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Electronic Signal Processing for Hand Hygiene in Public Health: a Hand Washing Station with a Brain Box

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***Abstract*—The hand is a vehicle for transmission of diseases from one person to another; either by direct contact or indirectly by touching contaminated surfaces. A simple, affordable and effective means of curbing the spread of diseases is hand hygiene which is regarded as a "Do-it-yourself-Vaccine" in Public Health. Proper hand washing requires soap and running water. COVID- 19 pandemic increased the awareness, importance, use, and demand for hand washing stations. The fight against COVID-19 gave birth to innovations in Africa for local development of hand washing stations, ventilators and other life-saving medical devices. Buckets are seen in schools, churches, mosques, health centers and other public places as hand washing has become a requirement to gain entrance into such places. It is high time African urban centers move away from bucket-and-bow-based hand washing stations and mechanical-pedals-based hand washing stations. The development of an electronic-signal-processing-based hand washing station is presented. Ultrasonic sensors are used to detect the presence of hands. The signals from the sensors are further processed and a microcontroller in a brain box (electronic control circuit) makes decisions to command actuators to dispense liquid soap, clean water, or switch ON a fan on request. The hand washing is contact-free and the used water is properly channeled away to the drainage system. Wastage of soap is avoided through efficient software developed for the microcontroller. The automated hand washing station is functional and affordable.**

Keywords— Public health; Hand hygiene; Disease spreading prevention; Signal processing; Sensors; Actuators; Automation; Fluid flow management;

I. INTRODUCTION

The hand is a vehicle of transmission of pathogens, microorganisms, bacteria, viruses, and infections from one person to another, from one patient to another, from one patient to another via a nurse or a doctor, from a patient to a doctor or a nurse, from a doctor or a nurse to a patient, from one family member to another, and from one neighbour to another [1]. Transmission may occur when the hand of an uninfected person directly touches the hand of an infected person or catches fluid or secretion from an infected person. Transmission may also occur when the hand of an uninfected person touches a surface already touched or contaminated by an infected person in one way or the other. COVID-19 spreads between people through direct close contact with infected people via mouth and nose secretions. COVID-19 also spreads indirectly by touching objects or surfaces already contaminated or touched by infected people [2]. The transmission process is completed when the hand eventually touches the eyes, nose or mouth.

A simple, affordable and effective means of curbing the spread of diseases is hand hygiene [1,2,3,4,5,6,7]. Hand washing with running water and soap is a confirmed way of stopping the spread of diseases among people. Hand hygiene is a practical and practicable infection control method in public health. October 15 is the Global Hand Washing Day for raising awareness of the importance of hand washing as an effective means of disease spreading prevention [7]. Hand washing with uncontaminated running water and soap is thought of as a "Do-it-yourself-Vaccine" [8].

Availability of hand washing stations is a challenge in low-resource settings where health-care is severely underfunded. There is a lack of adequate running water system, poor electricity supply, and other social amenities and infrastructures [9].

COVID- 19 pandemic increased the awareness, importance, use, and demand for hand washing stations. Necessity is said to be the mother of invention. People are coming up with hand washing devices and ventilators to stop the spread of COVID 19 and treat infected patients. COVID 19 pandemic and the associated lockdown taught nations the lessons of self-sufficiency and encouraged local production and fabrication of devices to meet the needs of the citizens [10,11].

According to Reuters, a Nigerian furniture maker, Bamigbose Adams, was turning old metal drums into customized hand washing stations during the COVID-19 pandemic to fight coronavirus as illustrated in Fig. 1 [12]. Veronica Bekoe, a biological scientist with the Public Health and Reference Laboratory of the Ghana Health Service, developed the Veronica Bucket which assisted in fighting coronavirus [13, 14]. The Veronica

Bucket consists of a bucket of water with a tap fixed near the bottom and a bowl to collect the used water. The Bucket is at a height higher than the bowl as shown in Fig. 2 [13,14].

Bekoe was looking for an alternative for herself and her colleagues to wash their hands with running water instead of all of them washing their hands traditionally in the same bowl which is counterproductive [13]. Similar buckets are used in schools, homes, churches, mosques, hospitals and other public places in most African countries as shown in Fig. 3(a) [14]. UNICEF Nigeria in commemoration of the Global Hand Washing Day donated hand washing stations to the Benue State Government in Nigeria; The wife of the Governor demonstrated proper hand washing at one of the donated stations in Fig. 3(b). Hand washing stations in Figs. 1, 2, and 3 require touching a tap which reduces the efficacy of the stations as such surface touching may lead to indirect transmission of diseases.

As shown in Fig. 4, Richard Kwarteng invented a solar-powered hand washing sink which uses a motion sensor to control the release of soap and water without the user having to touch the tap or any surface [16]. The Tippy Tap of Fig. 5 is a contact-free hand washing station first introduced in Zimbabwe [16]. It has been modified in several ways and adopted in other African countries.

Fig. 1. *A Nigerian artisan turns metal drums into customized hand washing station [12]*

(a) Veronica Bucket [13] *(b) A teacher demonstrated proper hand washing with Veronica Bucket [14]*

Fig. 2. *Veronica Bucket [13,14]*

(a) Buckets in schools and other public places in Africa [14]

(b) Wife of the Benue State Governor demonstrated proper hand washing at a hand washing station donated by UNICEF Nigeria [15]

Fig. 3. *Bucket-based hand washing stations in other African Countries [14,15]*

Fig. 4. *Solar-powered hand washing station with motion sensor [16]*

The mechanical hand washing station of Fig. 6 was developed at the University of Nigeria Teaching Hospital (UNTH) [17]. This station has a liquid soap container, a water dispensing container, a waste receptacle, and a WC basin. Foot pedals are provided to control the release of liquid soap and water for washing [17]. Hand washing stations in Figs. 4, 5, and 6 ensure zero physical contact of the user with any surface thereby enhancing the efficacy of Hand hygiene. Mechanical hand washing stations may suffer wear and tear with time.

