

Research Article

Gelatinization and Frying Temperatures Stabilization of a ‘Garri’ Frying Machine Using a PID Microcontroller-Matlab Simulink

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Abstract: PID micro controller are used with the objective of controlling the gelatinization temperature and the frying temperature of a garri frying machine to improve the quality and dietary standard of garri with little or no lumps formation and no significant sign of being charred. Most research works on the design of garri frying and processing are limited with the problem of temperature stabilization or control, hence, this flexible design will help to stabilize gelatinization and frying temperatures within a range of (70-90)°C and (180-200)°C respectively. Mathematical models of the gelatinization and frying chambers with their respective actuators were developed with the use of matlab simulink using Zeigler-Nichol tuning method to the PID parameters for a desired response of the systems when subjected to a unit step input. The schematic model and animated simulation was done to compliment and validate the system performance at these temperatures in the two chambers using a knowledge soft ware base –Proteus. A set of optimal parameters were obtained with using Zeigler Nicholas tuning after several iterations and simulation to have a desirable improvement with a focus on the settling time of 29.8seconds and 26.7seconds for drying and gelatinization process respectively to improve the robustness and stability of the entire system.

Keywords: PID Controller, Zeigler-Nichol tuning method, gelatinization and frying temperature control, ‘garri’ frying machine. Simulation with matlabsimulink and proteus.

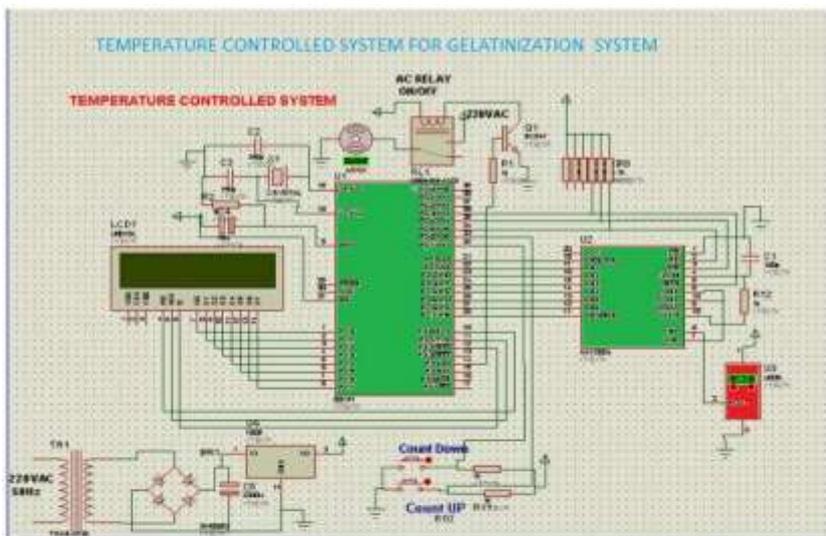
INTRODUCTION

Many designs on garri frying machines or systems had been done in the recent times –manual firing and stirring or turning, manual firing and adapted mechanical stirring or turning either horizontal or vertical orientations [1, 2]. These methods or designs were considered to have one limitation militating against having a simple design that would produce quality garri that will meet the demand of local and international markets [2]. On this background, the Design, Modeling and Simulation of a PID Microcontroller Based Temperature Control of the gelatinization and frying temperature stabilization is conceptualized to improve quality of garri production. This design is for a two-chamber machine for gelatinization and frying. On a visit at Enwan and Ibillo communities of Akoko –Edo local government, Agenebode community in Etsako East local government and Jattu in Etsako west local government in Edo State, it was gathered from local garri friers that care should be taken during gelatinization because at this point, bonds are broken off the sticky nature of the sieved cassava mash and it requires fast turning and pressing with broom which aids breaking of the particles to overcome lumps formation of the product. Besides, the speed or rate of stirring or turning the product is dependent on the heating, hence temperature control is still a problem [4] and sometimes time they have to rush out to pull out fire woods and glowing flame charcoals beneath the frying pan called ‘agbada’ and continue to stir as fast as possible to prevent the product from charring. It becomes imminent to conceptualize and screen a design that will guarantee a production of quality garri to meet both local and international standard through a knowledge base software-matlabsimulink and proteus to run modeling and simulation of the temperature control for a garri frying system.

