

An observer based temperature estimation in cooking heterogeneous mixtures: a Turkish coffee machine application

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Received: 04.09.2020

Accepted/Published Online: 03.09.2021

Final Version: 30.11.2021

Abstract: A high-precision temperature information is required to follow the recipe in automatic cooking processes of heterogeneous liquids. Therefore, measurement equipment plays a crucial role in appliances developed for automatic cooking processes. However, it is difficult to obtain the temperature information in such appliances since the sensors cannot be located inside the heterogeneous liquid and the diffusion model is not precise in general. In this manner, a method is proposed to estimate the temperature of the heterogeneous mixture during the cooking process. This is achieved by the utilization of only one temperature sensor located at the outside wall of the cooking chamber in a commercial Turkish coffee machine. The temperature of this point with the sensor is considered as the output while the mixture temperature is assumed as an internal state, then a model is generated based on collected data in a special experimental setup. Experimental results show that the Turkish coffee can be cooked with required taste and consistency by the application of the proposed method.

Key words: Cooking process control, model-based observers, temperature estimation

1. Introduction

The development of automated home appliances for cooking the heterogeneous food mixtures have been arisen for few decades led by the technological improvements. Resistive and induction heaters are widely used in such cooking machines, however induction heaters are preferred mostly due to their advantages such as fast and controllable heating, efficiency, cleaning and safety [1–3]. The measurement systems utilizing various type of sensors play a crucial role in such appliances as well for carrying out an accurate control of the process and an efficient operation. Especially, the increasing demand of the advanced operations such as temperature profile tracking or temperature control in domestic induction cookers, high-level sensor and data acquisition systems have gained critical importance.

Different temperature profiles are required in cooking process of different heterogeneous mixtures. Hence, various type of sensors have been utilized in numerous cooking applications in order to increase the quality of the process. Infrared temperature sensors [4, 5], negative temperature coefficient thermistors [6], resistance temperature detectors [7], inductive sensors consisting of a coil and an electronic circuit [8] are some examples of temperature sensors utilized to monitor the temperature in cooking processes. Since these sensors are capable of providing the temperature information for a special point or part, advanced estimation methods have to be

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applied accordingly. In this manner, multiple model reset observers [5], adaptive observers [6], extended Kalman filter [7] are implemented in the aforementioned studies.

Among the other automatic cookers, coffee makers have been produced widely for a few decades. And due to the high amount of consumption of coffee in global level, the parameters effecting the brewing process have been examined for different types of coffee drink [9–12]. In addition, model of extraction of coffee in espresso making process has been considered as well [13]. Different from the other kinds of coffee making processes, very finely ground Turkish coffee blend is cooked slowly in water to obtain a tasteful and consistent Turkish coffee. The level of the Turkish coffee mixture increases as the temperature approaches to the boiling point that is between 85 °C and 95 °C. The heater has to be turned off before the mixture boils, but after having as much as foam on the coffee [14]. Therefore, an effective sensing structure is required in automatic Turkish coffee machines.

Precise control is another important issue in automatic food cooking processes, and the control of the temperature in various cookers with induction heaters is also attracted the attention of the researchers. In addition, since placing a temperature sensor into the mixture is undesirable, observer or estimator design for the mixture temperature in automatic cookers or measurement devices is an essential work. In this manner, an adaptive and a switching observer have been designed providing the pan temperature estimation for a conventional PID controller in order to control the temperature in a cooking process [6]. In another study [7] of the same research group, another kind of observer is offered keeping the switching structure for different plant models. Then, an adaptive PI temperature controller is implemented using the observed output. Furthermore, the lack of dynamical model information, the existence of various disturbances and noises, and the changing structure of the mixture depending on ingredients effect the temperature dynamics making the cooking process more challenging. However, the temperature of the mixture inside the pot can be estimated by a thermal system model with the help of a temperature sensor placed outer surface of the pot. Since the parameters of the thermal model are unknown, the parameters can be determined by using system identification technique [15].

Considering Turkish coffee machine as a benchmark, many temperature sensors are located on a commercial coffee machine used in this study due to the high priority of the the mixture temperature. Implementing system identification technique, acquired data is used to generate linear time-invariant (LTI) models from induction heater to coffee temperature and from coffee temperature to the outer side temperature of the coffee pot that is the only measured data in the final product. Note that, taking the opportunity of heat conduction and the interaction between the pot and the coffee, proper LTI models could be constructed. Then, assigning the measured pot temperature as an output, a Luenberger observer is utilized to observe the temperature of the coffee mixture based on the LTI model. A sensor located in the mixture is used to measure the temperature in experimental setup, and the results prove that the real temperature can be followed by the observed temperature with a very low level of error. The proposed procedure can be applied in other kind of automatic cooking processes with different type of sensors since it is a generalized structure.

