YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

REALIZATION OF A CHAOTIC KITCHEN MIXER AND IT'S PERFORMANCE EVALUATION

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ABSTRACT

REALIZATION OF A CHAOTIC KITCHEN MIXER AND ITS PERFORMANCE EVALUATION

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In this thesis, chaotic systems, which work more efficiently than conventional methods, are considered, and it is aimed to develop a kitchen type chaotic mixer prototype and to perform efficiency analysis in cake dough mixture application.

Prototype mixer has been realized with hardware and software changes to be made on a commercial kitchen type mixer, which works originally with conventional method. For the chaotic operation of the mixer, a new control card is designed. Motor speed is controlled based on a micro controller, which transmits the speed signal to the power card driving the mixer motor. Chaotic signal is generated by a simple chaotic system, namely the logistic map, implemented in microcontroller. The generated chaotic signal is fed to drive the mixer motor in order to chaotify motor speed in a feedforward control scheme. By computing the Lyapunov exponent of the motor speed signal, it is observed that such a feedforward chaotification scheme is sufficient to achieve chaotic mixer speed. A tablet with Android operating system is provided for operating the mixer with the chaotic or conventional method, adjusting the engine speed, setting the test run time, entering the Proportional Integral Derivative controller parameter values, and checking the voltage-current information. A SCADA application has been written that can be used on all devices with Android operating system. Wireless Bluetooth communication has been chosen for SCADA software and control board communication to eliminate practicality and cable clutter.

The thesis demonstrates the efficiency of chaotic mixing in food engineering and, in particular, cake dough mixing. The experimental studies of the thesis include rheological, physical and sensory analyses of the cake product obtained by chaotic mixing. Consistency check is done for overall qualitative properties. The analyses shows that, as compared to the conventional one, namely the constant speed mixing, chaotic mixing provides the cake products to possess almost the same characteristics obtained with almost half of the energy and time consumption.

Key Words: Chaotic mixing, cake dough, chaotification, dc motor, rheological characteristics, microcontroller

ÖZ

KAOTİK MUTFAK TİPİ BİR MİKSERİN GERÇEKLENMESİ VE PERFORMANS DEĞERLENDİRMESİ

İZMİR, Tolga Tugay
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Ağustos 2019

Bu tezde, geleneksel yöntemlerden daha verimli çalışan kaotik sistemler ele alınmış, mutfak tipi bir kaotik karıştırıcı prototipi geliştirilmesi ve kek hamuru karışım uygulamasında verimlilik analizi yapılması amaçlanmıştır.

Prototip karıştırıcı, aslen geleneksel yöntemle çalışan ticari mutfak tipi bir karıştırıcıda yapılan donanım ve yazılım değişiklikleri ile gerçekleştirilmiştir. Mikserin kaotik çalışması için yeni bir kontrol kartı tasarlanmıştır. Motor hızı, hız sinyalini mikser motorunu çalıştıran güç kartına aktaran bir mikro kontrolör üzerinden kontrol edilmektedir. Kaotik sinyal, mikrodenetleyicide gerçekleştirilen basit bir kaotik sistem olan lojistik dönüşüm tarafından üretilir. Üretilen kaotik işaret, karıştırıcı motor hızını ileri beslemeli bir kontrol ile kaotikleştirmek için karıştırıcı motorunu sürmek için kullanılmıştır. Böyle bir ileri beslemeli kaotikleştirme yönteminin kaotik bir karıştırıcı hızı elde etmeyi başarmak için yeterli olduğu, motor hız işaretinin en büyük Liapunov üstelinin hesaplanması yardımıyla ile gösterilmiştir. Mikserin kaotik veya geleneksel yöntemle çalıştırılması, motor devrinin ayarlanması, test çalıştırma zamanının ayarlanması, Oransal İntegral Türev kontrolör değerlerinin girilmesi ve voltaj ile akım bilgilerinin izlenmesi için Android işletim sistemine sahip bir tablet kullanılmıştır. Android işletim sistemine sahip tüm cihazlarda kullanılabilecek bir SCADA uygulaması yazılmıştır. Pratikliği ve kablo karmaşasını ortadan kaldırmak için SCADA yazılımı ve kontrol panosu iletişimi için kablosuz Bluetooth iletişimi seçilmiştir.

Tez, kaotik karışımın gıda mühendisliğinde ve özelde de kek hamurunun karıştırılmasında etkinliğini göstermektedir. Tezin deneysel çalışmaları, kaotik karıştırmayla elde edilen kek ürününün reolojik, fiziksel ve duyusal analizlerini içerir. Genel nitel özellikler için tutarlılık kontrolü yapılmıştır. Analizler, kek ürünlerinin kaotik karışımın geleneksel karışıma kıyasla, enerji ve zaman tüketimi yönünden neredeyse yarısıyla hemen hemen aynı özelliklere sahip çıktılar sağladığını göstermektedir.

Anahtar Kelimeler: Kaotik karışım, kek hamuru, kaotikleştirme, dc motor, reolojik özellikler, mikrodenetleyici

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Tolga Tugay İZMİR

İzmir, 2019

TEXT OF OATH

I declare and honestly confirm that my study, titled "Realization of A Chaotic Kitchen Mixer And It's Performance Evaluation" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Tolga Tugay İZMİR

Signature

…………………………………..

November 3, 2019

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CHAPTER 1
INTRODUCTION

Chaos is the most complicated non-linear dynamical behavior of deterministic systems. In general, chaos is considered as a dynamical mode that should be suppressed to avoid its negative effects on the systems. However, in nature, chaos is a desired behavior of living systems. In 1990, Pecora and Carroll introduced a chaotic communication scheme to obtain security in the communication system (Pecora & Carroll, 1990). Cryptography another interesting application of chaotic signals (Kocarev, 2001). Among limited number of chaos applications, chaotic mixing has gained attention for its energy efficiency compare to the standard constant speed mixing (Ottino, 1990; Wiggins & Ottino, 2004; Ye & Chau, 2007; Şahin & Güzeliş, 2013). This thesis introduces a novel application of chaotic mixing in food engineering. The thesis study shows specifically that mixing cake dough in a chaotic way can provide better homogenization, so superior rheological characteristics.

There are various ways to produce, to consume and to serve food products. These varieties are shaped by some inside and outside factors such as the preferences of producers, consumers, the users and the facilities of production medium. So, different time and energy efficient production methods has been existing for different kinds of food products. At the same time, practical methods have always been searched as potential candidates to produce foods in good quality. Mixing liquids and/or solid materials is one of the most basic processes in food production. Duration and type of mixing process has a high effect on the quality of food product. On the other hand, mixing is time and energy consuming process. Despite its inefficiency, the most widely used mixing process technique used in the industry is conventional mixing that is the type of mixing with constant speed. Nowadays, many different applications and systems employ electronic devices to derive and control plants and processess. Because of these facts, energy efficiency gains importance from day today. In a conventional mixing process, high energy consumption and therefore high operating costs are usually required depending on the process capacity (Ascanio et. al, 2002; Paul et. al, 2004). Thus, cost saving opportunities via providing efficient mixing without changing the quality of the product is of great importance. When compared with the conventional methods, chaotic mixing provides significantly lower electrical energy consumption, less mixing time and more homogenous mixing (Ye & Chau, 2007; Şahin & Güzeliş, 2013). Then, searching new kind of mixing systems would be of interest also in food engineering area.

Considering the previous research in the chaotic mixing literature (Ottino, 1990; Wiggins & Ottino, 2004; Ye & Chau, 2007; Şahin & Güzeliş, 2013), this thesis aims to exploit the chaotic mixing in a new application area, namely in food production. The thesis aims to develop a chaotic mixer to provide an energy efficient homogeneous mixing for cake dough as a potential engineering application in food industry.

Cakes are defined as complex macro emulsion systems that are produced in order to obtain a foam from liquid mixture by a mechanical force. This foam (cake batter) is turned to porous material (cake) by increasing the temperature and it is crucial where the characteristics of cake is designated by foam's physical properties (Şahin, 2008). Among these properties, rheology and physiology play an important role where the characteristic properties are affected by the amount of gas bubbles incorporated into the foam structure that determines cake quality. In addition, density can be evaluated as one of the important parameters, because it is related with food aeration by means of mechanical action where it affects viscosity and bulk properties of cake batter. The measurement of quality properties of foodstuff where rheology, physiology and sensory characteristics are evaluated is important since it plays an important role for both product and plant design (Tabilo-Munizaga & Barbosa-Cánovas, 2005). Determining the rheological properties of cake batters leads to have correlation with quality characteristics of cake e.g. volume, texture, tensile resistance, sensory characteristics (Şahin, 2008).

Cake batter is mainly composed of various amounts of sugar, egg, butter, flour and baking powder. Some additional ingredients such as emulsifiers and milk powder can be used for commercial production (Indrani & Rao, 2008). The physical properties of cakes depend on many factors such as amount, quality, temperature, mixing order and/or combination of cake batter ingredients (Guadarrama-Lezama & Carrillo-

Navas & Pérez-Alonso & Vernon-Carter, & Alvarez-Ramirez, 2016) and the processing conditions (Ross & Pyrak-Nolte & Campanella, 2004).

Being one of the most used food processing operations, mixing has special importance for cake production. Generally, mixing process is applied at constant speed resulting not only high energy consumption, but also high operating costs based on the production capacity (John Wiley & Sons, 2004). For a more efficient emulsion production, it would be necessary to develop and to use mixing technique that could provide efficient mixing without compromising the quality of product. From this point of view, chaotic mixing has potential as a technique that provides efficiency in at least one of the criteria such as mixing time, energy used, improvement in food quality characteristics (Ye & Chau, 2007), (Şahin & Güzeliş, 2010). In addition, a general survey was performed to measure the strength of need for a chaotic mixer in case of cake batter. 123 of the 158 people who were asked questions stated that manual speed settings in the mixers they use at home were not practical but would need a mechanism that could automatically perform the speed transition effects. For this reason, it was decided to examine in the thesis the chaotic mixing system, which is a solution to the system requested by the users, on cake dough for such valid reasons.

The aim of this thesis is to determine the feasibility of the chaotic mixing to be used for preparation of cake batter in case of quality characteristics such as rheological, physical and sensory properties. For this purpose, a kitchen type mixer was designed to run at both chaotic and standard mixing modes and the effect of those mixing modes on rheological, textural and sensory characteristics were compared by taking cake batter as sample food material. Prototype mixer has been realized with hardware and software changes to be made on the commercial kitchen type mixer which works originally with conventional method. For the chaotic operation of the mixer, a new control card is designed. Motor speed is controlled based on a micro controller which transmits the speed signal to the power card driving the mixer motor. Chaotic signal is generated by a simple chaotic system, namely the logistic map, implemented in microcontroller. The generated chaotic signal is used in a feedforward control mechanism for driving the mixer motor in order to provide a chaotic motor speed. By computing the maximum Lyapunov exponent of the resulting motor speed signal, it is seen that the preferred chaotification scheme is successful to produce the desired chaotic speed for the mixer motor. A tablet with Android operating system is provided for operating the mixer with the chaotic or conventional method, adjusting the engine speed, setting the test run time, entering the Proportional Integral Derivative controller parameter values, and checking the voltage-current information. A SCADA application has been written that can be used on all devices with Android operating system. Wireless Bluetooth communication has been chosen for SCADA software and control board communication to eliminate practicality and cable clutter.

The thesis demonstrates the efficiency of chaotic mixing in cake dough mixing. The experimental studies of the thesis include rheological, physical and sensory analyses of the cake product obtained by chaotic mixing. Consistency check is done for overall qualitative properties. The analyses shows that, as compared to the conventional one, namely the constant speed mixing, chaotic mixing provides the cake products to possess almost the same characteristics obtained with almost half of the energy and time consumption.

The thesis is organized as follows. Chapter 2 provides the background for chaotification methods and chaotic mixing in food engineering. Chapter 3 presents hardware and software implementation of the kitchen type chaotic mixer used in mixing cake dough material. Chapter 4 summaries the experimental results obtained in the thesis studies on chaotic mixing of cake batter. Chapter 5 gives conclusions on the considered food engineering application of the chaotic mixing and possible future works.

CHAPTER 2
CHAOTIC MIXING IN FOOD ENGINEERING

This chapter provides a brief on chaos, chaotification and chaotic mixing as well as chaotic mixing in food engineering.

2.1. Chaos, Chaotification and Chaotic Mixing

Chaos is a random-like behavior of nonlinear dynamic deterministic system. It is the most complicated dynamical behavior of deterministic systems. Deterministic chaos appears in nonlinear dynamical systems of at least three dimensional if the systems are defined by integer dimensional ordinary differential equations. However, the deterministic chaos can be generated even in a single dimensional dynamical system when the system is defined as a recursion running in discrete-time. A chaotic trajectory of a nonlinear dynamical system defined is a complicated bounded solution of the associated differential equations that does not converge to an equilibrium point and to a periodic (or also a quasi-periodic) orbit. A deterministic system is called chaotic if it has an attractor, said strange attractor, which is topologically transitive and has the property of sensitive dependence on the initial conditions together with denseness of its periodical orbits (Şahin & Güzeliş, 2010). Chaos is observed in nature, particularly in biological, chemical, electrical, and weather systems. Deterministic chaos is shown to be produced by diverse mathematical models. Lorenz, Rössler and Chua's chaotic systems are among the continuous time chaotic system examples defined with third order nonlinear ordinary differential equations. Chaos is known to be generated also by first-order discrete-time systems, fractional-order dynamical systems and distributed systems defined with nonlinear partial differential equations. The vast amount of literature related to chaos is devoted to the analysis and control of chaotic systems. The works that consider chaos as a desirable property for real systems are quite a few. Secure communication, cryptology, and liquid mixing are among the rare engineering applications of chaos where chaotic dynamics has been shown successful.

One of the simplest chaotic systems is the following Logistic Map which defines a recursion over a single state variable $x \in [0,1]$ in discrete-time $k \in Z$.

$$x^{k+1} = r\, x^k\, (1 - x^k)$$

It was popularized by the biologist May (May, 1976) as the discrete-time version of the first order ordinary differential equation model of population growth which was introduced by the ecologist Verhulst in 1845. Depending on the choice of the parameter $r \in [0,4]$, the dynamical behavior of the Logistic Map becomes as asymptotically stable fixed point, limit cycle and chaos. Chaotic behavior appears for most values of r beyond 3.56995.

Chaotification, also called as anti-control or chaotization, is the process of making an originally non-chaotic system being chaotic by applying a suitable control input. This control might be a feedforward control scheme. In this scheme, a chaotic signal is produced by a known chaotic system, e. g. Lorenz system or Logistic Map, and this chaotic signal is used to drive the plant, which is desired to be chaotized. Although there is no guarantee that the system, which is forced by a chaotic signal, will become chaotic, the feedforward control scheme may be preferable in some applications due to its simplicity not requiring a costly hardware/software implementation of the chaotifying controller.

In the thesis study, considering the low cost hardware/software implementation property, one of the simplest chaotic systems, namely the Logistic Map was used as the chaotic signal generator with the expectation that the plant forced by a chaotic input signal will show a chaotic behavior. The chaotic signal produced by the Logistic Map with the parameter value $r = 4$ was fed to the mixer motor as the control input, so a feedforward control law was applied to chaotify the motor speed.

The feedforward control scheme used for the chaotification of the dc motor speed is depicted in Figure 2.1.

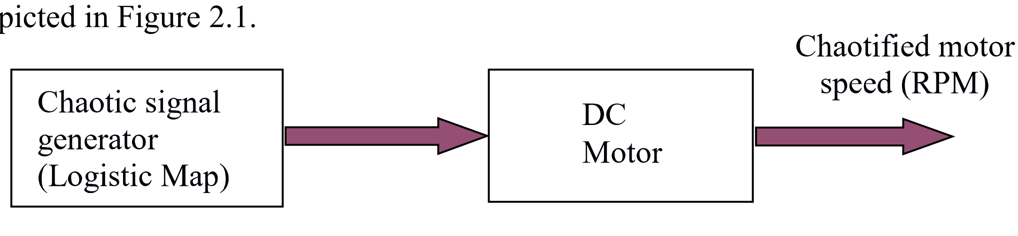


Figure 2.1. Feedforward chaotification of dc motor

The largest Lyapunov exponent of the motor speed signal, which was measured by means of the encoder mounted on the motor shaft, was computed as 0.2714 by using the TISEAN software package (Hegger et al., 1999; Hegger et al., 2007). The measured RPM (Rate Per Minute) signal is given in Figure 2.2.

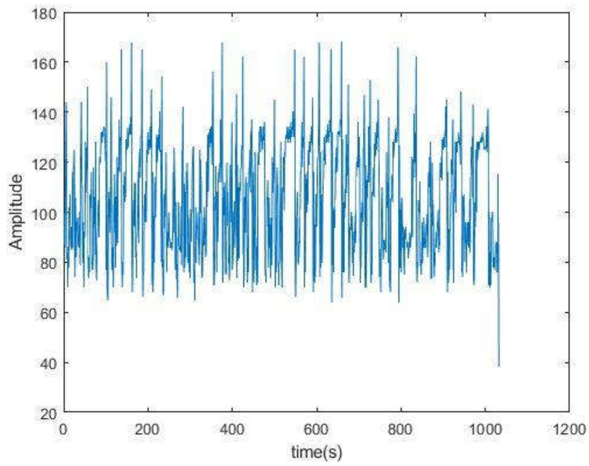


Figure 2.2. RPM signal measured from the chaotified motor shaft by the encoder

Considering the production of a positive largest Lyapunov exponent for the dc motor speed by the applied feedforward chaotification scheme employing the Logistic Map as the chaotic signal generator together with the hardware-software implementation suitability, the feedforward chaotification was found convenient in the thesis study in order to achieve the chaotification of the dc motor of the kitchen type mixer.

One may attempt to improve the kitchen type chaotic mixer in the direction of obtaining better mixing properties by employing other chaotification methods developed in the literature. Vanecek-Celikovsky method (Vanecek & Celikovsky,1994) constitutes such a possibility: It assumes a continuous-time control system in the Lure' s form and the existence of an odd monotonic nonlinearity in the feedback path, and a linear time-invariant system in the feed-forward path. To chaotify the plant, Vanecek-Celikovsky method adjusts the linear feedback gain to obtain i) a part of the closed-loop poles in the open left-hand side, ii) a part of the closed-loop poles in the right-hand side, iii) a part of the closed-loop poles on the negative real axis, iv) a part of the closed-loop poles with nonzero imaginary parts, and v) no pole on the jw-axis.