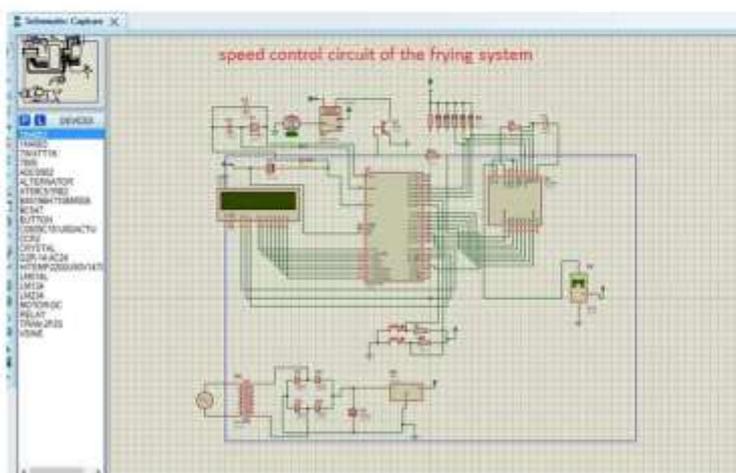
SYSTEM DESIGN

To achieve an improved stable system for temperature stabilization, a good design of a circuit whose operation is based on a PID Controller implemented on a microcontroller and a temperature sensor (LM135) is used [5]. The

temperature sensor converts change in temperature to change in electrical signal which is then compared by the PID controller control algorithm to activate the blowers that suck heat to supple or reduce the rate of heat flow into the two chambers. Relays becomes messengers in the fulfillment of the current interpretation in system [6]. The microcontroller accepts inputs from a simple four-key keypad which allow specification of the Set point temperatures and it displays both set-point and measured values chamber temperatures for gelatinization and frying using an LCD display. A pulse-width modulation (PWM) output from the controller is used to drive two relays which switch the two blowers off and on as the model is designed for the conditions in the two chambers. Figure1 shows the schematic representation of the system design on proteus.



i.



ii.

Fig-1: i. Electronic circuit representation of ii gelatinization and Drying chambers temperature control using Proteus

For simplicity in analyzing the system, the block diagram of the system design is shown in figure 2

TEMPERATURE CONTROL PROCESS DESIGN

The temperature control system was built around several mathematical models needed for the analysis of the system dynamics and the design and evaluation of the control system using a closed loop structure of a temperature controlled system. This structure comprises the models of the system dynamics; sensors, actuators and computational effects are the basic elements which often can not be changed for any reason since the system will be validated by simulating the PID controller model with the plant model, sensor and actuators or any combination of these components. The design and fine tuning of the PID controller will be the subject of the analysis which requires application of control system design theory to the dynamic models of the other elements from figure 3. A simplified mathematical model of the

overall system will be derived separately for gelatinization and frying chamber. The system should track and/or regulate the desired gelatinization and frying chambers temperature with minimum peak time, rise time, settling time and overshoot.

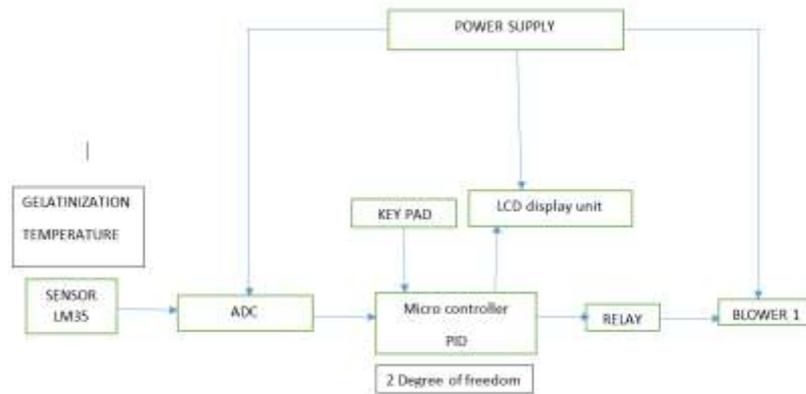


Fig-1:a.block diagram of the circuit design for gelatinization temperature chamber control
b.block diagram of the circuit design for frying temperature chamber control

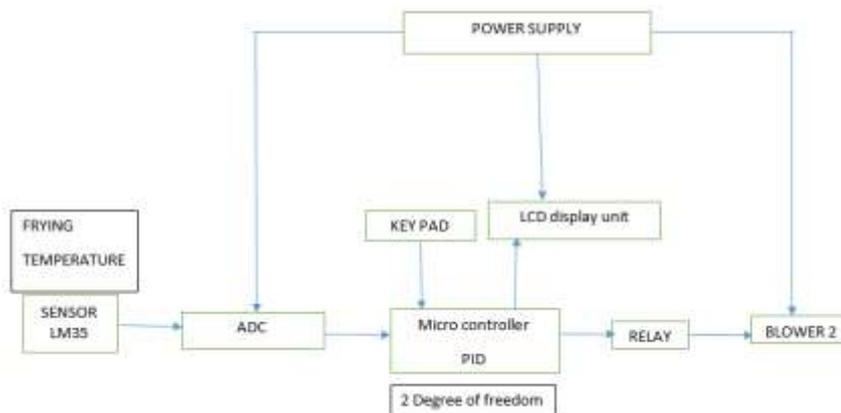


Fig-2: block diagramme of a close loop temperature control system for (a) gelatinization chamber and (b) frying chamber

MATHEMATICAL MODELS

(A) Gelatinization Chamber

If a mass M (Kg) of cassava mash at a temperature T is delivered into the gelatinization chamber environment at a prevailing temperature T_2 . Heat is transferred from this environment to the mass M (Kg) of the cassava mash will lead to a rise in temperature of the mash. Therefore, it showed that the heat added is proportional to the rise in temperature of the mass of the mash.