2. Setup and data acquisition

2.1. Experiment environment

Quantifying the liquid temperature in real time is one of the problems arising in the design phase of automatic heterogeneous liquid cooking devices. Placing the sensors inside the cooking chamber can be a solution to measure the liquid temperature as accurately as possible. However, this solution causes some problems such as

hygiene, poor image and low perception of quality. In order to prevent these problems and keep the perception of quality high, temperature measurement methods that are not in contact with food are preferred in home type induction heaters. The basic principle in noncontact measuring methods is to find a relation between the cooking state or temperature of the cooked food and the measured quantity.

In the induction Turkish coffee machine, the magnetic field formed by the coil causes more heat at the bottom of the cooking chamber. The sides of the chamber, on the other hand, have less heat compared to the bottom due to the magnetic flux density and the heat diffusion. Accordingly, it is almost impossible to measure the coffee temperature precisely because of heat distribution and dissipation. In addition, each temperature sensor placed inside the cooking chamber causes some aforementioned adverse effects. In order to develop a solution to this, a commercial product modified and equipped with numerous sensors is used as an experimental platform.

General structure of the experimental setup including the sensor allocation is depicted in Figure 1. As can be noticed in this structure, various sensors are located to measure the temperature of the cooking chamber, the steam temperature and the temperature of the mixture. Many different type of temperature sensors such as resistive, thermoelectric, semiconductor and optical are utilized in industrial areas and commercial devices. Optical temperature sensors, i.e. thermopile, are technologically new and expensive sensors though they can be used for noncontact temperature measurement. The semiconductor temperature sensors are not suitable for cooking processes as they are not capable of measuring high temperatures. Resistive temperature sensors such as NTC have the appropriate sensitivity and cost for brewing processes, but due to their high thermal inertia and slow response times, they are not preferred for a fast cooking application such as coffee brewing with an induction heater. In this application, it is preferred to use T-type thermocouple temperature sensors because of their satisfactory responses in the required temperature range, fast response, ease of implementation and low cost. The temperature measurement range of the T-type thermocouple is -270°C to 600°C with the sensitivity of $-270\mu^{\circ}\text{C}$. They are often employed in food temperature measurement applications, environmental temperature measurements and refrigeration applications [16]. In order to collect the temperature data from various locations on the cooking chamber and the mixture, seven T-type thermocouple sensors (TC1-TC7) placed at various positions in the setup. In addition, another thermocouple sensor (TC8) is located at the top of the cooking chamber to measure the steam temperature.

A computer and a data acquisition system are used to record the sensor data in real time. The data obtained from the thermocouple sensors are transferred to the computer with Keysight 34970A data acquisition device and Keysight 34901A multiplexer module. On the other hand, the amount of power transferred to the cooking chamber can be associated with the coil current due to the high efficiency in induction cooking systems. In this manner, the coil current and the applied voltage are measured and the data is transferred to the computer as well. Current, voltage and power information of the Turkish coffee machine is tracked and stored by the Chroma 66202 power analyzer during the operation. The general schematic of the acquisition system is given in Figure 2.

2.2. Data collection

In order to develop an effective method of having the temperature information in making Turkish coffee, some initial experiments have been implemented firstly to collect data. This data is obtained from aforementioned sensors contained in the data acquisition setup. The outputs of all temperature sensors have been recorded from beginning to the end of the cooking process and analyzed in this part. Being the nominal value of the

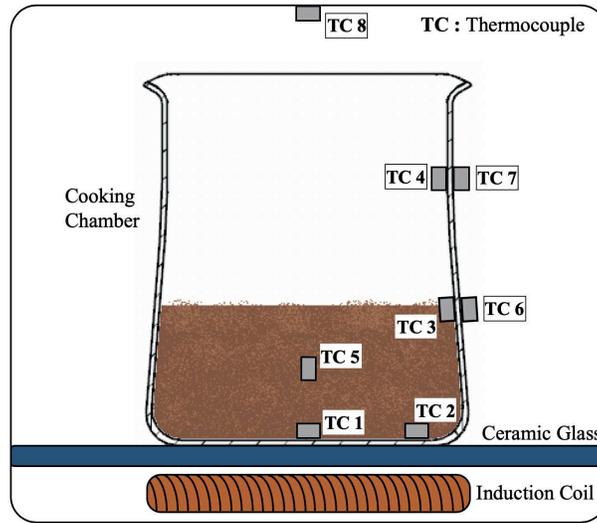


Figure 1. Experimental setup and sensor allocation.

