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Developing real-Time Boiler Control Algorithm for Fuel Consumption Savings

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Abstract: In this study, an automatic solid fuel control algorithm has been developed that provides maximum heating with minimal solid fuel waste in boiler systems. With the algorithm developed using the Atmega16 microcontroller, motors such as stoker, fan, water pump used in boiler control and features such as boiler temperature, temperature sensor, water pump temperature are controlled. In addition to these features, operations such as fuel loading, waiting, fan speed adjustment can be performed with the help of the menu controlled by interrupt functions. The boiler control algorithm developed for real-time control of the system is programmed with the AVR C language. In the system in which the developed algorithm is used, a user-friendly panel with a 7-segment display has been developed to facilitate the work of the users. With the help of this panel, the user will be able to make all adjustments that affect the operation of the boiler in a very short time. As a result of experimental studies, an increase in the life span of the controlled boiler elements has been determined and an annual fuel saving of approximately 20% has been achieved compared to conventional boiler control systems.

Keywords: boiler system; energy consumption; interrupt; microcontroller; boiler control algorithm

Yakıt Tüketim Tasarrufu için Gerçek Zamanlı Kazan Kontrol Algoritması Geliştirme

Öz: Bu çalışmada kazan sistemlerinde en az katı yakıt atığı ile maksimum ısınma sağlayan otomatik katı yakıt kontrol algoritması geliştirilmiştir. Geliştirilen algoritma ile Atmega16 mikro denetleyicisi ile kazan kontrolünde kullanılan stoker, fan, su pompası gibi motorlar ile kazan sıcaklığı, sıcaklık sensoru, su pompası sıcaklığı gibi özellikler kontrol edilmektedir. Bu özelliklere ek olarak kesme fonksiyonları ile kontrol edilen menü yardımıyla yakıt yükleme, bekleme, fan hızı ayarlama gibi işlemler gerçekleştirilebilmektedir. Sistemin gerçek zamanlı ve hızlı bir şekilde kontrol edilebilmesi için geliştirilen kontrol algoritması AVR C dili ile programlanmıştır. Geliştirilen algoritmanın kullanıldığı sistemde kullanıcılarının işlerini kolaylaştıracak şekilde 7 segment display göstergeli kullanıcı dostu bir panel geliştirilmiştir. Bu panel yardımıyla kullanıcı, kazanının çalışmasını etkileyen tüm ayarlamaları çok kısa sürede gerçekleştirebilecektir. Deneysel çalışmalar neticesinde kontrol edilen kazan elemanlarının hayat ömründe artış tespit edildiği gibi klasik kazan kontrol sistemlerine göre yıllık %20'ye yakın yakıt tasarrufu sağlanmıştır.

Anahtar Kelimeler: kazan sistemi; enerji tüketimi; kesme; mikro denetleyici; kazan kontrol algoritması

1. Introduction

Throughout history, people have developed sheltered structures to lead a more spacious and comfortable life. The construction of these structures has historically continued from the earliest years to the present. Today, buildings that protect us from environmental effects are called shelters.

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These shelters are indispensable in terms of allowing human beings to create their privacy and creating a productive environment free from environmental effects. It is important in today's conditions to protect buildings such as houses, workplaces, and offices, where people live for different purposes at the desired room temperature. According to researchers, the world population is expected to reach approximately 10 million by 2040 [1]. The cost of maintaining room temperature in buildings based on changing weather conditions increases due to the continuous increase in human population and the increase in energy need according to this increase in direct proportion to the population. In this sense, considering the limited energy resources, reserves, and increasing population, it is understood that controlled consumption should be increased. Due to the continued increase in the world population and the limited energy resources, academic research is needed to control and reduce energy consumption.

Temperature control is generally referred to as the process by which the temperature change inside a place or a device such as a boiler is measured and the passage of heat energy into or out of the space is made to set the desired average temperature [2]. In the literature, different studies developed to control room temperature in offices have been examined [3]–[5]. In these studies, studies are observed to be carried out to maintain room temperature. However, it is believed that it will not be enough to adjust the temperature of the rooms to the most suitable degree. At the same time, the boiler systems that provide heat to these rooms must pass certain controls. Electronic circuit input/output pins need to be controlled for different purposes such as keeping the boilers within the desired temperature ranges, controlling motors such as water pump, stoker, fan.

Greenhouse systems improve the growing conditions of vegetables, fruits, and ornamental plants and protect them from negative atmospheric factors. It also provides market durability, product quality, and higher productivity [6]. The crops produced in the greenhouse per unit of area are said to be produced more than the crops grown in the open field. For sustainable greenhouses, it is aimed to produce solid waste-free production by minimizing water consumption with different cultivation techniques and sufficient technological equipment. The drying air temperatures of carrots, zucchini, and eggplant produced in the greenhouse have been determined to vary [7]. The drying times of each production vary according to the applied temperature. For these reasons, it is necessary to control the boilers effectively both in the drying of greenhouse products and against the possibility of freezing. The boiler control algorithm developed under the stated objectives is designed to be used in all kinds of greenhouses. The control of boilers working with solid fuel is used not only to balance the temperature of human shelters but also to provide temperature stabilization of greenhouse regions that can be called vegetable and fruit shelters.