Heat Added to cassava mash \propto Rise in temperature of the mash

$$dq = MCdT_i \quad (1a)$$

$$\frac{dq}{M} = CdT_i \quad (\text{heat transfer per unit mass of cassava mash in the gelatinization chamber}) \quad (1b)$$

Where,

dq = elemental heat added (joule)

C = Specific heat capacity of cassava mash (joule/kg.kelvin)

M = mass of the cassava mash (Kg)

CM = thermal capacitance (joule/kelvin)

If the rate of temperature rise in the chamber is a function of time, hence

$$\frac{dq}{dt} = \phi = C \frac{dT_i}{dt} \quad (2)$$

$$\frac{dq}{dt} = C \frac{d\theta_1}{dt}$$

Where,

ϕ = is the rate of heat transfer per unit mass of the cassava mass and this is governed by thermal resistance between the hot air and the mash which analytically similar to the popular ohm's law of electricity.

$$\phi = \frac{T_i}{R} \quad (3)$$

$$\phi = \frac{\sum_{i=1,2} T_2 - T_1}{R}$$

R is the thermal resistance (K/watt)

$$\phi = C \frac{dT_i}{dt} = \frac{T_2 - T_1}{R} \quad (4)$$

$$C \frac{dT_i}{dt} = \frac{T_2 - T_1}{R} \quad (5)$$

$$\frac{dT_i}{dt} = \frac{CR}{T_2 - T_1} \quad (6)$$

$$\frac{dT_1}{dt} + \frac{T_1}{CR} = \frac{T_2}{CR} \quad (7)$$

if $\tau = CR$ (*)

τ is the product of the thermal resistance and thermal capacitance and it is the time constant

$$\frac{dT_1}{dt} + \frac{T_1}{\tau} = \frac{T_2}{\tau} \quad (8)$$

Migrating from a time function $\frac{d}{dt}$ to an S function the equation becomes