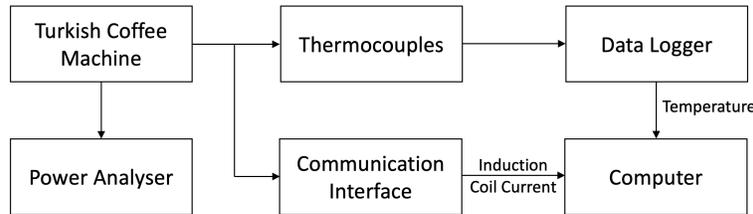


Figure 2. The data acquisition structure.

machine, the power of 500 W is transferred to the cooking chamber in these initial experiments. Water with an initial temperature of 20°C is used in the experiments. The amount of coffee and water mixture is set for two cups.

In a general cooking procedure, probably, the most important data to follow is the temperature. However, measuring the temperature of the mixture to be cooked is a very difficult task due to the unviability of placing temperature sensors inside. In addition, the temperature varies in different places in the chamber according to the diffusion. In order to track the temperature, eight sensors are fixed in the experimental setup in total. Six of these sensors are placed on the inside and outside surfaces of the chamber, one is placed in the center of the chamber to come into contact with the mixture, and one is placed at the top to measure the steam temperature. The data acquired from these sensors are presented in Figure 3.

The first result to notice is perhaps the difference between the data obtained from TC1 and TC2 that are located at the center bottom, and at the bottom edge, respectively. This difference is caused by the location dependent amount of the magnetic flux density at the bottom of the chamber created by the induction heating system. Since the magnetic flux density occurs at the edges of the bottom of the chamber compared to the center, the heat increases faster at the edges.

It can be observed that the difference between the measurements from TC3 and TC6 is very low due to the skin thickness and fast heat transfer characteristics of the metallic material. Similarly, the data obtained from TC4 and TC7 that are located a little higher compared to TC3 and TC6 gives the same conclusion.

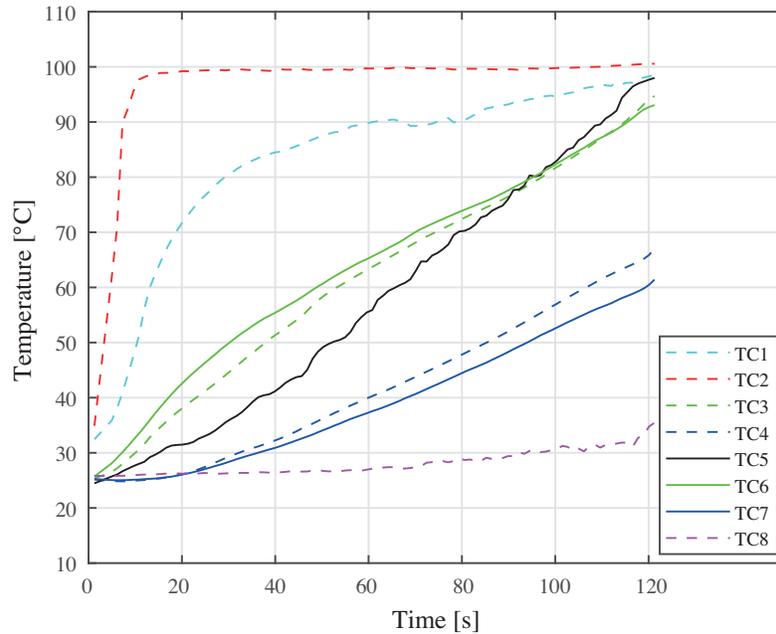


Figure 3. The collected data from temperature sensors.

However, the inner temperature takes higher values than the outer temperature as the location gets higher. The reasons for this are the skin effect and the proximity to the magnetic flux. For an induction heater, the outer surface of the chamber is always warmer than the inner surface of the chamber because of the skin effect. On the other hand, the lower part of the chamber warms up quickly, whereas the upper part of the chamber warms up slowly due to the proximity to the magnetic field. So, there is a very low magnetic flux at the upper part of the chamber and the mixture temperature is higher than the chamber temperature at this area. The mixture warms up the inner surface of the chamber by heat diffusion and the temperature value of the inner side wall of the chamber is a little higher than the outside. Another observation is that the temperature increases fast and it is always higher in the entire process in the neighborhood of the magnetic source.