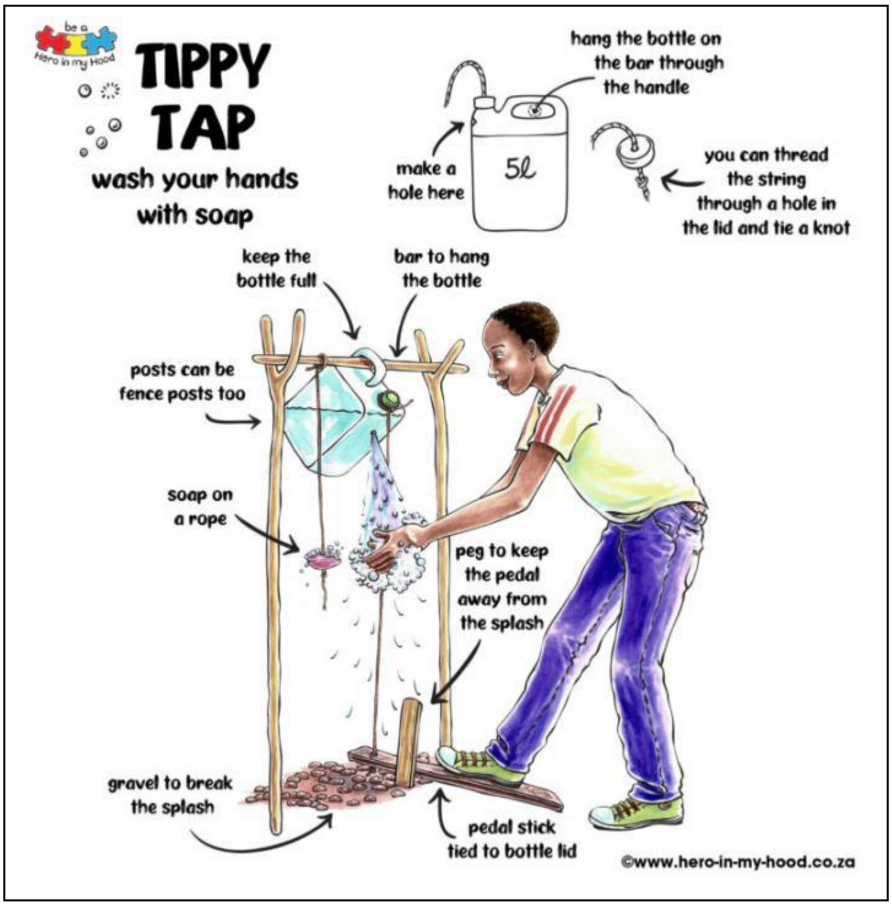


Fig. 5. *Tippy tap hand washing station {16}*

Fig. 6. *Mechanical hand washing station {17}*

Nigeria and other African countries are blessed with very good Artisans and Professionals who can develop and fabricate useful devices [18]. The present Naira to Dollar exchange rate discourages the importation of things that can be easily developed in Nigeria. Local development and mass production of devices in Nigeria and other African countries will provide economic use of some local materials and create employment opportunities [18,19]. In this work, the development of an electronic signal processing based hand washing station is presented. Some affordable degree of intelligence and automation are added to the hand washing station. Wastage of soap and water is avoided. The automated hand washing station is a system designed to make the process of hand washing completely contact-free.

II. Methodology

The Automated Hand Washing Station has four subsystems. These are the Mechanical Frame, the Plumbing Subsystem, the Electronic Hardware (the brain box), and the Software in the microcontroller.

A. *The Mechanical Frame*

The Mechanical Frame consists of the mechanical iron support or holder for the components of the Hand washing station. These components include the wash hand basin, inlet and outlet water pipes, water and soap hand-free taps, a manual valve, two solenoid valves, soap container, soap inlet pipe/hose, mechanical support for the fan, and mechanical support for the brain box which houses the electronic hardware.

Figs. 7 shows the Left and Right views of the mechanical frame. Fig. 8. shows the Front and the Top views of the mechanical frame. The 3D isometric view and the 3D solid view of the mechanical frame are presented in Fig. 9. These views together give the totality of the mechanical frame. Fig. 10(a) shows the complete fabricated hand washing station.

B. *The Plumbing Subsystem*

The plumbing subsystem is illustrated in Figs. 10(b), 11(a), and 11(b). Three different fluids are involved in the system. The first fluid is fresh clean uncontaminated water which enters the system from the water system of the building or premises or from a tank or a bucket placed higher in height compared with the hand washing station. A manual valve intercepts the inlet water first. The ordinary user has no business with this manual valve which is kept normally open but can be closed by the officer-in-charge when there is a need to shut down the hand washing station. A normally closed solenoid valve comes between the normally open manual valve and the clean water dispensing hand-free tap as illustrated in Figs. 10(b) and 11(a). This solenoid valve opens only when it receives a command signal from the microcontroller

Water is available at all times on request. The request is made by placing the hands under the water tap without touching any surface. When the water sensor SW detects the presence of the hands, it sends the information to the microcontroller which commands the clean water solenoid valve VW to open and dispense water to wash the hands. As shown in Fig. 11(a), the second fluid is used water which must exit to the drainage system of the building or premises without splashing on the user and other people as it is already contaminated or might have been contaminated.

