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DESIGN AND APPLICATION OF A LOW-COST MEASUREMENT CIRCUIT IN AUTOMOBILES

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ABSTRACT: The increase in the equipment in vehicles with the developing technologies has caused the electrical circuits in automobiles to become complex. For this reason, it takes a long time to find faults in electrical circuits in vehicles. In automobile services, the robustness of automobile fuses is checked using a multimeter and series lamp. In such a complex circuit, a series lamp cannot be used to decide whether the automotive electrical load or the receiver is operational or not. It is not always possible to measure the current drawn by the receivers with a multimeter in a practical way. Fuse current testers, which measure the current drawn by the receivers through the fuse, are also costly even for the service centers. By measuring the voltage drop across the fuses in vehicles with a multimeter and using the fuse voltage drop cards, it is possible to determine the current drawn by the load based on the color, the type, and the current value listed on a fuse label. It is not practicable to determine the current absorbed by the loads using this method. Arduino is a family of microcontroller development devices that are utilized in numerous measurement system applications. In this study, a fuse current tester is proposed for measuring the voltage drop across the fuses to calculate the load current in a vehicle using an Arduino development board. The developed current tester can be used in circuit studies in automotive electronics and electronics courses and in determining whether the fuse value is sufficient in automobiles or in detecting the overcurrent-drawing load in the event of a leakage current. The proposed system was tested on automotive fuses and it was found that the average absolute percentage error value of the load current is around 4%. This system can be used to perform tests in automotive electrical laboratories, or it can be implemented in the classroom to give students hands-on experience. Furthermore, it was found that by integrating this low-cost and easy-to-install system into the systems of motor vehicles, continuous monitoring of the electrical circuits of motor vehicles is possible, so that the vehicles can diagnose the failed electrical circuits themselves.

Keywords: Automobile fuse, fuse tester, load current measurement, microcontroller-based system, automobile load diagnosis.

1. INTRODUCTION

Microcontrollers include the microprocessor and the requisite hardware blocks (RAM, ROM, timers, etc.) for the microprocessor to function. Due to these characteristics and the ability to develop direct applications on a single chip, they are extensively utilized in amateur, semi-professional, and professional settings (Ibrahim, 2006). Numerous development boards with microcontrollers are marketed to rapidly learn microcontrollers and develop applications. The Arduino development board family is the most renowned and popular of these board families

(Banzi and Shiloh, 2022). Arduino is favored by amateur programmers because it is inexpensive, compatible with numerous expansion devices, and provides a free integrated development environment (IDE) (Integrated Development Environment). These development cards can be combined with sensors to establish a measurement system (Hakim et al. 2018; Dandıl and Demir 2020; Srividyadevi 2013). Educative laboratories have utilized Arduino-based designs in a variety of methods (Uzal, 2022; Duman, 2019; Kırıkkaya and Başaran, 2017; Organtini, 2018). In the literature, examples of Arduino-based systems have been developed for monitoring vehicle variables and automating measurements in automotive laboratories (Hakim et al., 2018; Dandıl and Demir, 2020; Vaishnavi, 2016).

Circuits and systems are protected from the harmful effects of high currents by fuses. There are numerous independent circuits and a fuse for each one of the systems in automobiles (Seo et al., 2011). These fuses are located in the fuse box of the vehicle. Due to the relatively high currents in automobiles and the numerous factors that can negatively affect the circuits, blown fuses are a common occurrence. In this regard, it can be stated that automotive electricians frequently inspect fuses when performing repairs (Li and Zhang, 2011).

There are many published studies on measuring electrical quantities with a microcontroller-based circuit (Mohammed et al., 2019). Some of them are equipped with Arduino development kits. Fan et al. proposed a computer-connected fuse tester based on an ARM microcontroller. Their system investigates the signal behavior of fuses and is not designed for automotive fuses (Fan et al., 2016). Li and Zhang proposed a device that informs the system of the status of all fuses in the fuse compartment of a vehicle. Their proposed system is based on LabView (Li and Zhang, 2011).

To the best of our knowledge, an Arduino-based system that automatically measures the status of automotive fuses based on the fuse voltage drop and the fuse voltage drop table has not yet been developed. In this study, an Arduino-based current tester device is proposed for automating the checking of the status of automotive fuses and measurement of the automotive load current in an automotive laboratory. Since this measurement device is composed of readily available and inexpensive components, it can be made by students and used to outfit a laboratory.

