ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 1, No. 44 April 2020, pp.103-110.
Journal Homepage: erj.bu.edu.eg

Fault Detection for Medical Equipment by Electrical Signature Analysis

E. E. Naguib[1] and S. A. Fawzi [2]

[1] Lab head committee consultant engineer, Center for Advanced Software and Biomedical Engineering Consultations, Faculty of Engineering, Cairo University, Cairo, Egypt.
[2] Associate professor, Systems and Biomedical Engineering Department, Faculty of Engineering, Cairo University, Cairo, Egypt.

Abstract. Medical equipment are critical and high cost components in the healthcare system. This paper presents an automatic fault detection system to increase reliability and efficient use of medical equipment. The system is implemented based on an embedded circuit that uses real-time, external and non-invasive electric current sensor to apply Electrical Current Signature Analysis (ECSA). The Root Mean Square (RMS) of the collected data were calculated, saved and analyzed. The system has been tested for two different models of medical equipment. Promising results were obtained from testing two types of laboratory equipment. The system was able to detect the occurrence of different faults during equipment use in several modes of operation.

Keywords: Medical equipment, predictive maintenance, fault detection, electrical current signature.

1. INTRODUCTION

Medical equipment faults represent great economic burden for healthcare institutes because they interrupt the working flow and lead to idle periods or downtimes [1]. Most downtimes are due to mechanical failures that can be detected by the excess consumption of electric current. Electric power drivers containing electronic components as electrolyte filtering capacitors and power semiconductors may also cause equipment failures and lead to downtimes [2-3].

Early fault detection enhances the equipment performance by speeding up the process of unscheduled maintenance related to the predictive maintenance strategies. The equipment downtimes are reduced by applying the condition monitoring and analysis of different parameters such as current, voltage, and time-frequency domain analysis methodologies [2, 4]. Thus, serious failures and downtimes can be avoided through enabling careful condition-based impulsive decisions [5].

The follow up of all equipment in medium or large size hospitals is a vital and difficult task. There is a need worth applying in monitoring the different types of the expensive medical equipment. This can be accomplished by developing new adaptive strategy to monitor the equipment. This can be accomplished by developing new adaptive strategy to monitor the equipment.

This is accompanied by predicting a fault occurrence warning or by issuing a fault alert before the occurrence of a disastrous breakdown in hospital equipment [6-7]. Early faults detection, in biomedical equipment systems, is of a vital importance in reducing the risk on patient's life especially in implanted and life-support system .This will increase system reliability, reduce hospitalization time, and decrease patient suffering [8].

The Motor Current Signature Analysis (MCSA) is usually used for condition monitoring of the different types of electric motors such as Induction Motor (IM) and certain loads connected to the motors. MCSA based fault detection method is developed to detect fault related signatures by non-invasiveness, a low cost sensor, and simple installation [9-10]. Henry [11] developed an advanced model-based fault diagnosis method for aircraft flight control systems faults detection, primarily sensor and actuator to control surface servo-loops.

Despite the technology of early fault detection known for prior decades in the different fields, it was not used yet in the medical equipment. Such a system would send a warning for the decision maker center in a hospital to take a proper action considering a conditional maintenance task. Such a task will be executed before the fault aggravation that may cause a total failure of the equipment. Similar to the MCSA method, this paper will prove that Electric Current Signature Analysis (ELSA) is a successful and promising technique to predict some faults in the medical equipment inside the hospitals.

2. METHOD

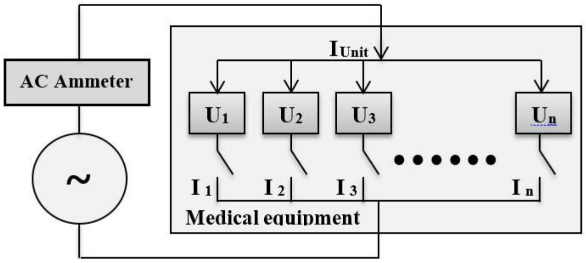


FIGURE 1. Electric Current Components Consumed by a Medical Device

The instantaneous consumption of electric current by any medical equipment is a function of its units according to its operating mode, as shown in Fig. 1. The total electric current consumed by a medical device I_{Total} is given by equation (1) where I_{Unit} represents the electric current consumption of each unit alone inside equipment.

$$\mathbf{I}_{\text{Total}} = \sum_{Unit=1}^{n} \mathbf{I}_{\text{Unit}} \quad (1)$$

The different modes of operation for equipment by calculation comprise the simultaneous running of multiple functioning parts at same time such as a light source, a paper feeding motor of thermal printer, a cooling fan, and any other component. The amount of current consumed during a certain operating mode is the sum of all the electric current of the operating units, in this mode. The maximum current consumption of the medical equipment will be detected when all the constituent parts operate simultaneously. The resulting consumption represents that of the internal components inside the medical equipment.