The results obtained from the temperature sensor located in the middle of the mixture (TC5) allow us to notice that the temperature of the liquid has a linear-like relation with the input. This linearity is violated at the beginning and at the end of the process. This linear-like behavior is completely lost when the foaming phase begins. On the other hand, no significant change is observed in the thermocouple sensor located to measure the temperature of the steam until the beginning of the foaming phase. Therefore, it is not possible to obtain the temperature information of the mixture by using the steam temperature.

After an examination of the collected data from the sensors, it is convenient to conclude that the usage of temperature sensors may be viable to track the coffee temperature and cooking state. In this case, the data obtained from temperature sensors located at different locations outside of the chamber would be reliable and effective since the measurements are in a correlation with the data received from temperature sensor located inside the mixture. Note also that it is possible to track the mixture temperature and control the cooking procedure during the whole process when temperature sensors are utilized to the mixture by direct contact. However, placing a sensor inside the mixture is undesirable, and a method is presented in the next section to avoid it.

3. Proposed method

The temperature sensors located at different places on the chamber have been utilized in the Turkish coffee machine setup and acquired data has been discussed in the previous section. A method to collect the necessary data to cook Turkish coffee is presented in this part using only one temperature sensor placed outside of the cooking chamber. This is achieved carrying out the dynamical relation between induction heater, the mixture temperature and the outer side temperature of the chamber. For this purpose, a control structure is utilized by using this model and one temperature sensor outside of the chamber since placing a sensor inside of the chamber is not preferable.

The temperature data of the mixture and the outer side wall of the chamber, and the measured induction coil current values are employed to generate the dynamical model. In order to construct a mathematical relationship between the outside and inside temperatures, the temperature sensors located in the mixture and on the outside of the chamber are considered initially, and the recorded data sets are used to identify the system behavior. The data from induction coil current is also used to form a model having the input as the exerted power and the output as the mixture temperature.

In the induction heating process, the heat transfer to the ferromagnetic cooking chamber starts when the heating coil is driven by alternating current. Then the temperature of the bottom of the cooking chamber increases. This is followed by the heat diffusion and the temperature of the coffee and the side walls of the cooking chamber increase as well. This physical system can be expressed as in Figure 4 where the input is the coil current and the outputs are the cooking chamber temperature and the coffee temperature. It is important to note here that the coffee temperature required for the control of the cooking process is a system state that cannot be measured directly.

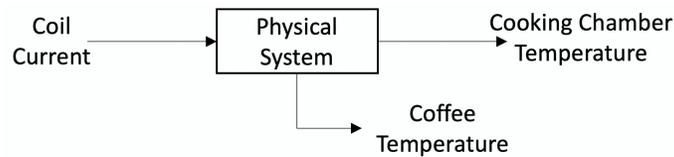


Figure 4. Block diagram of the physical system.

In order to apply the system identification procedure, System Identification Toolbox in MATLAB is used with the acquired input-output data. The input-output relationship is considered linear, and a linear time invariant model in discrete-time has been obtained accordingly. The output resulted in the simulations by the implementation of the dynamical model is compared with the data obtained from experiments in order to improve the model. Then, the difference between the outputs of the model and the real system has been evaluated by the toolbox using root-mean-square error method to obtain the parameters of the final model. The parameters of the state-space representation of the system model are determined using the predicted model with the best fit rate.

The heat transfer causes the temperature of the mixture in contact with the bottom of the cooking chamber to increase. Indeed, the side of the cooking chamber is minimally affected by induction. And the heat of the side and of the mixture begins to rise by a heat exchange supplied by the bottom. The mathematical model of the system is constructed according to this physical relation. It is important to note that the temperature of the cooking chamber is used as the output since it is the only measurable quantity. Therefore, the overall model is considered to have one input and one output that are coil current and measured chamber temperature, respectively. However, since the required system state is coffee temperature, it is assumed that the model

consists of two cascaded subsystems where the coffee temperature is the output of the first subsystem and the input of the second subsystem (see Figure 5). This proposed structure for the dynamical model of the coffee machine allows us to estimate the coffee temperature with a correction factor obtained from the measured output.

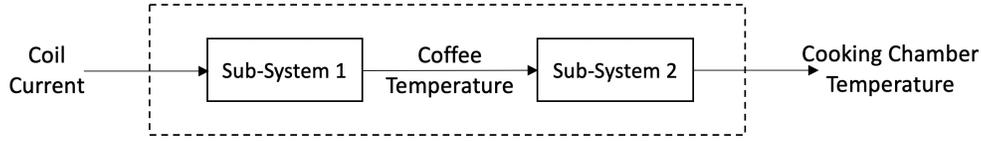


Figure 5. General block diagram of the proposed model.