The study is arranged as follows. In the second section, the hardware of the proposed Arduino-based test system is presented and it is described how its program operates. The experimental results of the proposed system are presented and discussed in the third section. The study is concluded with a discussion and results section.

2. MATERIALS AND METHOD

2.1. Automobile Fuses and The Fuse Box Experimented in This Study

In vehicles, fuses are used to protect the electrical system and circuit elements by interrupting the circuit in the event of a high current draw by the circuit. In the motor vehicles, the fuses can blow for three reasons: an incorrect wiring or connection, a short circuit, and a high current consumption of the load. If a fuse blows constantly, it is essential to investigate the cause. The maximum current value it can carry or its rated current is indicated on the top of a fuse. The fuse is connected in series to the positive lead of the circuit. Although glass fuse and stone fuse types are commonly used in automobiles, blade fuses are also used in today's vehicles. Only blade fuses were used in this study. There is a color standard system that specifies the currents and types of these fuses. The information on the colors and voltage drop values of the fuses used in the automotive industry is listed in Table 1.

Table 1. The fuse voltage drop table in milivolts and the load current in miliamperes. (Web 1, 2022).

Fuse Voltage Drop Chart - Standard Fuse (ATO,ATC)
Circuit Current Across Fuse (milliAmps)

Fuse Color	Black	Grey	Violet	Pink	Tan	Brown	Red	Blue	Yellow	Clear	Green	Blu-Green	Orange
Measurement mV	Standard 1 Amp	Standard 2 Amp	Standard 3 Amp	Standard 4 Amp	Standard 5 Amp	Standard 7.5 Amp	Standard 10 Amp	Standard 15 Amp	Standard 20 Amp	Standard 25 Amp	Standard 30 Amp	Standard 35 Amp	Standard 40 Amp
[illegible]	1	2	3	4	6	9	[illegible]	21	30	40	51	62	69
[illegible]	2	4	6	9	11	18	[illegible]	42	59	79	102	124	139
[illegible]	2	6	10	13	17	27	[illegible]	63	89	119	152	186	208
[illegible]	3	7	13	18	22	37	[illegible]	83	118	159	203	248	278
[illegible]	4	9	16	22	28	46	[illegible]	104	148	198	254	311	347
[illegible]	5	11	19	26	34	55	[illegible]	125	178	238	305	373	417
[illegible]	6	13	23	31	39	64	[illegible]	146	207	278	355	435	486
[illegible]	7	15	26	35	45	73	[illegible]	167	237	317	406	497	556
[illegible]	7	17	29	39	50	82	[illegible]	188	266	357	457	559	625
[illegible]	8	19	32	44	56	92	[illegible]	208	296	397	508	621	694
[illegible]	9	21	35	48	62	101	[illegible]	229	325	437	558	683	764
[illegible]	10	22	39	53	67	110	[illegible]	250	355	476	609	745	833
[illegible]	11	24	42	57	73	119	[illegible]	271	385	516	660	807	903
[illegible]	11	26	45	61	78	128	[illegible]	292	414	556	711	870	972
[illegible]	12	28	48	66	84	137	[illegible]	313	444	595	761	932	1042
[illegible]	13	30	51	70	90	147	[illegible]	333	473	635	812	994	1111
[illegible]	14	32	55	75	95	156	[illegible]	354	503	675	863	1056	1181
[illegible]	15	34	58	79	101	165	[illegible]	375	533	714	914	1118	1250
[illegible]	15	36	61	83	106	174	[illegible]	396	562	754	964	1180	1319
[illegible]	16	37	64	88	112	183	[illegible]	417	592	794	1015	1242	1389
[illegible]	17	39	68	92	118	192	[illegible]	438	621	833	1066	1304	1458
2.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	286	458	651	873	1117	1366	1528
[illegible]	19	43	74	101	129	211	[illegible]	479	680	913	1168	1429	1597
2.4	20	45	77	105	134	220	312	500	710	952	1218	1491	1667
2.5	20	47	80	110	140	229	325	521	740	992	1269	1553	1736
2.6	21	49	84	114	146	238	338	542	769	1032	1320	1615	1806
2.7	22	50	87	118	151	247	351	563	799	1071	1371	1677	1875
2.8	23	52	90	123	157	257	364	583	828	1111	1421	1739	1944
2.9	24	54	93	127	162	266	377	604	858	1151	1472	1801	2014
3	24	56	96	132	168	275	390	625	888	1190	1523	1863	2083
3.1	25	58	100	136	174	284	403	646	917	1230	1574	1925	2153
3.2	26	60	103	140	179	293	416	667	947	1270	1624	1988	2222

By measuring the voltage drop across a fuse whose type is known and using the values in Table 1, it is possible to estimate the current flowing through the fuse. To measure the current drawn by the loads of the indicator lighting system, which is highlighted in red in the voltage drop table of the fuses in Table 1, a voltage drop value of 2.2 mV was determined with the aid of a multimeter across the red-colored 10 A rated fuse in the circuit of the indicator lighting. This value corresponds to a current of 286 milliamperes or 0.286 Amperes on the voltage drop card of the fuse. This value was compared with the experimental value measured in the Arduino system later.