$$\frac{d(T_1)}{dt} + \frac{T_1}{\tau} = \frac{T_2}{\tau} \quad (9)$$

$$S(T_1) + \frac{T_1}{\tau} = \frac{T_2}{\tau} \quad (10)$$

$$\frac{S\tau(T_1 + T_1)}{\tau} = \frac{T_2}{\tau} \quad (11)$$

$$T_1(S\tau + 1) = T_2 \quad (12)$$

$$\frac{T_1}{T_2}(S) = \frac{1}{S\tau + 1} \quad (13)$$

Where,

τ is the resident time for the mass M (kg) in the gelatinization chamber

$\tau = 6 \text{ minutes} = 360 \text{ seconds}$

Equation .13 becomes

$$\frac{\theta_1}{\theta_2}(S) = \frac{1}{360S + 1}$$

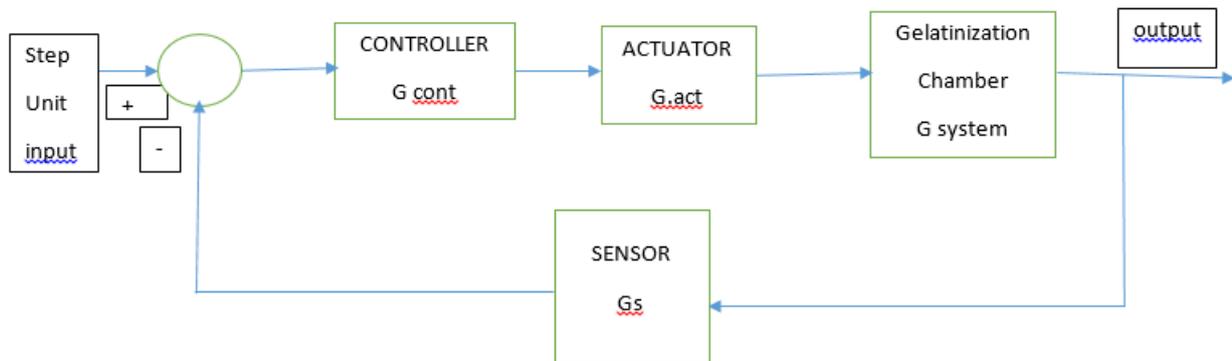


Fig-3: block diagramme for gentilization chamber model

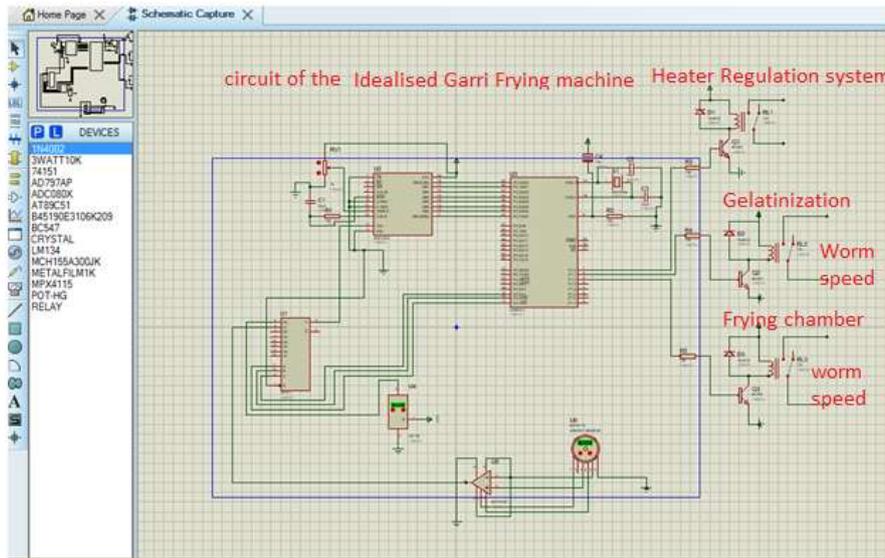


Fig-4: Interface Diagram showing output and input interfaces to embedded microcontroller (Circuit Diagram) in fig 1

Model For The Actuator

Temperature fluctuation is non linear owing to conditions like losses and surge from heating and this impose the disturbing challenge of temperature control. The relationship between the applied voltage and the energy generated by electrical heating elements is non-linear. This work aimed to linearised the relationship by driving the blower supplying hot air to the gelatinization chamber from a Pulse Width Modulated (PWM) signal. A pulse width modulated signal is generated from the microcontroller as shown in Fig. 5 where M and S are the mark and the space of the waveform, and T is the period, i.e.

$$T = M + S. \quad (14)$$

This waveform is used to control a power MOSFET switch where the fan element is connected as the load of this device. The votalge applied to the blowere has a r.m.s value of the current through the blower can be calculated as:

$$I_{r.m.s} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} \quad (15a)$$

$$I_{r.m.s} = \sqrt{\frac{1}{T} \int_0^M I_0^2} \quad (15b)$$

$$I_{r.m.s} = I_0 \sqrt{\frac{M}{T}} \quad (15c)$$

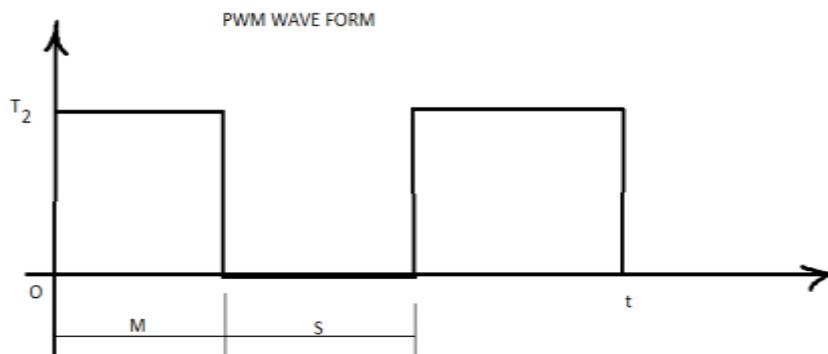


Fig-5: PWM Wave form for the blower to gelatinization chamber.(page 11)

Model For The Sensor (Lm135)

The temperature sensor is a semiconductor device with a linear voltage-temperature relationship specified as

$$10 \frac{mV}{^{\circ}C}$$

$$\frac{V_0}{T} = 0.01 \quad (16)$$

Where,

V_0 is the sensor output voltage in volts and

T is the temperature in $^{\circ}C$.

For a range of temperature of $(70-90)^{\circ}C$, the voltage range will be (0.7 to 0.9)volts.

(B)Frying Chamber

If a mass M (Kg) of gelatinized cassava mash at a temperature θ_2 from gelatinization chamber is delivered into the frying chamber environment at a prevailing temperature θ_3 . Heat is transferred from this environment to the mass M (Kg) of the cassava mash will lead to a rise in temperature of the mash. Therefore, it showed that the heat added is proportional to the rise in temperature of the mass of the mash.