Greenhouse products, which are planned to be produced by targeting markets selling to the public, and where full control over crop quality and yield is desired, should be heated when they fall below the recommended temperature. Apart from increasing the greenhouse temperature to the temperature determined according to the products inside, heating should also be applied in cases where air humidity needs to be reduced. In these heating systems, besides preventing plant freezing, the emergence of different diseases such as fungus is prevented [6]. In cold countries, greenhouses are heated for most of the year, while in temperate climates, the heating time may be shorter. Heating gains importance in greenhouses in many regions with the possibility of freezing as a result of the increase in the degree of coldness in winter. In the spring and summer periods, the air temperature can change rapidly at night. For this and similar reasons, one of our main motivations within the scope of our work is to ensure the balanced heating of greenhouses and human shelters.

In addition to the above-mentioned purposes, it has been determined that many studies have been carried out in many European countries to eliminate harmful emissions resulting from solid fuel combustion [8]–[11]. Liao and Dexter stated in their study that the emission value created by fuel systems corresponds to approximately one-fourth of the total emission value [10]. In parallel with this determination, the harmful emission rate resulting from the fuel burned in shelters in Europe corresponds to approximately one-third of the total emission rate [12]. Due to the stated situations, it is aimed to control the boiler systems that provide heat to these environments most effectively and efficiently by targeting the shelters where people live and the greenhouses where vegetables are grown. Within the scope of this study, one of our main motivations is to prevent emission gas formation with effective stoker control.

There are follow-up studies in the form of continuous monitoring of the temperature values of the server rooms where the web pages are published [13], automatic information transfer to the responsible persons when the boiler temperature values exceed a determined value [14]. In addition, studies in the literature such as making a warning sound in case the water temperature value in the boiler exceed a certain threshold value [15] have been examined. When these studies are examined, it is seen that there are microcontroller-based applications that control different types of boiler systems such as solid fuel [16], industrial [17], pellet [18], steam [19], and water [20]. According to studies in the literature, it is a very laborious task for a boiler attendant to constantly try to load the fuel into the boiler. The algorithm developed to assist the employee in loading fuel into the boiler and to ensure that the fuel is loaded automatically at certain intervals can be made automatic fuel loading and waiting by using the stoker.

Microcontrollers are used in different tasks such as fuel consumption [19], temperature control [3], water level control [15], electromagnetic valve control [21], solar radiation measure [22], driver control system [23] and solid fuel combustion capacity [24]. Sagouong and Tchuen [19] developed a microcontroller-based system to reduce fuel consumption to determine which of the three heat systems widely used in the Cameroon region is the most efficient. Amoo et al. [3] designed a microcontroller-based system to automatically control the temperature of the room in their studies. Wellem and Setiawan [13] used a microcontroller to monitor the room temperatures of the servers where the web pages are constantly published. In steam boiler systems, as in other boiler systems, electrical and water levels must be controlled for the boiler to work correctly, properly, and stably. It is reported that the control structures do not work stably in case of any electrical irregularity. To eliminate the mentioned problem, Shome and Ashok [25] ensured that the microcontroller and fuzzy-based methods worked together. Karuppiah et al. [14] monitored the water temperature value transferred to the main boiler by several different boilers using a microcontroller. It has developed a system that informs the responsible person when any of the boilers that make up the system exceeds a figure determined as the temperature value. Man et al. [26] proposed a fuzzy-based system to control superheated steam. Kumar et al. [27] designed a logic controller to control the pressure and temperature of the boilers with a programmable logic controller. They proposed an FPGA-based structure to realize the designed system. Jalal et al. [28] developed a microcontroller-based robot for automatic fault detection of heat boiler systems in the power plant. Ashwin and Manoharan proposed a structure that warns when the water level in the boilers of power plants increases above a certain value [15]. Śladewski et al. [24] developed optimization software that normalizes the combustion process in order to increase the combustion capacity of solid fuel in power plants. It aims to increase fuel efficiency with the specified software.

The main contributions of the proposed algorithm in this article are given in the form of items.

- With the effective boiler control developed, it is used not only to balance the temperature of human shelters but also to provide temperature stabilization of greenhouse regions that can be called vegetable and fruit shelters.
- With the proposed algorithm, the life of the circuit elements is increased by preventing the unnecessary and wasted operation of the boiler circuit elements.
- A system has been developed to assist boiler workers who continuously refuel.
- An interrupt-based menu system has been developed so that users who do not have any knowledge about the boiler system can manage it.

- With the effective control of the engines in the boiler systems, the rate of harmful emissions has been reduced.
- Within the scope of this study, it will be possible to grow greenhouse products at a balanced temperature or dry them at the desired temperature depending on the type of product.
- Fuel savings of up to 20% have been achieved in the algorithmic boiler systems recommended compared to conventional boiler systems.

The next part of the article is organized as follows. In the Material and Methods section, detailed information about the microcontroller used in the article is given. Afterward, details about the algorithm that effectively controls the motors and sensors in real-time are presented. In the section titled Results and Discussion, the results of the real-time study obtained as a result of experimental studies, the user panel design, and the circuit design are given. In the section titled Conclusions, the study is concluded.

2. Material and Methods

2.1. Microcontroller Configurations

All proposed algorithms are written in the AVR C language. The written algorithm functions were converted to hex code and sent to Atmega16. The microcontroller used, Atmega16, is an eight-bit microcontroller operating between 4.5 and 5.5V with a CMOS-based AVR series RISC architecture. The main reason for choosing this microcontroller is that many boiler elements need to be controlled.