Vehicles can have more than one fuse box containing the fuses used for this purpose. The experimental tests of the Arduino-based system were carried out on the electrical system and fuse box of a diesel vehicle of a Ford Transit Connect. There are two fuse boxes in the vehicle cabin and under the hood of the vehicle. In Figure 1, The experiments were carried out on the fuse box under the hood of this vehicle shown in Figure 1. The small boxes in the fuse boxes are relays. Under the cover of the fuse box, there are the figures or the names indicating which fuse belongs to which system.

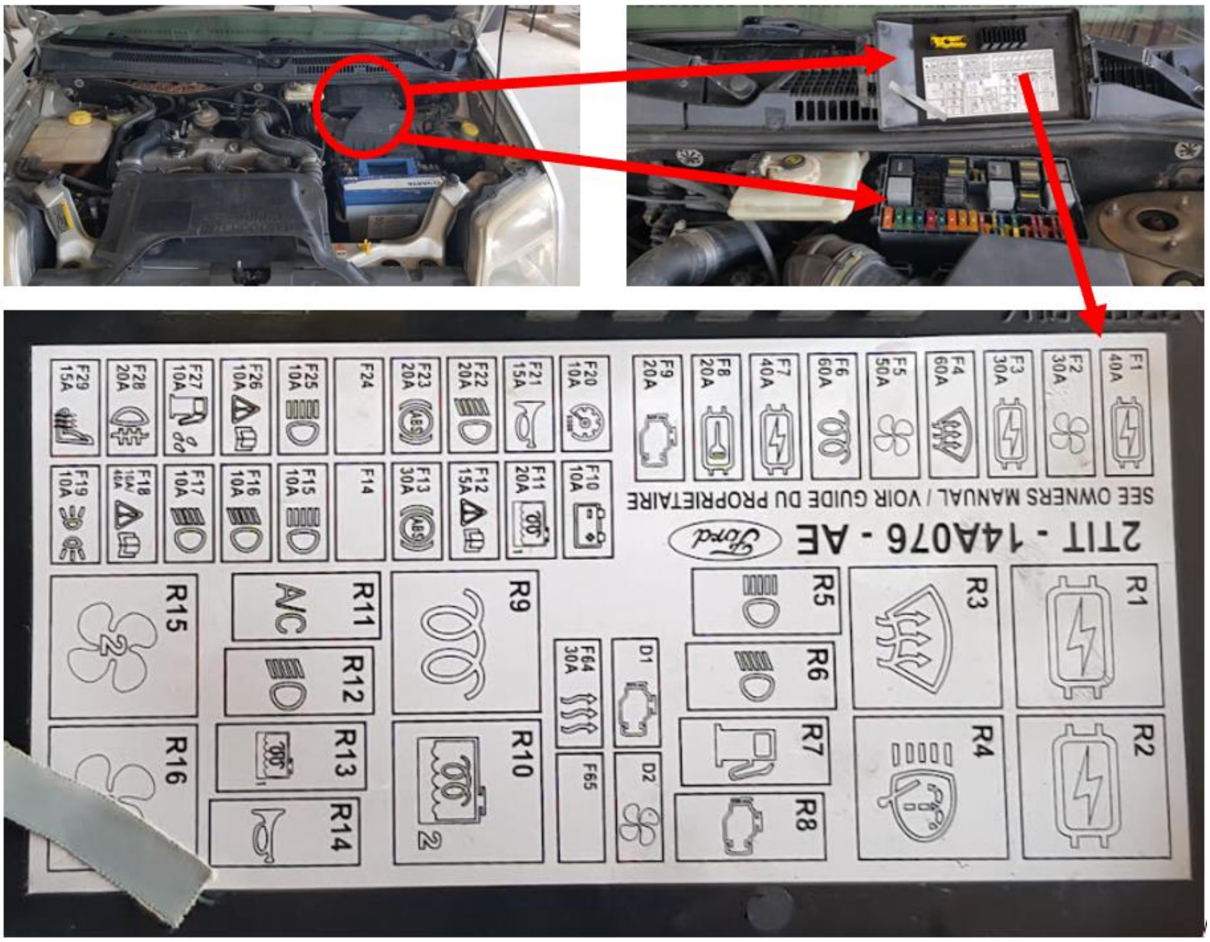

Figure 1. The fuse box under the hood of the vehicle where the experiments were carried out and its cover.