Chen's method of chaotification (Chen & Lai, 1996) assumes that the plant has a discrete time model in the form of $x(k+1) = f\big(x(k)\big) + u(k)$ and apply a static feedback control $u(k) = K\, g(\sigma \cdot x(k))$. Herein, K is the controller gain, $\sigma > 0$ is the frequency and $g(\cdot)$ is a sine or piecewise-linear saw-tooth function. The amplitude K and the frequency $\sigma > 0$ are adjusted to ensure positive Lyapunov exponents for the closed-loop system.

As the third alternative, the model based chaotification methods might be implemented in two different ways as with employing static feedback (Morgül, 2003). The model-based static feedback chaotification first transforms a reference chaotic system such as Lorenz system into the Brunovsky canonical form, and then matching the plant of the same order to the transformed reference chaotic system by the static feedback. The dynamic feedback chaotification method does not necessitate the transformation of the reference chaotic system into the Brunovsky form, so having the possibility of using already available efficient hardware realizations of the reference chaotic system.

The above mentioned alternative methods of chaotification may be exploited by future researches in improving the kitchen type chaotic mixer developed in this thesis.

2.2. Mixing In Food Engineering

Mixing of liquids and/or solids is a vital process in food industry. Mixing is realized usually for increasing the homogeneity of a system by reducing non-uniformity or gradients in composition, properties or temperature. Mixing also controls of the rates of heat and mass transfer as well as the rates of reactions and structural changes. The important outcomes of mixing can be extended to handle sanitary design, complex rheology, and continuous processing issues and to have positive effects on final product texture and sensory characteristics.

2.2.1. Importance of Quality Characteristics in Foods

Food quality characteristics can be evaluated as a combination set of various parameters that make up a product, which is used by different consumer segments to evaluate it. Although quality characteristics can be based on different quantitative and qualitative bases depending on food groups, it can also be evaluated as the compliance of structural, physical and sensory criteria with product based references. This constitutes the degree of acceptance of the food product considered.

The viscosity and rheological properties of fluid food products are important properties utilized during many processes. Knowing these features, it is possible to design the processes (conveying, pumping, heat transfer, evaporation, mixing, etc.) applied in the production stages, to save energy with the right equipment design, quality control of intermediate and final products, to obtain the data required for sensory evaluations and to understand the structure of the examined product. (Guerrero & Alzamora, 1997; Krokida et al., 2001).

The flow characteristics of foods must be considered at every stage of production. Knowing the rheological behavior of the product to be processed during the selection of equipment such as pipes, heat exchangers and mixers to be selected during the installation phase of the production line ensures the establishment of the most suitable systems. For example, if the fluidity of the product flowing through the pipes during the pasteurization process is affected by the temperature change, this also changes the efficiency of the process. Increased product fluidity with temperature may cause the product to be exposed to the pasteurization process for a longer period of time and deteriorate its structure. Decrease in product viscosity may result in insufficient time remaining in the system and insufficient processing (McKenna & Lyng, 2003).

Rheological problems are encountered in all areas of production. The yield stress is an important rheological property, especially for the coating process, which is frequently used in the confectionery and chocolate industries. The yield stress is lower than desired, making it difficult for the coating material to adhere to the product. High yield stress values do not allow the formation of thin coatings and are not economically efficient (McKenna & Lyng, 2003).

The flow properties are also used for quality control purposes. It provides information on the composition, processing efficiency and product temperature in products such as viscosity, chocolate and ice cream. For some products such as ketchup, fluidity is a direct quality control parameter (McKenna & Lyng, 2003).

Within the scope of the thesis study, the changes of rheological, physical and sensory properties mentioned above according to different mixing type (traditional mixing and chaotic mixing) were examined.

CHAPTER 3

HARDWARE AND SOFTWARE IMPLEMENTATION OF CHOTIC MIXER

The kitchen type chaotic mixer prototype is produced in the thesis by chaotifying the dc motor rotating the mixer. The dc motor is chaotified in a feedforward way with applying the chaotic voltage signal generated by the Logistic Map. This theoretically simple method uses less processor cycles, so allows it to be implemented in real time on the electronic cards. As the shaft of the dc motor turns in a chaotic way, the rotational speed of the agitator impeller can follow the chaotic signal simultaneously. To generate the chaotic signal, the following logistic map is used with the r parameter value 4.

$$x^{k+1} = r\, x^{k}\, (1 - x^{k})$$

The rotational speed of the motor is increased or decreased by the voltage whose values are obtained by scaling the numbers x^{k} between 0 and 1 produced by this recursion.

During the implementation stage, a kitchen type commercial mixer was purchased first and the electronic card was removed away from the chassis. The motor assembly and the motor drive of the stirrer were left in a modular structure to be driven by a new electronic board designed for chaotic mixing (See Figure 3.1.). The rest of this chapter will describe the hardware and software implementation details of the developed kitchen type chaotic mixer.

Figure 3.1. Inside view of the commercial mixer KitchenAid

3.1. Hardware

Since the realization of the mechanical equipment is out of the scope of the thesis, a commercially available kitchen mixer was purchased and its electronic hardware/software were modified. Mechanical design, dimensions, productivity, Max-Min Rotation speed etc. are the factors affecting our choice in purchasing KitchenAid Brand "5KSM7591X BWH" model product (See Figure 3.2.).

Technical specifications, which were taken under consideration, are listed in Table 3.1.

Figure 3.2. KitchenAid which was purchased

Table 3.1. KitchenAid Properties

TECHNICAL SPECIFICATIONS	
Wattage (W)	500
Motor type	DC
Voltage (V)	220-240
Frequency (Hz)	50/60
Max. rotation speed	200
Min. rotation speed	40
Max. mass of mix bowl for flour	2,2
Body material	Zinc
Electrical speed control present	Yes
Height of the product	419
Width of the product	287
Depth of the product	371
Height of the packed product	495
Width of the packed product	335
Depth of the packed product	430
Net weight (kg)	13,08
Gross weight (kg)	14,78
Pie crust: kg of flour	1,15
Egg white	19
Max. content of whipped cream	1,9
Cake	4,5
Bread dough (stiff yeast dough = 55% Absorbtion ratio)	3,8
Mashed potatoes	3,6
Cookies (standard 5.1 cm - 2 inch cookie)	168

In order to determine the differences between the original mixer and the chaotified mixer in terms of parameters such as RPM, Current, Voltage, Motor Temperature, the specified parameters were measured before and after changes were made in the supplied device.

Considering the results of these tests, no significant difference was observed except for the increase in the motor temperature.

The original mixer used in the thesis study consists of Motor, Reducer, Control Card, Network Filter Unit and Chassis.

3.1.1. Motor

The mixer has 1 DC motor with 1,3HP, 240VDC, Input 500W, Output 375W, 2.1A 10,000 RPM. There is 1 cooling fan and 8 pole magnetic encoders on the rear shaft of the motor (See Figure 3.3.).

Figure 3.3. Inside view of the dc motor used in the KitchenAid

Since the features of the magnetic encoder on the rear shaft of the motor did not meet the required specifications, the current encoder was re-drawn as 1 pole according to the original dimensions in the SolidWorks program and 3D printing was taken. In accordance to the new design, a new encoder was placed on the motor. No problem was observed in the tests performed after the replacement.

3.1.2. Reduction

The front output shaft of the motor is equipped with a 90 ° 1/50 gear unit shown in Figure 3.4. It reduces the high rotational speed from the engine to 1 in 50, providing the required torque for dense viscous mixtures.

Figure 3.4. Rotational Speed Reduction Mechanism

3.1.3. Control Card

As a result of the existing control card examination, it has been determined that it consists of two parts as control and power parts. The necessary hardware changes for obtaining chaotic mixing have been identified as follows. A microcontroller must be used in order to provide chaotification in the mixer. A new control card has been designed due to the fact that the existing control card does not allow any modification to be made on its hardware.

The components and technical specifications of the new control card designed to collect the necessary data are listed in the following subsections. Interconnection of the units of the newly designed control card is provided by the block diagram in Figure 3.5.

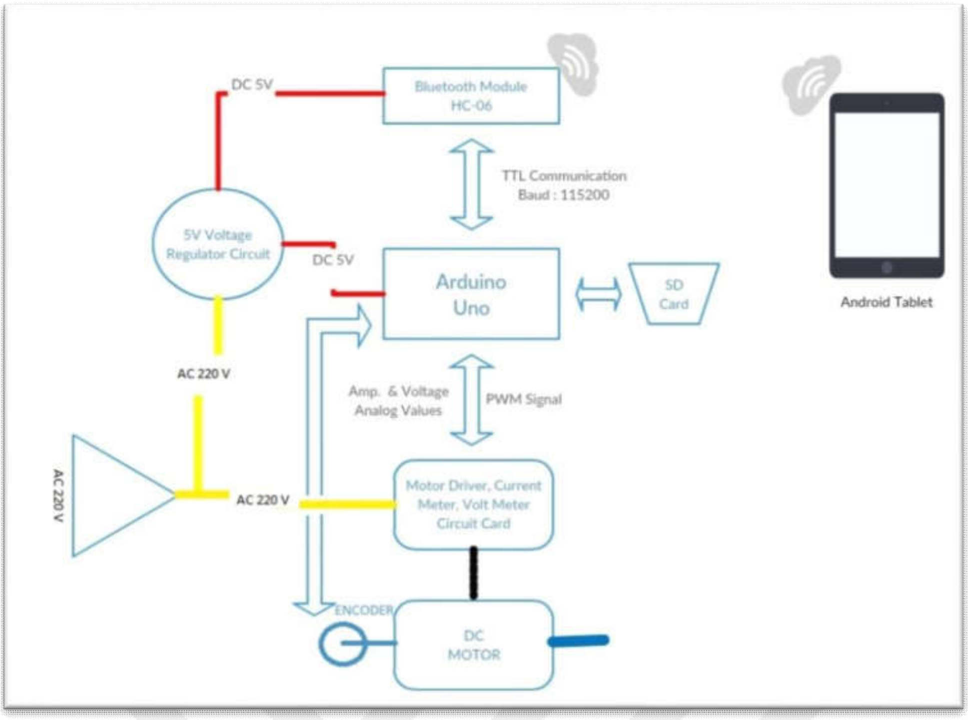


Figure 3.5. Block Diagram of the Designed Control Card

3.1.3.1. Atmega328p - 8-Bit Avr Microcontroller

The ATmega328p, which is shown in Figure 3.6, is a high-performance, low-power 8-bit microcontroller. Technical specifications are given in Table 3.2.

During the tests, ATmega328p has been used Logistic Map calculations, current measurements, voltage measurements, wireless communication, data storage and many other operations that can be easily replaced by internal and external circuit elements.

Table 3.2. ATmega328P Properties

28-pin AVR Microcontroller
Flash Program Memory: 32 Kb.
EEPROM Data Memory: 1 Kb.
SRAM Data Memory: 2 Kb.
I/O Pins: 23
Timers: Two 8-bit / One 16-bit
A/D Converter: 10-bit Six Channel
PWM: Six Channels
RTC: Yes with Separate Oscillator
MSSP: SPI and I²C Master and Slave Support
USART: Yes
External Oscillator: up to 20MHz

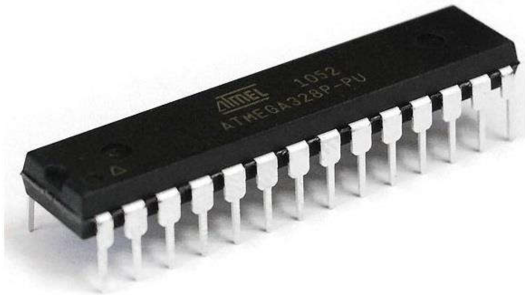


Figure 3.6. ATmega328P

3.1.3.2. ACS714 Current Sensor

This module is used to measure the instantaneous current value of the motor and is, indeed, a linear current sensor of allegro's ACS714 magnetic effect ± 30A. This version allows two-way current input up to 30 amps. It outputs 2.5V analog voltage (66 mV / A) with an error margin of less than 1.5%. This output is converted to digital data via the analog input of the ATmega328P.

The internal resistance of the conductor track is typically 1.2 mΩ and the PCB is 2-oz copper. There is therefore little power loss on the card. The technical specifications of ACS714 displayed in Figure 3.7 are listed in Table 3.3.

Table 3.3. ACS714 Properties

Current sensitivity: 0.066V/A(Vcc=5V)
Min. Vorking Voltage: 4.5V
Maks. Vorking Voltage: 5.5V
Operating Current: 13mA
Dimensions: 1,77x2,03 cm
Weight: 1.3 gr

Figure 3.7. ACS714 Current Sensor

3.1.3.3. HC-06 Bluetooth Module

The HC06 Bluetooth-Serial Module Card given in Figure 3.10 is designed for the use of Bluetooth SSP (Serial Port Standard) and wireless serial communication applications. It is used to transfer the data (rpm, voltage, current, value of the Logistic map variable, operating time, etc.) generated during the test to the user screen. The user screen is explained in Subsection 3.2.2 (See Figure 3.8.). Supported with Bluetooth 2.0, this card allows communication at a frequency of 2.4GHz and has a communication distance of approximately 10 meters in outdoor environment. Its technical specifications are listed in Table 3.4.

Table 3.4. HC06 Bluetooth-Serial Module

Bluetooth Protocol: Bluetooth 2.0 + EDR (Enhanced Data Rate)
2.4GHz communication frequency
Sensitivity: ≤-80 dBm
Output Power: ≤ + 4 dBm
Asynchronous Speed: 2.1 MBps / 160 KBps
Synchronous Speed: 1 MBps / 1 MBps
Security: Authentication and Encryption
Operating Voltage: 1.8-5V (Recommended 3.3V)
Current: 50 mA
Dimensions: 43x16x7mm

Figure 3.8. HC06 Bluetooth-Serial Module

3.1.4. Line Filter Unit

ElectroMagnetic Interference (EMI) Filter, which is an electronic passive device shown in Figure 3.9, is used in order to suppress the conducted interference that is present on a signal or power line.

Figure 3.9. Line Filter Unit

3.1.5. Power Card

The power card displayed in Figure 3.10 was obtained by making modifications on the kitchen mixer's existing control card. The components on the power board are listed below.

- Diode Bridge
- Capacitor
- 24N50 Power Mosfet
- Relay
- Resistor
- Heatsink for 24N50
- Fuse

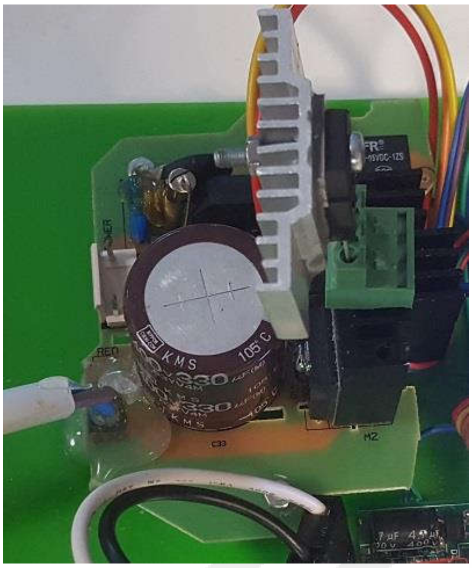


Figure 3.3. The Modified Power Card

3.2. Software Implementation of the Developed Chaotic Mixer

3.2.1. Atmega328p

Arduino provides an open-source platform widely used for implementing electronics projects. Arduino comprises a hardware, which is the physical programmable circuit board, namely the microcontroller, and software, or IDE (Integrated Development Environment) to run on a computer, which is for writing and uploading computer codes to the microcontroller.

Apart from the other commonly used microcontrollers, Arduino uses USB cable not rather than necessitating an additional hardware for loading new codes to the programmable circuit board. On the other hand, Arduino IDE exploits a simplified version of C++ that provides an easy way of programming. It also provides a standard form factor in order to break out microcontroller functions into an accessible package.

ATmega328P codes written in C are listed in “APPENDIX 1”.

3.2.2. Development of Android Application

The application development platform "App Inventor" was used to create .APK files, an Android application file. This platform is intended for use by non-translators in programming and allows the Android application development.

App Inventor is an open source web application originally created by Google Company and later supported by the Massachusetts Institute of Technology (MIT). The platform is a block-based mobile application-programming tool. Users can assemble blocks of code and produces games, applications, as well as jigsaw puzzles. With App Inventor, highly advanced mobile applications can be made. Currently only Android apps are being developed with the App Inventor. Users can also add their applications to the Play Store, earning revenue and, more importantly, opening up to the World. They have the chance to promote and use their applications on the phone.

Within the thesis studies, the android application was used only for easier control of tests and mobility. It is aimed to perform safer tests at certain distances by getting rid of cable clutter.

The main screen images of the designed application are given in Figure 3.11, Figure 3.12 and Figure 3.13.