The usual technique of fault detection is checking the measured variables with tolerance margin and alerts the operator to do an appropriate action if a drift, from normal values of the operating parameters, was detected [12, 13].

Consider the normal measured electric current consumed by a specific mode of operation I_{Normal} at a certain time required some internal components of medical equipment to be run such as a basic consumed electric current by an equipment I_{Basic}, electric motor current I_{Motor}, and light source electric current I_{Light}, as in equation (1).

$$\mathbf{I}_{\mathbf{Normal}}(\mathbf{t}) = \mathbf{I}_{\mathbf{Basic}}(\mathbf{t}) + \mathbf{I}_{\mathbf{Motor}}(\mathbf{t}) + \mathbf{I}_{\mathbf{Light}}(\mathbf{t}) \quad (2)$$

If the faulty electric current consumed at that same mode (I_{Fault}) is not equal to normal measured electric current (I_{Normal}), then a fault is detected. To detect which component is not working properly, for example, it may be equal to the basic equipment current (I_{Basic}) and the motor current (I_{Motor}) components only without light source current (I_{Light}). Equation (2) explains this case under condition: $I_{Fault} < I_{Basic}$ that indicates the light source not working.

$$\mathbf{I}_{\mathbf{Fault}}(\mathbf{t}) = \mathbf{I}_{\mathbf{Basic}}(\mathbf{t}) + \mathbf{I}_{\mathbf{Motor}}(\mathbf{t}) + \mathbf{0} \quad (3)$$

Generally, the fault is detected if: $I_{Fault} \neq I_{Basic}$.

The purpose of this paper have two targets. The first target is fabricating faults and checking an effect for changing electric current consumption. The aim of the second target is accomplishing the first target by designing a common non-invasive method to do early fault detection for medical equipment inside hospitals to reduce downtime, cost due to lost time of repairing faults, and unavailability.

3. PROPOSED SYSTEM

Fig. 2 shows the block diagram of proposed circuit. The target is detecting medical equipment faults during operation. The faults of selected equipment are related to three different types of operation problems. The detected operating faults are light source, cooling fan, and thermal printer malfunctions.

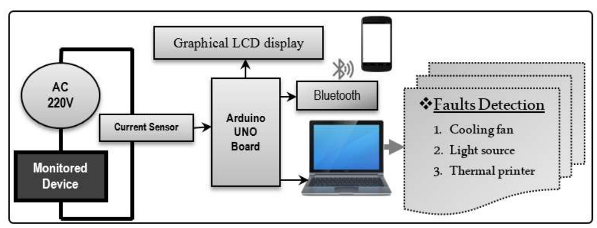
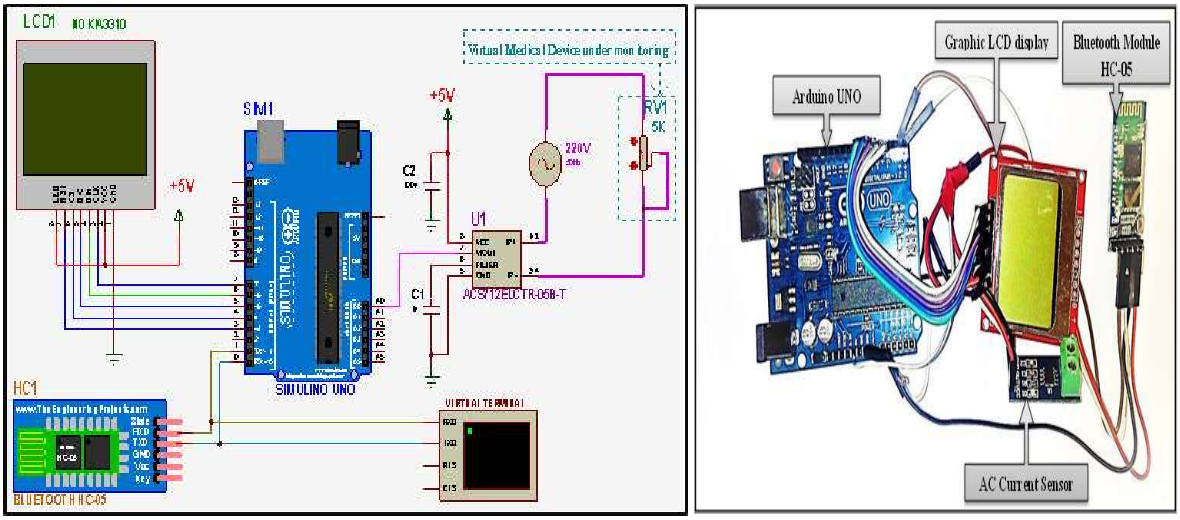


FIGURE 2. Block Diagram of Proposed Circuit with Required Result

The Analog to Digital Converter (ADC) with a sampling rate of 1000 samples per second is used to collect samples of the electric current consumption. The schedule routine of the proposed circuit is as shown in Fig. 3. The peek-to-peek voltage V_{PP} was obtained and the root mean square of the electric current measured was calculated to detect the I_{RMS}. The calculated I_{RMS} were smoothed by a digital low pass filter LPF and sent to a smart phone and PC to be displayed and saved in an Excel format.