Heat Added to gelatinized cassava mash \propto Rise in temperature of the gelatinized mash

$$dq = MCd\theta_i \quad (17)$$

$$\frac{dq}{M} = Cd\theta_i \quad (\text{heat transfer per unit mass of cassava mash in the gelatinization chamber})$$

Where,

dq = elemental heat added (joule)

C = Specific heat capacity of cassava mash (joule/kg.kelvin)

M = mass of the cassava mash (Kg)

CM = thermal capacitance (joule/kelvin)

If the rate of temperature rise in the chamber is a function of time, hence

$$\frac{dq}{dt} = \phi = C \frac{d\theta_i}{dt} \quad (18)$$

$$\frac{dq}{dt} = C \frac{d\theta_i}{dt}$$

Where,

ϕ = is the rate of heat transfer per unit mass of the gelatinized cassava mash and this is governed by thermal resistance between the hot air and the gelatinized mash which analytically similar to the popular ohm's law of electricity.

$$\phi = \frac{\theta_i}{R} \quad (19)$$

$$\phi = \frac{\theta_3 - \theta_2}{R}$$

R is the thermal resistance (K/watt)

$$\phi = C \frac{d\theta_i}{dt} = \frac{\theta_3 - \theta_2}{R} \quad (19)$$

$$C \frac{d\theta_i}{dt} = \frac{\theta_3 - \theta_2}{R}$$

$$\frac{d\theta_i}{dt} = \frac{\theta_3 - \theta_2}{CR} \quad (20)$$

$$\frac{d\theta_i}{dt} = \frac{\theta_3}{CR} - \frac{\theta_2}{CR}$$

$$\frac{d\theta_2}{dt} + \frac{\theta_2}{CR} = \frac{\theta_3}{CR} \quad (21)$$

if $\tau = CR$

τ is the product of the thermal resistance and thermal capacitance and it is the time constant

$$\frac{d\theta_2}{dt} + \frac{\theta_2}{\tau} = \frac{\theta_3}{\tau} \quad (22)$$

Migrating from a time function $\frac{d}{dt}$ to an S function the equation becomes

$$\frac{d(\theta_2)}{dt} + \frac{\theta_2}{\tau} = \frac{\theta_3}{\tau} \quad (23)$$

$$S(\theta_2) + \frac{\theta_2}{\tau} = \frac{\theta_3}{\tau}$$

$$\frac{S\tau(\theta_2 + \theta_2)}{\tau} = \frac{\theta_3}{\tau} \quad (24)$$

$$\theta_2(S\tau + 1) = \theta_3$$

$$\frac{\theta_2}{\theta_3}(S) = \frac{1}{S\tau + 1} \quad (25)$$

Where,

τ is the resident time for the mass M (kg) in the frying chamber

$$\tau = 4\text{minutes} = 240\text{seconds}$$

$$\frac{\theta_1}{\theta_3}(S) = \frac{1}{240S+1} \quad (27)$$

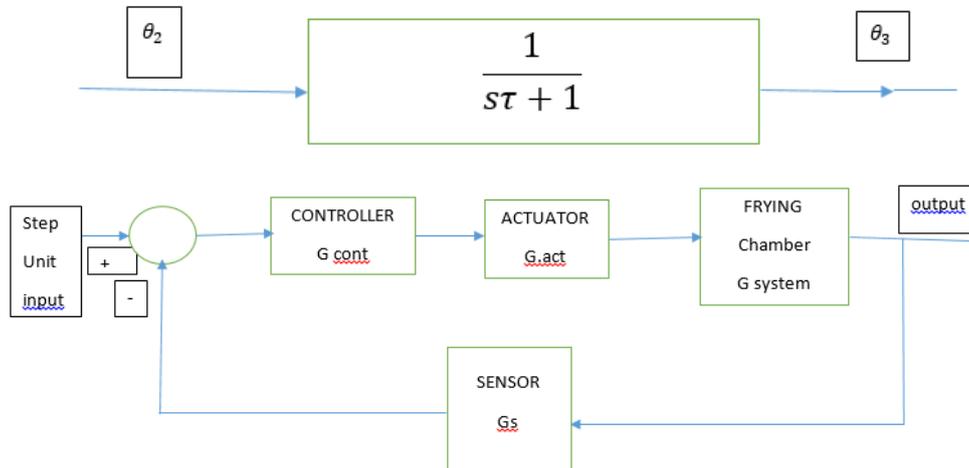


Fig-6: block diagramme for frying chamber model

Model For The Actuator

Temperature fluctuation is non linear owing to conditions like losses and surge from heating and this impose the disturbing challenge of temperature control. The relationship between the applied voltage and the energy generated by electrical heating elements is non-linear. This work aimed to linearised the relationship by driving the blower supplying hot air to the frying chamber from a pulse width modulated (PWM) signal. A pulse width modulated signal is generated from the microcontroller as shown in Fig. 5 where M and S are the mark and the space of the waveform, and T is the period, i.e.