Figure 3.11. Device Selection Screen

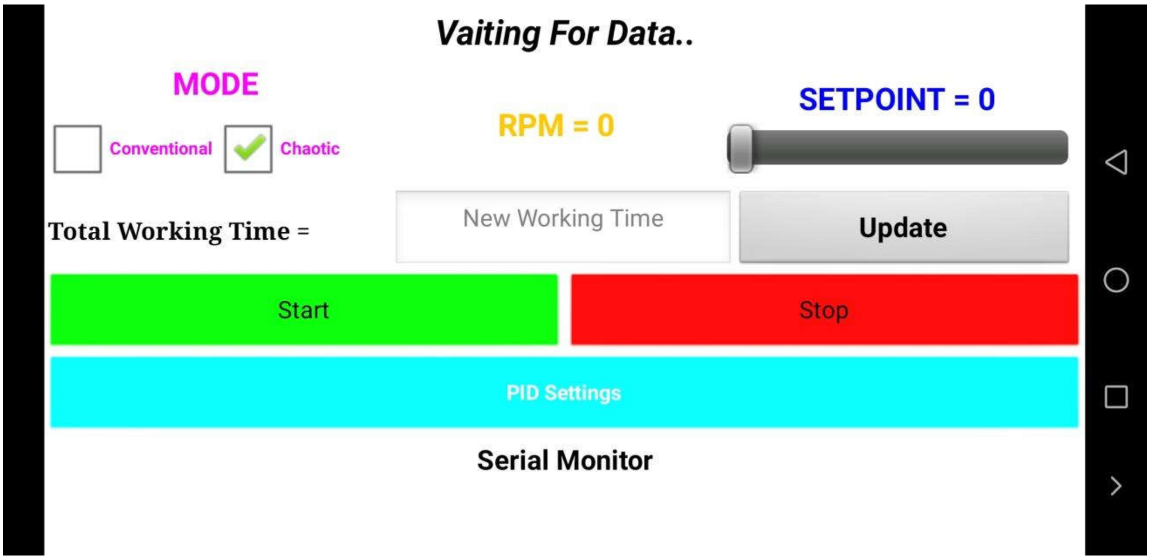


Figure 3.12. Application Home Screen

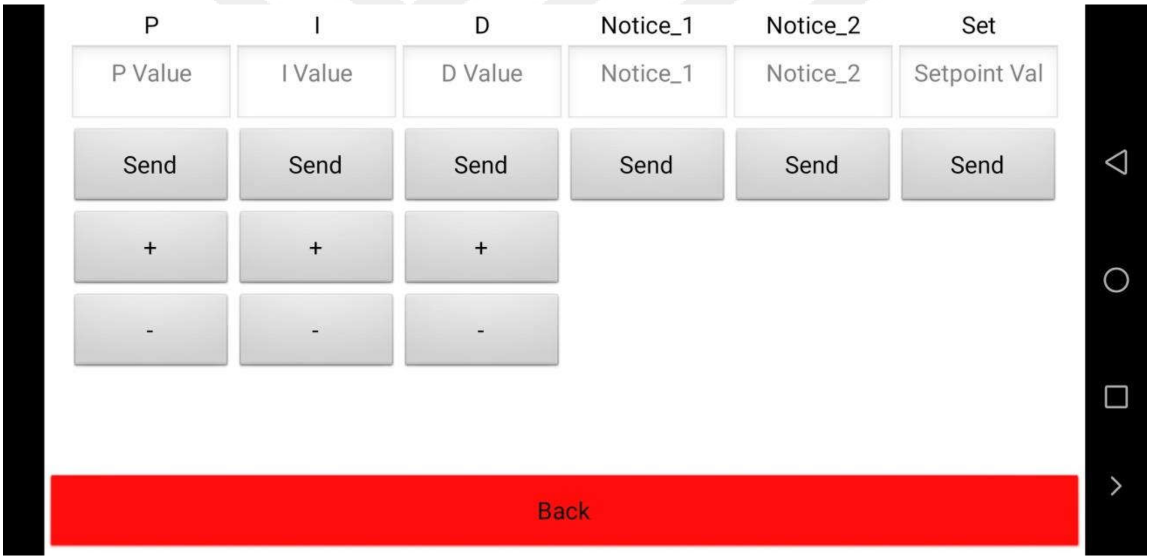


Figure 3.4. PID Setting Screen

The explanations of the Android application are provided in the sequel.

The variables used in the application from the beginning to the end are defined in Figure 3.14.

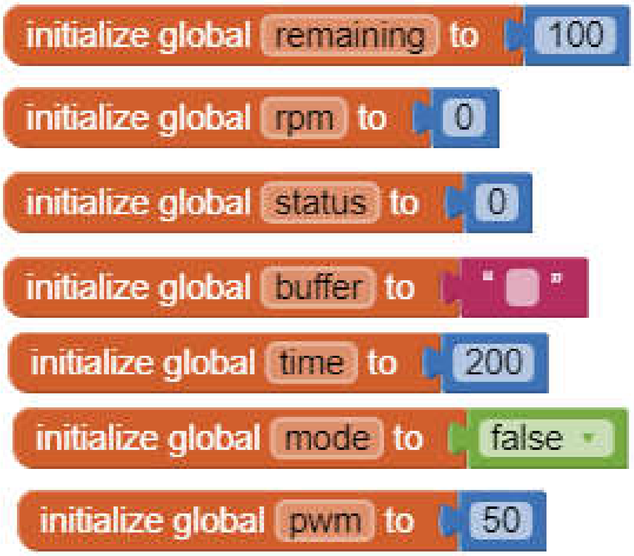


Figure 3.54. Variables

Required blocks were added to prevent accidental user exit during the test. When the Exit / Back key is detected (Block 1), the user is informed via the exit confirmation screen (Block 2). The application closes if the user approves the exit (See Figure 3.15).

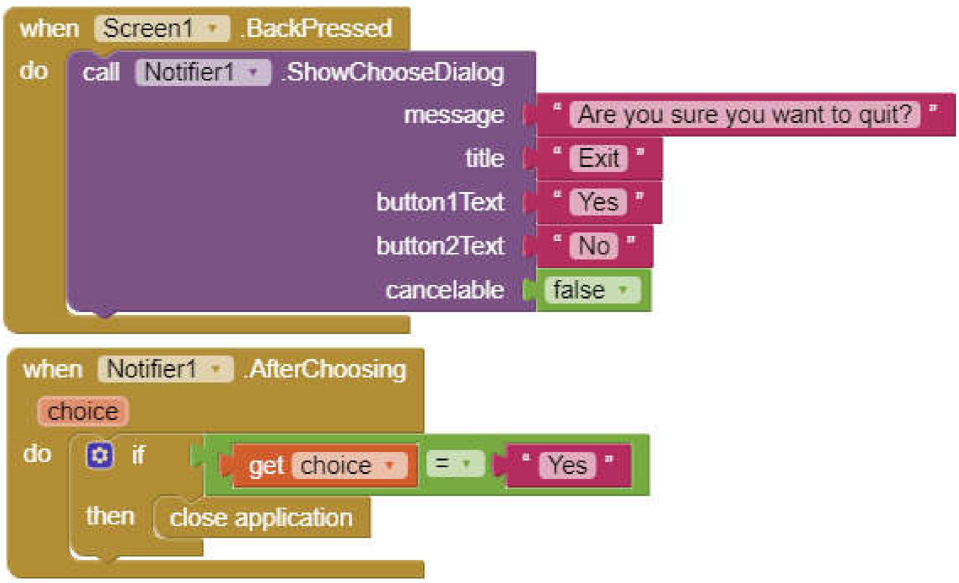


Figure 3.15. Program Exiting Control

Following the first opening of the Android application, the below given block snippet works with the loading of the components on the screen. In this block snippet, the default values of the components on the screen are set to check whether the Bluetooth feature is used for communication enabled. If the Bluetooth is not enabled on the device, the user prompts to turn it on (See Figure 3.16.).

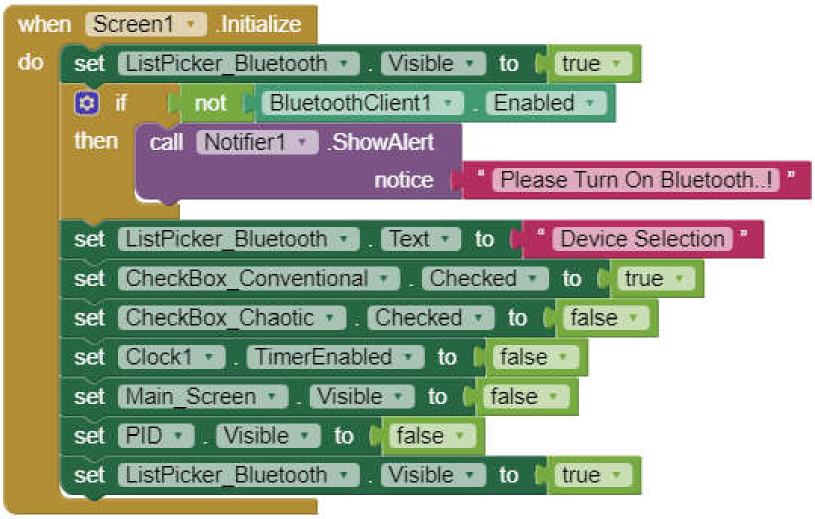


Figure 3.16. Initialize Blocks

As the next step, the application asks the user to select the Bluetooth device to which he/she wants to connect. The application scans the Bluetooth-enabled devices in its environment and creates a list. When the user selects the device from the list, a connection request is sent to the selected device. If the selected device is a paired device, the pairing step is skipped and the communication protocol is checked. If the check is confirmed, a connection is established with the device. If a device is not paired before, pairing is started (See Figure 3.17.).

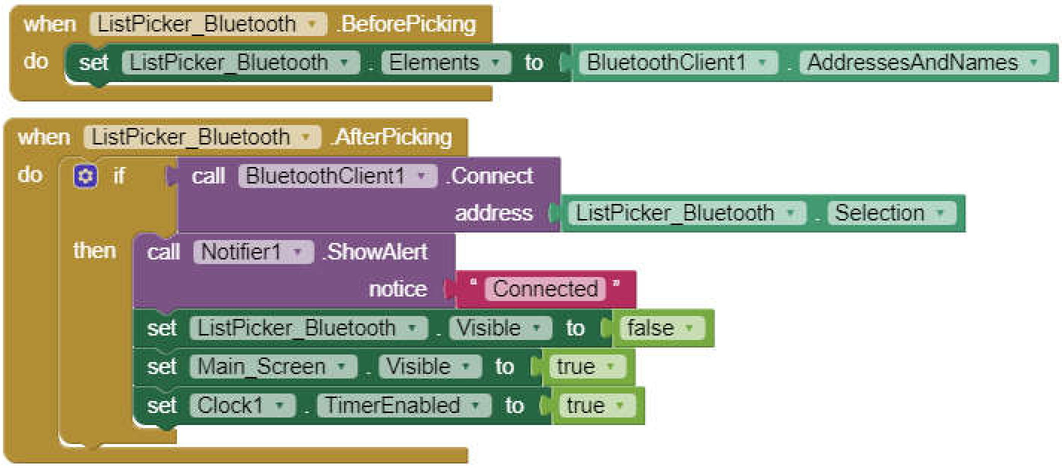


Figure 3.17. Connection Blocks

Within the thesis studies, the application has been made with different predefined parameters. These tests included variables such as total time, motor rotation speed (RPM) and operating mode (Chaotic / Standard) (See Figure 3.18). The control of these variables over the application is as follows.

An input field is located on the main screen for the control of the running time, in which the value of the total running time can be entered (See Figure 3.19). Since the current tester has certain operating limits, these limits are set both in the application and in the Arduino software. The maximum continuous running time written in the datasheet of our tester engine is 10 minutes. Therefore, the maximum value that can be entered from the application interface is limited to 600 seconds.

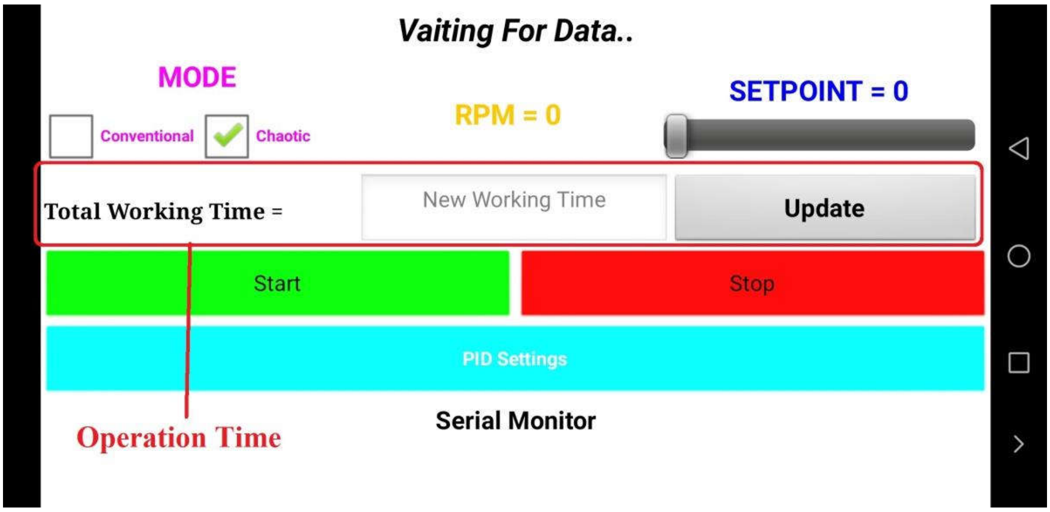


Figure 3.18. Operation Time Area

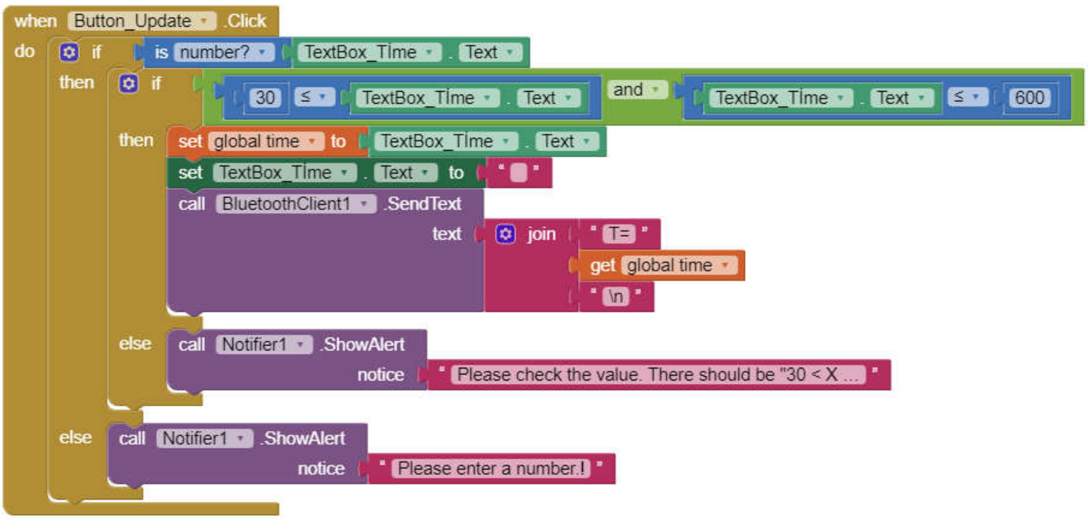


Figure 3.19. Operation Time Blocks

The selection of Standard and Chaotic modes used in the thesis is made by the code block via the screen shown in Figure 3.20. By selecting the desired mode, the desired mode is sent to Arduino, which is the main controller of the tester (See Figure 3.21).

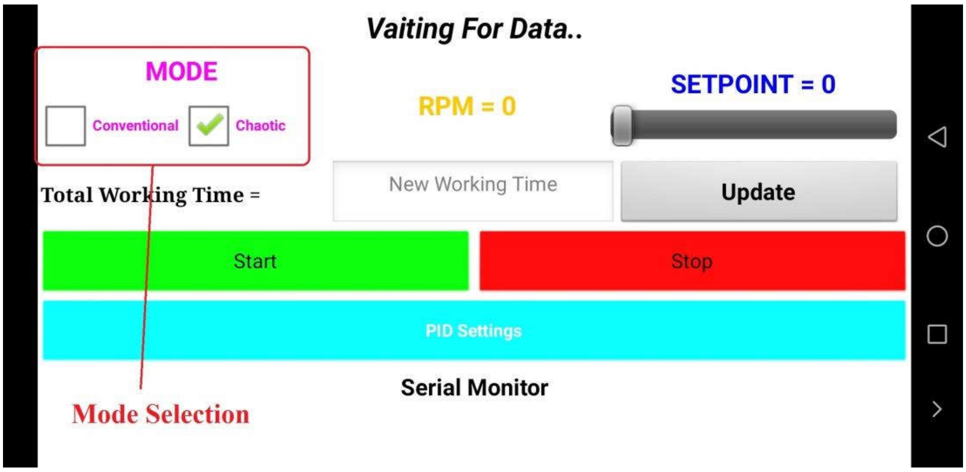


Figure 3.20. Mode Selection Area

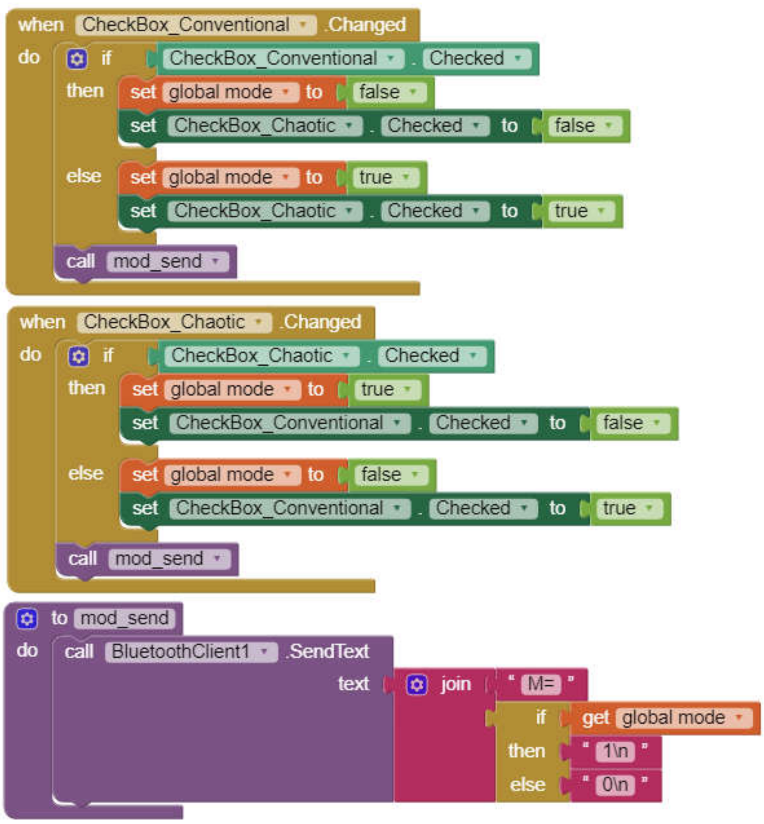


Figure 3.21. Mode Selection Blocks

A sliding bar with PWM value can be set on the main screen for motor rotation control (Slide 24). The maximum and minimum values of sliding bars are defined as 10-110 in PWM for the test device to operate within the operating limits. These values are determined by measuring the mixing tip rotation speed of the device at the production stage.

