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Design and Development of a Non-volatile Counter for Metered Dose Inhaler (MDI)

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Abstract: In 2014, Global Asthma Report 2014 stated there were 334 million of people in the worldwide suffering of asthma and the population was increased 99 million compared in 2011. Asthma is the leading chronic childhood disease with albatross on affected children and their families. It occurs when the pulmonary airway is blocked or the airways become narrowed and result in difficult breathing. When asthma under attack, asthma patients normally use metered dose inhaler (MDI) to inhale the salbutamol to restore normal breathing. Therefore, MDI currently available in market unable to monitor the remaining amount of puffs available in the MDI canister and may lead problems for the user due to inability to monitor the amount of salbutamol in the MDI canister. Besides this, some manufacturers developed MDI with counter but it had the limitation such as unable to store memory of the last counting value if power failure occurs, uses non-rechargeable battery and are disposable. Hence, this paper is to present the development of a device consist of a non-volatile counter. It is designed using EEPROM to save the memory of the last counting value and to prevent data loss due to power failure. The MDI was installed with the limit switch for counter and the MDI press is attached to MDI canister so that when the user presses both simultaneously then it provides enough pressure to the limit switch to update the counter. The MDI cover is developed to protect the internal connection and to prevent the user from accidently pressing the limit switch. 7.4V Li-ion rechargeable battery was employed to supply power source for system operation. Arduino UNO (ATmega328P) act as microcontroller to control the system operation of this device. The device is capable of displaying the number of used salbutamol puff on the liquid crystal display (LCD). Furthermore, RGB LED is integrated into the device as visualization to indicate the level of salbutamol in the MDI canister. It consists of four levels indication which is high, medium, low and empty canister of used puff. The high level of used puffs is between 0 to 120 puffs with green colour indicator, medium level is between 121 to 160 puffs with yellow/orange colour indicator, low level is between 161 to 199 puffs with red colour indicator and empty canister without any colour of indicator when the used puffs reached to 200. This device could remind the user to prepare a new MDI canister since it had indicated of low level of salbutamol in the MDI canister. Besides this, it also could reduce the deaths from asthma due to the user would prepare a new MDI canister before attacked by asthma.

Keywords: Arduino Uno, Digital counter, metered dose inhaler (MDI), asthma.

1. Introduction

According to the Global Asthma Report 2011 [1], it reported 235 million of people in the worldwide estimated suffering from asthma disease. In 2013, the people in the worldwide who suffering from asthma increased to 241 million of people due to the Global Burden Disease [2] and this population is keep increasing over the years. There were 334 million of people in the worldwide suffering of asthma according to Global Asthma Report 2014 [3]. Hence, it was increased 99 million of people in the worldwide suffering of asthma disease compared between year 2011 and 2014. In 2016, Ministry of Health Malaysia stated that around 1.6 million to 2 million of Malaysian estimated having asthma and this population keep increasing over the years [4]. Asthma is the leading chronic childhood disease with albatross on affected children and their families [5, 6]. It occurs when the pulmonary airway is blocked or the airways become narrowed. This may affect the person and result in difficult breathing and shortness of breath [7]. A study shows that asthma disease is the most frequently occurs in town or city than rural community [5, 8, 9]. Asthma more occurs in urban areas due to often there is haze and air pollution such as fumes from vehicles, factories and so on. Normally asthma patients use metered dose inhaler (MDI) to take inhalation of salbutamol through the mouth to recover from the asthma attack because the MDI only require to shake for 10 seconds before use it [10].

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Metered dose inhaler (MDI) is a portable inhaler used to assist with pulmonary drug delivery [11]. MDI also known as pressurized metered dose inhaler (pMDI) has become the most widely used treatment for controlling symptoms of asthma and chronic obstructive pulmonary disease (COPD) [12, 13]. Current MDI sold in market mostly cannot monitor the remaining amount of puffs available in the MDI canister [14]. The MDI is encompassed of several components which included container, actuator, metering valve, propellants, and drug formulation. Therefore, the MDI canister made by aluminium which contained salbutamol or albuterol, and propellant, also known as container. Salbutamol is a short-acting β2-adrenergic receptor agonist used for the relief of bronchospasm in conditions such as asthma and chronic obstructive pulmonary disease [15, 16]. Salbutamol is a type of medicine where to help to relax the smooth muscles in the air passages in the lungs and it can help to open the airways [17] where easier to breath. Salbutamol is used to treat asthma where to relieve bronchospasm within minutes [18]. Therefore, this may lead to problems for the user due to inability to monitor the amount of salbutamol in the MDI canister. Some manufacturers developed MDI with counter but these devices had their limitation such as unable to store memory of the last counting value if power failure occurs, uses non-rechargeable battery and are disposable.