The temperature sensor is placed outside of the chamber in the candidate commercial product as a design request. Hence, one of TC6 and TC7 can be used to measure the temperature. The procedure is repeated for each and the results are compared in order to select one of these alternative sensors. The parameters for the model of second subsystem have been created for each different sensor location while the model of the first subsystem has been same for each case. The structure of mathematical models is given as

$$x_n(k+1) = A_n x_n(k) + B_n u_n(k) \quad (1)$$

$$y_n(k) = C_n x_n(k), \quad (2)$$

where $n = 1, 2$ denotes the subsystem index, x_n represent the state vectors, A_n , B_n , and C_n are system, control and output matrices respectively, and k is the discrete time variable.

After a mathematical model is constructed, a Luenberger observer is proposed to observe unmeasured temperature of the mixture. It is aimed here to estimate the coffee temperature during the cooking process in an induction Turkish coffee machine with a temperature sensor placed on the outer side wall of the cooking chamber instead of measuring it with a sensor placed inside the chamber. Considering that the input of the first subsystem is a constant given by u_c , and that the output of the first subsystem is the input to the second subsystem, (1) can be rewritten for each subsystem as

$$x_1(k+1) = A_1 x_1(k) + B_1 u_c(k) \quad (3)$$

$$x_2(k+1) = A_2 x_2(k) + B_2 C_1 x_1(k). \quad (4)$$

On the other hand, the observer dynamics can be given as

$$\hat{x}_1(k+1) = A_1 \hat{x}_1(k) + B_1 u_c(k) + k_o B_1 C_2 (x_2(k) - \hat{x}_2(k)) \quad (5)$$

$$\hat{x}_2(k+1) = A_2 \hat{x}_2(k) + B_2 C_1 \hat{x}_1(k), \quad (6)$$

where k_o is the scalar observer gain. Subtracting (5) from (3) and (6) from (4), one can obtain

$$\tilde{x}_1(k+1) = A_1 \tilde{x}_1(k) - k_o B_1 C_2 \tilde{x}_2(k) \quad (7)$$

$$\tilde{x}_2(k+1) = A_2 \tilde{x}_2(k) + B_2 C_1 \tilde{x}_1(k), \quad (8)$$

where $\tilde{x}_1(\cdot)$ and $\tilde{x}_2(\cdot)$ give the observer errors. The last two equations can be reorganized to obtain the matrix form of the closed-loop observer dynamics

$$\begin{bmatrix} \tilde{x}_1(k+1) \\ \tilde{x}_2(k+1) \end{bmatrix} = \begin{bmatrix} A_1 & -k_o B_1 C_2 \\ B_2 C_1 & A_2 \end{bmatrix} \begin{bmatrix} \tilde{x}_1(k) \\ \tilde{x}_2(k) \end{bmatrix}. \quad (9)$$

Note that the observed temperature of the mixture is denoted by $\hat{x}_1(\cdot)$. The block diagram of this structure is presented in Figure 6. Accordingly, the observer error is determined by taking the difference of the temperature read from sensor and the estimated temperature by the observer. This error is multiplied by the constant observer gain k_o and fed back to the system. Note also that, the system matrix of the closed-loop observer dynamics plays a crucial role on stability and the value of it has to be assigned accordingly. In this application, the optimal value of the observer gain has been determined by means of simulations with provided experimental data using the least squares method [17].