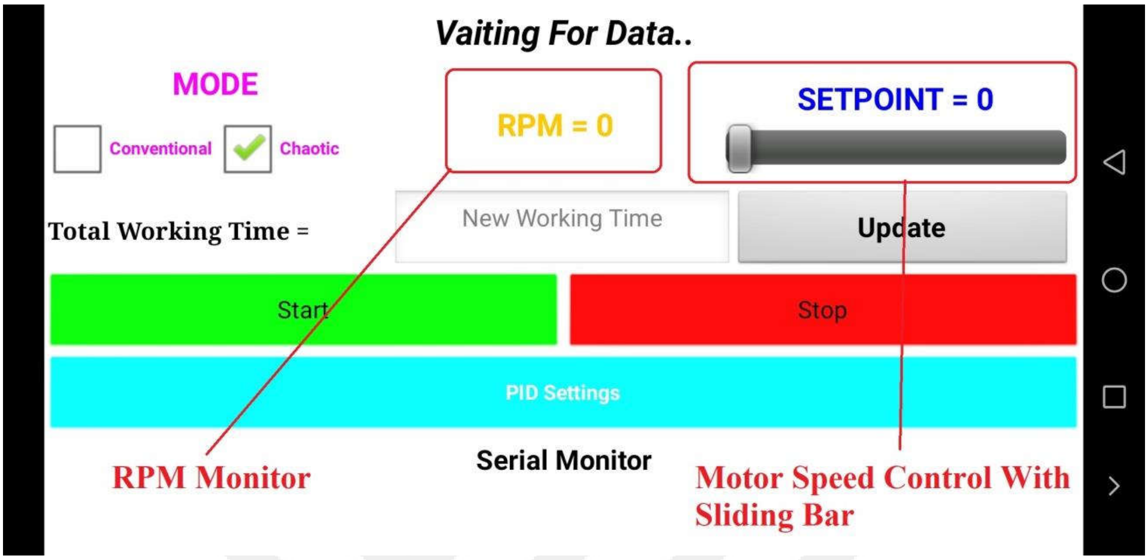


Figure 3.22. PWM Monitoring and Selection Area

In the application, the command functions sent by the start and stop buttons are shown in the following blocks of Figure 3.23.

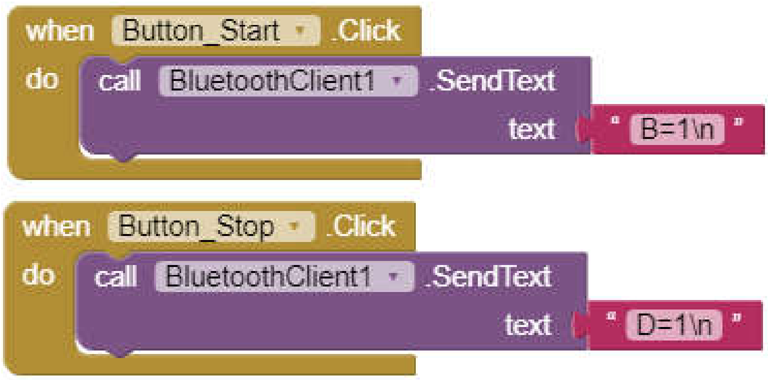


Figure 3.23. Start/Stop Button Blocks

The current application is designed as a beginning level application and is open to be extended with add-ons and enhancements.

3.3. Mixing Equipment

The choice of the mixer attachment is important according to the type of mixture to be prepared. Therefore, a mixer attachment suitable for the desired viscosity of the mixture, the materials to be added to the mixture and the mixing time should be selected. The mixer attachment types and the mixing properties that should be used are listed below.

3.3.1. Wire Whip

This equipment is used where the mixture needs to be whipped and air bubbles are added, so smoothness can be obtained. The whipping tip is formed by joining the wires at a common point.

Figure 3.24. Wire Whip

3.3.2. Flat Beater

The flat beater is suitable for operations that do not require ventilation when mixing. That means it can use it to mix cold butter, cream cheese for cheesecakes or cookie dough.

Figure 3.25. Flat Beater

3.3.3. Burnished Spiral

This is a type of dough hook shaped as a corkscrew. This equipment shuffles the dough by pushing it under the bowl. It is usually used in large volume mixing vessels.

Figure 3.26. Burnished Spiral

3.3.4. Dough Hook

A dough hook is a hook shaped like a helix. It is used in the production of foods, which need great forces to mix such as pizza dough and cookie batter.

Figure 3.276. Dough Hook

Due to the characteristic properties of cake dough (such as viscous, homogeneous, air bubble) wire whip attachment was used.

CHAPTER 4
EXPERIMENTAL STUDY ON CHOTIC MIXING OF CAKE BATTER

4.1. Material and Methods

Cakes are defined as complex macro emulsion systems that are produced in order to obtain a foam from liquid mixture by a mechanical force. This foam (cake batter) is turned to porous material (cake) by increasing the temperature and it is crucial where the characteristics of cake is designated by foam's physical properties (Şahin, 2008.). Among these properties, rheology and physiology play an important role where the characteristic properties are affected by the amount of gas bubbles incorporated into the foam structure that determines cake quality. In addition density can be evaluated within important parameters because it is related with food aeration by means of mechanical action where it affects viscosity and bulk properties of cake batter. The measurement of quality properties of foodstuff where rheology, physiology and sensory characteristics are evaluated is important since it plays an important role for both product and plant design (Tabilo-Munizaga & Barbosa-Ca´novas, 2005). Determining the rheological properties of cake batters leads to have correlation with quality characteristics of cake e.g. volume, texture, tensile resistance, sensory characteristics (Şahin, 2008.).

Cake batter is mainly composed of various amounts of sugar, egg, butter, flour and baking powder. Some additional ingredients such as emulsifiers and milk powder can be used for commercial production (Indrani & Rao, 2008). The physical properties of cakes depend on many factors such as amount, quality, temperature, mixing order and/or combination of cake batter ingredients (Guadarrama-Lezama & Carrillo-Navas & Perez-Alonso & Vernon-Carter & Alvarez-Ramirez, 2016) and the processing conditions (Ross & Pyrak-Nolte & Campanella, 2004).

Being one of the most used food processing operations, mixing has special importance for cake production. Generally, mixing process is applied at constant speed resulting not only high energy consumption, but also high operating costs based on the production capacity (John Wiley & Sons, 2004). For a more efficient emulsion production, it would be necessary to develop and to use mixing technique that could provide efficient mixing without compromising the quality of product. From this point of view, chaotic mixing has potential as a technique that provides efficiency in at least one of the criteria such as mixing time, energy used, improvement in food quality characteristics (Ye & Chau, 2017), (Şahin & Güzeliş, 2010). In addition, a general survey was performed to measure the strength of need for a chaotic mixer in case of cake batter. 123 of the 158 people who were asked questions stated that manual speed settings in the mixers they use at home were not practical but would need a mechanism that could automatically perform the speed transition effects. For this reason, it was decided to examine the chaotic mixing system, which is a solution to the system requested by the users, on cake dough for such valid reasons.

The aim of the study is to determine the feasibility of the chaotic mixing to be used for preparation of cake batter in case of quality characteristics such as rheological, physical and sensory properties. For this purpose, a motor was designed to run at both chaotic and standard mixing modes and the effect of those mixing modes on rheological, textural and sensory characteristics were compared by taking cake batter as sample food material.

Before proceeding in the mixing experiments of cake batter, cake batter ingredients that are used in conventional mixing have been examined from the literature. So, the cake batter recipe has been finalized as it is attached in Table 4.1.

Table 4.1. Cake Batter Ingredients

Material	Measure	Material Weight (grams)	Order to Add to Mixture (1-5)
Eggs	4 Piece	192	1
Sugar	2 Cup	300	2
Milk	1 Cup	240	3
Sunflower Oil	1 Cup	230	4
Flour	3 Cup	420	5
Baking Powder	1 Package	10	
Vanilla Powder	1 Package	10	

Totally 5 trials were performed to obtain appropriate cake batter composition and to optimize the quantity and distribution of the ingredients in the final mixture. The first four of the ingredients (eggs, sugar, milk and sunflower oil) given in Table 4.5 were selected in the appropriate amount and were mixed by adding one after the other. The remaining three ingredients of flour, baking powder and vanilla powder were firstly mixed in each other in order to form a homogenous powdered mixture and then was dispersed in the first mixture composed of four ingredients and finally a single cake batter was obtained.

Experimental studies and preliminary trials were done at "DYO Boya Fabrikaları San. ve Tic. A.Ş." which is located in İzmir, Turkey. Within the scope of experiments, rheological properties of the cake dough were examined by studying the speed and time variables of the classical and chaotic mixing patterns. After considering 23 trials dor mixing time and speed variations, the experimental conditions to be used in the study were fixed to the extent indicated in Table 4.2.

Table 4.2. Cake Dough Trial Conditions and Test Numbers Made Using Kitchen Mixer

		Mixing speed (rpm)			
		75		120	
Time (sec)	150	Conventional mixing (experiment number:1)	Chaotic mixing (experiment number:7)	Conventional mixing (experiment number:3)	Chaotic mixing (experiment number:5)
	300	Conventional mixing (experiment number:2)	Chaotic mixing (experiment number:8)	Conventional mixing (experiment number:4)	Chaotic mixing (experiment number:6)
		Grup I		Grup II	

The effects of mixing type on the shear rate and shear stress characteristics of cake batter were investigated. The tests were performed in "DYO Paint Factories Industry and Trade Inc." by using Anton Paar MCR302 Modular Compact Rheometer Device. For conventional and chaotic mixing, tests have been performed at at least three times.

4.2. Test Equipments

The following devices were used during the tests.

4.2.1. Anton Paar Rheometer: MCR 302

Anton Paar rheometers (See Figure 4.1) are built for everyday use in the lab and are the key to all possible kinds of rheological investigations and material characterization. The application field of the MCR series ranges from quality control to high-end research and development tasks.

The innovative EC-motor in combination with the low-friction air bearing, the integrated normal force sensor, and a high-resolution optical encoder form the heart of an MCR rheometer. The unique sample-adaptive controller TruRate™ (in rotation and step strain) and the fast and accurate strain control due to improved real-time position control TruStrain™ (in oscillation) guarantee highly precise measurements even at the lowest torques (<2 nNm). The steel frame is optimized for mechanical and thermal stiffness and minimizes torsional and axial compliance. The residual compliance is known and corrected during the measurement, eliminating the need for post-measurement corrections.

Whatever your rheological applications are and will be in the future rheometers are quickly and easily adapted to meet your needs. An extensive range of application-specific accessories is available to extend the rheometer's capabilities, including DMA measurements, extensional rheology, rheo-optics (e.g. microscopy and Raman spectroscopy), magneto- and electrorheology, dielectric spectroscopy, interfacial rheology, UV curing, pressure- and humidity-dependent rheology, tribology, and many more. Temperature accessories in the temperature range from -160 °C to 1000 °C are also available.

Figure 4.1. Anton Paar Rheometer: MCR 302

4.2.2. Shimadzu Ags-X Series Universal Pull-Out Device

Shimadzu's AGS-X series universal test frames (See Figure 4.2) combine advanced specifications with a versatile and modern design. By incorporating multiple control options, a wide-capacity range of load cells, the utmost in safety considerations, and an extensive selection of testing accessories, the AGS-X series delivers practical testing solutions for many applications.

Offers real-time auto tuning of control parameters, based on measured test force and strain data. Can safely make comparisons to unknown sample data without the need for preliminary tests. In addition, the autotuning function easily performs strain control, an ISO 6892-2009 requirement.

Figure 4.2. Shimadzu Ags-X Series Universal Pull-Out Device

4.3. Rheological, Physical and Sensory Analyses of Cake Produced by Chaotic Mixing

4.3.1. Rheological Analysis

Cake batter shows a typical characteristic property of pseudoplastic fluids. It is also known as shear-thinning (dilatant) flow. Its rheological behaviour is frequently represented by the Ostwald–de Waele model. The viscosity of cake batter decrease depending on the exposure to shear force of mixing operation. After mixing, the viscosity can be turned back to original value. So, this flow type can be concluded to show thixotropic property. Within the scope of rheometric measurements, there is a waiting time of 240 s between the flow and return curves in the Group I trials indicated in Figure 4.3. As it can be seen from Figure 4.32, the negative effect of waiting time on cake dough sample was found to be less in Group 1 trials than Group 2 trials. The most important proof of this is the clearance between the flow and return curves in Figure 4.3. In Figure 4.3, group I and II. Shear strength diagrams versus shear rate are given to represent group samples. Turning curves above the flow curves showed that the cake dough sample had a more intense consistency as time progressed. The observed increase in the consistency of the cake dough samples is negative in terms of sensory properties because it causes the cake dough to be cooked to give a solid cake shape. In Group I, the flow curve was closer to the return curve. In other words, II. Less change was observed in group samples than in group 1, the structure was more stable in group 1 samples. In summary, it should be noted that the rheological properties of the cake dough have been positively affected under conditions of low mixing speed "independent of mixing mode".

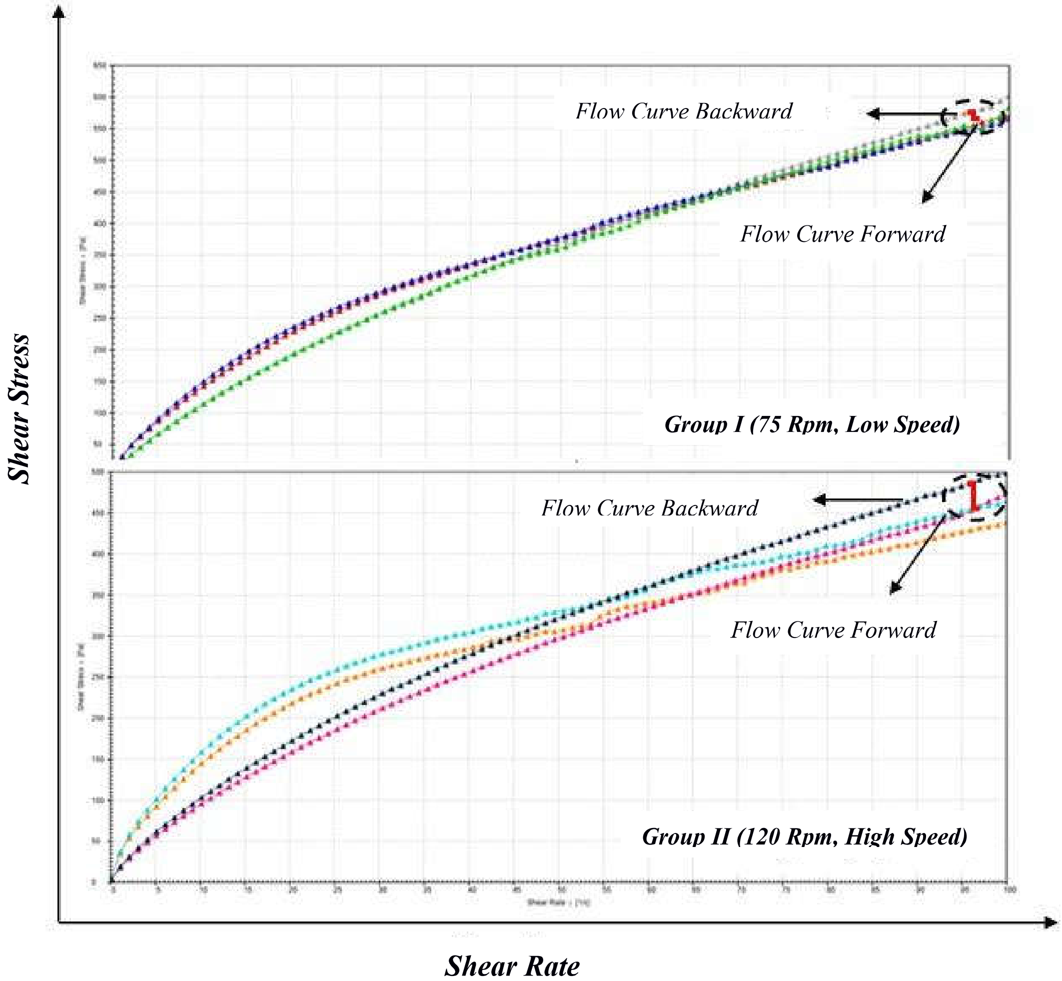


Figure 4.3. Change of rheological properties of cake batter according to mixing speed.

The effect of time was investigated in the next trials. The increase in time had a positive effect on the rheological properties of cake batter. From this point, low speed and longer duration of mixing gave more positive results in the rheological properties of the cake batter regardless of the mixing method. For this reason, in the next stage of the experiments, 75 rpm and 300 sec tests were performed to determine the efficiency of the estimated yield and the effect of the mixing method. At the end of the experiments, the low speed and long-term experiments obtained by chaotic mixing as shown in Figure 4.4 gave the best results in terms of rheological properties of the cake batter and was proved superiority compared to the experiments made under same condition.