FIGURE 3. Process of the Software Routine



(a) The circuit diagrams (b) The implemented system

FIGURE 4. The Proposed System

Fig. 4-a shows the designed circuit diagram of the proposed system that is composed of an Arduino board (UNO), a current sensor acs712, a graphic LCD Nokia 5110, and a Bluetooth module HC-05. Fig. 4-b shows the implemented system. The RMS output data of an Arduino board is connected either directly to computer or indirectly (wireless) to smartphone by Bluetooth module. On the other hand, the data sent will be processed off-line to detect faults and then sending alert to decision making center.

The ACS712 is an integrated Circuit (IC) based on a Hall-effect , dealing with both direct and alternative electric current, containing capacitors for noise decaying filter and other one for bypassing , and producing accurate analog output voltage responding linearly with the input sensed current [14-15]. The electric current sensor (ACS712-05B) is measuring the AC electric current consumed by the medical device with maximum reading equal to five Amperes.

The Arduino UNO board is an inexpensively open-source platform with an 8-bits microcontroller based on ATMEGA 328p and it has 14 digital input/output pins, 6 analog inputs, 5 volt power supply, 16 MHz crystal oscillator, and USB port to interface with PC via built-in software [16-18].

The output analog voltage of the electric current sensor is fed to the analog pin A0 of an Arduino board UNO. After processing, the Arduino UNO board will send the output data to Nokia 5110 graphic monochromatic LCD screen to draw a graphic chart of RMS electric current over time. Concurrently, the Arduino UNO board will send data output serially to a Bluetooth module HC-05 and PC via Universal Serial Bus (USB) port. HC-05 module is a simple Bluetooth short distance communication with a Serial Port Profile (SPP). Its coverage distance is up to 10 m between devices with a short-wavelength radio waves and operating at 2.4GHz [19-20]. The HC-05 Bluetooth module supporting different baud rates transfer such as 9600, 19200, 38400, 57600, 115200, 230400, 460800 bits per second [21]. Whereas the used data transfer of these experiments (about: 128 bits per second) is less than the minimum of baud rates 9600 bits per second. The proposed circuit has many automatic functions as the following:

1- Reading an AC electric current consumption of device by a current sensor.
2- Calculating Root Mean Square (RMS) from peak-to-peak reading V_{pp}.
3- Activating digital low pass filter LPF of an output reading.
4- Displaying reading as a chart on the graphic display.
5- Sending reading to PC in real-time to save it and analyzing it later.
6- Sending wireless reading by Bluetooth for displaying to smartphone.

Fig. 5 shows the flow chart of fault detection system. It detects faults by comparing the stored reading of a normal operating device and reading of another similar device for fault detection. The monitored device will run properly if the results of the stored electrical current signature and the consumed electrical current are approximately equals for same mode of operation. Otherwise, in case of non-equal results, a fault detection warning is issued for a malfunction component.