2. Materials and Method

2.1 Current MDI counter in the market

The MDI available in the market is divided into two types which are MDI electronic counter and MDI mechanical counter. Recently, many manufacturers have begun to develop several types of MDI electronic counter that available in the market. First type of MDI electronic counter is low-cost smart inhaler counter with inhaler APP [19], this type of MDI electronic counter can only display the available puffs of salbutamol on the smartphone but it could not display the value of the counter on the particular device.

The second type of the MDI electronic counter is PuffMinder Doser [20]. This MDI electronic counter can display the available salbutamol puff on the LCD screen as well as the number of inhalations taken per day. It has a warning system to indicate low dose when less than 20 puffs of salbutamol remains in the MDI. Unfortunately, this device work only for 12 months due to built in non-rechargeable battery.

The third type of the MDI electronic counter is called SmartTouch Ventolin [21]. This kind of MDI electronic is able to record the date and time, and the actuation number. Hence it could record the available puffs in the MDI canister. The recorded data is stored in a memory chipset but it requires USB (Universal Serial Bus) cable to transfer or monitor the recorded data on a computer. Furthermore, this device also have a built in non-rechargeable battery and it is an updated version from the previous device which is the Smartinhaler Tracker [22].

The MDI mechanical counter utilize mechanical concept in a form of a mechanical 3-digits meter to display the available puff in the MDI canister. It uses the rotary gear to rotate the 3-digits meter tape to display the value of available puffs in the MDI canister [23]. Table 1 presents the summary of product types available in the market with specific function.

Table 1. Summary of MDI device available in the market

Types of Products	Function
Low-cost smart inhaler counter with inhaler APP [19]	Display the available puff of salbutamol on the smartphone.
PuffMinder Doser [20]	Display the available puff of salbutamol on the liquid crystal display (LCD).
SmartTouch Ventolin monitor [21]	Record the date and time an inhaler is inserted or removed from its case.
MDI mechanical counter [23]	Using mechanical concept to count the available puff in the MDI canister and display with 3-digit meter.

2.2 Metered Dose Inhaler circuit design

Figure 1 demonstrated the block diagram of the non-volatile MDI counter. A 7.4V Li-Ion rechargeable battery provides 5VDC through the use of a 5V voltage regulator. Two of 10KΩ resistor connected to 7.4VDC battery, which forms a voltage divider, proposed to display the percentage of battery. 5VDC supply deliver power to the microcontroller (ATmega328P) and the liquid crystal display (LCD). The limit switch act as an input to the counter to update the number of salbutamol puff inside the MDI canister. To reset the counter, a push button is included. To overcome problems with memory loss due to power failure, Electrically Erasable Programmable Read-Only Memory (EEPROM) is used to save the memory of the last counting value of the counter. RGB LED is a visual indicator to show the level of salbutamol puffs inside the MDI canister.

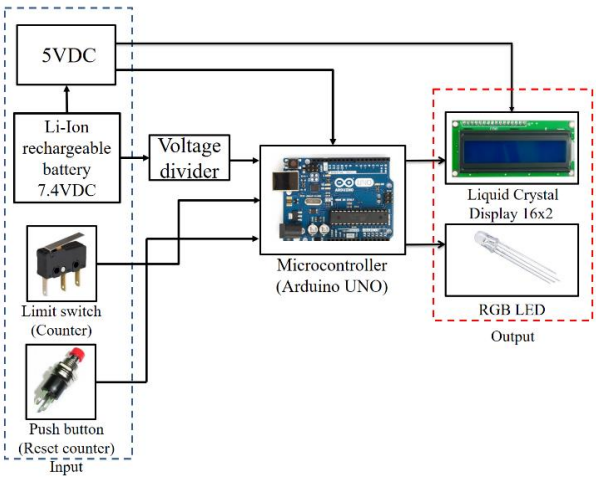

Figure 1. Circuit design of metered dose inhaler counter

Figure 2 shows the flow chart of system operation for proposed device. The function count of used puff for MDI canister starts when the MDI is pressed. At the same time, the value of the counter increases by one and write the value of counter into Electrically Erasable Programmable Read-Only Memory (EEPROM) by using an address.