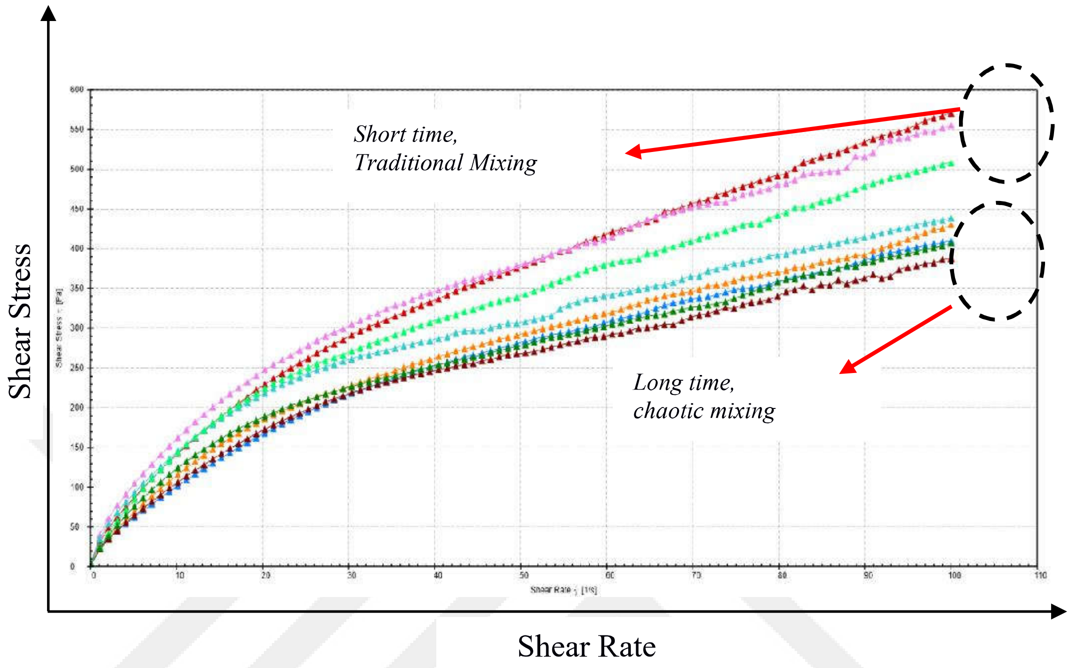


Figure 4.4. Variation of rheological properties of cake dough according to mixing.

4.3.2. Physical Analysis

At the stage of measuring the rheological properties of cake dough, it was found that the samples with low viscosity had better sensory properties. The sensory property discussed is the spongy structure observed in the samples after baking the cake dough. Since the test results can be supportive, Katip Çelebi University Mechanical Engineering laboratory infrastructure was used to perform 8 test samples in the last stage (See Figure 4.5).

Figure 4.5. SHIMADZU AGS-X Series Universal Pull-Out Device

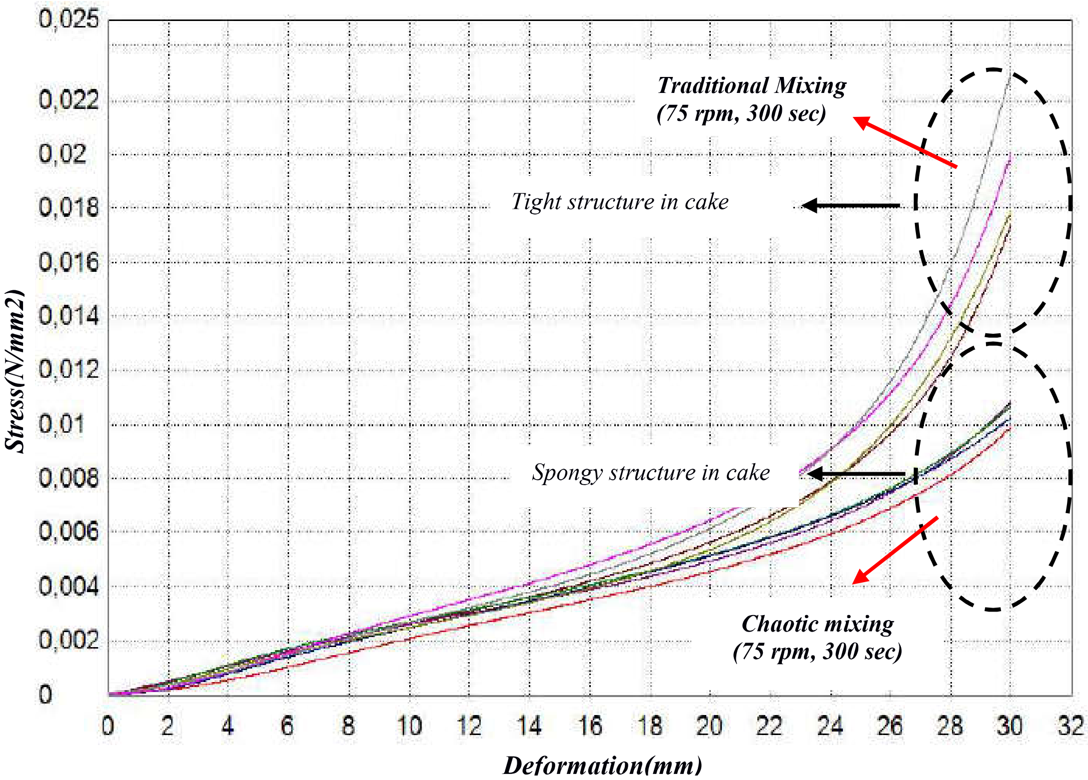


Figure 4.6. Variation of the sensory properties (spongy structure) of the cake samples according to the mixing type.

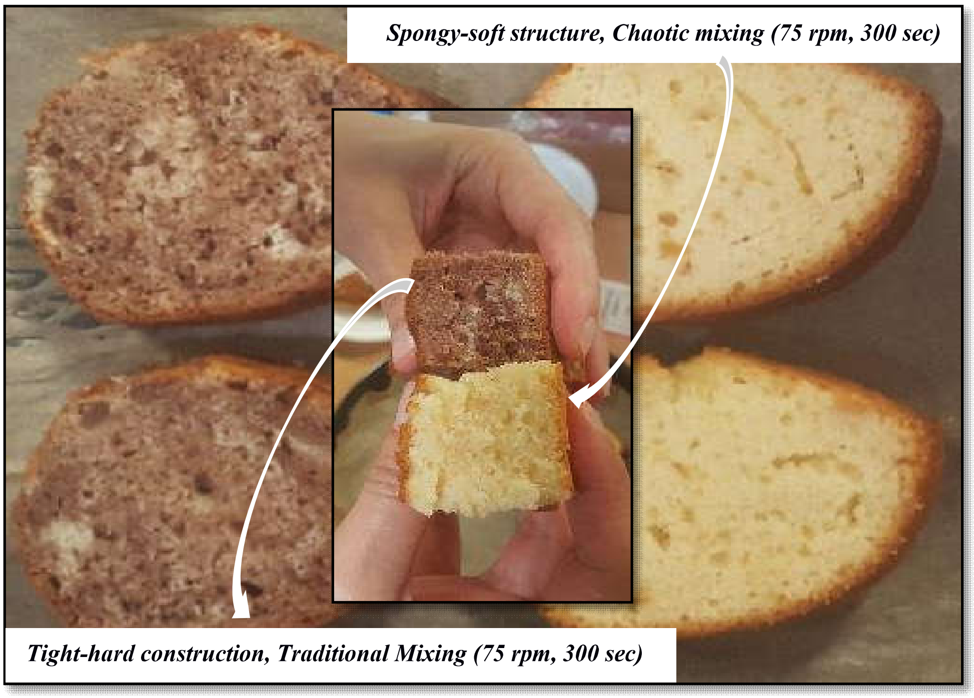


Figure 4.7. Variation of the sensory properties (spongy structure) of the cake samples according to the mixing type.

For compression test, 8 samples were prepared as cylindrical sections with equal surface area. In all samples, the force (N) required for a constant 30 mm deformation was measured (Figure 4.6). Thus, the sample with the minimum force that will require uniform deformation was softer, in other words, spongy. The increase in strength signaled the tight structure (tightening means negativity for physical and sensory characteristics). In Figure 4.6 and Figure 4.7, the cake samples were compared for physical changes depending on the mixing mode. The test conditions where the spongy structure was observed were observed in the formed intensely in chaotic mixing, at low speed and over a long period of time. The most efficient condition was achieved in chaotic mixing mode at 75 rpm, 300 sec, in accordance with rheometric measurements.

4.3.3. Sensory Analysis

Sensory analysis was done with a group of 10 people (6 women and 4 men). The panelists were assigned from all trained panelists. In addition, introductory technical information which consists of the properties of cake batter and ingredients, the importance of mixing order on cake quality, effect of mixing method and process parameters on rheological characterization, etc. was given to the panelists. Analyzes were performed on separate tables at controlled room temperature under fluorescent light (daylight). Quality attributes were rated using the numerical scale for the pre-discussed properties of cake batter samples. The parameters that express the quality characteristics of the samples were also added to the evaluation criteria. So, a test card was prepared including the parameters of appearance, taste, aroma and texture. A total of 40 samples (2 per panelist, 20 of each mixing type) were given to the panelists, respectively. Panelists evaluated the new sample after completing the evaluation of the previous sample. In the evaluation, a score scale of 1 to 10 was determined in which panelists could indicate their preferences. The data obtained from the panelists were evaluated by variance analysis.

Table 4.3. Effects of mixing method on sensory properties of cakes

Sensory Property	Mixing Method	
	Classical Mixing	Chaotic Mixing
Crust Color	4.10±0.41	4.30±0.58
Inside Color	3.50±0.39	3.60±0.46
Pore Homogeneity and Size	3.80±0.66	4.70±0.36
Odor	4.40±0.44	4.45±0.52
Taste	4.25±0.45	4.28±0.33
Softness / Volume	3.76±0.46	4.55±0.39
Dissolution in mouth	4.16±0.37	4.21±0.64

Data on the effect of mixing method on the cake batter property were analyzed with Duncan's multiple comparison test ($p < 0.05$) using the SPSS software package, version 13.0 (SPSS Inc., Chicago, IL, USA)20. The statistical analyses were conducted using SPSS software (SPSS Inc., version 11.0) by analysis of variance (ANOVA). Sensory analysis results of cakes produced using classical and chaotic mixing methods are given in Table 4.3 and in Figure 4.8. Statistical analysis indicated that all the parameter interactions were significant ($P < 0.05$). In general, if an evaluation is made according to the criteria determined by the panelists, it is determined that the most preferred cake is the cake produced by using chaotic mixing method with a mean score of 4,299. It was observed that the cake samples produced using the classical mixing method with a general average score of 3.996 were less preferred than the samples produced by the chaotic mixing method in terms of "Pore Homogeneity and Size" and "Softness" criteria.

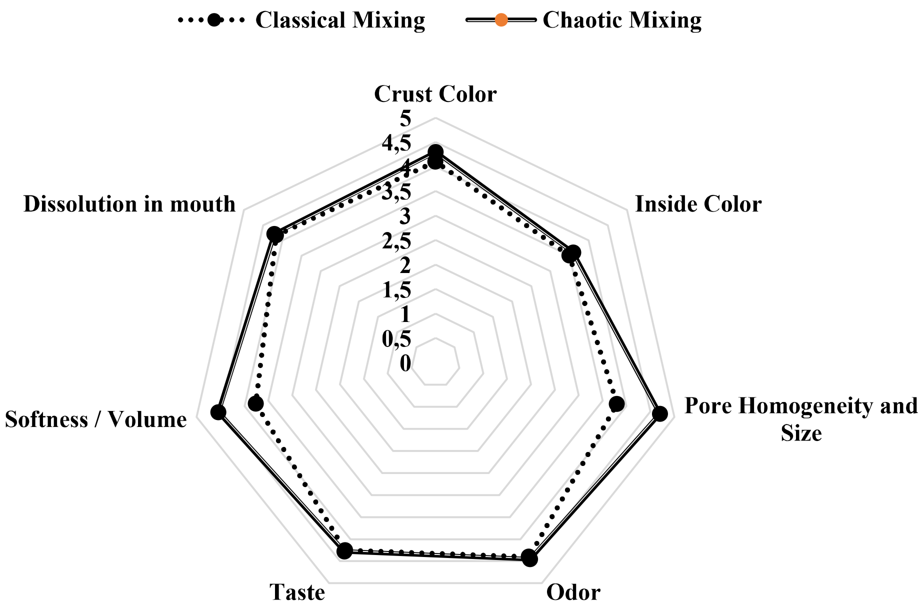


Figure 4.8. Effects of mixing method on sensory properties of cakes

These sensory test results were supported by rheological tests and physical strength tests, respectively. The comparison of cake samples according to different criteria can be seen in Figure 4.9.

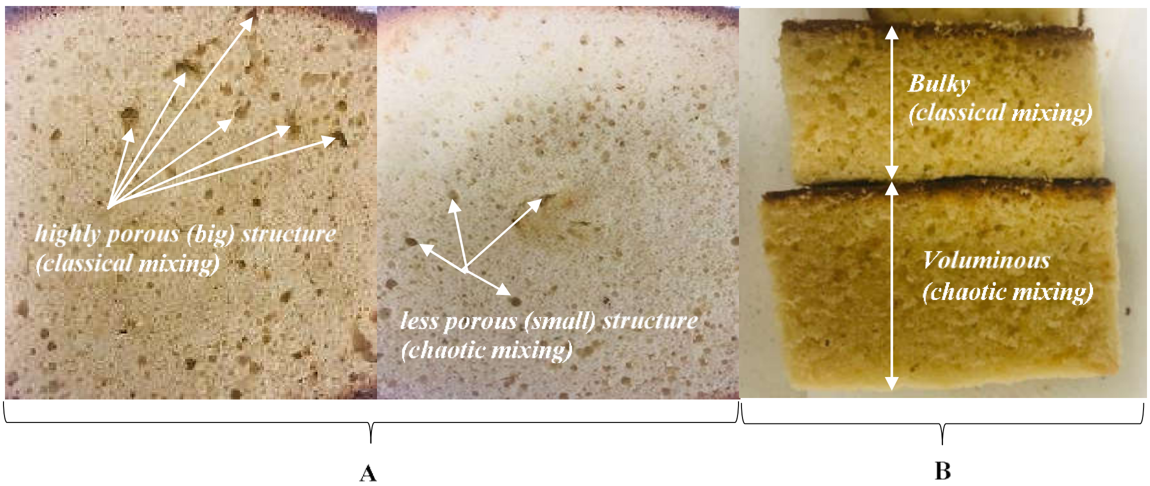


Figure 4.97. Appearance of the effect of mixing method on cake samples. A: Pore Homogeneity and Size, B: Softness / Volume

4.4. Energy Consumption

In the experiments conducted in the kitchen type mixer using cake dough, no positive result is obtained in terms of energy consumption. This is because the mixing time of the cake dough is very short. Figure 4.10 shows the average energy consumed. However, in cake dough samples where chaotic mixing was applied, better quality samples were obtained with rheologically significant difference compared to classical mixing. In connection with this situation, the cakes obtained after baking the cake doughs obtained with the chaotic mixing form showed a better quality, softer and more regular air bubbles in terms of sensory properties.

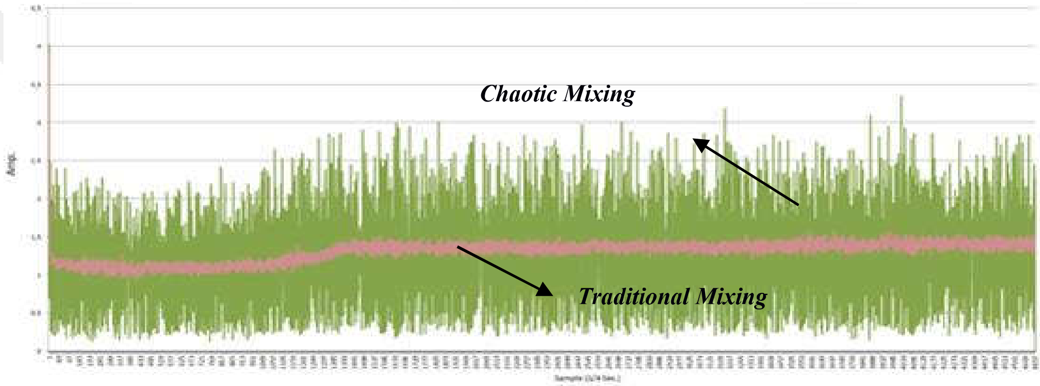


Figure 4.10. Average energy consumed in different mixing modes

In summary, the following positive outcomes were achieved.

- Reduction in energy consumption required for product of the same quality.
- To obtain more qualified food products with the same energy consumption.

Based on these results, it has shown that the chaotic mixing pattern used for the independently studied food samples is more advantageous than the conventional mixing pattern.

CHAPTER 5
CONCLUSION

The thesis introduces a new engineering application of chaotic systems. The thesis studies show that, considering the time/energy consumption and the quality of the product together, the chaotic mixing is more beneficial than the conventional constant speed mixing for the cake dough. This application of chaos in food engineering area extends the domain of real world applications of chaos, which is known restricted to the very limited applications including secure communication, cryptography and liquid mixing.

Within the thesis studies, a kitchen type mixer was modified to run not only at the conventional (i.e. constant) mixing mode but also at the chaotic mode. So, then, by taking cake batter as sample food material, the effects of these two mixing modes on rheological, textural and sensory characteristics were compared. In terms of these qualitative characteristics obtained under almost the same time/energy consumption, the chaotic mixing mode was found superior to the constant mixing mode. The prototype mixer was realized with hardware and software changes made on a commercial kitchen type mixer. A new control card was designed to supply the chaotic mixing in addition to the constant mixing. The mixer motor speed was chaotified by driving the dc motor with a voltage signal generated by a simple chaotic system, namely the logistic map, implemented in a microcontroller. Such a simple feedforward chaotification method was found sufficient to obtain the chaotic mixing of cake batter. As a part of the experimental set up, a tablet with Android operating system was used to operate the mixer in a chaotic or conventional way, to adjust the engine speed, to set the test run time, to enter the proportional Integral Derivative controller parameter values and to check the voltage current information. Wireless Bluetooth communication was provided with a SCADA application that can be used on all devices with Android operating system.

The kitchen mixer performance, in which the mixing type was modified as chaotic mixing mode, was tested for the cake batter material. The formulation of the optimized cake batter mixture quality was compared in different parameters in conventional and chaotic modes. When the test results obtained in both mixing modes were evaluated, it was seen that better values were recorded in the structural, physiological and sensory properties of the cake batter when the chaotic mixing mode was used.

The thesis studies can be extended by future research in the following directions. The chaotic mixing and its comparative performance analysis done in the thesis can be applied to other food products whose production process requires mixing liquid and/or solid materials. The simple feedforward chaotification method, which employs the Logistic Map to generate chaotic signal, used in the thesis studies can be replaced with an advanced chaotification method for developing a robust chaotic mixing. The kitchen type small-scale chaotic mixer system can be scaled up for developing industrial type chaotic mixers by means of necessary hardware and software changes.