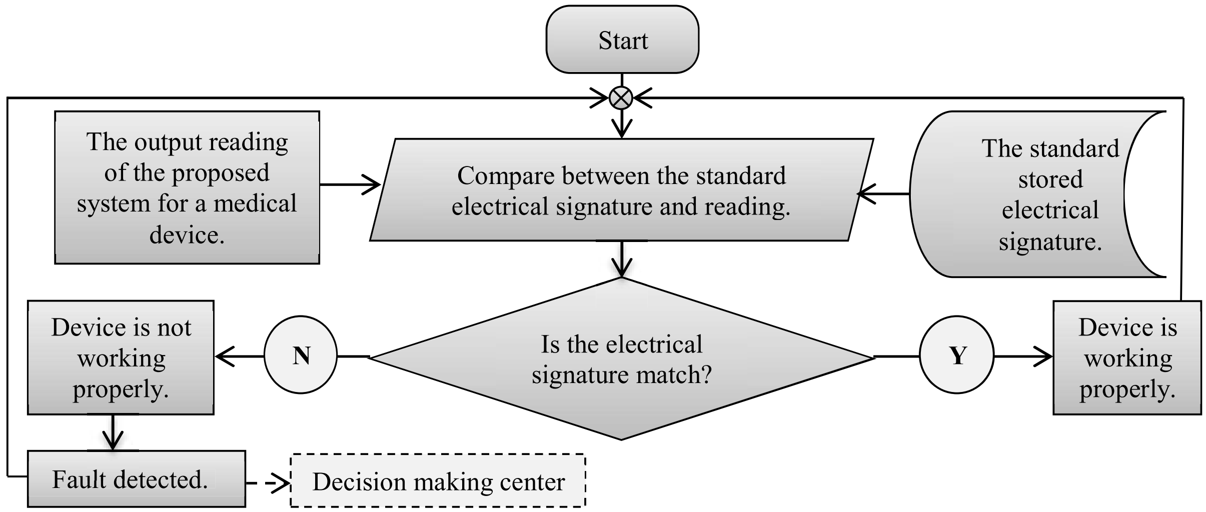


FIGURE 5. Flow Chart of Fault Detection System

Sketch of the Arduino software uses 10936 bytes (33%) of program storage space from maximum flash ROM capacity 32256 bytes and global variables use 839 bytes (40%) of dynamic memory from maximum RAM capacity 2048 bytes.

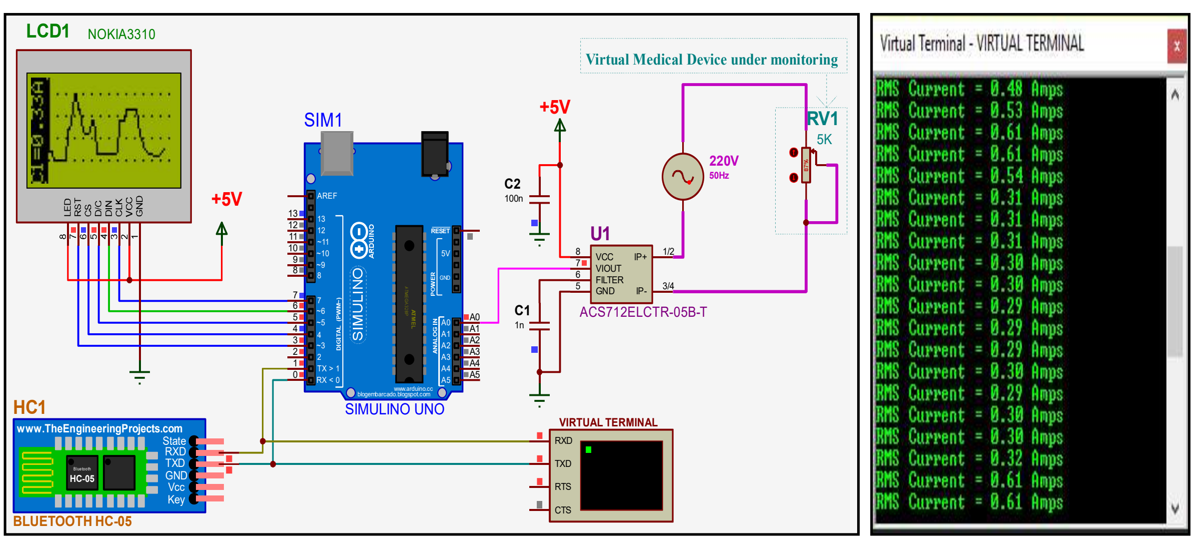
4. EXPERIMENTS AND RESULTS

These experiments check the output of designed circuit during operation by simulation and analyzing the results of two different types of medical equipment in time domain. To verify the performance of proposed design, the multi-meter model UT61E [22] is used to compare its results with the results of the proposed circuit for same equipment.

The tested medical devices have single-phase electric power supply with electric current consumption less than 5 Amperes. The experiments are repeated several times to ensure precise and repeatable results. The medical equipment components that consume basic electric currents during its operation such as a main boards, power supply, display, etc., will be referred to as main components.

4.1. Simulating the Proposed System

This validity experiment tests functionality of the proposed circuit by simulation to checkup its performance before building hardware and starting the practical experiments. Fig. 6 shows the results of simulating test for the proposed system by simulator software have a full improvement platform with circuit simulation, design achievement, and precise testing called Protues [23]. The serial output connected to both PC through USB port of an Arduino UNO board and wirelessly to a smartphone through the Bluetooth module HC-05.



(a) The simulated circuit (b) Serial RMS data

FIGURE 6. Simulation of the Proposed System

4.2. Experimental test of the proposed system

The system was used to monitor the faults of two equipment of the laboratory department, spectrophotometer and chemistry analyzer by fabricating manually faults and then measuring a related changing in electric current consumption. The chemistry analyzer has more features than the last spectrophotometer, as built-in samples incubator, but both devices have almost the same running units. The faults were induced manually to evaluate effectiveness of the proposed system. The required results to evaluate the performance of this system are faults detection of medical equipment only. The other results is used as a standard electrical current signature comparator only distinguishing of drifting electrical current to detect faults during equipment testing. Otherwise, results are not important throughout this scope of searching.

4.2.1. *Spectrophotometer*

The model of this device is Photometer 4040 and Robert Riele KG – Germany. This model functioning parts are a filter wheel DC motor, a fan motor, a light source (dominant part) that should be on as long as the equipment is on, a printer, and other main units. The main units inside this medical device are compound components consisting of a power supply, an electronic boards, a display, a light source, and cooling fan. These main units consume the main electric current that represents the electrical current signature for this device.