2.2. The Fuse Current Tester Hardware

Figure 2 depicts the proposed hardware's fundamental layout. In the system's central processing unit, there is an Arduino Nano development board. This board's processing core is a microcontroller, which is notable for its affordability, accessibility, and ease of programming (Patnaik, 2017). This development board was selected due to these qualities. To measure the current flowing through the automotive fuse, it is necessary to know both the voltage drop across the fuse while the current flows through it and the electrical resistance of the fuse. A differential amplifier is installed detect the voltage drop across the fuse. The operational amplifier shown in Figure 2 is chosen as an LM358 since it is cheap and it can operate with a single power supply. One of the microcontroller's analog inputs is connected to the output of the differential amplifier. This allows the microcontroller to read the voltage between the fuse's two ends. An LCD panel display and an LCD controller are available for the system's communication with the user. The LCD panel display and the microcontroller communicate using the I2C (Inter-Integrated Circuit) protocol (Liu et al., 2019). Thus, relatively few the microcontroller connections are utilized. Using the system's joystick, the fuse type and color can be selected.

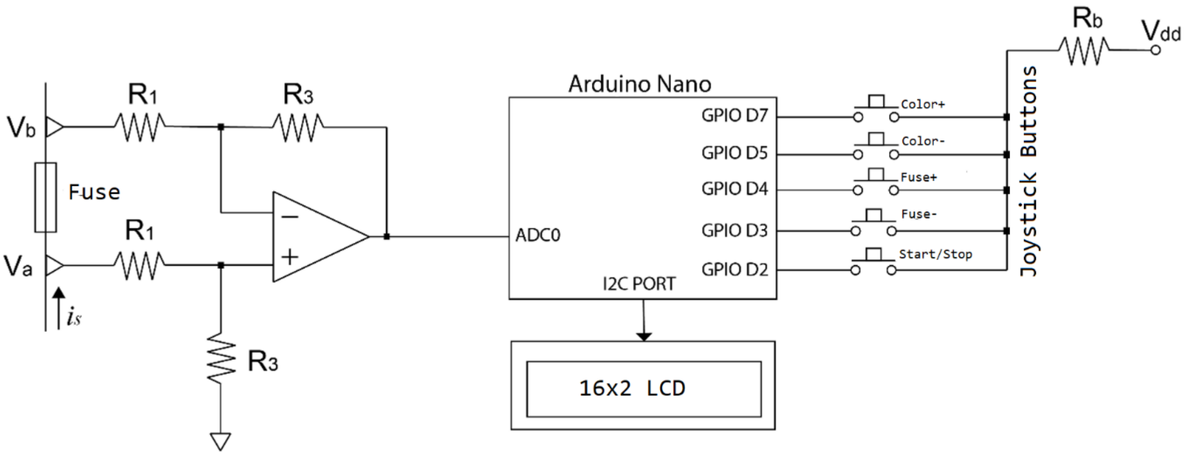

Figure 2. The fuse current tester circuit.

The output voltage of the differential amplifier shown in Figure 2 is given as:

$$V_{ADC0} = (V_a - V_b)\frac{R_3}{R_1} \quad (1)$$

where the output voltage of the differential amplifier is V_{ADC0}, and, V_a and V_b are node voltages at ends both ends of the fuse to be measured.

The microcontroller calculates the current flowing through the fuse using Ohm's law as:

$$i_F = \frac{V_{ADC0}}{R_F} \quad (2)$$

where R_F is the electrical resistance of the measured fuse.

In most of the electrical systems, the voltage drop across the fuse is usually accepted as negligible, i.e., as 0 volts. However, in automobiles, a substantial voltage drop is measured across the fuse. This value varies according to the color codes of the fuses. These color codes of the automobile fuses are given in Table 1. When the voltage values in this table are divided by the current value of the fuses according to Ohm's law, the fuse resistance value R_F is found.