The 7.4VDC battery connects to two resistors to form a voltage divider. Hence, the output signal from the voltage divider is converted into actual voltage. The obtained actual voltage is calculated into percentage. Therefore, the percentage of the battery displayed on the LCD. There are four conditions while the counter is counting the used salbutamol puffs for MDI canister that are the high, medium and low level, and empty canister. The RGB LED indicate different colour for different level of salbutamol available in the canister. Green indicate high level, yellow/orange colour indicate medium level, and red colour indicate low level and no indicator for empty MDI canister. The function of reset counter value is executed when the counter value reaches 200 or the MDI canister empty. When the empty MDI canister is replaced with a new MDI canister, the user must reset the counter value by pressing the reset push button for 5 seconds or more. The value of used puffs will display on the LCD is "0".

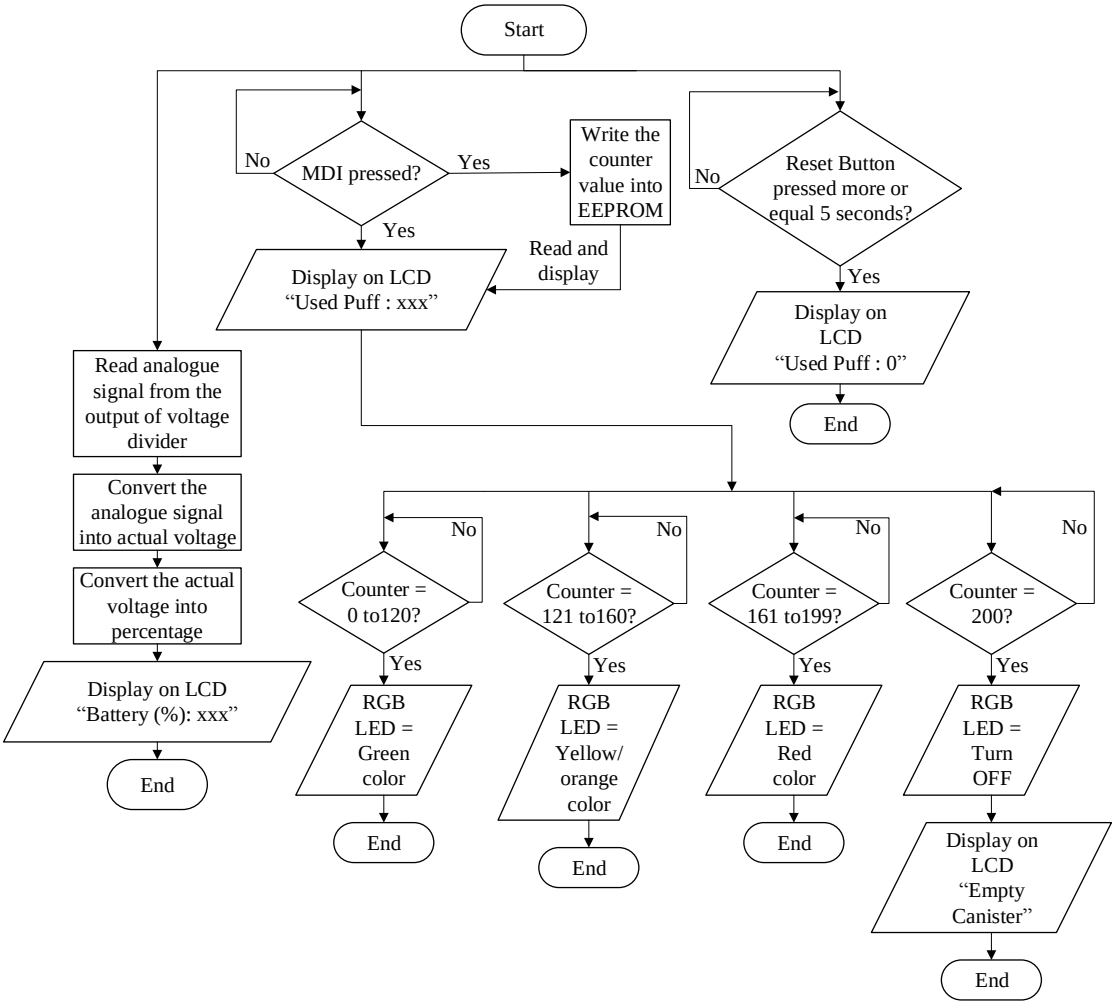

Figure 2. Flow chart of system operation

2.3 Development of the metered dose inhaler housing

The casing is designed for safety purpose. It was developed by using 3D printer and 3D printing filament (Polylactic Acid (PLA) 1.75mm) is the material to develop the housing. Figure 3 shows the housing that was designed individually. The designed cover includes an upper cover, bottom cover, MDI cover, MDI press and curve holder for asthma spacer. The main housing of this prototype was the upper cover and bottom cover which to protect the electronic circuit from electric shock or another hazard. Therefore, the both upper and bottom cover is assembled by using