The Atmega16 controller has 40 pins. Each pin can be used for different tasks. Contains 32 general-purpose instruction sets. The Atmega16 microcontroller contains 2 x 8-bit timers, 1 x 16-bit timer, JTAG, analog comparators, Power-on reset, a counter with separate pre-scaler, a counter with compare mode, counter with capture mode, UART, ADC, interrupt controller, and PWM generators. In addition, it has an EEPROM memory with a write/erase capacity of 100,000 times [29]. Timer interrupt functions, which are among the mentioned features, are used to enter the real-time menu system.

The pre-pin adjustments required for the developed boiler control algorithm to work are shown in Figure 1. A value is assigned to the ADPS0, ADPS1, and ADPS2 bits of the ADCSRA register in the settings made before the analog temperature measurement processes. With the adjustments made, the integrated clock speed works at 8 MHz, while the ADC structure works at 62.5 kHz. The frequency speed of the CPU affects the operating speed of all structures connected to the circuit. The frequency rate has been adjusted as a result of experimental studies. The adjusted 8 MHz frequency speed also affects the timer controls used to create counter values such as fuel-related fueling time (FLT), fuel waiting time (FWT) after fueling, and end of the combustion process (EC) used in the boiler control algorithm. While the system is running, the control of FLT, FWT, EC values is provided by the timer controller. Atmega16 has two 8-bit timer counters with separate pre-scaler and compare mode. In addition to this feature, Atmega16 has a 16-bit timer counter with three modes: separate pre scalers, compare mode and capture mode.

Table 1. 7 segment display pin adjustments

Pin Number	0	1	2	3	4	0	1	2
Letter	e	d	dp	c	g	b	f	a
Port			PORTA				PORTB	

In this study, 7 segment screens were used to show the output of the application. The task of the 7-segment display is to show all algorithm outputs in order. To show some letters or numbers on the 7 segment display, the LEDs must be combined. 7 segment displays are of two types, common anode and cathode, and consist of seven LEDs and a point structure. In this sense, a microcontroller-based digital clock has been developed in order not to miss daily activities by using a 7-segment display [30].

Table 2. PORTC port structuring

PORTC	Pin Number	0	1	2	3	4	5	6	7
	Task	water pump	fan	buzzer	digit1	digit2	digit3	stoker	temperature sensor

Table 3. PORTD port structuring

PORTD	Pin Number	2	3	4	5	6	7
	Task	zero crossing	fan speed	buton4-PD4	buton3-PD5	buton2-PD6	buton1-PD7

7 segment screens are used for many different purposes and tasks, such as a 6-digit time display on a 4-digit 7-segment display [31], a digital thermometer showing temperature values [32], student electronic training outputs [33], a screen showing the results of electrical energy measurement [34], displaying the number of heartbeats [35]. 7-segment displays have the feature of both occupying less space and being cheaper than LCDs. In the study carried out, PORTA port was used to set a 7 segment display screen using microcontroller. In addition to Table 1, the 5th pin of the PORTA port is left blank. The reason for leaving it blank is to have an empty pin structure in case any sensor is needed other than the current pin use.

In Table 2, the pin assignments of the PORTC port are defined. All pins on the PORTC port are set as output. To detect square wave zero regions, the second pin of PORTD is defined as the interrupt input. PORTD port configurations are given in Table 3. The 3rd pin is defined as the output for the fan speed configuration. 4,5,6,7. pins are defined as button inputs. In the proposed algorithm step, the task definition of each button is made in detail.

2.2. Proposed Algorithm

As shown in Figure 1, the proposed algorithm works in two different ways, validMode=0 (MODE_START) and validMode=1 (MODE_FORWARD). MODE_START, one of the specified mode values, includes the initial assignments made without entering the application loop step. In addition, it is the operating mode that is defined in the application before going to the stage where different pumps and sensors are active. In this mode, it can be said that the interrupt and timer controls of the algorithm are inactive. In the MODE_FORWARD state, the interrupt and timer controls required for the stoker control of the operation are active.

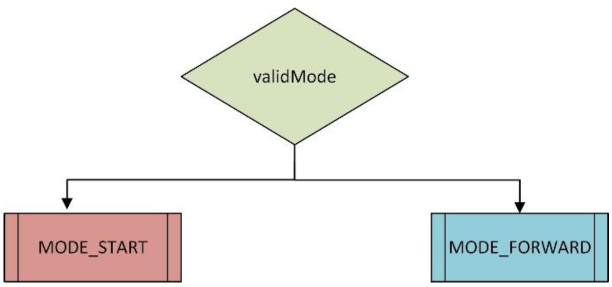

Figure 1. Valid mode types

The basic adjustments shown in Figure 2 represent all basic adjustments such as ADC, 7 segment display pin adjustments, mode, timer/counter/interrupt adjustments defined to perform FLT, FWT, and EC operations. While Timer1 is used for long waits, Timer0 and Timer2 are used for the remaining short waits. The selection of long and short waits is assigned in the MODE_START step.

The most important registers affected when using interrupts are the TIMSK (Timer Interrupt Mask Register) and TIFR (Timer Interrupt Flag) registers. In TIMSK, there are bits TOIE0, OCIE0, TOIE1, OCIE1B, OCIE1A, TICIE1, TOIE2, OCIE2, from the zero to the seventh bit, respectively. TIMSK is used to determine which interrupts are active at runtime and which interrupts are inactive at runtime (TIFR) with the specified eight bits. In the case of the EC status on the display screen in the implemented system, a sound should be emitted from the buzzer sensor. An 8-bit Timer0 interrupt is used to perform this operation while the process is in progress.