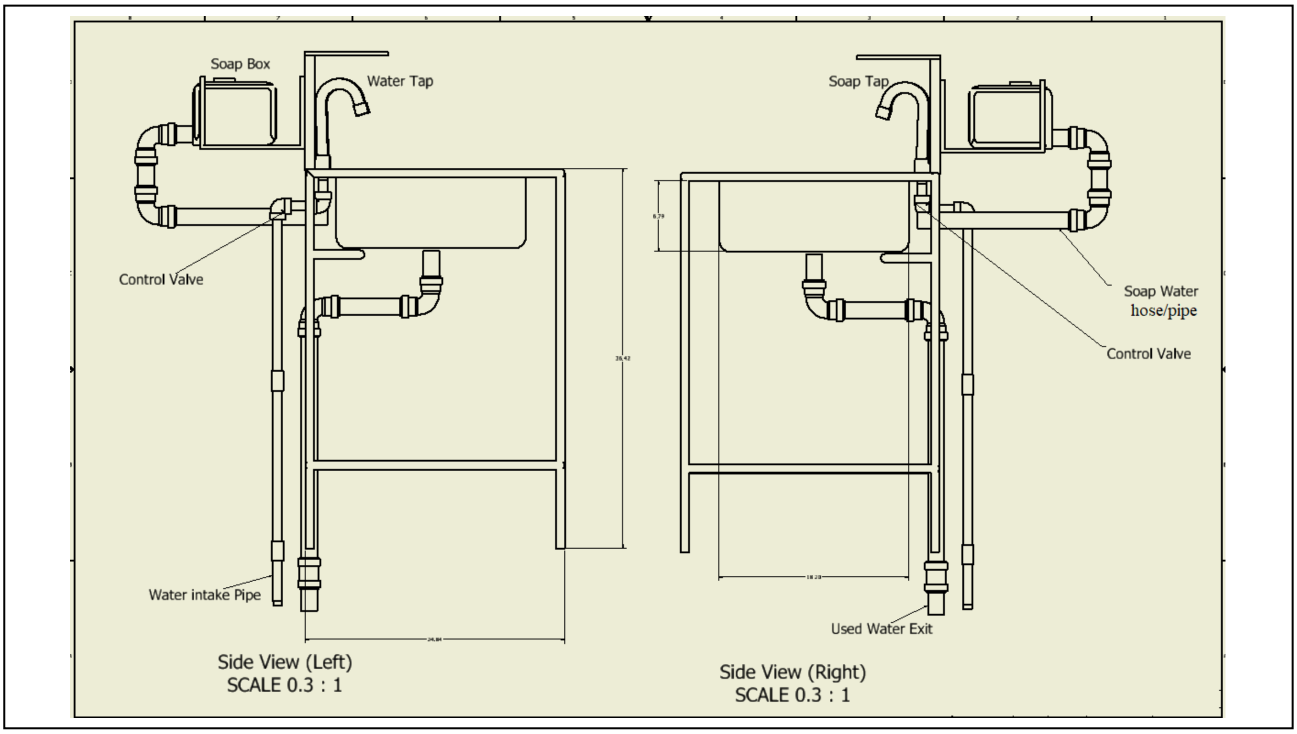


Fig. 7. *Left and Right views*

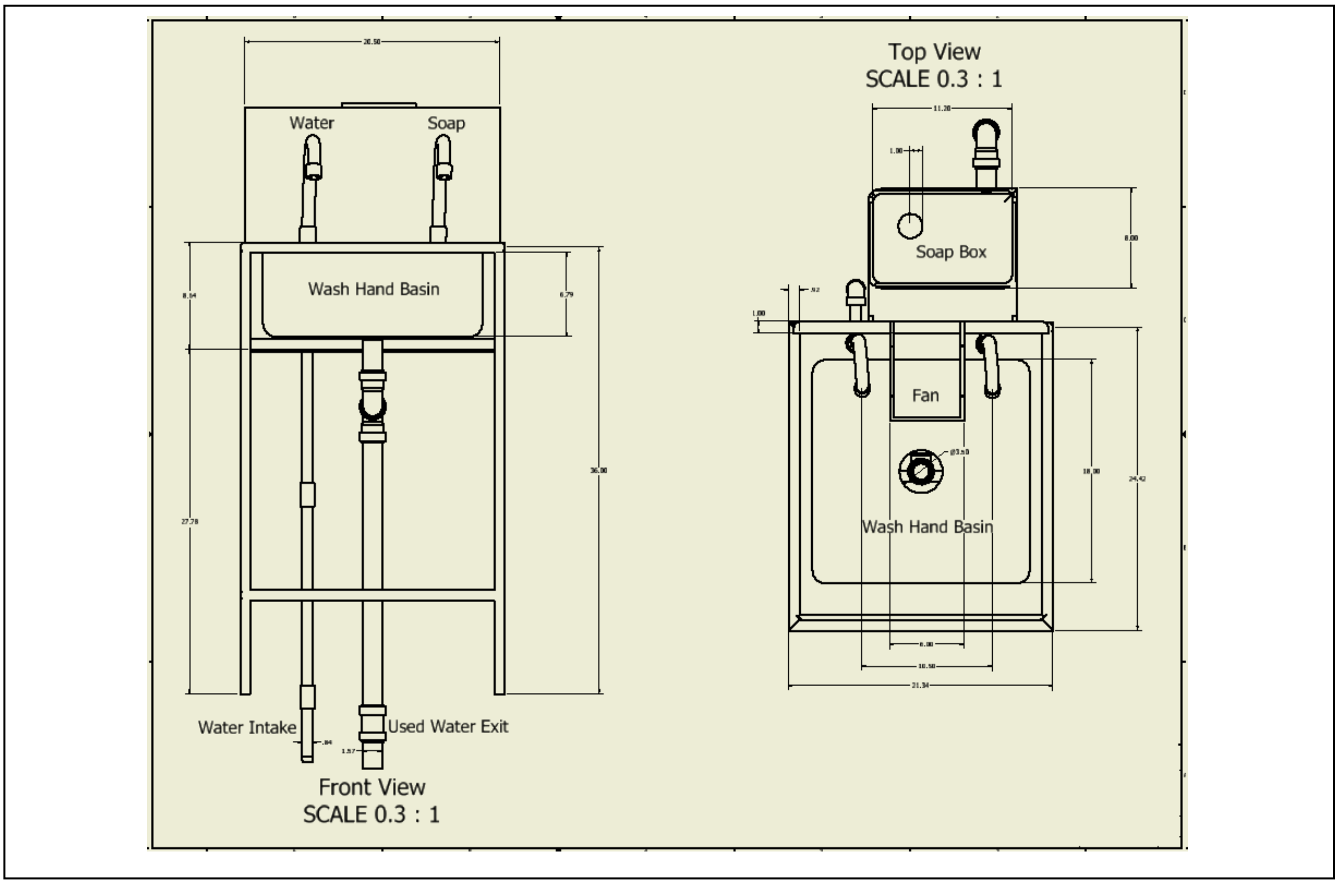


Fig. 8. *Front and Top views*

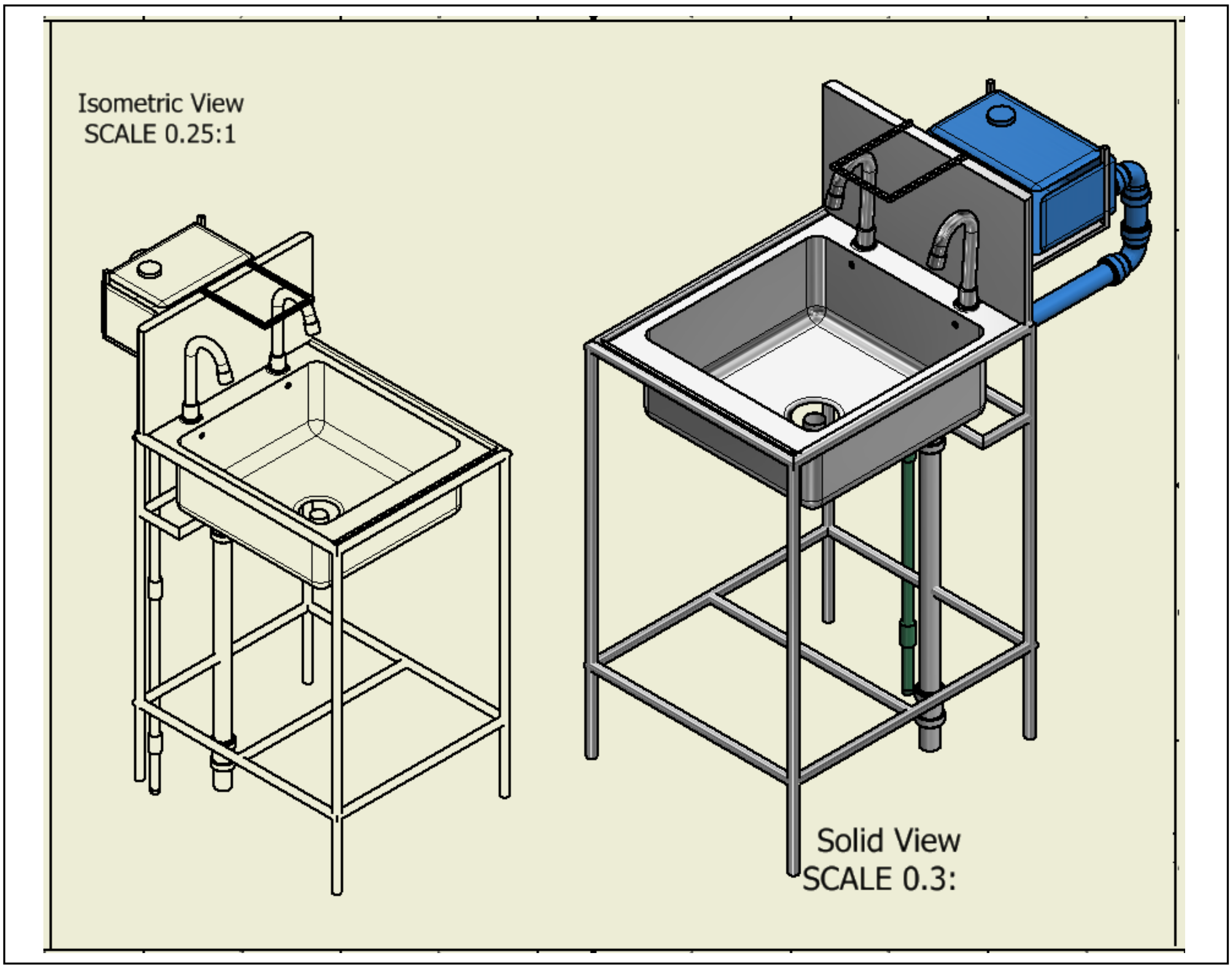
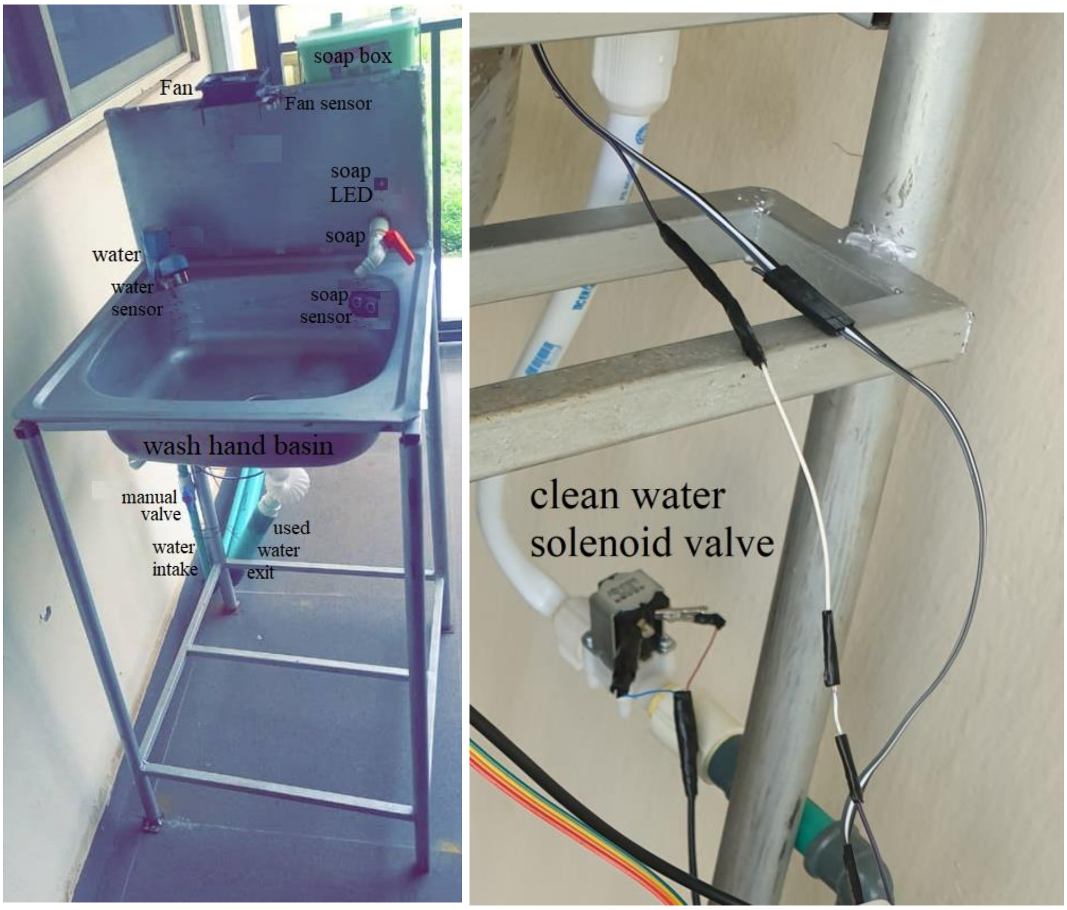
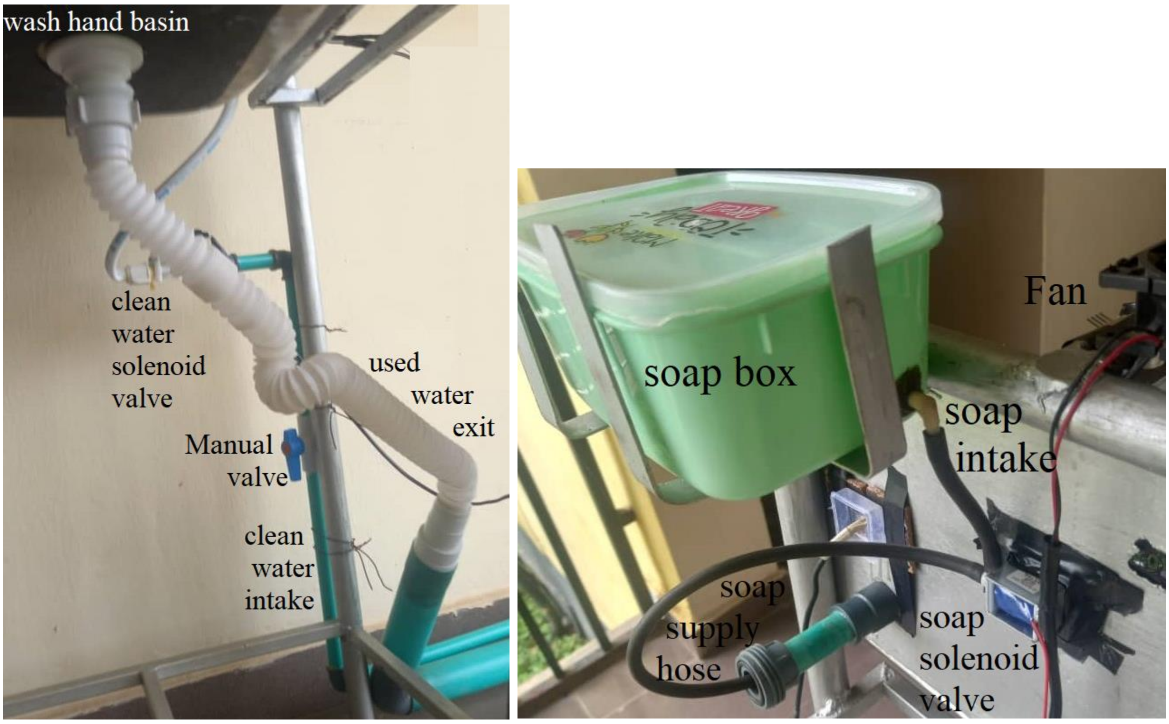


Fig. 9. *Isometric and Solid views*



(a) The complete view of the fabricated hand washing station *(b) Plumbing subsystem: Clean water solenoid valve*

Fig. 10. *Fabricated hand washing station*



(a) Plumbing subsystem: clean water inlet and used water exit *(b) Plumbing subsystem: Liquid soap flow*

Fig. 11. *Plumbing subsystem*

The third fluid is liquid soap which comes from a box and passes through a normally closed solenoid valve to the liquid soap dispensing hand-free tap as illustrated in Fig. 11(b). This solenoid valve also opens only when it receives a command signal from the microcontroller. The microcontroller is programmed not to release liquid soap all the time to avoid wastage but only for 10 seconds on request. The request is made by placing the hands under the liquid soap tap without touching any surface. When the liquid soap sensor SS detects the presence of the hands, it sends the information to the microcontroller which commands the liquid soap solenoid valve VS to open and dispense soap to rub the hands.