Fig. 7 illustrates the different faults during operation. This equipment has many components that consume electric current such as motor of filter wheel, motor of motor feed printer, motor of fan, and light source. The marker (1) to marker (9) represents the following modes of operation:

(1) Power is off.

(2) Startup.

(3) Light source is switching off, and basic units are on.

(4) Light source is switching on, and basic units are on.

(5) Printer is working, light source on, and basic units are on.

(6) Filter wheel is rotating, light source on, and main units are on.

(7) Fan off, light source on, and basic units are on.

(8) Fan are on but blades not moving, light source and basic units are on.

(9) Shutdown.

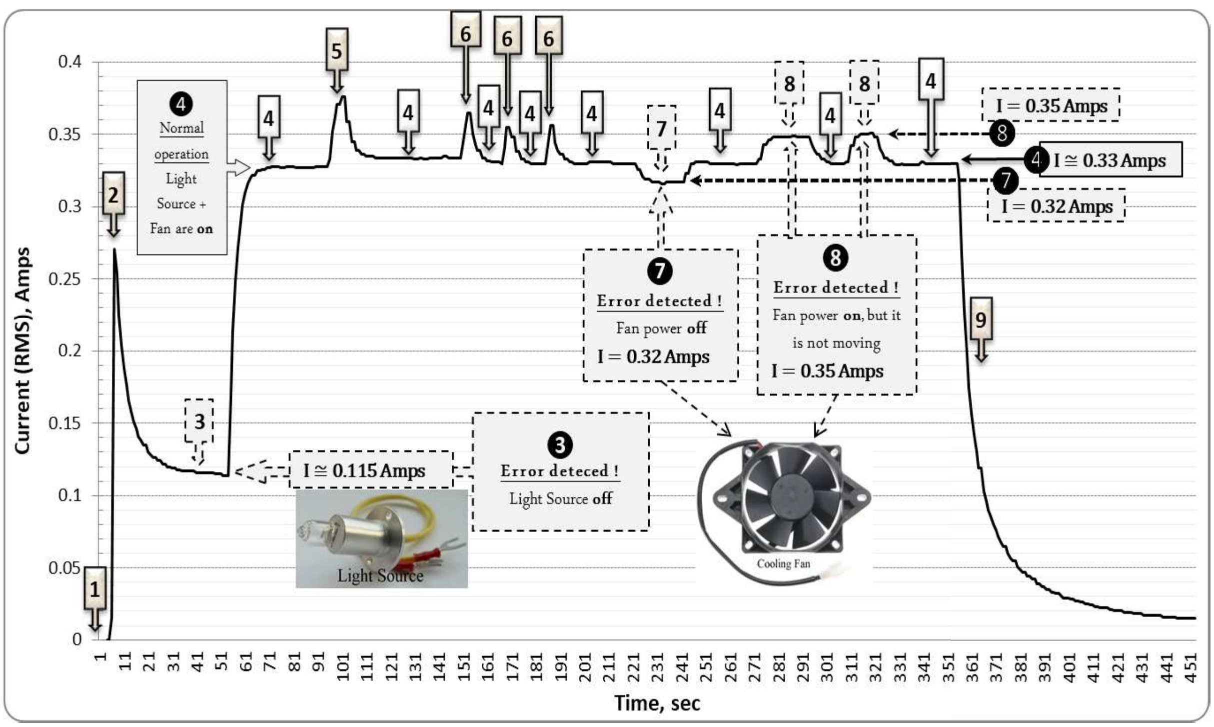


FIGURE 7. Electric Current Consumption over time for Photometer 4040

In this experiment, the electrical current consumption of basic units includes the consumption of cooling fan also. The light source fault detected at marker (3) while the fan operation faults detected at marker (7) and marker (8) with different problems. The standard electrical signature for normal operation at marker (4) having electric current value is equal to 0.33 Amperes approximately. The marker (4) reflects a summation of operating compound units inside the device when it is switched on. It includes both of the light source and the cooling fan. There are three cases for a fault detection as following:

1- If the reading of electric current consumption of standard electrical signature of normal operation at marker (4) dramatically drops from 0.33 to 0.115 Amperes approximately at marker (3), this case indicates that the light source inside the device is not working.

2- If the reading of the electric current consumption for the standard electrical signature for normal operation at marker (4) slightly decreased from 0.33 to 0.32 Amperes approximately at marker (7), this case indicates that the cooling fan is power off.

3- If the reading of the electric current consumption for the standard electrical signature for normal operation at marker (4) slightly increased from 0.33 to 0.35 Amperes approximately at marker (8), this case indicates that the cooling fan is powering on but its blades are not rotate.

