meat are used for defrosting mode, finally pieces of chicken are used for cooking mode. Actually these measurements are applied especially for setting fuzzy rules of the FLC, many experiences is repeated to fine-tune these rules to get best duration times for different food and for different processing modes.

Conclusions

In this paper new ideas have been proposed to develop the operation of MWOs, where the aim of this work was to modify the recent MWOs to be as other automatic devices that reduces the manual usage as much as possible. The design performance was evaluated in the experimental work where the output times applied on the MWO, as the results of the reheating and defrosting modes are proved to be practical and suitable for the tested food, but for the cooking mode the results show that the microwave alone is not enough radiation to stew the food, so this mode requires a grill heater besides the microwave radiation, therefore it must be mentioned that the considered times is set according to this assumption.

References

1- Zhenfeng L., "Aroma Detection and Control in Passive and Dynamic Food Systems for Superior Product", Doctor thesis, Department of Bioresource Engineering, McGill University, Quebec- Canada, March 2008.

2- Cirstea M., Dinu A., Khor J., McCormick M., “Neural and Fuzzy Logic Control of Drives and Power Systems”, Newnes, ISBN 0 7506 55585, 2002.

3- Bitter R., Mohiuddin T. and Nawrocki M., “LabVIEW Advanced Programming Techinques”, CRC Press LLC, 2001.

4- Liang L., Mao Z., Cheng Y., "Study on the Application of Freeze Drying and Microwave Drying to Flower", ASAE paper No. 036075. St. Joseph, Mich.: ASAE, 2003.

5- Changrue V., Sunjka P. S., Gariepy Y., Raghavan G.S.V., and Wang N., "Real-Time Control of Microwave Drying Process”, The Proceedings of the 14th International Drying Symposium, Sao Paulo, Brazil, August 24, 2004.

6- Wang G., Wang Z., Zhang X. and Xu H., "The Application of Fuzzy-neural Network Based on HGA in The Washing Machine Control System", International Conference on Intelligent Computation Technology and Automation, ISBN: 978-0-7695-4077-1/10,2010.

7- Rakhmankulov D.L., Shavshukova S., Latypova N., and Zorin V., “Laboratory and Industrial Applications of Microwave Techniques”, Russian Journal of Applied Chemistry, Vol.75, No.9, PP.1377-1383, 2002.

8- Shaiyek M. Buland T., Shaikh M. Rubayiat T., "Investigation of Suitability of Operating Frequency and Electro technical Modeling of Microwave Oven" IEEE transaction 978-1-4244-8782-0/11. 2011.

9- Young-Jin W., Sang-Kyung K., and Gyu-HyeongC., "Voltage Clamped Class E Inverter With Harmonic Tuning Network for Magnetron Drive", IEEE Transactions on Circuits and Systems—II: Express Briefs, Vol. 53, No. 12, pages: December, 2006.

10- Buffler C. R., "Microwave Cooking and Processing", New York: Van Nostrand Reihold ISBN 10- 0442008678, 1993.

11- The Government of the Hong Kong Special Administrative Region, "Microwave Cooking and Food Safety", Food and Environmental Hygiene Department, Risk Assessment Studies No.19, June 2005.