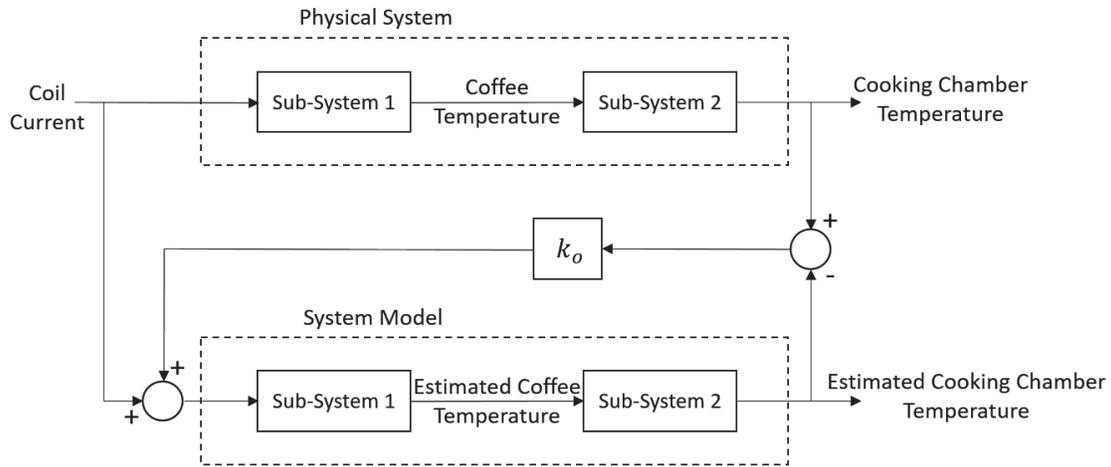


Figure 6. Observer structure for coffee temperature estimation.

4. Results and discussion

In the experiments carried out within the scope of the study, the temperature information has been obtained for both inside and outside of the cooking chamber during the cooking process. Also, the induction coil current values corresponding to these temperature values have been recorded. This data has been used to create the mathematical model of the system with the system identification method, as well as to test the accuracy of the sensing system model. The data sets previously recorded for verification tests have been transferred in the MATLAB Simulink environment and simulated values of the sensing system model have been obtained to estimate the mixture temperature. The model matrices resulted from the identification procedure for the first subsystem, and for the second subsystem with TC6 and TC7 are given approximately as

$$A_1 = 10^{-3} \begin{bmatrix} 1010.57 & 14.94 & -3.27 \\ -140.52 & 816.79 & -16.39 \\ -2.54 & 4.33 & 845.66 \end{bmatrix}, B_1 = 10^{-6} \begin{bmatrix} -3.13 \\ -3420.42 \\ -9377.82 \end{bmatrix}, C_1^T = \begin{bmatrix} -406.12 \\ -2.89 \\ -0.32 \end{bmatrix},$$

$$A_{2,TC6} = 10^{-3} \begin{bmatrix} 1025.83 & -30.77 & -1.13 \\ 64.18 & 942.63 & -79.11 \\ 19.76 & -1.81 & -938.08 \end{bmatrix}, B_{2,TC6} = 10^{-3} \begin{bmatrix} 0.22 \\ -0.47 \\ -20.97 \end{bmatrix}, C_{2,TC6}^T = \begin{bmatrix} 186.97 \\ -2.65 \\ 0.02 \end{bmatrix},$$

$$A_{2,TC7} = 10^{-3} \begin{bmatrix} 995.05 & -4.96 & 4.27 \\ -65.16 & 896.27 & -27.22 \\ 144.54 & 286.96 & 509.43 \end{bmatrix}, B_{2,TC7} = \begin{bmatrix} -0.01 \\ 0.27 \\ 2.04 \end{bmatrix}, C_{2,TC7}^T = \begin{bmatrix} -22.75 \\ 0.0089 \\ -0.0267 \end{bmatrix}.$$

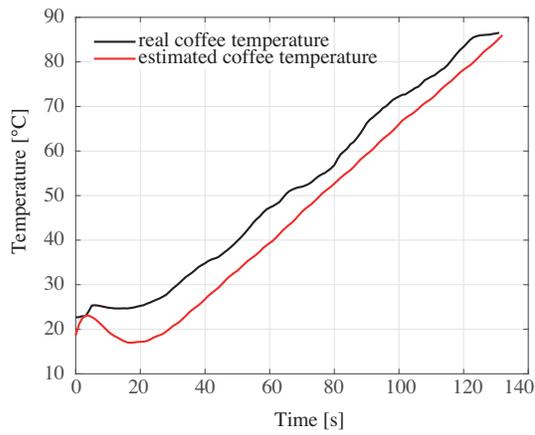
The Turkish coffee machine used in the study has been programmed to transfer 500 W power to the cooking chamber and the system model has been obtained accordingly. On the other hand, in order to test the proposed sensing system model, Turkish coffee machine has been programmed to transfer 480 W and 520 W to the cooking chamber, so the effect of different input signals has been observed. Water with an initial temperature of 20 °C is used in the experiments. The amount of mixture is set for two cups consisting of 14 g of coffee and 150 mL of water. Sampling time is set to 1 s, and the value of the observer gain is adjusted to 0.01 and 1.62 in first and second models, respectively.