Soap will not be available for the next 35 seconds after it was last dispensed. When the soap is not available, the soap LED blinks and stops blinking when the soap is available. A hose is used to convey the liquid soap from the soap box to the soap tap to minimize liquid soap wastage. The liquid soap is dispensed for the first 10 seconds, the user can proceed to wash his/her hands and dry them under the fan for as long as he/she wishes.

The fan is also available at all times on request. The request is made by placing the hands under the fan without touching any surface. When the fan sensor SF detects the presence of the hands, it sends the information to the microcontroller which commands an electronic switch F to switch ON the fan to dry the wet hands.

C. The Brain Box: Electronic Hardware

The block diagram of the Electronic Hardware is shown in Fig. 12. The electronic hardware is the brain box. The components of the electronic hardware include a power supply unit, three ultrasonic sensors, two LEDs, two solenoid valves, an electronic switch, a fan for drying wet hands, and a stm32f103c8 Microcontroller which is the heart of the system [20]. The power supply unit provides the required voltage levels for the components. An Ultrasonic Sensor shown in Fig. 13 is a non–contact transducer or sensor which uses the principle of ultrasonic wave transmission and reflection to sense the presence of an object and if necessary to measure the distance of the object from the sensor [10, 21,22,23]. The sensor transmits ultrasonic wave which is intercepted and reflected back by an object as illustrated in Fig. 14 [10,21,22,23]. The reflected wave detects the presence of the hands and notifies the microcontroller to open the desired valve. The soap LED blinks when the liquid soap is not available and stops blinking when the liquid soap is available. The second LED is the PLED which indicates that the electronic hardware is ON. Fig. 15 shows the circuit diagram.

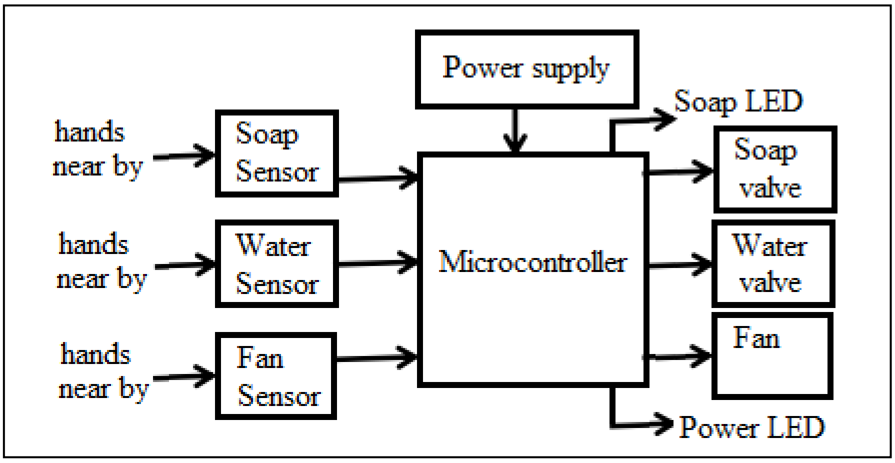


Fig. 12. *Block diagram of the electronic hardware*

Fig. 13. *An ultrasonic sensor*

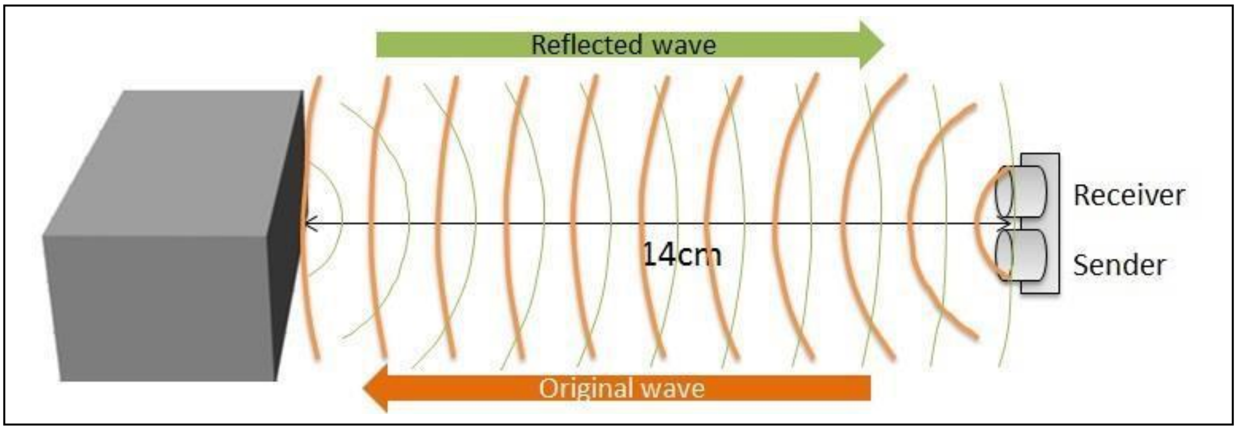


Fig. 14. *Ultrasonic sensor: Principle of transmission and reflection of ultrasonic wave*