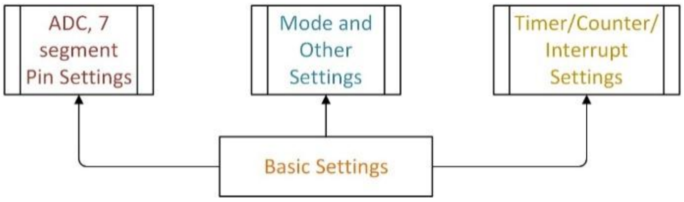

Figure 2. Basic settings

Since it is 8 bits, the value of the TCNT0 register, which is the Timer0 interrupt register, changes until the limit value is obtained by subtracting a value from the eighth power of the two [36]. The CS02, CS01 bits in the TCNT0 register are used to set the frequency values.

One of the main purposes of the boiler control algorithm is to ensure that fuel is automatically loaded into the boiler system at specified time intervals. The fuel system controlled by the algorithm works according to the rules defined in MODE_START mode. For the system to be shut down, the algorithm must detect that the EC process is complete. Timer2 interrupt in Atmega16 microcontroller is used in FWT operation. FWT times can be changed from the menu in real-time without interrupting the boiler operation. TCCR2 register is used to perform this operation. There are CS20, CS21, CS22, WGM21, COM20, COM21, WGM20, FOC2 bits in the TCCR2 register, from zero to seventh bit, respectively. The interruption mode varies according to the selection made by these modes. At the same time, the Timer1 interrupt was used to keep the fan running at a certain speed with a zero-crossing configuration. By default, the fan speed is set to fast in classic boilers. In the boiler system with the proposed algorithm, the fan can operate continuously at 3 different speeds as slow, medium, and fast. As with other controls, the desired speed can be selected with the help of the fan speed adjustment menu.

This operation is one of the operations that will prevent the fan motor from operating at the highest speed. Another is that if the temperature does not rise for a certain period after the fuel is finished, the fan is automatically turned off.

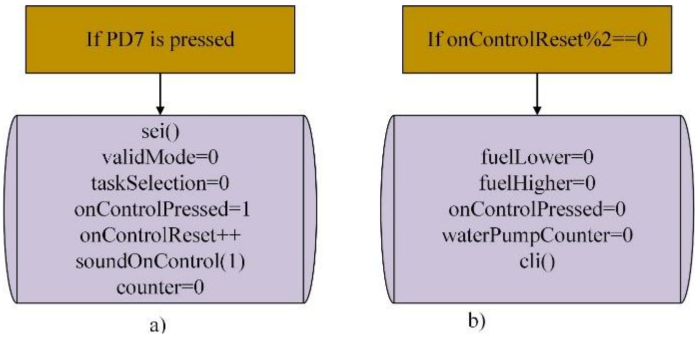

Figure 3. Algorithm active and passive status check

The developed boiler control algorithm is mod-based. User approval is required to control the circuit elements. In the first confirmation process, the values are assigned to the basic parameters, and the operation starts in MODE_START mode. The algorithm starts with the PD7 button shown in Figure 3. The PD7 button shown in Figure 3a starts or stops the system. While the sei function generally activates the interrupt function, the cli function disables it. With validMode=0, it is stated that the system will work in MODE_START mode. When entering the menu with taskSelection=0, it is determined which of the defined tasks will run.

Starting from Figure 3, the value of 0, which is also present in the other steps of the algorithm, represents the passive value, and the value of 1 represents the active value. When the remainder of the onControlReset value divided by two, shown in Figure 3b, is equal to zero, the system switches to the off state. In Figure 3b, when the water temperature of the fuelLower boiler is below 30 degrees, the flag value becomes 1. In the same image, when the fuelHigher boiler water temperature rises above 60, the flag value becomes 1. When waterPumpCounter=0, the counter value is 1, the water pump is running. The button connected to the PD4 pin triggers the MODE_FORWARD mode.

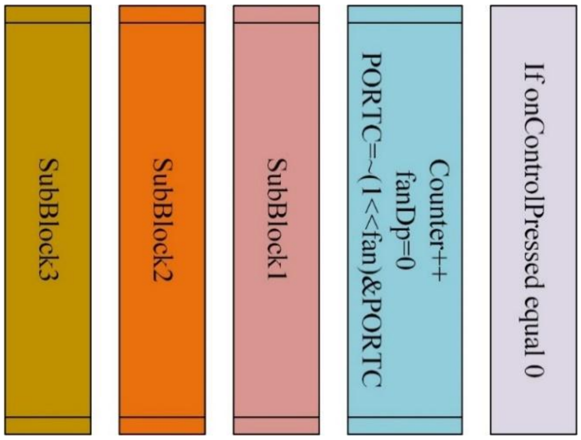

Figure 4. Turn off the pumps

If the onControlPressed value is not active when the specified button is pressed, MODE_FORWARD mode will not be switched. When the onControlPressed value is active, the startControlButtonPressed value is also active. Along with this value, the upWardDownWard flag is also active. OriginHead and counter values are inactive. upWardDownWard enables different options to move forward and backward when the application menu is entered while the system is running.