4.2.2. *Chemistry Analyzer*

The model of this device is Photometer 5010 and Robert Riele KG – Germany. The equipment functioning parts are filter wheel DC motor, incubator, light source (dominant part), printer, and other main units. The thermal printer contains three parts; power driver, thermal head, and paper feed motor.

Fig. 8 illustrates the different faults during operation. The direct relation between electric current consumption and speed can be deducing it. This device has many components which consuming electric current such as motor of filter wheel, motor of motor feed printer, light source, and three temperature levels of built-in incubator. The marker (1) to marker (11) represents the following modes of operation:

(1) Power off.
(2) Startup.
(3) Light source is switching off, and basic units are on.
(4) Light source is switching on, and basic units are on.
(5) Printer is working normally, light source and basic units on.
(6) Printer paper feed is not rotate, light source and basic units are on.
(7) Filter wheel is rotating, light source on, basic units are on.
(8) Incubator is on at 30°C, light source is on, and basic units are on.
(9) Incubator is on at 37°C, light source is on, and basic units are on.
(10) Incubator is on at 25°C, light source is on, and basic units are on.
(11) Shutdown.

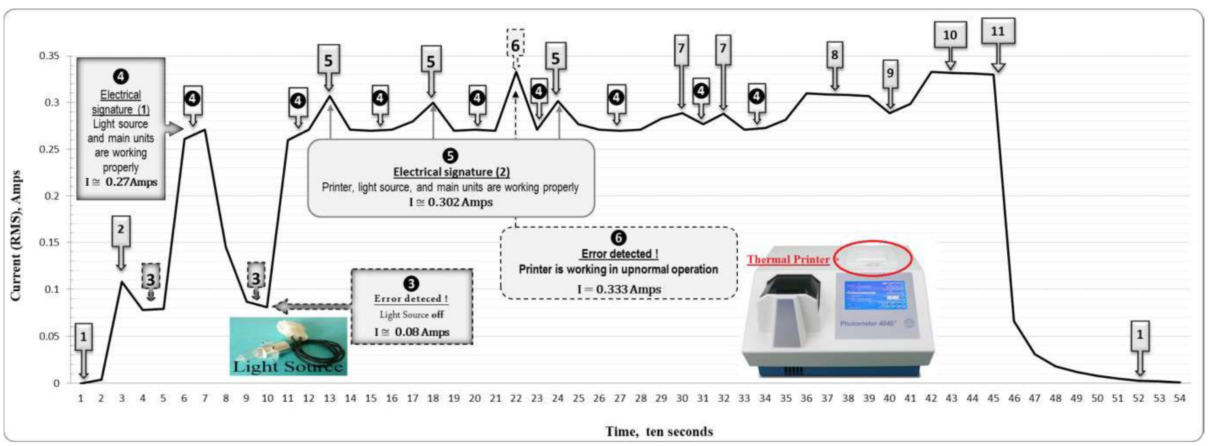


FIGURE 8. Electric Current Consumption with time for Photometer 5010

The marker (4) reflects a summation of operating compound units inside a device when switching on including the light source and basic units. The first standard electrical signature for normal operation at marker (4) having electric current value is equal to 0.27 Amperes approximately. The light source fault detected at marker (3) and the printer fault detected at marker (6) during running of paper feed motor.

The second standard electrical signature for normal operation at marker (5) is equal to 0.302 Amperes approximately. The marker (5) reflects a summation of operating compound units inside device when switching on, the light source, and thermal printer. There are two cases for fault detection as following:

1- The first standard electrical signature at marker (4) is equal to 0.27 Amperes approximately. If the consumption of electric current dramatically drop at marker (3) to value equal 0.08 Amperes approximately, this indicates that the light source is not working.

2- the second standard electrical signature for normal operation at marker (5) with value equal to 0.302 Amperes, if the reading of the electric current consumption slightly increased at marker (6) with value equal to 0.333 Amperes, this case indicates that a feed paper motor inside thermal printer module is not running properly (paper feed or paper jam problems).

5. DISCUSSION

The faults detection by the proposed system was tested many times to ensure quality of results for two types of laboratory equipment; spectrophotometer and chemistry analyzer. Faults were induced either to internal component such as light source and cooling fan, in case of spectrophotometer that indicates abnormal operation such as printing problem due to manual mechanical resistance, in case of chemistry analyzer. The results prove that a margin error range of the potential power fluctuating and its harmonics have no overlapping or significant effect upon results especially in power elements as a light source. This is an important tool for an alert station that detects faults occurrence in real-time.

In the spectrophotometer experiment, an electrical signature was used to detect light source and cooling fan motor faults to send a warning to the decision making center. In the light source fault case, this problem may be due to a lamp burn (review a lifetime of lamp in hour's unit), malfunction of driver of light source (repair), or a lamp-fitting problem (fix a lamp fitting). In the cooling fan motor fault, an important component may affect the performance of different units inside the equipment. Its role is to remove extra internal heat because an accumulation of heat may gradually cause damages to other equipment components, as the power supply and the light source. The detection of the effect of heat accumulation cannot be detected directly but it may cause failure for some sensitive internal components inside a device.