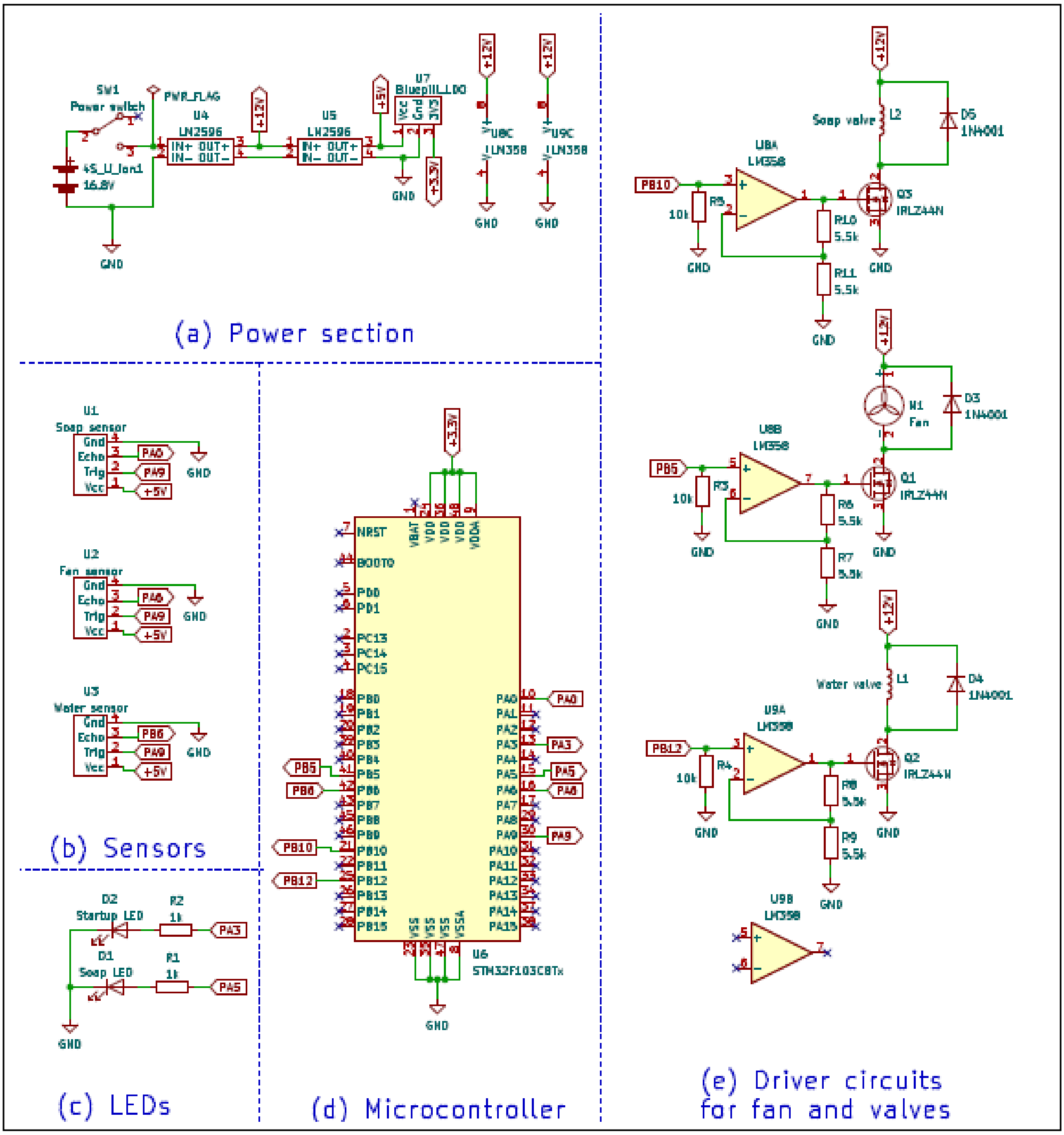


Fig. 15. *The circuit diagram*

D. The Software

The software controls the operation of the brain box (the electronic hardware). Fig. 16. shows the flow chart for the software program. The three sensors are labelled as SS, SW, and SF for the liquid soap, clean water, and fan respectively. Each of these variables goes high (1) when the hands are near or sensed; otherwise low (0). The two normally closed solenoid valves are VS and VW for the liquid soap and clean water respectively while F is the normally open electronic switch for the fan. Each of these variables goes high (1) when activated (valve opens or electronic switch closes); otherwise low (0) (valve closes or electronic switch opens)

For clean water, when the hands are present near the water tap, SW is set to 1, VW is set to 1, the water solenoid valve is opened and water is dispensed. When the hands are not present near the water tap, SW is set to 0, VW is set to 0, the water solenoid valve remains closed and water is not dispensed. For fan, when the hands are present near the fan, SF is set to 1, F is set to 1, the electronic switch F switches ON the fan. When the hands are not present near the fan, SF is set to 0, F is set to 0, and the fan remains OFF.

The handling of the liquid soap is more complex. Two other digital variables x and y are initially set low (0) and can be manipulated by an interrupt service. When the hands are not present near the soap tap and x is 0, VS is set to 0, the valve remains closed, soap is not dispensed and the soap LED is set to 0 and is OFF.

When the hands are present near the soap tap and x is 0, VS is set to 1, the timer is started and interrupt service is called, the soap solenoid valve is opened , soap is dispensed and the soap LED is set to 0 and is OFF. Between the time $t = 0$ and $t < 10$, the interrupt service sets x to 1 and sets y to 0, VS remains 1, soap is dispensed and the soap LED is set to 0 and is OFF. It is better to retain the hands during the first 10 seconds to collect as much soap as possible. Even if the hands are removed during this period, soap will be dispensed. Between time $10 \le t < 45$, the interrupt service sets x to 1 and sets y to 1, VS is set to 0, soap is not dispensed and the soap LED is set to 1 and is ON (blinking). This blinking indicates that the soap is not available for the next 35 seconds. During this period, the user can wash his/her hands with water and dry with the fan.