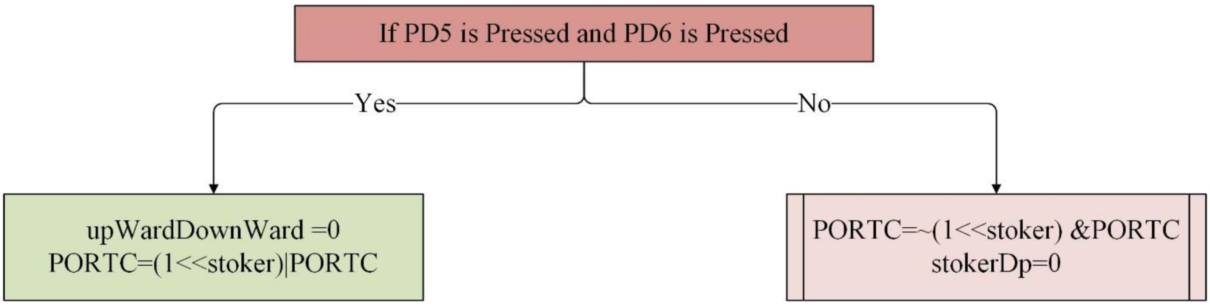

Figure 5. Pressing the forward and backward buttons at the same time

With the originHead value, the values defined in the menu are increased or decreased forward or backward, and the buzzer sensor makes a sound when the first button is pressed. If the PD5 button is pressed, the downWardControlPressed value becomes active. It is understood that the values in the menu can be changed downwards when this value is active. The PD6 button, on the other hand, activates the upWardControlPressed value. This provides an increase in value. From the menu, the boiler temperature, water pump temperature, timer 1, controlled fan speed adjustment, fuel loading time, and fuel waiting time can be adjusted in real-time.

In Figure 4, the forward and reverse buttons are passive and in the onControlPressed=0 state, pumps such as the fan and the water pump are stopped. Subsequently, the blocks are shown in Figure 4 run SubBlock1, SubBlock2, SubBlock3, respectively. Details of SubBlock1, SubBlock2, SubBlock3 block structures are shown in Figure5, Figure6, and Figure7, respectively.

In the structure in Figure 5, which is defined as SubBlock1, it is explained what to do and what not to do in the case of pressing the forward and reverse buttons at the same time while the system is in the off state. In case of pressing both buttons, fuel loading is performed manually, while the stoker is kept closed in case of not pressing.

Figure 6 shows the structure of SubBlock2. If onControlPressed is passive, the water temperature value is compared to the defined lower, upper, and a certain freezing degree. If the temperature value exceeds the defined upper or lower limit or falls below a certain freezing point, the water pump and stoker are activated. Otherwise, the stoker and the fan remain closed.

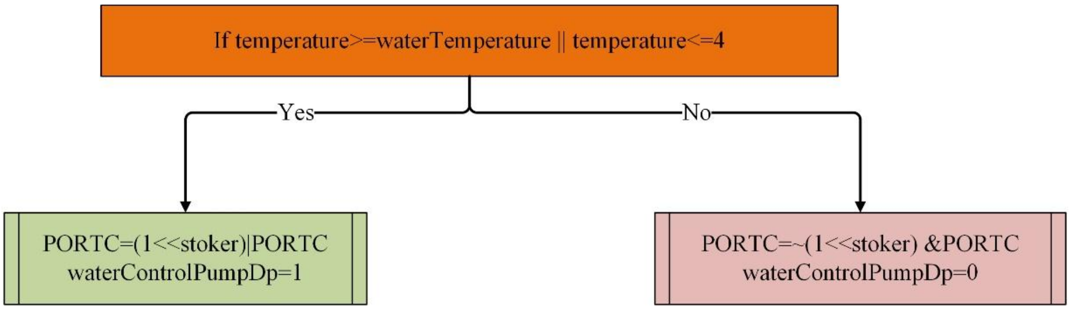

Figure 6. Water temperature control

Finally, the detail of the SubBlock3 block structure is defined in Figure 7. In this block, if onControlPressed is inactive, the brand=1 flag value is checked. If this value is active, the brand value is displayed. Otherwise, the temperature value and the off text are displayed in a rotating way between certain seconds.

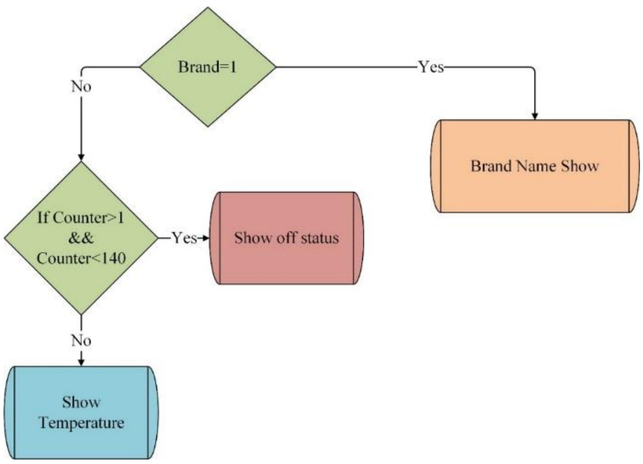

Figure 7. Show brand while waiting

3. Results and Discussion

Due to the increase in the human population and the need for energy demand according to this increase, the room temperature in the buildings should be protected according to the changing weather conditions. In this sense, the need for controllable heating systems is increasing day by day. A real-time boiler control algorithm has been developed by using AVR C language in line with different motivations and targets to reduce harmful emission rates in boiler systems and to provide heat production. The use of different circuit elements at 8 MHz frequency as input or output is provided by the algorithm realized in the AVR C language. The main goal of the developed control algorithm is to ensure that the system works continuously with predefined adjustments. Another goal is to make the desired adjustments by entering the menu during the real-time operation of the heating system. All interrupt functions supported by the Atmega16 microcontroller are used for different tasks in performing these operations.