The proposed fault detection system issues a fault alarm before the machine is damaged. This early fault detection of the absence of cooling fan may preserve the lifetime and reliability of the equipment avoiding the problem of overheated components. The electric current is gradually reaching zero in about three minutes due to inductive behavior inside power supply of medical equipment that resist electric current cut-off where the coils are working as an energy storage [24]. This inductive behavior is changing from device to other according to its internal induction values.

In the chemistry analyzer experiment, two electrical signatures are used, one to detect light source fault and other one to detect cooling fan motor. In the light source fault, it is similar to the experiment of spectrophotometer. In the paper feed fault, the consumed electric current increased by a paper resistance of a feed paper rotating motor. Detecting this fault early avoid not only the waste of thermal paper, printing time, quality of printing but also protects the built-in thermal printer before total damage.

These experiments proved that the consumption levels of an electric current by the medical equipment change while running according to its modes of operation. Hence, it is an effective method to monitor faults during running. The components inside medical device that consume a lot of an electric current such as motors, electric valves, electric heaters, or electric drivers can be detected the faults of each component separately. The monitored faults change from a medical device to another according to its type. Every device have an individual functions, so it is important to study every case alone except the devices with identical brand name and model.

Sampling rate and a resolution of an analog-to-digital converter are important parameters to identify a quality of the modes of operation for medical device. For same sampling rate, it is possible to reduce transmitting data rate to PC and smartphone by increasing number of an average samples to smooth signal shape as long as the detected information about an inner faulty components of a monitored device are sustaining from changing or losing (refer to experiment of a chemistry analyzer 5010). The performed experiments in the multi phases describe a new technique to detect the partial failure of medical equipment during its operation through external reading for power consumption with no influence on the device operation.

This faulting detection strategy has no effect on the equipment operation and satisfies the international standards of an indirect power consumption measurement. Applying this technique on different medical equipment showed that each one has a characteristic curve of current consumption. This curve is specific for that equipment and may vary with the model, manufacturer and mode of operation. The amount of AC current consumption during a certain operation mode depends on the running components such as motors, electric valves, electric heaters or electric drivers. The detection of a remarkable deviation in current consumption pattern during a certain mode of operation is an indication of a faulty situation of one or more components. The stored reference database containing the different electric current signatures for each device during its proper operation is using it as a reference to detect the faulty operations in time domain.

In addition, an over electric current detection is an important tool for protection. It can be a good prediction indicator to detect faults before total failure. Usually, the internal fuses are used as hardware protection and it can protect the vital internal components inside equipment from failure. Whatever, with the same earlier method, it can predict and protect medical equipment before fuse blow by calculating over electric current $\mathbf{I}_{\text{Over\_current}}$ based on the next equation.

$$(\mathbf{I}_{\text{Total}} + \mathbf{I}_{\text{Margin}}) > \mathbf{I}_{\text{Over\_current}} > \mathbf{I}_{\text{Total}} \qquad \textbf{(4)}$$

Where: $\mathrm{I}_{\text{Margin}}$ is a constant value expressing the safety electric current margin before fuse blow. It has a variable values according to a highest permitted electric current consumption for each equipment

6. CONCLUSIONS

This study considered the extension of the electrical current signature analysis approach for automatic fault detection in medical equipment. Such an approach is non-intrusive. It depends on storing a referential consumption pattern of the eclectic current of the equipment. A drift from this pattern means a fault occurrence of the equipment under test. Careful study of the fault may lead to determine the damaged component.

Two equipment from the hospital lab department were selected. The results showed the effectiveness of this approach and its ability to detect hidden faults that may cause equipment failure. It has been shown that the possibility to extend this approach to cover the fault detraction for the hospital electromechanical medical equipment.

Automatic detection of the equipment mal function will increase patient safety and reduce its downtime. It preserves the equipment availability, and reduces the scheduled regular maintenance cost by adopting the conditional maintenance.

REFERENCES

[1]. Arévalo, F., Oestanto, E., & Schwung, A. "*Development of a Mobile App for Fault Detection Assessment based on Information Fusion*", IEEE 16th International Conference on Industrial Informatics (INDIN), (pp. 635-640), IEEE, July 2018.

[2]. Luo, B., Wang, H., Liu, H., Li, B., & Peng, F. "*Early fault detection of machine tools based on deep learning and dynamic identification*" IEEE Transactions on Industrial Electronics, Vol. 66(1), p. 509-518, 2019.

[3]. Riera-Guasp, M., Antonino-Daviu, J. A., & Capolino, G. A.. "*Advances in Electrical Machine, Power Electronic, and Drive Condition Monitoring and Fault Detection: State of the Art*" IEEE Trans. Industrial Electronics, Vol. 62(3), p.1746-1759, 2015.