$$T = M + S. \quad (28)$$

This waveform is used to control a power MOSFET switch where the fan element is connected as the load of this device. The voltage applied to the blower has a r.m.s. value of the current through the blower can be calculated as:

$$I_{r.m.s} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} \quad (29a)$$

$$I_{r.m.s} = \sqrt{\frac{1}{T} \int_0^M I_0^2} \quad (29b)$$

$$I_{r.m.s} = I_0 \sqrt{\frac{M}{T}} \quad (29c)$$

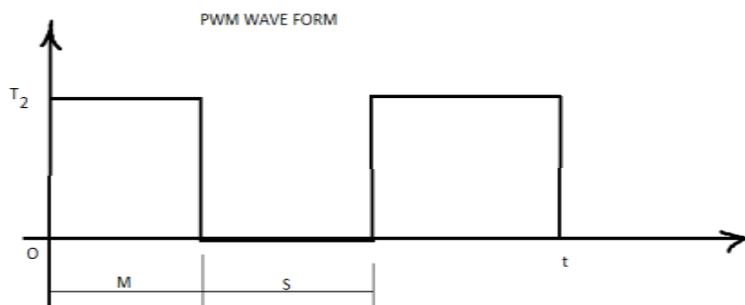


Fig-7a: PWM Wave form for the blower to frying chamber.(page 11)

Model For The Sensor (Lm 135)

The temperature sensor is a semiconductor device with a linear voltage-temperature relationship specified as

$$10 \frac{mV}{^{\circ}C}$$

$$\frac{V_0}{T} = 0.01$$

Where,

V_0 is the sensor output voltage in volts and

T is the temperature in $^{\circ}C$.

For a range of temperature of ($180-200$) $^{\circ}C$, the voltage range will be (1.8 to 2)volts.

Model For The Microcontroller

Modeling the controller, the PID controller was selected because of it versatile extensive use in industrial applications and processes. Zeigler Nichols tuning method [9] was applied in the design and simulation of the parallel proportional-Integral-Derivative Controller for optimal gelatinization and frying temperatures stabilization.

Considering the algorithms

$$U_t = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(t) dt + K_p T_d \frac{de(t)}{dt} \quad (30)$$

Migrating to S domain from t domain

$$U(s) = K_p \left[1 + \frac{1}{T_i s} + T_d \cdot s \right] E_s \quad (31)$$

PID controller can be determined by Z-transfer of the equation ---in a descret form,thus

$$U(z) = E(z) K_p \left[1 + \frac{T}{T_i(1-z^{-1})} + T_d(1 - z^{-1}) \right] \quad (32)$$

Expanding the equation 32 ,this is simply

$$\frac{U(z)}{E(z)} = a + \frac{b}{1-z^{-1}} + c(1 - z^{-1}) \quad (33)$$

Where

$$a = K_p$$

$$b = \frac{K_p}{T_i} T$$

$$c = \frac{K_p T_d}{T}$$

For a continous parallel PID Controller

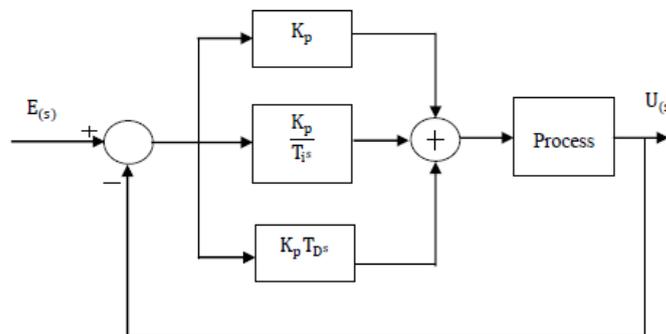


Fig-7b: Block diagram of a continuous parallel PID controller

SIMULATION AND RESULTS

The system was modeled and simulated using Matlab/Simulink. The simulated results of the system control with PID tuning were analyzed. Figure 8 shows the simulink block diagram of the temperature control system