The open diagram of the circuit elements described in the article is shown in Figure 11. Water pump, fan, stoker, 7 segment display connections, and button connections controlling these operations are shown in detail within the specified circuit. The relay connection, defined as the water circulation in Figure 11, represents the area where the water pump is active or passive. The relay connection, which is shown as fuel loading, shows the area where the stoker is opened and closed. The connection area of the air blower relay represents the connection area where the speed system of the fan structure is configured. Utilizing the room thermostat connection on the same figure, automatic operation of the boiler system can be achieved at desired temperature ranges. In this sense, it can be used in vegetable and fruit drying when it is desired to bring the environment to the desired temperature ranges in greenhouse systems or by adjusting the drying degrees of different fruits mentioned in [7].

The boiler control algorithm developed within the scope of the article was compiled and uploaded to atmega16. After loading the specified microcontroller, the system works with the connections shown in Figure 11. The printed circuit format of the developed study was designed in the proteus environment. It has undergone numerous experimental tests on development boards before moving to the printed circuit stage to reduce costs. The 4, 5, 6, 7. pins connected to the port PORTD represent the Up, Down, Menu, On, and Off buttons, respectively. The symbols on the right side of Figure 8 show the symbols and errors that may occur during the operation of the system. Pr shows the programmed temperature, Fn fan speed, CP water pump, FLT fuel loading time, FWT fuel waiting time. AnT shows the temperature value that increases excessively. With this control, the explosion of the overheated heating system is prevented. A possible error condition is displayed on the analog sensor used in Sen. On the other hand, FO shows the state of running out of fuel even though the circuit elements work in the boiler system. In addition, iso 9001 and ce on the right in Figure 8 show the standard values. These standard values can be added to the panel on request from the boiler manufacturers.

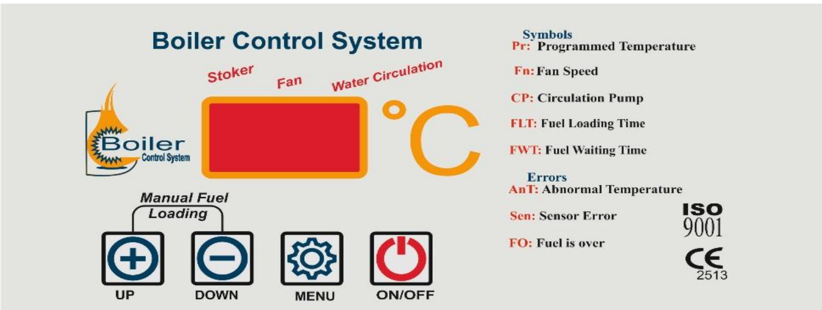

Figure 8. Boiler control system panel

The suggested algorithm steps are shown in Figures 1-8. In Figure 11, detailed drawings and connections of the designed electronic board are presented in detail. The real-time operating results of the system consisting of the specified connections are shown in Figure 11. The fact that the system is real-time provides the opportunity to continuously change the boiler operating settings as desired, even during operation. In this sense, it will provide great convenience to the user who does not know the operation of the boiler system.

a) b)

Figure 9. Real-time operating states: a) off state, b) active state

At the same time, the objective is to be a useful tool for boiler workers. The part that is especially emphasized in this study is that the study brings an algorithm that can work quickly and in real-time to the literature. Figure 9a shows the system inactive in real-time, while Figure 9b shows the active state. According to the standards published by TURKISH STANDARDS INSTITUTION (TSE), it is seen that different materials such as concrete blocks, glazed bricks, gypsum, and particle boards, wood-based boards are used in thermal insulation. Building heating needs are calculated in Turkey according to the TS 825 standard [37]. This standard is used to determine the calculation rules for the net heating energy needed in buildings in our country. At the same time, these standards are updated at different times and are harmonized with the standards of the European Union [38]. Our country imports a large amount of energy from foreign countries [39]. About one-fifth of this energy is used in residences [37]. The architectural characteristics of residences or buildings where the energy will be used are considered an important variable in affecting heat loss. For these reasons, instead of controlling the conventional boiler systems, we suggested in this study to control the fuel systems by software-based fuel systems. To measure the efficiency of the proposed system, while calculating the conventional and fuel savings in the new type of boiler system, the calculation was carried out using a formula consisting of the following criteria.

Parameters affecting fuel consumption are given below with their units:

- Calculated total heat loss of the building (CTHB) (kcal/h),
- boiler annual operating time (BAOT) (h),
- the lower calorific value of the fuel (LCVF) (kcal/kg),
- boiler efficiency (BE).