Since changing the amount of the mixture and the temperature of the water may cause the time delays and/or model mismatching, some undesired results could be generated when the model developed for fixed amount and initial temperature value is used. In order to avoid such errors, different models can be formed based on different experiment conditions covering the changes in the quantity and initial temperature of the mixture. In Turkish coffee machines existing in the market, the information regarding the amount of the water pumped into the cooking chamber can be gathered with one or more coffee cup size selection buttons [18]. In this way, the amount of water transferred to the cooking chamber is known by the microprocessor and the cooking algorithm suitable for this amount of water can be selected. Similarly, the proposed method to observe the temperature can be implemented to generate the system models for different working and environment conditions. Then, these models are switched during the operation as per the required amount or observable initial conditions. Note that the liquid temperature can also be estimated by using the initial temperature value which is measured by the temperature sensor located outer side of the pot. It has been observed that the effect of the change in the ambient temperature on the system model is negligible according to the results obtained in the experiments.

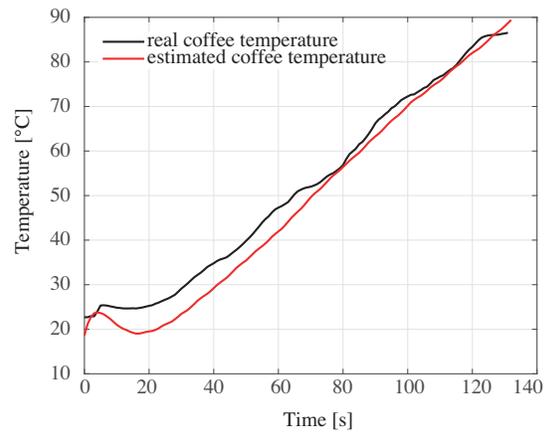
The obtained coffee temperature estimation data has been compared with the actual coffee temperature data measured by TC5 located inside the mixture. In addition, the average and maximum temperature estimation errors during the cooking have been calculated by taking the absolute value of the difference between the actual coffee temperature and the estimated coffee temperature values corresponding to each sampling time during the cooking process to see the performance of the proposed structure.

Figures 7a, 7c and 7e present the results of the first model in which TC6 is used. The input power has been adjusted to 480 W, 500 W and 520 W in these tests, respectively. The results for the second model in which TC7 is used are depicted in Figures 7b, 7d and 7f for the same values of input power. Provided experimental results show that the prediction error takes high values at the beginning. But, the estimation values converge to the real values as the temperature increases. When Turkish coffee reaches the boiling temperature (approx. 85 °C), the foaming phase begins and the temperature remains constant. However, the temperature of the cooking chamber continues to rise due to heat transfer. Due to the fact that the designed system model is linear and the coffee and the cooking chamber do not show the same characteristics at the time of foaming, some prediction errors occur at temperatures above 85 °C. However, it is observed that the prediction error is quite low at high temperatures (approximately 90 °C) where the coffee making process is ended. It can be observed that the tracking error between real and estimated values takes lower values when the second model using TC7 is implemented. Note also that the best responses are obtained in each case when the nominal power is applied. As the input power is changed to 480 W and 520 W, the responses are disturbed.

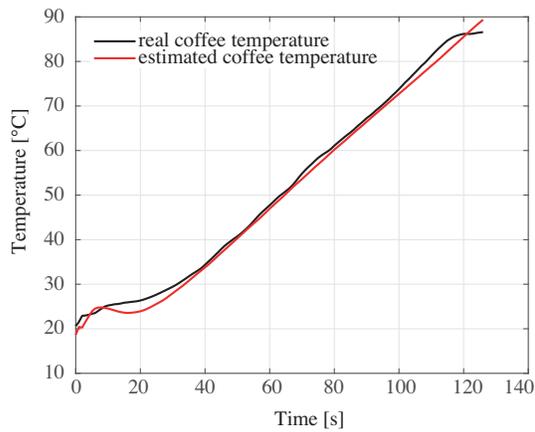
The maximum and average of absolute error values obtained from the results for both models. In addition to the whole temperature range of 25 °C–90 °C, a smaller range of 70 °C–90 °C are presented in Tables 1 and 2, respectively. It can be observed that the lower values of estimation error are obtained when the second



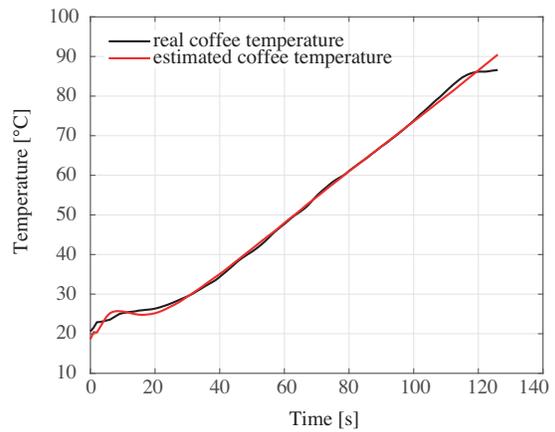
(a) Data from TC6 with input power of 480 W.