When time $t = 45$, the interrupt service sets x back to 0 and sets y back to 0, the timer stops, the interrupt service ends, VS is set to 0, soap is not dispensed and the soap LED is set to 0 and is OFF and is not blinking. Soap is now available although the current user may still be busy trying to round up his/her hand washing. The process is repeated for the next user.

The stm32f103c8 microcontroller has interrupt controllers NVIC and EXTI to manage different types of interrupts. An interrupt is a signal to the processor to suspend its current tasks and attend to a particular event. When an interrupt occurs, an interrupt service routine is called in order to execute tasks that need immediate attention from the processor. After exiting the interrupt service routine, the processor resumes the task it was handling before the interrupt occurred [20,24]. The software program was written in C. It was developed in the STM32CubeIDE which is the Integrated Development Environment for STM32 [25].

III. Results

The Hand washing station was tested several times and found to function as designed. The presence of the hands near to liquid soap tap resulted in the dispensing of liquid soap for 10 seconds after which the soap LED blinks for 35 seconds. During this period of 35 seconds, the presence of hands near the soap tap could not dispense soap. The presence of the hands near the water tap resulted in the dispensing of clean water. The presence of the hands near the fan switched ON the fan. The user does not need to touch any surface while at the hand washing station.

IV. Conclusion

Electronic signal processing has been applied for Hand hygiene. A microcontroller-based brain box has been incorporated into a Hand washing station. Users can wash their hands without touching any surface. Liquid soap and water are dispensed easily on request. The fan is switched ON when there is a request. Wastage of liquid soap is avoided. Most of the materials used are available locally. Fabrication of the mechanical frame and the plumbing subsystem were also done locally. It is high time African urban centers move away from bucket-and-bowl-based hand washing stations and mechanical-pedals-based hand washing stations to automated hand washing stations. Four stations can share one brain box to further reduce the cost.

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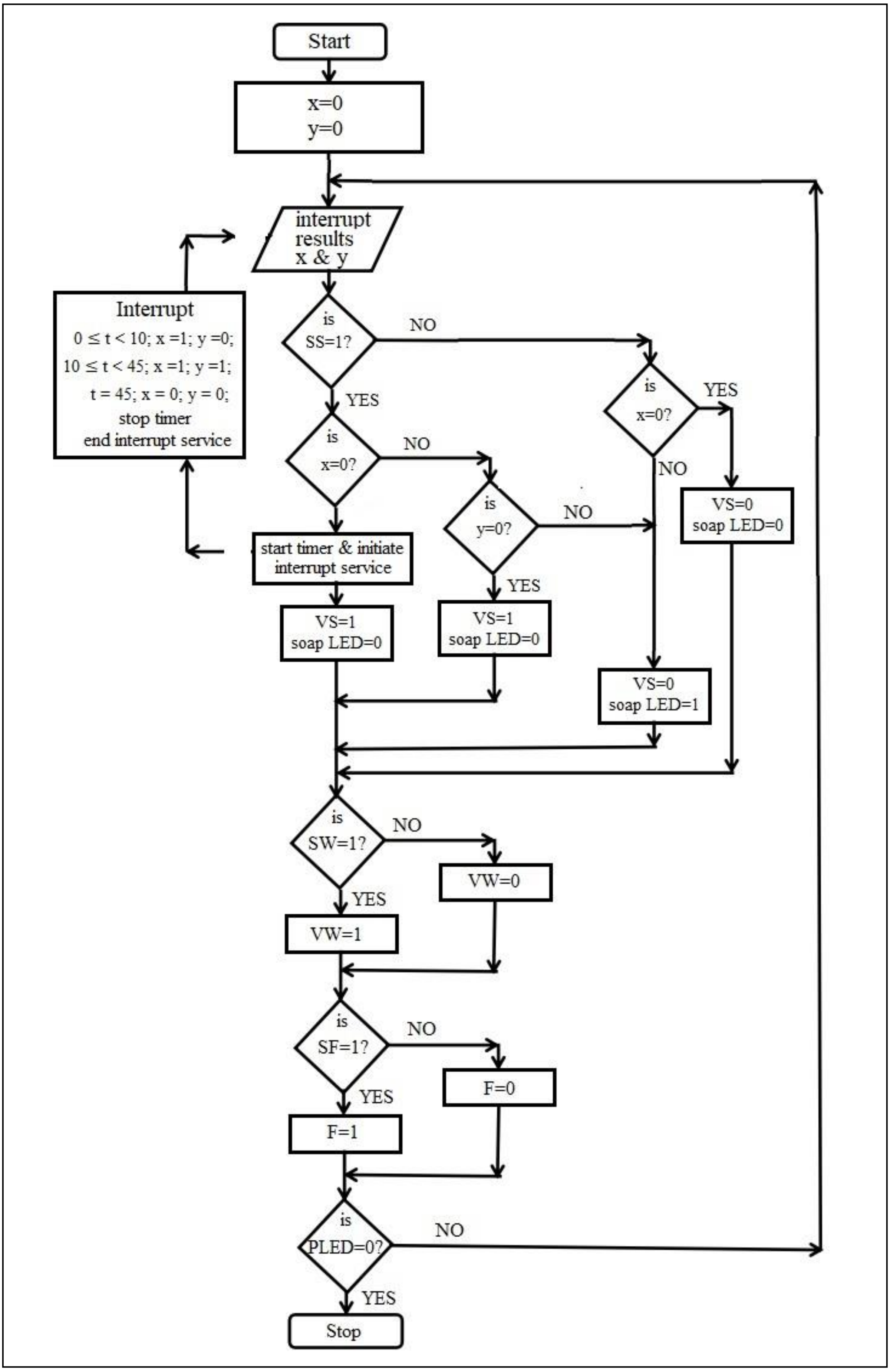

Fig. 16. *The flow chart*

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