According to the specified parameters, CTHB, LCVF, BE are considered constant, while BAOT varies in both boilers. A real performance evaluation was carried out in the same building, in the same boiler, using the same fuel. The main parameter that varies here is the operating time of the boiler.

$$Fuel\ consumption = CTHBxBAOT/(2xLCVFxBE)(\text{kWh/m}^2) \quad (1)$$

The lack of effective control of motors such as fans, stokers, and water pumps in conventional boiler systems affects the life span of the boiler circuit elements. In this case, these engines and other boiler circuit elements that assist these engines work uninterruptedly until the user arrives. As a result of this process, harmful gases that have no calorific value are given to the air and unburned solid wastes continue to pollute nature.

Table 4. Performance chart

Year	Month	Conventional (h)	Proposed (h)
2020	December	430	370
2021	January	426,25	361
2021	February	423,5	345
2021	March	529,5	452
2021	April	216	190
2021	May	34,75	24,2
2021	June	52,75	41
2021	July	43,25	34
2021	August	66	40
2021	September	37,75	30
2021	October	174,75	126
2021	November	299,75	143,2
2021	December	461,25	400
Total		**3195,5**	**2556,4**

An algorithm has been proposed for the effective control of boiler circuit elements, which will affect the reduction of this problem. To measure the effectiveness of the proposed algorithm, the performance results obtained in the experimental studies were compared. The comparison was made by paying attention to the fact that all other effects did not change despite a single changing effect. The comparison of the conventional and the proposed system was made according to this effect.

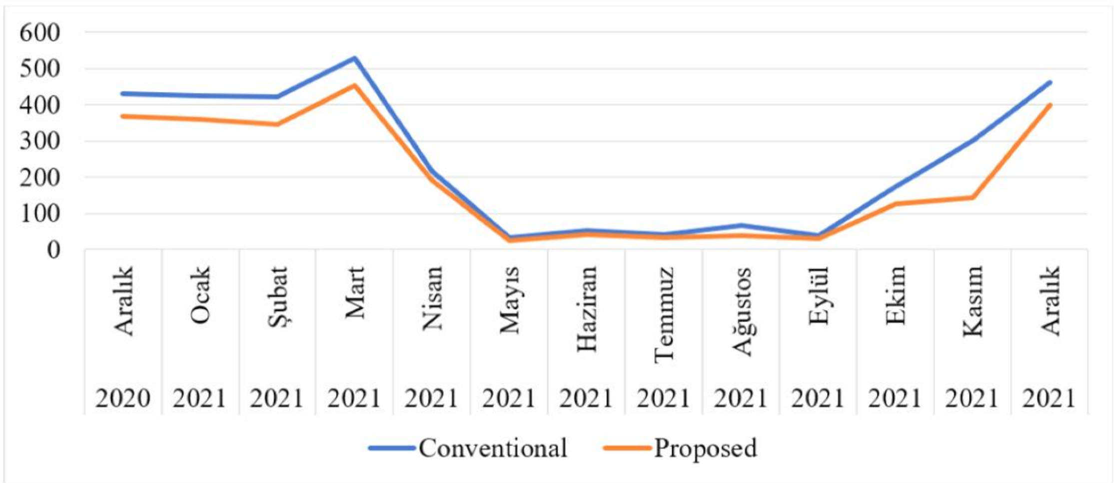

Figure 10. Fuel consumption comparison chart

The operating times of the boiler system controlled by the conventional and real-time circuit according to the formula in Equation 1 are given in Table 4 in hours. The results obtained over the measured values are presented in Figure 10 as a performance graph. According to the given figure and table, there is a close difference between the conventional and the proposed control algorithm system. In experimental studies on the same type of boiler, it can be said that the boiler elements are that work is more wear out more than the proposed system. While performing the heating task in both systems, the proposed system provides a more effective performance.