A photograph of the proposed design is given in Figure 3. The circuit is powered by a 9 V battery and controlled by an Arduino Nano. The user interacts with the system via the LCD and joystick. As seen on LCD, the user determines the type and color of the fuse. The photograph given in Figure 4 depicts the application of the voltage drop measurement of an automotive fuse with the designed system.

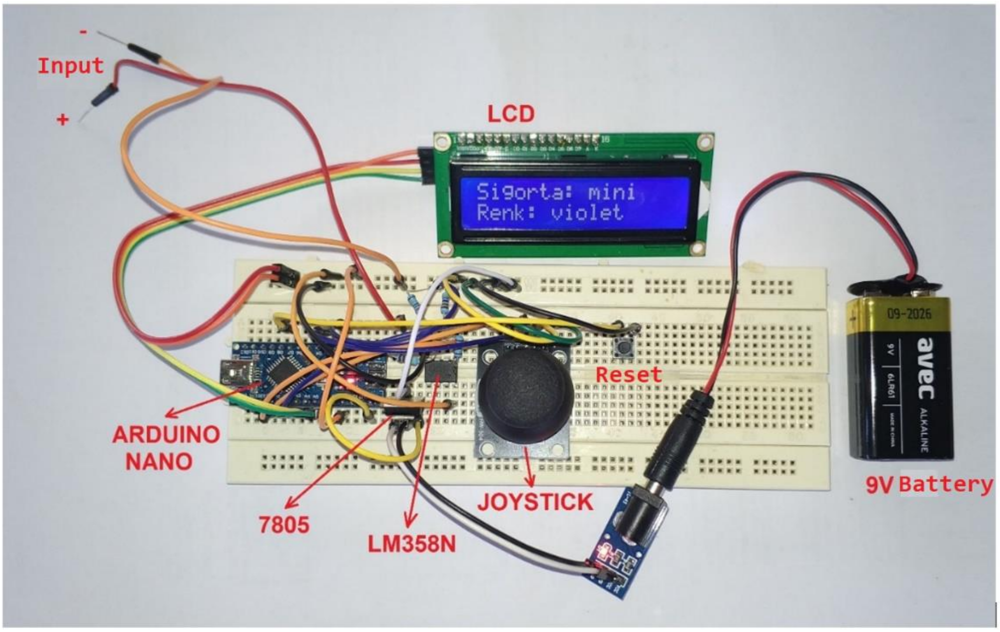

Figure 3. The current detection circuit.

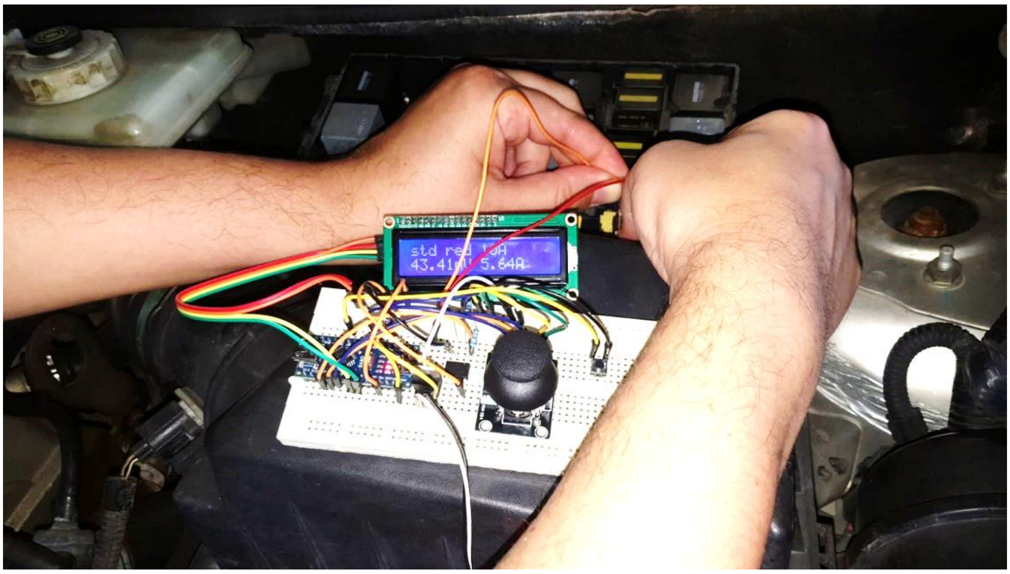

Figure 4. The voltage drop measurement with the designed circuit.

The Extech EX410A multimeter served as a standard for measuring the voltage drop across the fuses. Table 2 lists the general specifications of the Extech EX410A multimeter.