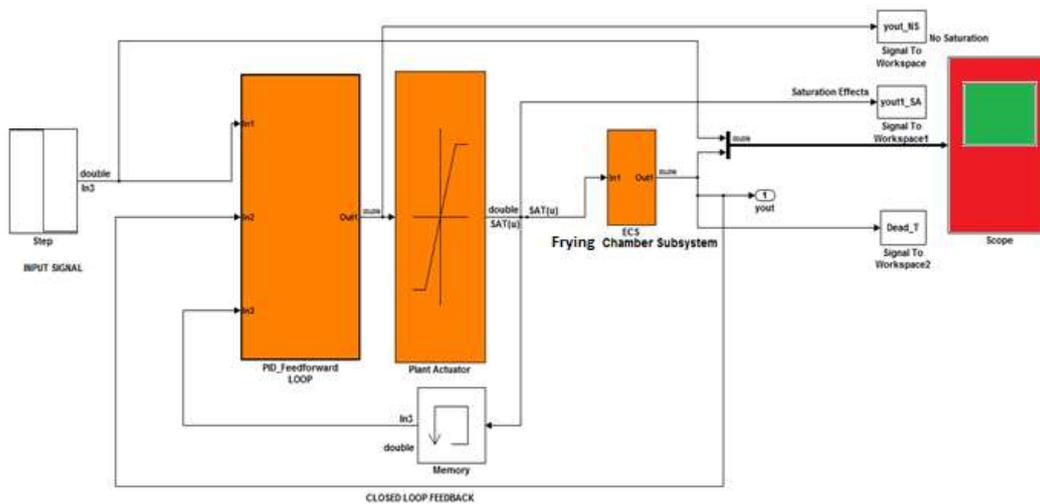


Fig-8: block diagram for a continuous parallel PID controller

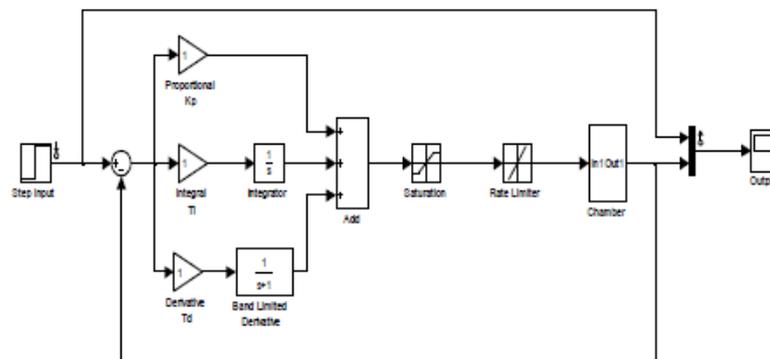


Fig-9: simulink block diagram for gelatinization temperature control and frying temperature control

A. Test 1:

Consider the following assumed values of the parameters of the PID controller and the response of the system to these values.