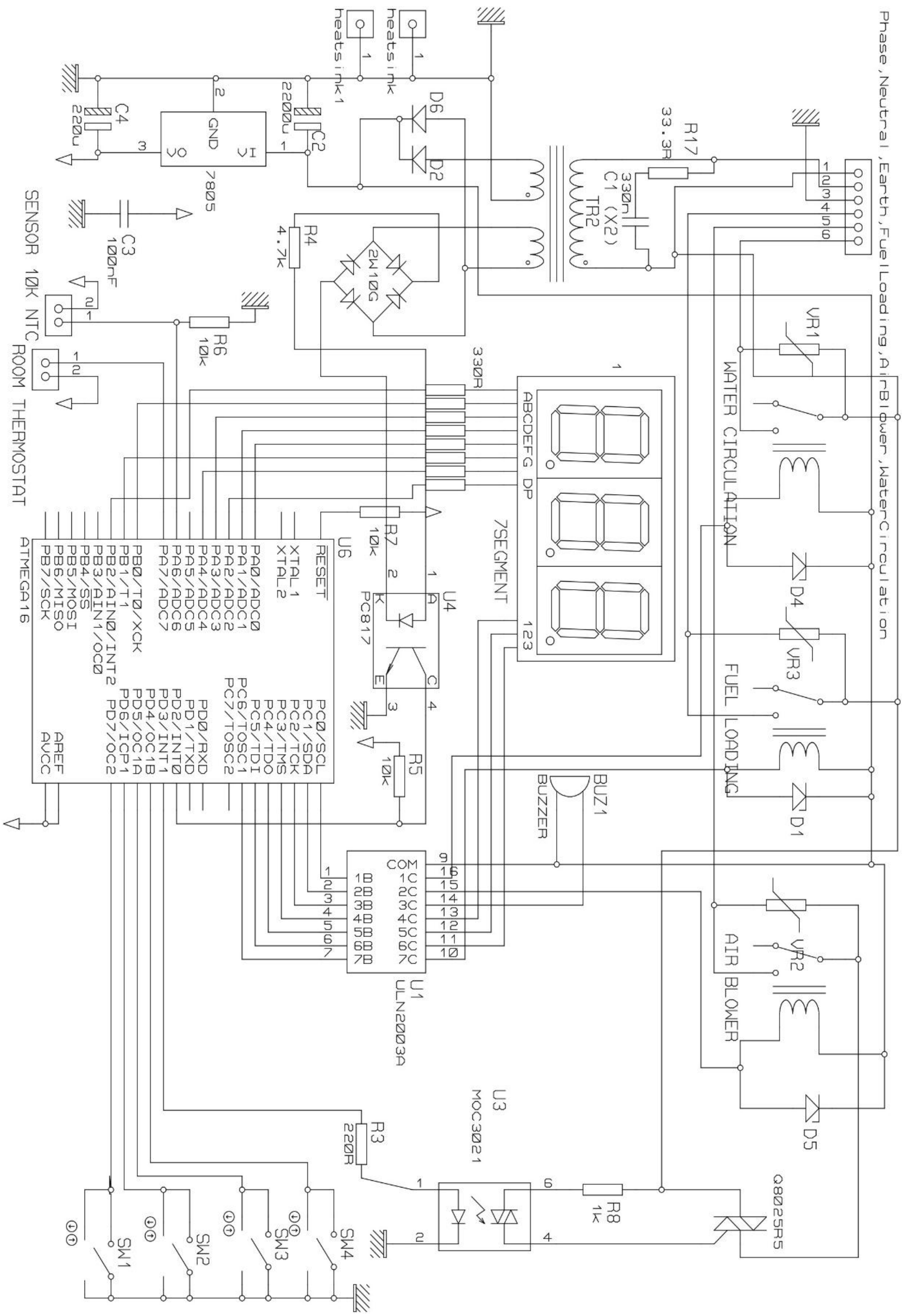

Figure 11. Design of the boiler control system

Although it is thought that the areas other than the operation of the boiler are fixed and the same in the study, when the literature is examined, it is stated that the continuous cleaning of the boiler directly affects the energy efficiency in solid fuel boilers [11]. Some parameters are out of control like this. With these uncontrollable parameters, it is stated in the literature that only mechanical boiler manufacturing is not sufficient for energy efficiency and the reduction of harmful gases [40]. Srivastava et al. [40] acknowledge that optimizing energy consumption will minimize harmful emissions to the environment. At the same time, it is reported that adjusting the solid fuel circulation time and the height of the fuel loading chamber will reduce the emission values [9]. Considering that there are many parameters affecting fuel performance in line with the information in the literature, it has been proven that controlling the operating performance of the boiler system will improve fuel economy. When the different emission reduction studies in the literature are examined, it is seen that the study adds a different perspective on effective boiler operating systems.

4. Conclusions

The proposed boiler control algorithm controls all circuit elements in real-time, especially the main circuit elements such as fuel, water, and air of the boiler used as the heating system. In the industrial sense, based on this system, the system can be operated in such a way that there is no waste material in the boiler system. Automatic control of new-generation boiler systems was carried out without using any manpower, with the specified targets.

While the fan normally runs at high speed, two different speed levels, slow and medium, have been added to the system. The fan can operate in 3 different speed structures in total. The boiler user can perform the specified speed level adjustment process in real-time from the menu at any time. The user can choose whether the boiler system works fast or slow. As a result of the speed preferences made, the fan ensures the ignition of the boiler at the desired speed. If the fuel runs out, the pumps are automatically shut down after waiting for a user-definable time in the system. The result obtained in terms of energy savings and the service life of the products used is important for boiler manufacturers and users. In addition, a new boiler control algorithm has been developed that can be used for different tasks such as maintaining humidity and drying fruits and vegetables produced in greenhouse systems. When the proposed boiler control algorithm and the no algorithm boiler system were compared in the new type of boiler system, it was determined that approximately 20% of fuel savings were achieved. This shows that the proposed algorithm produces meaningful results. While carrying out the proposed study, engine control was performed that provides slow, medium, and fast combustion of solid fuel. Motor control ensures that the motors rotate at the desired speed. This advantage ensures that the calories from solid fuels, such as hazelnuts, are slowly burned without going outside. To perform this operation, the TRIAC control, which is one of the boiler elements, is provided. In this TRIAC control, the PWM signal, which is defined as pulse width modulation, is effectively controlled. Since the lower and upper drying values of each fruit are different, the proposed system is suitable for use to create controlled heating systems between the specified lower and upper values. In future studies, it is planned to be used in all buildings as well as in greenhouses, which are active agricultural production areas, to keep temperature values constant and to dry different fruits.

Competing Interests

This article does not contain potential conflicts of interest. The study declares that it is original to new algorithm development and does not require the permission of the ethics committee or any special permission.

Author's Contributions

H Çetiner designed and coded the algorithm based on AVR C mentioned in the article. At the same time, he researched and wrote all sections related to the algorithm in the article and designed the user panel. On the other hand, I. Çetiner was interested in the electronic circuit and printed circuit design in which the codes are run. In addition, it has enabled the research of products similar to the developed product and the detection of missing points.

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