REFERENCES

24N50 Power Mosfet (2019). Retrieved 3 May 2019, from http://www.unisonic.com.tw/datasheet/24N50.pdf

Abu-Jdayil, B. (2003). Modelling the time-dependent rheological behavior of semisolid foodstuffs. *Journal of food engineering*, *57*(1), 97-102.

Ahmed, J., Ramaswamy, H. S., & Hiremath, N. (2005). The effect of high pressure treatment on rheological characteristics and colour of mango pulp. *International journal of food science & technology*, *40*(8), 885-895.

ACS714 Current Sensor. (2019). Retrieved 3 May 2019, from https://www.pololu.com/file/0J196/ACS714.pdf

Ascanio, G., Brito-Bazán, M., Brito-De La Fuente, E., Carreau, P. J., & Tanguy, P. A. (2002). Unconventional configuration studies to improve mixing times in stirred tanks. *The Canadian Journal of Chemical Engineering*, *80*(4), 558-565.

Allais, I., Edoura-Gaena, R. B., Gros, J. B., & Trystram, G. (2006). Influence of egg type, pressure and mode of incorporation on density and bubble distribution of a lady finger batter. *Journal of Food Engineering*, *74*(2), 198-210.

Allais, I., Edoura-Gaena, R. B., & Dufour, É. (2006). Characterisation of lady finger batters and biscuits by fluorescence spectroscopy—Relation with density, color and texture. *Journal of food engineering*, *77*(4), 896-909.

Baixauli, R., Sanz, T., Salvador, A., & Fiszman, S. M. (2008). Muffins with resistant starch: Baking performance in relation to the rheological properties of the batter. *Journal of Cereal Science*, *47*(3), 502-509.

Baptista, M. S. (1998). Cryptography with chaos. *Physics letters A*, *240*(1-2), 50-54.

Bellido, G. G., Scanlon, M. G., Page, J. H., & Hallgrimsson, B. (2006). The bubble size distribution in wheat flour dough. *Food Research International*, *39*(10), 1058-1066.

Bellido, G. G., Scanlon, M. G., Page, J. H., & Hallgrimsson, B. (2006). The bubble size distribution in wheat flour dough. *Food Research International*, *39*(10), 1058-1066.

Cuomo, K. M., & Oppenheim, A. V. (1993). Circuit implementation of synchronized chaos with applications to communications. *Physical review letters*, *71*(1), 65.

Chen, G., & Lai, D. (1996). Feedback control of Lyapunov exponents for discrete-time dynamical systems. *International Journal of Bifurcation and Chaos*, *6*(07), 1341-1349.

Chesterton, A. K. S., Moggridge, G. D., Sadd, P. A., & Wilson, D. I. (2011).

Modelling of shear rate distribution in two planetary mixtures for studying development of cake batter structure. *Journal of food engineering*, *105*(2), 343-350.

Guadarrama-Lezama, A. Y., Carrillo-Navas, H., Pérez-Alonso, C., Vernon-Carter, E. J., & Alvarez-Ramirez, J. (2016). Thermal and rheological properties of sponge cake batters and texture and microstructural characteristics of sponge cake made with native corn starch in partial or total replacement of wheat flour. *LWT-Food Science and Technology*, *70*, 46-54.

Guerrero, S. N., & Alzamora, S. M. (1997). Effect of pH, temperature and glucose addition on flow behaviour of fruit purées I. Banana purée. *Journal of Food Engineering*, *33*(3-4), 239-256.

Hegger, R., Kantz, H., & Schreiber, T. (1999). Practical implementation of nonlinear time series methods: The TISEAN package. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 9(2), 413-435.

Hegger, R., Kantz, H., & Schreiber, T. (2007) The package of TISEAN programs and concomitant documentation. Access mode: https://www.pks.mpg.de/tisean/Tisean 3.0.1/index.html

Indrani, D., & Rao, G. V. (2008). Functions of ingredients in the baking of sweet goods. *Food engineering aspects of baking sweet goods*, 31-47.

Jakubczyk, E., & Niranjan, K. (2006). Transient development of whipped cream properties. *Journal of food engineering*, *77*(1), 79-83.

Kavaslar, F., & Guzelis, C. (1995). A computer-assisted investigation of a 2-D array of Chua's circuits. *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, *42*(10), 721-735.

Kocarev, L., Halle, K. S., Eckert, K., Chua, L. O., & Parlitz, U. (1992). Experimental demonstration of secure communications via chaotic synchronization. *International Journal of Bifurcation and Chaos*, *2*(03), 709-713.

Kocarev, L. (2001). Chaos-based cryptography: a brief overview. *IEEE Circuits and Systems Magazine*, *1*(3), 6-21.

Lamberto, D. J., Muzzio, F. J., Swanson, P. D., & Tonkovich, A. L. (1996). Using time-dependent RPM to enhance mixing in stirred vessels. *Chemical Engineering Science*, *51*(5), 733-741.

Lara, A. R., Galindo, E., Ramírez, O. T., & Palomares, L. A. (2006). Living with heterogeneities in bioreactors. *Molecular biotechnology*, *34*(3), 355-381.

Li, W. L., & Song, Y. Z. (2008). Chaos anti-control of nonlinear system with uncertainties.

McKenna, B. M., & Lyng, J. G. (2003). Introduction to food rheology and its measurement. *Texture in food*, *1*, 130-160.

Meza, B. E., Chesterton, A. K., Verdini, R. A., Rubiolo, A. C., Sadd, P. A., Moggridge, G. D., & Wilson, D. I. (2011). Rheological characterisation of cake batters generated by planetary mixing: comparison between untreated and heat-treated wheat flours. *Journal of Food Engineering*, *104*(4), 592-602.

Morgül, Ö. (2003). A model-based scheme for anticontrol of some chaotic systems. *International Journal of Bifurcation and Chaos*, *13*(11), 3449-3457.

Morgül, Ö. (2004). A model-based scheme for anticontrol of some discrete-time chaotic systems. *International Journal of Bifurcation and Chaos*, *14*(08), 2943-2954.

Morgül, Ö., & Solak, E. (1996). Observer based synchronization of chaotic systems. *Physical Review E*, *54*(5), 4803.

Nienow, A. W., EDWARDS, M. F., & Harnby, N. (1997). *Mixing in the process industries*. Butterworth-Heinemann.

Ottino, J. M. (1990). Mixing, chaotic advection, and turbulence. *Annual Review of Fluid Mechanics*, *22*(1), 207-254.

Paul, E. L., Atiemo-Obeng, V. A., & Kresta, S. M. (Eds.). (2004). *Handbook of industrial mixing: science and practice*. John Wiley & Sons.

Parker, T. S., & Chua, L. O. (1987). Chaos: A tutorial for engineers. *Proceedings of the IEEE*, *75*(8), 982-1008.

Pecora, L. M., & Carroll, T. L. (1990). Synchronization in chaotic systems. *Physical review letters*, *64*(8), 821.

Quemada, D. (1978). Rheology of concentrated disperse systems II. A model for non-newtonian shear viscosity in steady flows. *Rheologica Acta*, *17*(6), 632-642.

Ross, K. A., Pyrak-Nolte, L. J., & Campanella, O. H. (2004). The use of ultrasound and shear oscillatory tests to characterize the effect of mixing time on the rheological properties of dough. *Food Research International*, *37*(6), 567-577.

Rossler, O. E. (1979). An equation for hyperchaos. *Physics Letters A*, *71*(2-3), 155-157.

Sahin, S. (2008). Cake batter rheology. *Food engineering aspects of baking sweet goods*, 99-119.

Skiadas, C., & Skiadas, C. H. (2008). *Chaotic modelling and simulation: analysis of chaotic models, attractors and forms*. Chapman and Hall/CRC.

Sumnu, S. G., & Sahin, S. (2008). *Food engineering aspects of baking sweet goods*. CRC Press.

Sprott, J. C., & Sprott, J. C. (2003). *Chaos and time-series analysis* (Vol. 69). Oxford: Oxford University Press.

SPSS. SPSS for Windows, 2010, Version 11.0.1, SPSS Inc., Chicago, IL.

Şahin, S., & Güzeliş, C. (2013). A dynamical state feedback chaotification method with application on liquid mixing. *Journal of Circuits, Systems and Computers*, *22*(07), 1350059.

Şahin, S., Isler, Y., & Güzelis, C. (2010, July). A microcontroller based test platform for controller design. In *2010 IEEE International Symposium on Industrial Electronics* (pp. 36-41). IEEE.

Tabilo-Munizaga, G., & Barbosa-Cánovas, G. V. (2005). Rheology for the food industry. *Journal of food engineering*, *67*(1-2), 147-156.

Wang, X. F., & Chen, G. (1999). On feedback anticontrol of discrete chaos. *International Journal of Bifurcation and chaos*, *9*(07), 1435-1441.

Wang, X. F., Chen, G., & Yu, X. (2000). Anticontrol of chaos in continuous-time systems via time-delay feedback. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *10*(4), 771-779.

Wiggins, S. (2003). *Introduction to applied nonlinear dynamical systems and chaos* (Vol. 2). Springer Science & Business Media.

Wiggins, S., & Ottino, J. M. (2004). Foundations of chaotic mixing. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *362*(1818), 937-970.

Wolf, A., Swift, J. B., Swinney, H. L., & Vastano, J. A. (1985). Determining Lyapunov exponents from a time series. *Physica D: Nonlinear Phenomena*, *16*(3), 285-317.

Xue, J., & Ngadi, M. (2007). Rheological properties of batter systems containing different combinations of flours and hydrocolloids. *Journal of the Science of Food and Agriculture*, *87*(7), 1292-1300.

Ye, S., & Chau, K. T. (2007). Chaoization of DC motors for industrial mixing. *IEEE Transactions on Industrial Electronics*, *54*(4), 2024-2032.

APPENDIX 1 – Software Code (ATmega328P)

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <Timer.h>

#define Out_Pwm       9
#define Out_Kontak    A1
#define In_Pot        A0

#define Btn_Mod       10
#define Btn_Start     11
#define Btn_Stop      12

#define Led_Start     3
#define Led_Stop      6
#define Led_On        2
#define Led_Kaotik    7
#define Led_Sabit     4
#define Led_Iletisim  5

Timer t;
LiquidCrystal_I2C lcd(0x3F,20,4);  // set the LCD address to 0x27 for a 16 chars and 2 line display

//++++++++++++++++++++++++-----VARIABLES-----++++++++++++++++++++++++
int toplamsure = 200;
bool mod=0;

int Setpoint = 60;
int calismaaralik = 50;
int cmax=Setpoint+calismaaralik;
int cmin=Setpoint-calismaaralik;

float xold=0.49;
float xnew;

unsigned long uyari_1 = 0;
unsigned long uyari_2 = 0;

// For Serial Communication
String inputString = "";         // a string to hold incoming data
boolean stringComplete = false;  // whether the string is complete

// Milis() Variables
int Out;
double Output;
unsigned long start;
unsigned long timeold;
int x=100;
```

```
int y;
int Gecen_Sure;
bool durum = 0;
//------------------------+++++VARIABLES+++++------------------------

void SerialSend();
void Stop();
void Start();
void lcd_yenile();
void SerialEvent();
static void hesap();

//++++++++++++++++++++++++-----SETUP-----++++++++++++++++++++++++
void setup() {
  inputString.reserve(200);
  Serial.begin(115200);

  pinMode(Out_Pwm, OUTPUT);
  pinMode(Out_Kontak, OUTPUT);
  pinMode(Led_Start, OUTPUT);
  pinMode(Led_Stop, OUTPUT);
  pinMode(Led_On, OUTPUT);
  pinMode(Led_Kaotik, OUTPUT);
  pinMode(Led_Sabit, OUTPUT);
  pinMode(Led_Iletisim, OUTPUT);
  pinMode(In_Pot, INPUT);
  pinMode(Btn_Mod, INPUT);
  pinMode(Btn_Start, INPUT);
  pinMode(Btn_Stop, INPUT);

  analogWrite(Out_Pwm, 0);
  digitalWrite(Out_Kontak, HIGH);
  digitalWrite(Led_On, HIGH);
  digitalWrite(Led_Stop, HIGH);
  digitalWrite(Led_Start, HIGH);
  digitalWrite(Led_Kaotik, HIGH);
  digitalWrite(Led_Sabit, HIGH);
  digitalWrite(Led_Iletisim, HIGH);

  lcd.init();
  lcd.backlight();
  lcd.setCursor(10,1);  lcd.print("KALAN=");
  lcd.setCursor(12,2);  lcd.print("RPM=");
  lcd.setCursor(0,2);   lcd.print("HIZ=%");
  lcd.setCursor(10,0);  lcd.print("MOD=");
  lcd.setCursor(0,1);   lcd.print("SURE=");
  lcd.setCursor(12,3);  lcd.print("SET=");
```

```
  t.every(10, SerialEvent);
  t.every(100, SerialSend);
  t.every(750, hesap);
  t.every(300, lcd_yenile);
}
//-----------------------+++++SETUP+++++-----------------------

//+++++++++++++++++++++++-----MAIN LOOP-----+++++++++++++++++++++++
void loop() {
  t.update();

  if (digitalRead(Btn_Mod)== LOW) {
    delay(150);
    while (digitalRead(Btn_Mod) == LOW);
    if(mod == 1) mod=0;
    else mod=1;
  }

  if (digitalRead(Btn_Start)== LOW) {
    delay(150);
    while (digitalRead(Btn_Start) == LOW);
    if(toplamsure > 0 && durum == 0) Start();
  }

  if (digitalRead(Btn_Stop)== LOW) {
    int flag = 0;
    delay(150);
    while (digitalRead(Btn_Stop) == LOW)
    {
      while(digitalRead(Btn_Start)== LOW)
      {
      Setpoint = map(analogRead(In_Pot), 0, 1015, 60, 195);
      cmin=Setpoint-calismaaralik;
      cmax=Setpoint+calismaaralik;
      lcd.setCursor(5,2);
      int val = map(Setpoint, 60, 195, 1, 100);
      if (val < 10)  lcd.print(" ");
      if (val < 100) lcd.print(" ");
      lcd.print(val);

      lcd.setCursor(16,2);
      int valrpm = map(val, 1, 100, 100, 6000);
      if (valrpm < 10)   lcd.print(" ");
      if (valrpm < 100)  lcd.print(" ");
      if (valrpm < 1000) lcd.print(" ");
      lcd.print(valrpm);
```

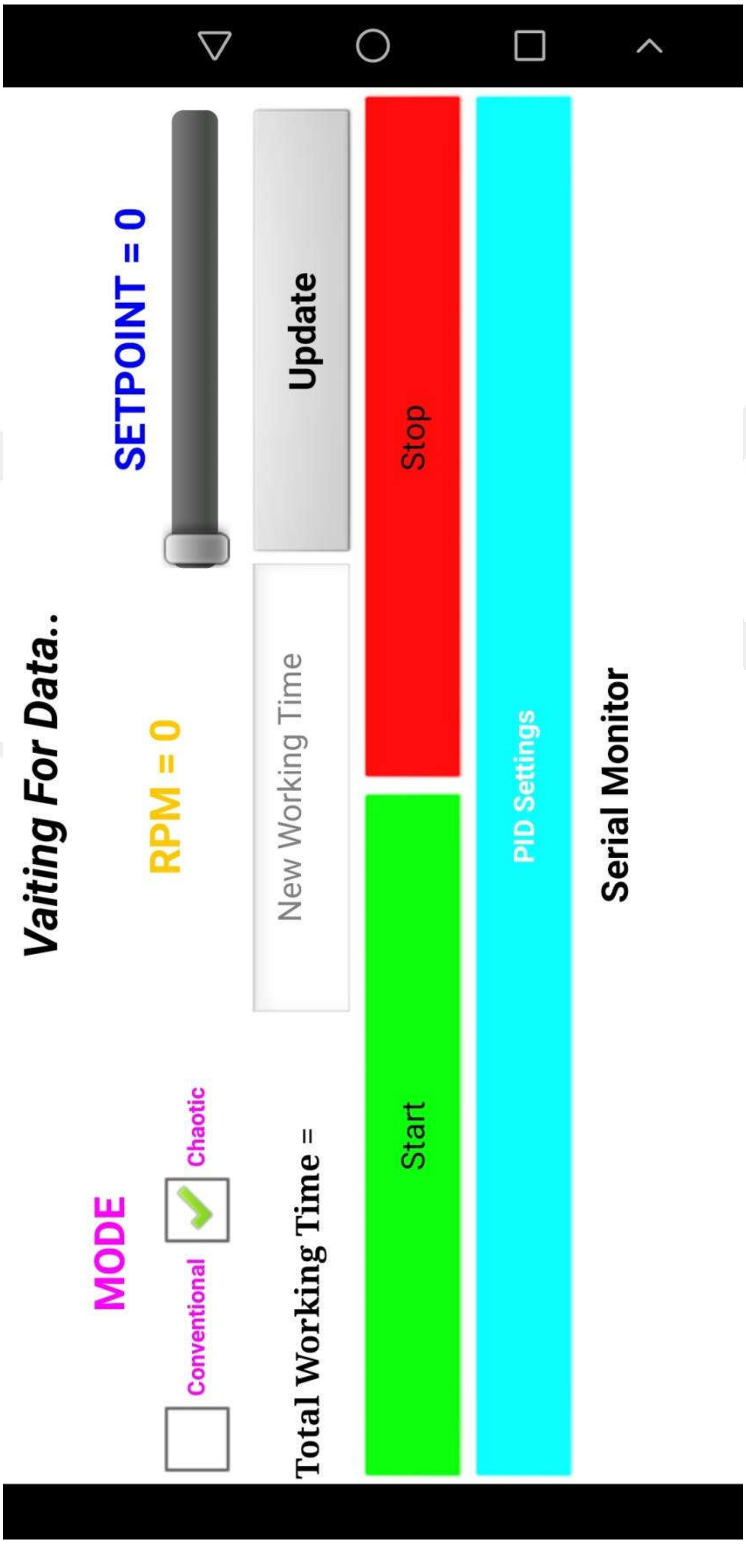
```
    lcd.setCursor(0,3);
    for (int i = 0; i < 10; i++) {
    if(map(val, 0, 100, 0, 10) > i) lcd.print(">");
    else lcd.print(" ");
    }