Table 1: The first assumed values of the parameters of the PID controller

PARAMETER	Kp	Ti	Td
VALUES(sec.)	0.2851	0.1171	0.3625

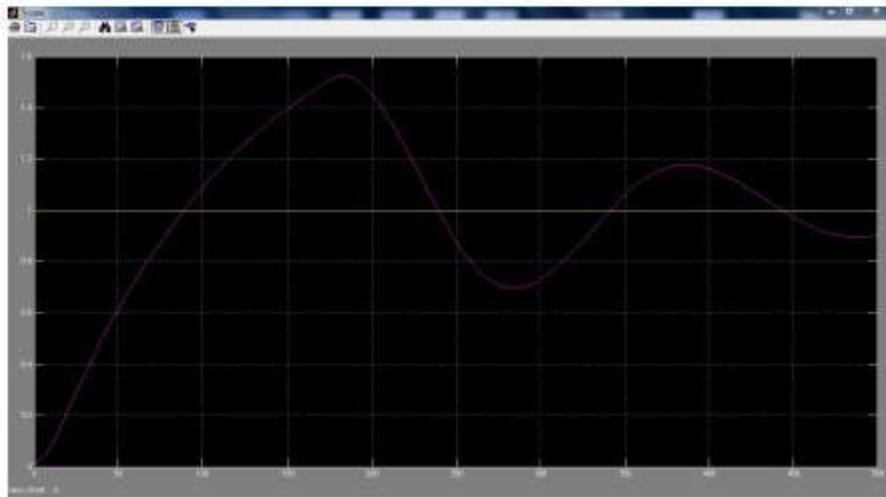


Fig-10: Scope of the unit step response of the system for test 1

Table 2: Result of test 1

PARAMETER	tr	Tp	ts	Mp
VALUE (sec.)	37.7	100	727	57.9

Table 3: The second assumed values of the parameters of the PID controller

PARAMETER	Kp	Ti	Td
VALUE(sec)	1.9688	0.0504	0.6300

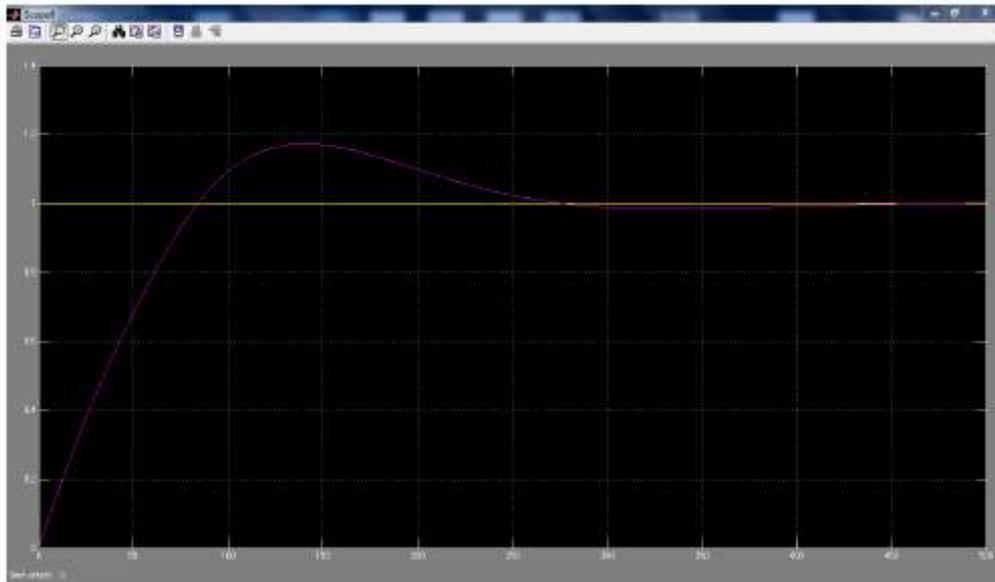


Fig-11: Scope of the unit step response of the system for test 2

Table 4: Result

parameter	tr	tp	ts	Mp
Values(sec)	61.9	137	248	14.9

Table 5: The third assumed values of the parameters of the PID controller

parameter	Kp	Ti	Td
value	16.373	0.1324	3.327

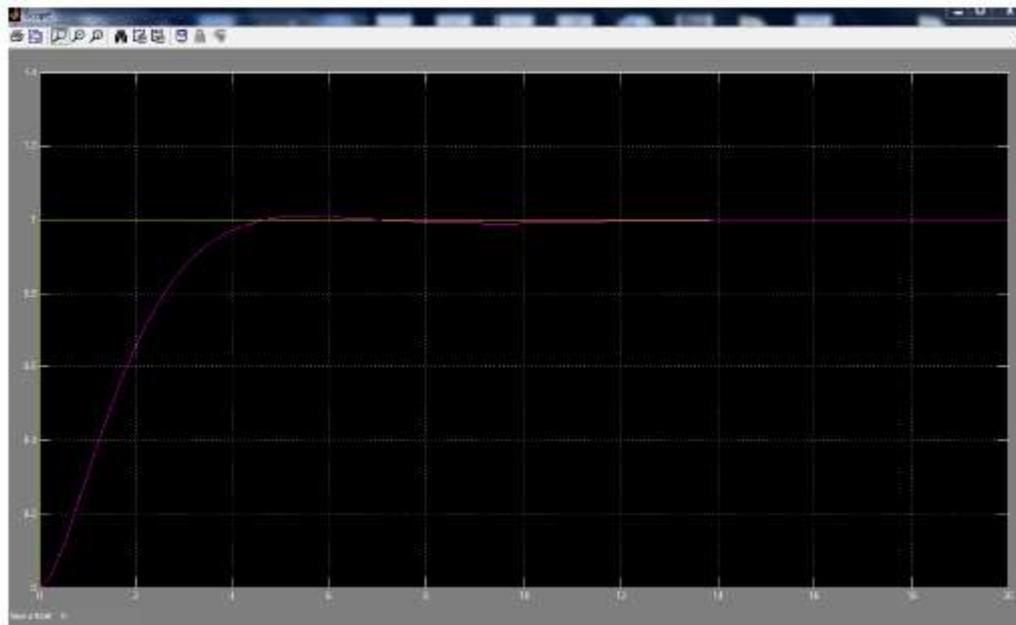


Fig-12 stable display

RESULT

Table 6: result of test 3

parameter	tr	tp	ts	Mp(%)
Values	16.7	-	29.8	-

RESULTS ANALYSIS

Using Matlab/Simulink toolbox, various parameters were tested and the best parameters were used for PID implementation on the microcontroller. The results showed the system responses to a step input with varying PID controller parameters based on Zeigler-Nichols tuning method. It can be inferred from the results that the optimal set of parameters that give a more desirable transient response in terms of short rise time, low overshoot, short settling time, low steady state error are got from the results of test 3 where:

- Proportional gain, $K_p = 16.373$,
- Integral time, $T_i = 0.1324$,
- Derivative time, $T_d = 3.3287$.

Hence, a PID algorithm implemented on a microcontroller, simulated and fine tuned using the set of parameters obtained from test 3 will exhibit a better control performance to changing temperature conditions in the garri fryer system

CONCLUSION

The performances of control strategies with feedback for a microcontroller based temperature control in gelatinization and frying chambers of a garri frying machine have been investigated [10] A comparative study of performance of PID based controllers is studied. The aim of the proposed controller is to regulate the temperature of the system to a desired temperature in the shortest possible time with minimum or no overshoot, short rise time, small peak time and short settling time. Mathematical model was efficiently used for the design of the temperature control system of a garri frying machine with the best results obtained using Zeigler-Nicholss tuning technique with an overshoot, short rise time, small peak time and short settling time respectively gelatinization chamber and frying chamber with short settling time 29.8seconds respectively

FUTURE WORK

Alternative processor architectures such as FPGAs/CPLDs with PID gain control should be explored for Garri processing drying design that is idealized to have two chambers. The PID graphical design method is capable of ensuring closed loop stability for arbitrary order plants with additive uncertainty, and PID has wide range of plants application capability. Future researches can be done in the area of controller design for multiple input output system, with special consideration on multivariable feedback control systems, and robust performance for arbitrary order plants with additive

uncertainty in the PID design this will help in expanding designs for CIM, (Computer Integrated Manufacturing) system for agro processing of food items. A performance evaluation of the control algorithm should be initiated in future research endeavors while applying the stability design initiatives in high order processor integrations.

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