Table 2. The general specifications of Extech EX410A multimeter.

Features	Levels
Basic Accuracy (VDC)	0.5 ±%
Alternating Current Voltage	600 V – 1 mV
DC voltage	0.1 V – 600 V
AC current	0.1 mA – 10 A
DC current	0.1 µA – 10 A
Resistance	0.1 Ω – 20 MΩ
Temperature (Type K)	-4 to 1382 ° F (-20 to 750 ° C)

2. 3. On the Device Software

Figure 5 displays the Arduino software's flowchart. First, the software defines the arrays to contain the constant values. The array *fuseTypes* stores the fuse types to be measured, the array *fuseColorCounts* stores the number of colors available for each fuse type, and the array fuseResistanceValues stores the resistance values corresponding to the color of each fuse type. The resistance values of the fuses are calculated using Ohm's law and the current and voltage values of the fuses given in Table 1 for each fuse type. The *fuseColors* array stores the colors available for all fuse types, while the *fuseValues* array stores the rated fuse current value corresponding to the color of each fuse type.

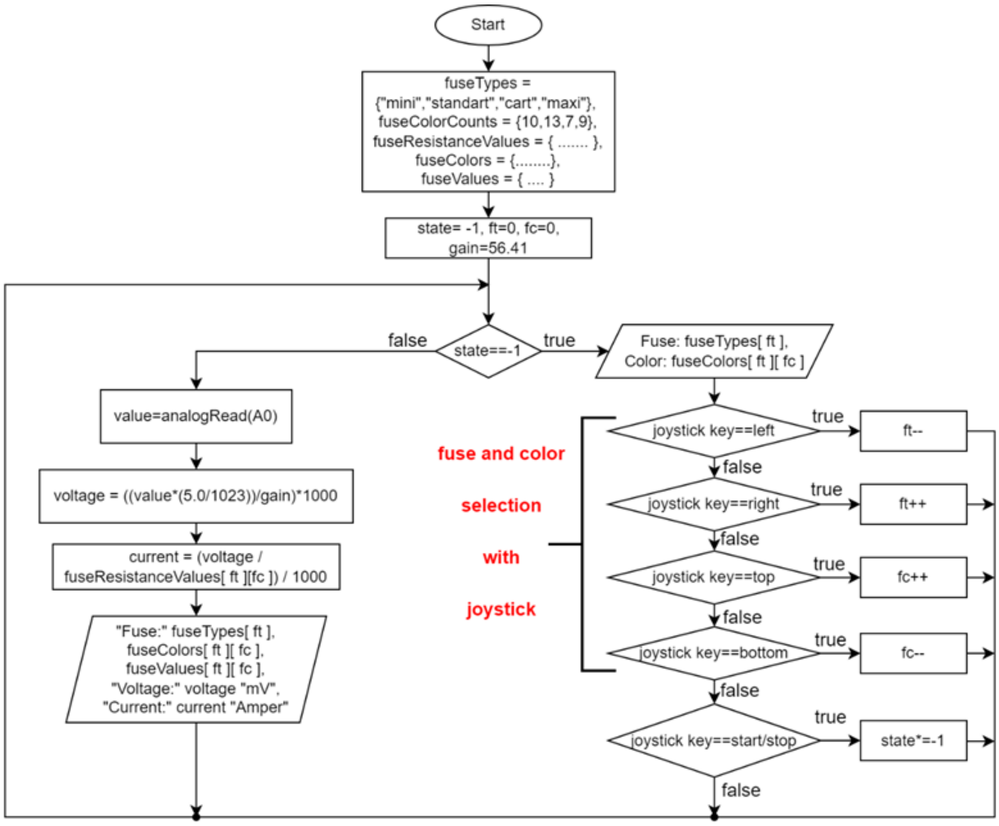

Figure 5. Flowchart of the Fuse Measurement System program.

3. EXPERIMENTAL RESULTS

Experimental tests of the system were performed on the electrical system and fuse box of a Ford Transit Connect model vehicle. An Extech EX410A multimeter was used as a reference measurement device. The results of four different automobile load measurements are shown in Table 3.

Tablo 3. Results of the Measurement.