    lcd.setCursor(16,3);
    if (Setpoint < 10)   lcd.print(" ");
    if (Setpoint < 100)  lcd.print(" ");
    if (Setpoint < 1000) lcd.print(" ");
    lcd.print(Setpoint);
    delay(250);
    flag=1;
    }
  }
  if(!flag) Stop();
}


if (stringComplete)
{
  if(inputString.startsWith("D=", 0)) { Stop();                                        }    // Acil Durum Durdurma
  else if(inputString.startsWith("U1=", 0)) { uyari_1   = inputString.substring(3).toInt(); }    // Uyarı1 Ayar
  else if(inputString.startsWith("U2=", 0)) { uyari_2   = inputString.substring(3).toInt(); }    // Uyarı2 Ayar
  else if(inputString.startsWith("T=", 0)) { toplamsure = inputString.substring(2).toInt(); }    // Süre Ayar
  else if(inputString.startsWith("P=", 0))
  { Setpoint = inputString.substring(2).toInt(); cmin=Setpoint-calismaaralik; cmax=Setpoint+calismaaralik; }    // PWM  Ayar
  else if(inputString.startsWith("M=", 0))                                                        // Mod Ayar
    {
           if(inputString.startsWith("1", 2))    mod = 1;
      else if(inputString.startsWith("0", 2))    mod = 0;
    }
  else if(inputString.startsWith("B=", 0)) // Başlat
    {
      if(toplamsure > 0 && durum == 0)
      {
          Start();
      }
    }
  inputString = "";
  stringComplete = false;
}


if(durum == 1)
{
  Gecen_Sure = (millis() - start)/1000;
  if(Gecen_Sure < toplamsure)
```

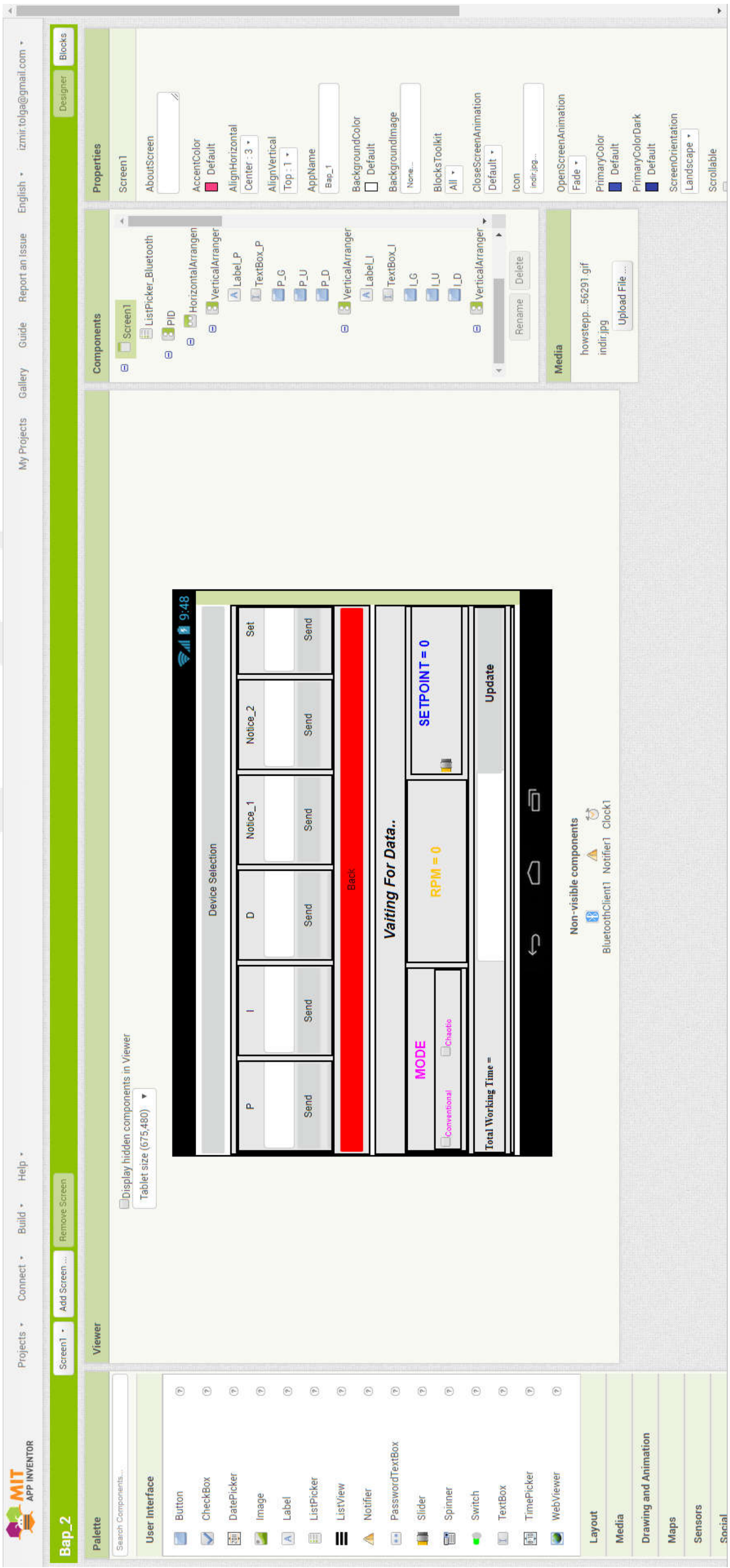
```
    if(Gecen_Sure < toplamsure)
      {
      //Zaman uyarı Buzzer Kodları
      //if(Gecen_Sure == uyari_1) {digitalWrite(Buzzer_Pin, HIGH); delay(500); digitalWrite(Buzzer_Pin, LOW); }
      //else if(Gecen_Sure == uyari_2) {digitalWrite(Buzzer_Pin, HIGH); delay(500); digitalWrite(Buzzer_Pin, LOW);}
      }
    else
      {
        Stop();
        //Bitis uyarı Buzzer Kodları
        /*for(int i=1;i<5;i++)
          {
            digitalWrite(Buzzer_Pin, HIGH);  delay(250);
            digitalWrite(Buzzer_Pin, LOW);   delay(250);
          }*/
      }
  }

}
//------------------------+++++MAIN LOOP+++++------------------------

//++++++++++++++++++++++++-----SERIAL DATA TRANSFER-----++++++++++++++++++++++++
static void SerialSend()
{
  Serial.print("-G-");
  Serial.print("<>D=");
  Serial.print(durum);
  Serial.print("<>M=");
  Serial.print(mod);
  Serial.print("<>P=");
  Serial.print(Setpoint);
  Serial.print("<>O=");
  Serial.print(Out);
  Serial.print("<>T=");
  Serial.print(toplamsure);
  Serial.print("<>K=");
  if(durum) Serial.print(toplamsure-Gecen_Sure);
  else Serial.print("0");
  Serial.println("<>+G+<>");
  digitalWrite(Led_Iletisim, !digitalRead(Led_Iletisim));
}
//------------------------+++++SERIAL DATA TRANSFER+++++------------------------


//++++++++++++++++++++++++-----MOTOR FİRST START-----++++++++++++++++++++++++
static void Start()
{
```

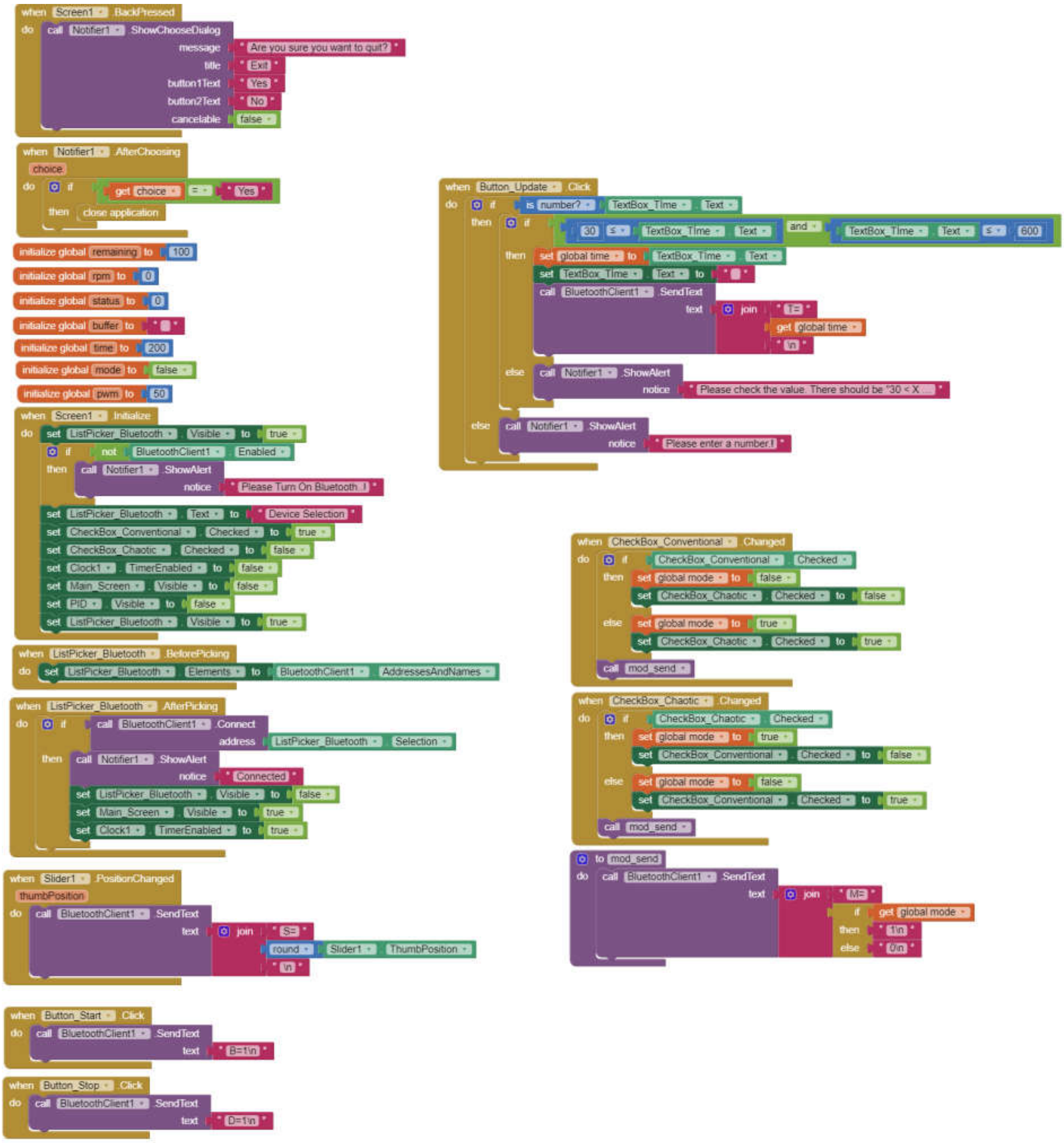
```
{
  durum = 1;
  digitalWrite(Out_Kontak, LOW);
  start = millis();
  //for (int fadeValue = 0 ; fadeValue <= 50; fadeValue += 5) {analogWrite(Out_Pwm, fadeValue); delay(250);}
}
//------------------------+++++MOTOR FİRST START+++++------------------------

//++++++++++++++++++++++++-----MOTOR STOP-----++++++++++++++++++++++++
static void Stop()
{
  //for (int fadeValue = Output ; fadeValue >= 0; fadeValue -= 5) {analogWrite(Out_Pwm, fadeValue); delay(100);}
  analogWrite(Out_Pwm, 0);
  digitalWrite(Out_Kontak, HIGH);
  Out = 0;
  durum = 0;
}
//------------------------+++++MOTOR STOP+++++------------------------

//++++++++++++++++++++++++-----SERİAL READ-----++++++++++++++++++++++++
void SerialEvent()
{
  while (Serial.available())
  {
    char inChar = (char)Serial.read();        // get the new byte:
    inputString += inChar;                    // add it to the inputString:
                                              // if the incoming character is a newline, set a flag
                                              // so the main loop can do something about it:
    if (inChar == '\n') { stringComplete = true; }
  }
}
//------------------------+++++SERİAL READ+++++------------------------
static void hesap()
{
  if(durum)
  {
  if (mod) { xnew = 4 * xold*(1- xold);  Out = map(xnew*100, 0, 100, cmin, cmax);   xold=xnew;  analogWrite(Out_Pwm, Out);}
  else     { xnew = 0.48; Out = Setpoint; analogWrite(Out_Pwm, Out);}
  }
}

//------------------------+++++LCD+++++------------------------
static void lcd_yenile()
{
  lcd.home();
  if(durum) {digitalWrite(Led_Start, HIGH); digitalWrite(Led_Stop, LOW); lcd.print("CALISIYOR"); lcd.setCursor(16,1);
  if (toplamsure-Gecen_Sure < 10)   lcd.print(" ");
```

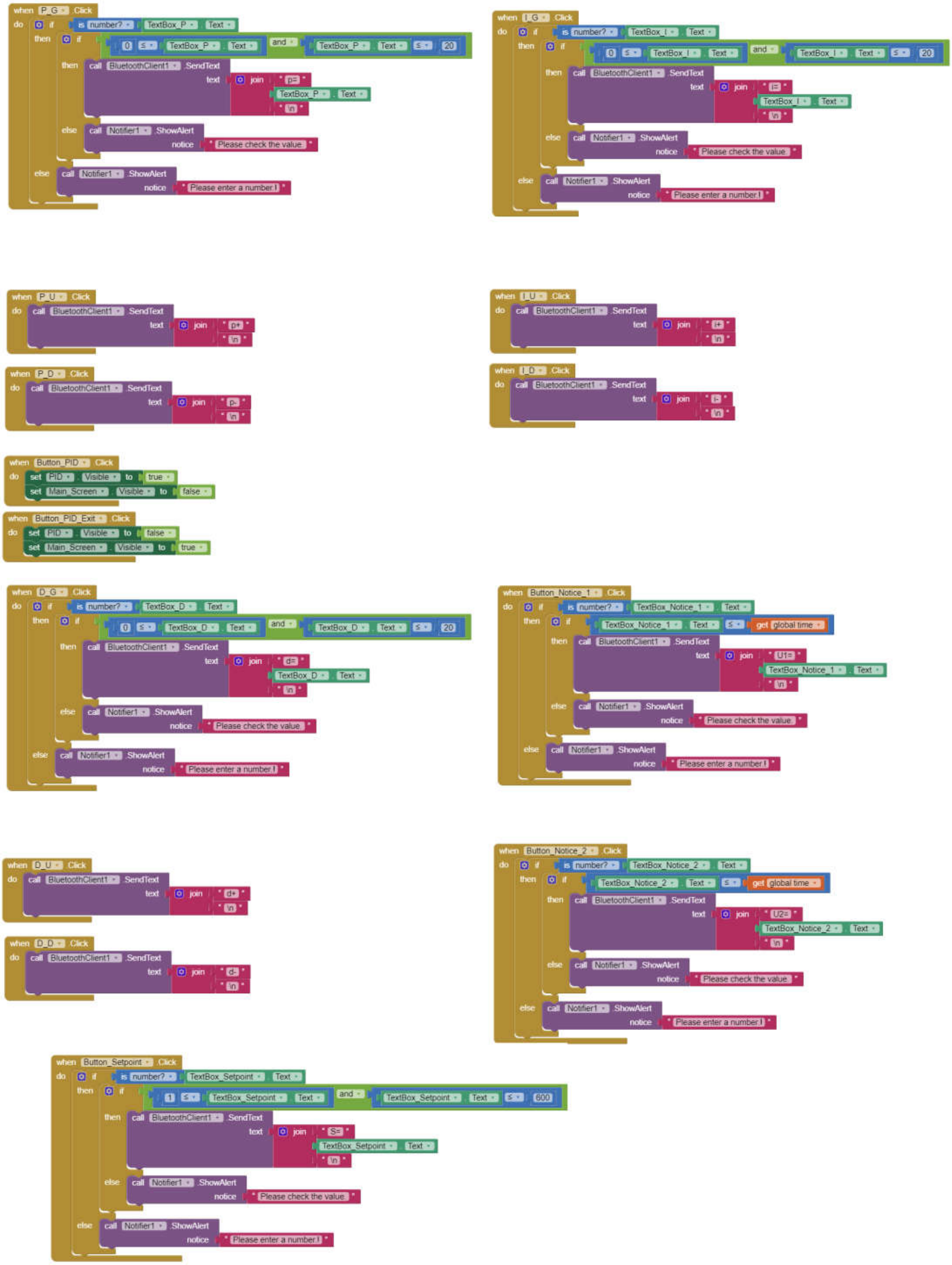
```
  if (toplamsure-Gecen_Sure < 100)  lcd.print(" ");
  if (toplamsure-Gecen_Sure < 1000) lcd.print(" ");
  lcd.print(toplamsure-Gecen_Sure);}
  else {digitalWrite(Led_Start, LOW); digitalWrite(Led_Stop, HIGH); lcd.print("HAZIR    "); lcd.setCursor(16,1);
  if (toplamsure < 10)   lcd.print(" ");
  if (toplamsure < 100)  lcd.print(" ");
  if (toplamsure < 1000) lcd.print(" ");
  lcd.print(toplamsure);}


  lcd.setCursor(14,0);
  if(mod) {digitalWrite(Led_Kaotik, HIGH); digitalWrite(Led_Sabit, LOW); lcd.print("KAOTIK");}
  else {digitalWrite(Led_Kaotik, LOW); digitalWrite(Led_Sabit, HIGH); lcd.print(" SABIT");}


  lcd.setCursor(5,1);
  if (toplamsure < 10)   lcd.print(" ");
  if (toplamsure < 100)  lcd.print(" ");
  if (toplamsure < 1000) lcd.print(" ");
  lcd.print(toplamsure);

  lcd.setCursor(5,2);
  int val = map(Out, 0, 255, 0, 100);
  if (val < 10)  lcd.print(" ");
  if (val < 100) lcd.print(" ");
  lcd.print(val);

  lcd.setCursor(16,2);
  int valrpm = map(val, 0, 100, 0, 6000);
  if (valrpm < 10)   lcd.print(" ");
  if (valrpm < 100)  lcd.print(" ");
  if (valrpm < 1000) lcd.print(" ");
  lcd.print(valrpm);