[4]. Dwiputranto, T. H., Setiawan, N. A., & Aji, T. B. "*Machinery equipment early fault detection using Artificial Neural Network based Autoencoder*" In Science and Technology-Computer (ICST), 3rd International Conference on (pp. 66-69). IEEE, July , 2017.

[5]. Ibrahim, R., Watson, S., Djurovic, S., & Crabtree, C., "*An Effective Approach for Rotor Electrical Asymmetry Detection in Wind Turbine DFIGs*" IEEE Transactions on Industrial Electronics, 2018.

[6]. Maktoubian, J., & Ansari, K., "*An IoT architecture for preventive maintenance of medical devices in healthcare organizations*", Health and Technology, 1-11, 2019.

[7]. Hong, J. S., "*Association between years since manufacture and utilization of computed tomography scanner in South Korea: A cross-sectional study*", (a STROBE-compliant article). Medicine, Vol. 97, p.43, 2018.

[8]. Alkharabsheh, A. R., Momani, L., Al-Nuaimy, W., Ababneh, J., Alwada'n, T., & Hawatmeh, A. "*Early fault prediction and detection of hydrocephalus shunting system. Journal of Biomedical Science and Engineering*" Vol. 6(03), p.280, 2013.

[9]. Naha, A., Samanta, A. K., Routray, A., & Deb, A. K., "*Low complexity motor current signature analysis using sub-Nyquist strategy with reduced data length*", IEEE Transactions on Instrumentation and Measurement, Vol. 66(12), p.3249-3259, 2017.

[10]. Choudhary, A., Goyal, D., Shimi, S. L., & Akula, A, "*Condition Monitoring and Fault Diagnosis of Induction Motors: A Review*", Archives of Computational Methods in Engineering, p.1-18, 2018.

[11]. Henry, D., Zolghadri, A., Cieslak, J., & Efimov, D., "*A lpv approach for early fault detection in aircraft control surfaces servo-loops*" IFAC Proceedings Volumes, Vol. 45(20), p.806-811, 2012.

[12]. Isermann, R., "*Fault-diagnosis systems: an introduction from fault detection to fault tolerance*", Springer Science & Business Media, 2006.

[13]. Korbicz, J., Kościelny, J. M., Kowalczuk, Z., & Cholewa, W., "*Fault Diagnosis: Models, artificial intelligence methods, applications*", 2004.

[14]. Ante, M. G. E., Garcia, K. A. N., Gonzales, B. A. A., Mendoza, J. T. D., & Roque, M. A. C., "*Microcontroller-based power monitoring and switching device for appliances over a zigbee network*", Journal of Telecommunication, Electronic and Computer Engineering (JTEC), Vol. 10(1-6), p.93-97, 2018.

[15]. Acakpovi, A., Odazie, C., Majeed, I. B., Eduful, G., & Asabere, N. Y., "*Transformer Wireless Monitoring System Using Arduino/XBEE*", American Journal of Electrical Power and Energy Systems, Vol. 8(1), p.1-10, 2019.

[16]. Murthy, B. R., Jagadish, O., Alam, K. T., Dada, V. M., & Gandhi, K. P., "*Development of GSM Based Advanced Alert Home Locker Safety Security System Using Arduino UNO*", 2018.

[17]. Mondal, P., & Mondal, M., "Laser Based Security System Using Arduino UNO", International Journal of Engineering Science, 1846, 2018.

[18]. Sipani, J. P., Patel, R. H., Upadhyahya, T., & Desai, A., "*Wireless Sensor Network for Monitoring & Control of Environmental Factors using Arduino*", International Journal of Interactive Mobile Technologies (iJIM), Vol. 12(2), p.15-26, 2018.

[19]. Cameron, N. "*Bluetooth Communication*", In Arduino Applied, (pp. 289-310), Apress, Berkeley, CA., 2019.

[20]. Khan, M. F., & Kumar, A., "*White Cane Navigation Using Arduino Uno*", In Intelligent Communication, Control and Devices (pp. 1719-1727), Springer, Singapore, 2018.

[21]. HC-05 Bluetooth to Serial Port Module, https://www.academia.edu/33886254/HC-05_Bluetooth_module, Access at: 30/6/2019.

[22]. UT61E, "Operating Manual", www.manualslib.com/products/Uni-T-Ut61e-3834617.html, (Accessed: 15/2/2019).

[23]. Fan, C., Liu, X., Ling, R., & Si, B., "*Application of proteus in Experimental Teaching and Research of Medical Electronic Circuit*", In 2018 3rd International Conference on Modern Management, Education Technology, and Social Science (MMETSS 2018), Atlantis Press, November, 2018.

[24]. Rizzoni, G., "*Fundamentals of electrical engineering*", New York: McGraw-Hill, 2009.