Number of measurements (n)	Circuit name	Color code of the circuit fuse	The rated current value of the circuit fuse (A)	The voltage drop across the fuse measured with the multimeter (V_m) (millivolt)	The current value read from the fuse voltage drop card (I_T) (A)	The voltage value measured by the proposed measuring system (V_F) (millivolt)	The current value measured by the proposed measuring system (I_F) (A)	$\%e_V$	$\% e_I$
1. Measurement	**Dipped Beam Circuit**	**Red**	10	35.4	4.55	36.56	4.75	3.28	4.40
2. Measurement	**High Beam Circuit**	**Red**	10	42	5.45	43.50	5.64	3.57	3.49
3. Measurement	**Rear Fog Lamp**	**Yellow**	20	5.6	1.657	5.81	1.72	3.75	3.80
4. Measurement	**Instrument Lighting**	**Red**	10	2.2	0.286	2.34	0.30	6.36	4.90

Using a multimeter to measure the current drawn by the lighting system's receivers, a voltage decrease of 35.4 mV was detected at the 10-amp rated red fuse in the low beam circuit. On the fuse voltage drop card, this value draws a current of 4.55 Amps, according to the fuse's characteristic. Using the apparatus designed to measure the current drawn by the lighting system receivers, a voltage of 36.56 mV was measured on the red fuse rated for 10 Amps in the low beam circuit, and 4.75 Amps was determined to be the current drawn by the receiver.

A multimeter was used to measure a voltage of 42 mV across the red fuse rated for 10 Amps in the high beam circuit in order to determine the current consumed by the lighting system receivers. According to the characteristics of the fuse, this value is referenced in the voltage drop table of the fuse. With the apparatus designed to measure the current drawn by the high beam circuit, 43.50 mV was measured at the red fuse with a rating of 10 Amps in the high beam circuit, and 5.64 Amps was reported as the current drawn by the receiver.

To measure the current drawn by the lighting system's receivers,a multimeter was used to measure a voltage of 5.6 mV across a 20-ampere-rated yellow fuse in the rear fog light circuit. Depending on the fuse characteristic in the fuse voltage drop table, this value is assumed to consume 1.657 Amps. The apparatus designed to measure the current drawn by the rear fog light circuit measured a voltage of 5.81 mV at the yellow fuse with a rating of 20 Amps in the high beam circuit and a current of 1.72 Amps drawn by the receiver.

Using a multimeter, a voltage drop of 2.2 mV across the red-colored 10 Ampere-rated fuse was measured in the circuit of the flashing lights to measure the current drawn by the lighting system's load. This value corresponds to a current of 0.28 Amps according to the fuse voltage drop chart. Using the system for measuring the current drawn by the lighting system's loads, a voltage drop of 2.34 mV was measured across the 10-Amp red fuse in the circuit of the flashing lights, and a load current of 0.30 Amperes was calculated.

Using the measured and the read voltage drop value across the fuse, the absolute percent error value of the fuse voltage of the proposed measuring device is calculated as:

$$\%e_V = \left|\frac{V_s - V_m}{V_m}\right| x100 \quad (3)$$

where V_s is the voltage measured by the designed device and V_m is the voltage measured by the reference device, the Extech EX410A multimeter.
Using the calculated/measured fuse current and the fuse current read from the voltage drop table of the fuse, the absolute percent error value of the fuse current of the proposed measuring device is:

$$\%e_I = \left|\frac{I_F - I_T}{I_T}\right| x\ 100 \quad (4)$$

where I_s is the current measured by the designed device and I_T is the current read from the voltage drop table of the fuse.

The mean absolute percentage error of the fuse current tester can be calculated as:

$$\%e_T = \frac{\sum_{i=1}^{n} \%e_i}{\mathrm{n}} \quad (5)$$

where n is the number of measurements. According to the experimental results of this study, the mean absolute percentage error value for the voltage and current values was calculated as 4,24% and 4,1475%, respectively.

4. CONCLUSION and SUGGESTIONS

Based on the color, type, and rated current of the fuse, one can determine how much current the load draws by measuring the voltage drop across the fuse with a multimeter with the help of voltage drop charts for fuses. In this study, a measuring device, a fuse current tester, that can simultaneously display on a single screen the voltage drop across the fuse and the current drawn by the receiver, is proposed and designed. With the designed measurement tool, it is possible to easily measure the current drawn by the loads by reading the voltage drop across of the fuse in the vehicle and it can be used as a low-cost alternative tool to determine the current drawn by the electrical loads of a vehicle by means of the voltage drop maps of the fuses. By using the proposed Arduino-based fuse testing system, the time lost in searching for faults in the electrical loads of the vehicles can be reduced as the electrical circuits in the vehicles are becoming more complex due to the increasing equipment. In addition, since the proposed system is economical, the financial burden on the services for providing fuse current testers that measure the current drawn by the receivers through the fuse will be reduced.