  lcd.setCursor(0,3);
  for (int i = 0; i < 10; i++) {
  if(map(val, 0, 100, 0, 10) > i) lcd.print(">");
  else lcd.print(" ");
  }

  lcd.setCursor(16,3);
  if (Setpoint < 10)   lcd.print(" ");
  if (Setpoint < 100)  lcd.print(" ");
  if (Setpoint < 1000) lcd.print(" ");
  lcd.print(Setpoint);
}
```

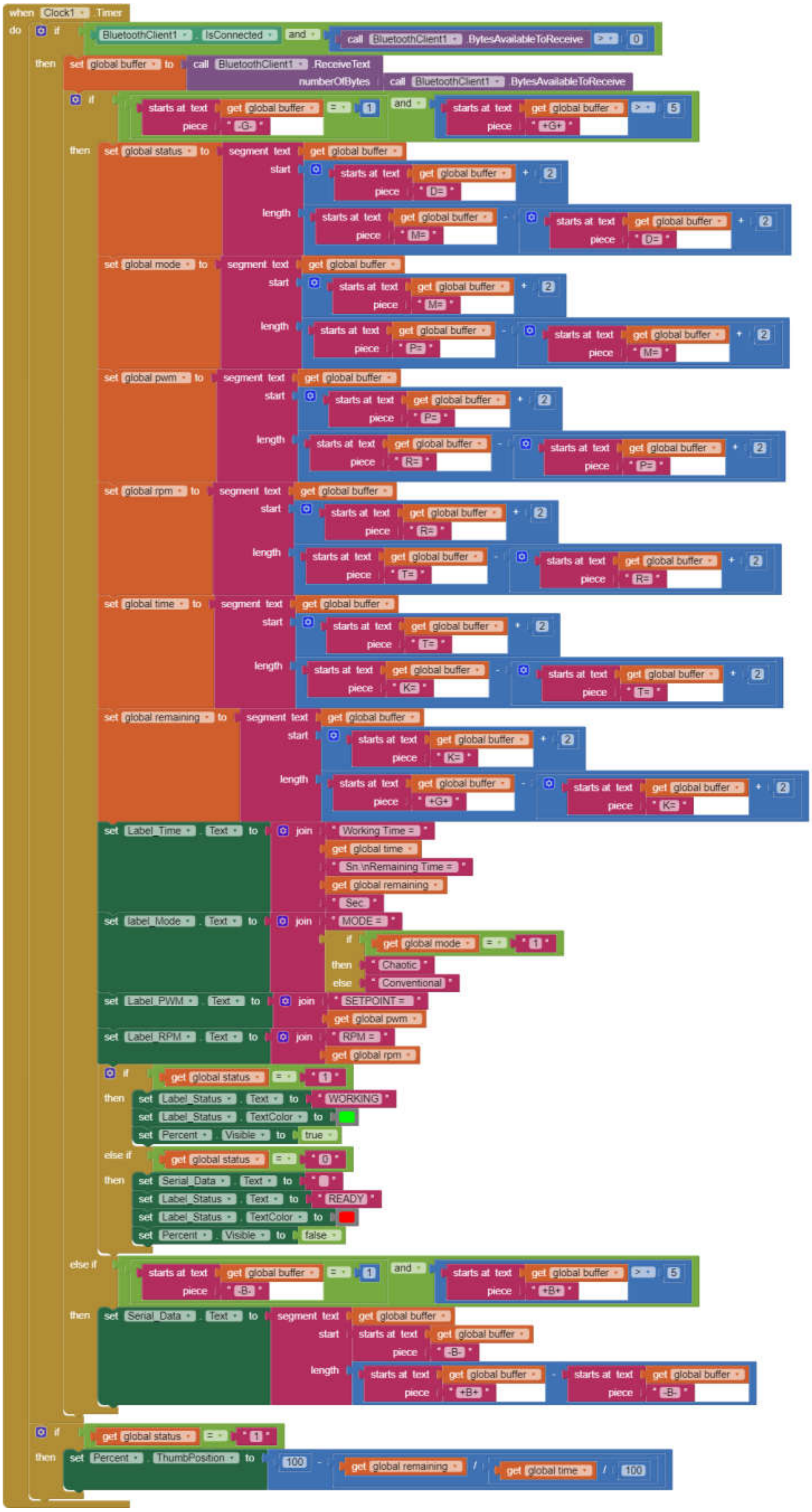
APPENDIX 2 – Software Code (Android)



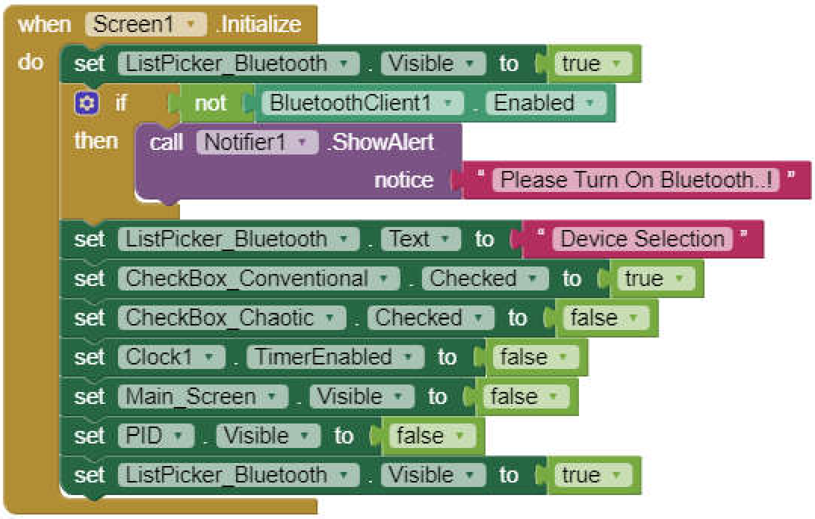

MIT APP INVENTOR
Bap_2
Palette
User Interface
Viewer
Components
Properties
Device Selection
P
I
D
Notice_1
Notice_2
Set
Send
Back
Vaiting For Data..
MODE
RPM = 0
SETPOINT = 0
Total Working Time =
Update
Non-visible components
BluetoothClient1
Notifier1
Clock1




when P_G .Click
do if is number? TextBox_P . Text
then if 0 ≤ TextBox_P . Text and TextBox_P . Text ≤ 20
then call BluetoothClient1 .SendText text join "p=" TextBox_P . Text "\n"
else call Notifier1 .ShowAlert notice "Please check the value"
else call Notifier1 .ShowAlert notice "Please enter a number!"
when I_G .Click
do if is number? TextBox_I . Text
then if 0 ≤ TextBox_I . Text and TextBox_I . Text ≤ 20
then call BluetoothClient1 .SendText text join "i=" TextBox_I . Text "\n"
else call Notifier1 .ShowAlert notice "Please check the value"
else call Notifier1 .ShowAlert notice "Please enter a number!"
when P_U .Click
do call BluetoothClient1 .SendText text join "p+" "\n"
when I_U .Click
do call BluetoothClient1 .SendText text join "i+" "\n"
when P_D .Click
do call BluetoothClient1 .SendText text join "p-" "\n"
when I_D .Click
do call BluetoothClient1 .SendText text join "i-" "\n"
when Button_PID .Click
do set PID . Visible to true
set Main_Screen . Visible to false
when Button_PID_Exit .Click
do set PID . Visible to false
set Main_Screen . Visible to true
when D_G .Click
do if is number? TextBox_D . Text
then if 0 ≤ TextBox_D . Text and TextBox_D . Text ≤ 20
then call BluetoothClient1 .SendText text join "d=" TextBox_D . Text "\n"
else call Notifier1 .ShowAlert notice "Please check the value"
else call Notifier1 .ShowAlert notice "Please enter a number!"
when Button_Notice_1 .Click
do if is number? TextBox_Notice_1 . Text
then if TextBox_Notice_1 . Text ≤ get global time
then call BluetoothClient1 .SendText text join "U1=" TextBox_Notice_1 . Text "\n"
else call Notifier1 .ShowAlert notice "Please check the value"
else call Notifier1 .ShowAlert notice "Please enter a number!"
when D_U .Click
do call BluetoothClient1 .SendText text join "d+" "\n"
when D_D .Click
do call BluetoothClient1 .SendText text join "d-" "\n"
when Button_Notice_2 .Click
do if is number? TextBox_Notice_2 . Text
then if TextBox_Notice_2 . Text ≤ get global time
then call BluetoothClient1 .SendText text join "U2=" TextBox_Notice_2 . Text "\n"
else call Notifier1 .ShowAlert notice "Please check the value"
else call Notifier1 .ShowAlert notice "Please enter a number!"
when Button_Setpoint .Click
do if is number? TextBox_Setpoint . Text
then if 1 ≤ TextBox_Setpoint . Text and TextBox_Setpoint . Text ≤ 600
then call BluetoothClient1 .SendText text join "S=" TextBox_Setpoint . Text "\n"
else call Notifier1 .ShowAlert notice "Please check the value"
else call Notifier1 .ShowAlert notice "Please enter a number!"

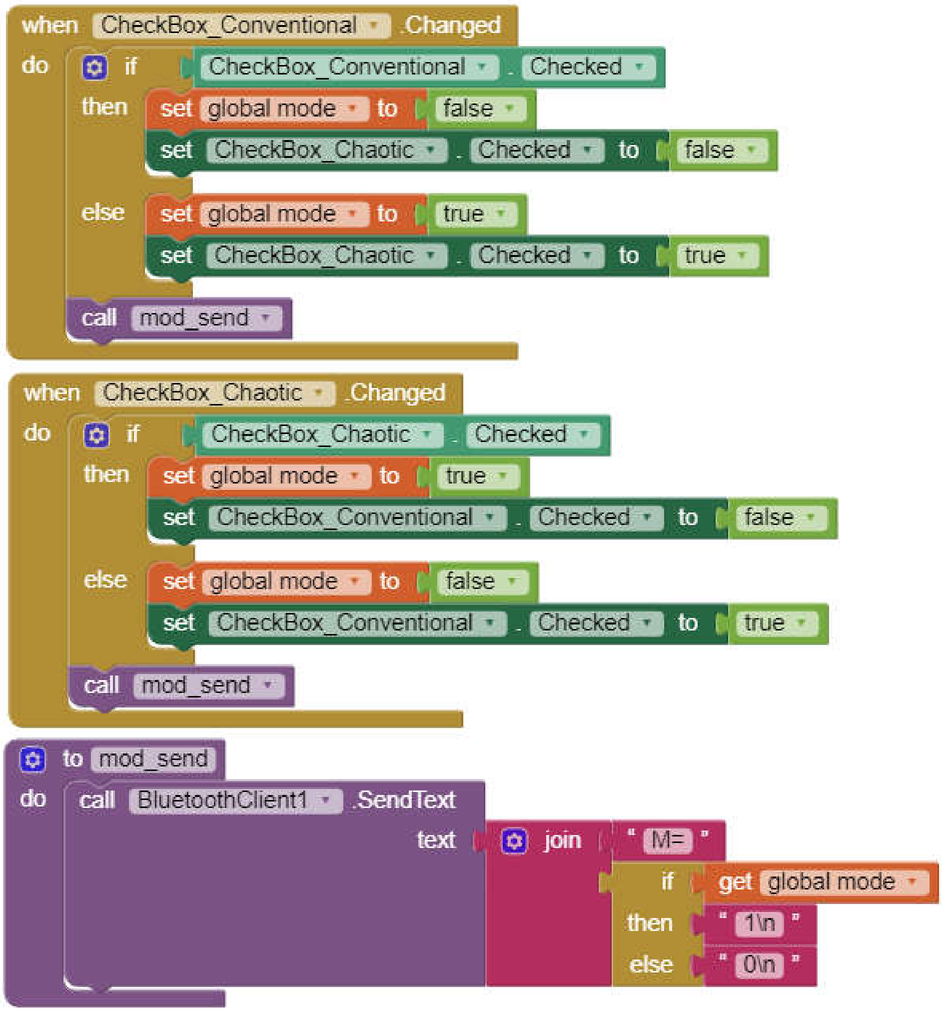


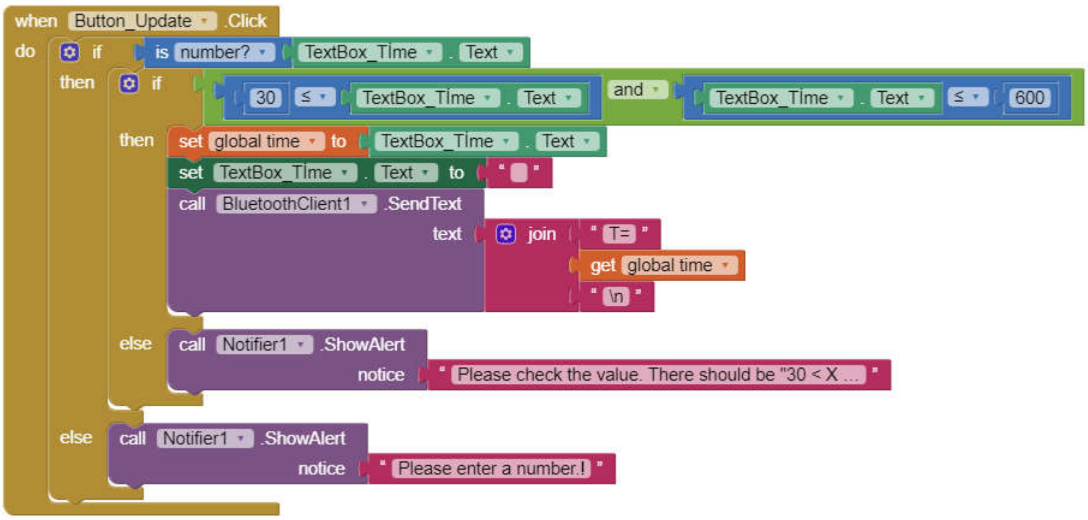
when Clock1 .Timer
do
if
BluetoothClient1 . IsConnected
and
call BluetoothClient1 .BytesAvailableToReceive
then
set global buffer to
call BluetoothClient1 .ReceiveText
numberOfBytes
starts at text
piece
get global buffer
segment text
start
length
set global status to
set global mode to
set global pwm to
set global rpm to
set global time to
set global remaining to
set Label_Time . Text to
join
Working Time =
get global time
get global remaining
Sec
set label_Mode . Text to
MODE =
get global mode
Chaotic
Conventional
set Label_PWM . Text to
SETPOINT =
get global pwm
set Label_RPM . Text to
RPM =
get global rpm
get global status
set Label_Status . Text to
WORKING
set Label_Status . TextColor to
set Percent . Visible to
true
else if
set Serial_Data . Text to
READY
false
else
set Percent . ThumbPosition to
100

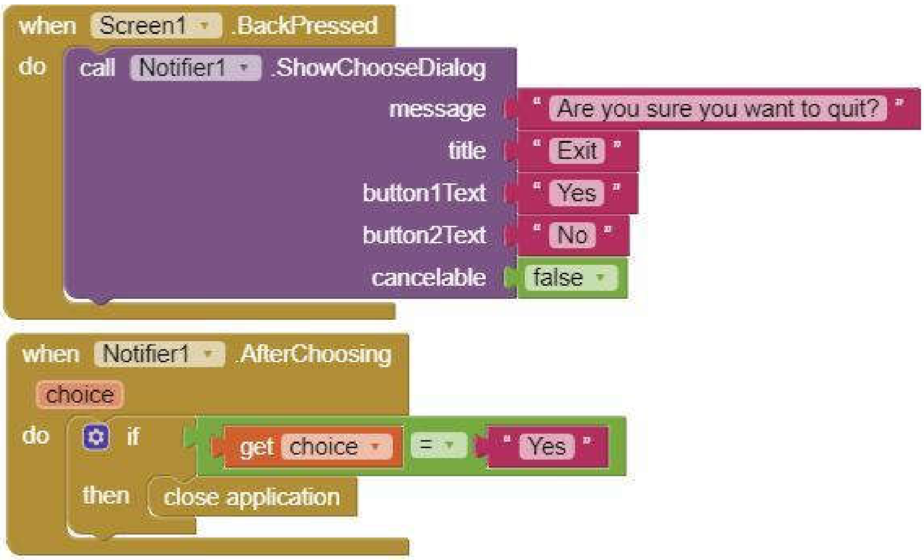

when Screen1 .Initialize
do
set ListPicker_Bluetooth . Visible to true
if not BluetoothClient1 . Enabled
then call Notifier1 .ShowAlert
notice " Please Turn On Bluetooth..! "
set ListPicker_Bluetooth . Text to " Device Selection "
set CheckBox_Conventional . Checked to true
set CheckBox_Chaotic . Checked to false
set Clock1 . TimerEnabled to false
set Main_Screen . Visible to false
set PID . Visible to false
set ListPicker_Bluetooth . Visible to true


when Button_Start .Click
do call BluetoothClient1 .SendText
text " B=1\n "


when Button_Stop .Click
do call BluetoothClient1 .SendText
text " D=1\n "


when CheckBox_Conventional .Changed
do if CheckBox_Conventional . Checked
then set global mode to false
set CheckBox_Chaotic . Checked to false
else set global mode to true
set CheckBox_Chaotic . Checked to true
call mod_send
when CheckBox_Chaotic .Changed
do if CheckBox_Chaotic . Checked
then set global mode to true
set CheckBox_Conventional . Checked to false
else set global mode to false
set CheckBox_Conventional . Checked to true
call mod_send
to mod_send
do call BluetoothClient1 .SendText
text join " M= "
if get global mode
then " 1\n "
else " 0\n "


when Button_Update .Click
do if is number? TextBox_Time . Text
then if 30 ≤ TextBox_Time . Text and TextBox_Time . Text ≤ 600
then set global time to TextBox_Time . Text
set TextBox_Time . Text to " "
call BluetoothClient1 .SendText
text join " T= "
get global time
" \n "
else call Notifier1 .ShowAlert
notice " Please check the value. There should be "30 < X ... "
else call Notifier1 .ShowAlert
notice " Please enter a number.! "


when Screen1 .BackPressed
do call Notifier1 .ShowChooseDialog
message "Are you sure you want to quit?"
title "Exit"
button1Text "Yes"
button2Text "No"
cancelable false
when Notifier1 .AfterChoosing
choice
do if get choice = "Yes"
then close application