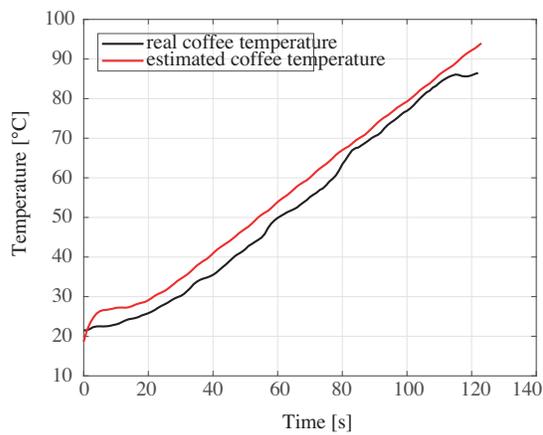
(b) Data from TC7 with input power of 480 W.



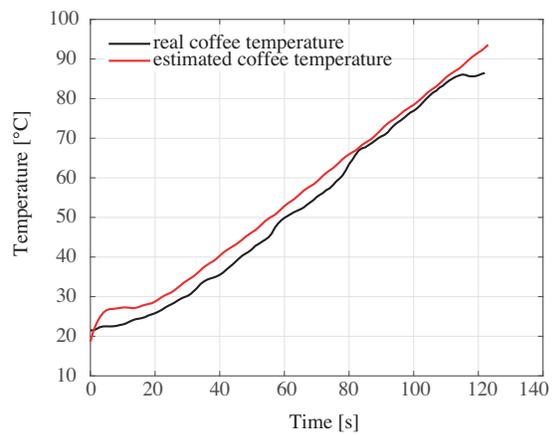
(c) Data from TC6 with input power of 500 W.



(d) Data from TC7 with input power of 500 W.



(e) Data from TC6 with input power of 520 W.



(f) Data from TC7 with input power of 520 W.

Figure 7. Experimental data, measured and observed values.

model with TC7 is utilized. This is caused by the fact that TC6 is closer to the magnetic field produced by the induction coil. The temperature in this area rises faster than the mixture temperature inside the chamber after starting of the cooking process. This issue violates the heat transfer dynamics of the proposed model. It can be concluded that the model created with the utilization of TC6 would be more sensitive to power changes or current oscillations in the system. The area where TC7 is attached is a suitable position to model the heat transfer dynamics between the mixture and the outer surface of the chamber.

Table 1. The average and maximum of absolute error values in the range of 25°C–90°C.

Power (W)	Average error (°C)		Maximum error (°C)	
	TC6	TC7	TC6	TC7
480	6.04	3.17	8.74	6.02
500	2.24	1.66	6.17	5.56
520	3.81	3.14	6.83	6.36

Table 2. The average and maximum of absolute error values in the range of 70°C–90°C.

Power (W)	Average error (°C)		Maximum error (°C)	
	TC6	TC7	TC6	TC7
480	5.04	1.34	6.93	2.82
500	2.25	1.78	4.85	5.01
520	2.85	2.05	6.45	5.93

5. Conclusion

A method to estimate the unmeasured temperature of heterogeneous liquids in a cooking machine has been presented. The temperature of the mixture is considered as a state variable of the dynamical system while the temperature of the outer side of the pot is defined as the output. Then, a dynamical model is identified utilizing the collected data from a commercial Turkish coffee machine. Involving an observer scheme and using the developed dynamics, the proposed estimation structure is verified experimentally in Turkish coffee making process. Some innovative ideas that can be derived from the proposed method and can be used for future studies are listed below:

- The method offered in this paper can easily be applied in different cooking procedures in which the temperature information is available only for the outside of the cooking pot. This can be achieved independent from the type of the implemented sensor, and from the type of the heater.
- The proposed scheme can be used to obtain the system models for different amount of liquid and various initial temperature values. These models can be switched during the operation in order to enhance the performance and to improve the results. In addition, a dynamical model holding the system nonlinearities and time-delay specifications can be derived to be utilized in controller design procedure.
- Multiple sensors of same type or not can be used in automatic cooking applications in order to estimate the temperature of the mixture more precisely. In that manner, sensor fusion algorithms combined with the developed system model in closed-loop form can be implemented as well to obtain advanced results.

Therefore the idea and the application presented in this work may have an original effect for future studies in the same area.

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