When compared with the existing measurement tools in terms of ease of use, cost and use in student workshops in automotive programmes in Vocational colleges, it was found that the developed measurement tool has an advantageous structure by displaying the voltage drop on the fuse and the current drawn by the receiver on the same screen. In addition, due to the designed system's simplicity, students can create their own fuse testing devices using readily available and inexpensive materials. As a result, the construction and testing of this measurement system can become a classroom exercise, and it can also be used to equip a large number of automotive electrical businesses.

Due to the low cost and ease of installation, by integrating this system into the automotive systems using artificial intelligence, continuous monitoring of the electrical circuits of the automobiles can be ensured, the faults that will occur in the electrical circuits of the vehicles can be diagnosed quickly and easily, and the electrical circuits of the vehicles can be enabled to self-diagnose. Thanks to the continuous monitoring of the electrical circuits, vehicle fires caused by malfunctions in the electrical circuits can be prevented.

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REFERENCES

Banzi M., Shiloh M., Getting started with Arduino, (2022). Maker Media, Inc..

Dandıl E., Demir E., Gerçek Zamanlı Araç Hız Ölçümü ve Takip Sistemi Tasarımı, Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, (2020) 10(1): 13-27.

Duman O., Eğitimde arduino kullanımı ile ilgili yapılan çalışmalar. XII. Uluslararası Eğitim Araştırmaları Kongresi, (2019) April 25-28, Rize, Turkey.

Fan T., Hu L., Zuo D., Chen R., Li F., Zhou B., The general Design of Tester System Based on ARM of Fuse, (2016) In 2016 4th International Conference on Machinery, Materials and Computing Technology (pp. 1049-1055). Atlantis Press.

Hakim L., Sitorus Z., Maududy M. M.A., Design tool of Motor Vehicle Emissions Measurement Devices with Based on Arduino Nano with Android Smartphone Viewer, (2018) International Journal of Applied Engineering Research,13, Number 6, 3975-3978.

Ibrahim D., Microcontroller based applied digital control, (2006). John Wiley & Sons.

Kırıkkaya E. B., Başaran B., Fizik Laboratuvarında Gerçekleştirilen Elektrik Deneylerinin Arduino Programı İle Yeniden Düzenlenmesi, (2017) IV. International Eurasian Educational Research Congress 2017 Bildiri Kitabı , 351-356

Li Y., Zhang Z. H., Circuit testing system of vehicle fuse box based on LabVIEW, (2011). In Applied Mechanics and Materials (Vol. 43, pp. 132-136). Trans Tech Publications Ltd.

Liu C., Meng Q., Liao T., Bao X., Xu C., A flexible hardware architecture for slave device of i2c bus, (2019) In 2019 International Conference on Electronic Engineering and Informatics (EEI) (pp. 309-313). IEEE.

Mohammed S. L., Al-Naji A., Farjo M. M., Chahl J., Highly accurate water level measurement system using a microcontroller and an ultrasonic sensor, (2019,). In IOP Conference Series: Materials Science and Engineering (Vol. 518, No. 4, p. 042025). IOP Publishing.

Organtini G., Arduino as a tool for physics experiments, (2018) J. Phys.: Conf. Ser., 1076, 012026

Patnaik Patnaikuni D. R., A Comparative Study of Arduino, Raspberry Pi and ESP8266 as IoT Development Board, (2017).International Journal of Advanced Research in Computer Science,8(5).

Srividyadevi P., Pusphalatha D. V., Sharma P. M., Measurement of power and energy using arduino, (2013) Research Journal of Engineering Sciences, 2278, 9472.

Seo H. J., Kim Y. K., Kim C. S., Kwon O. Y., Jeon, J. J., Kim T. J., The fatigue lifetime prediction of a fuse box under complex environment, (2011) (No. 2011-28-0130). SAE Technical Paper.

Uzal G., The Use of Arduino in Physics Laboratories, (2022) The Turkish Online Journal of Educational Technology, 21, 88-100.

Vaishnavi D., Sundari E., Sangeetha T.V., Shrinidhi S., Saravanan P., Design and Development of Computational Intelligence for Enhanced Adaptive Cruise Control Using Arduino, (2016) Applied Mechanics and Materials, 852, 782-787.

Web 1, https://www.scribd.com/document/381313888/Fuse-Voltage-Drop-Chart-Standard-Fuse-pdf, (2022) (Erişim Tarihi: 15/11/2022).