PCB stand (3mm diameter) on the four corners of the housing and screw with 3mm length of screws. The components included in the both upper and bottom cover are microcontroller, LCD display, Li-ion rechargeable battery, push button for reset counter and RGB LED. The both MDI press and cover was designed for MDI to count the used puff of the MDI canister. The both upper and bottom cover should be assembly on the asthma spacer together with the MDI.

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Hence, the curve holder was designed to hold the both upper and bottom cover along the asthma spacer.

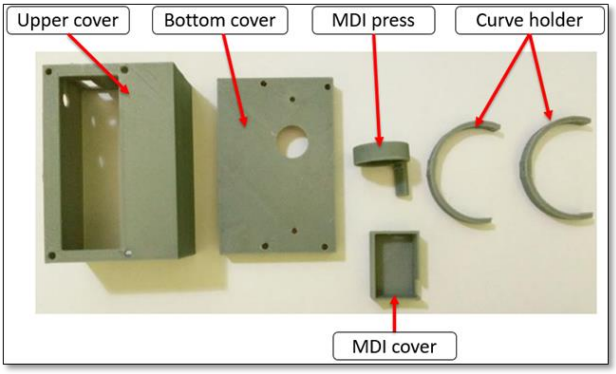
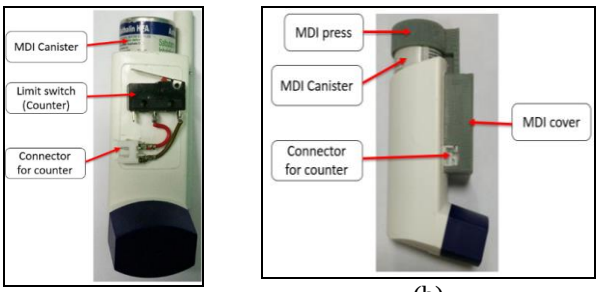


Figure 3. 3D printed cover

The MDI was installed with the limit switch for the counter has presented in Figure 4(a). The MDI cover is developed to protect the internal connection. It is also used to prevent the user from accidently pressing the limit switch. The MDI press is attached to MDI canister so that when the user presses both simultaneously, it will also provide enough pressure to the limit switch to update the counter as shown in Figure 4(b). The connection of the limit switch to microcontroller employed 2 ways 2020 series PCB connector to connect it.

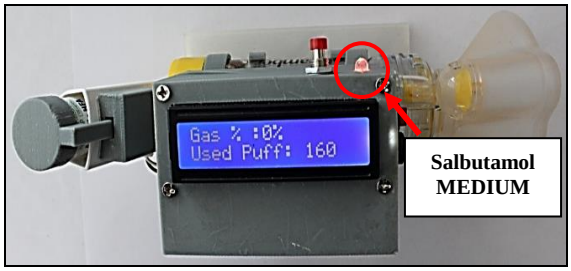


(a) (b)

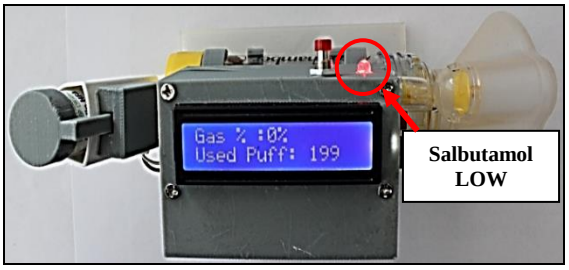
Figure 4. (a) MDI installed with the limit switch (b) MDI assembly with the MDI press and MDI cover

3. Results and Discussion

A metered dose inhaler counter has been developed to assist asthma users. Figure 5 shows the counter display. The RGB LED act as visual indicator to alert the user of the level of the salbutamol in the MDI canister as depicted in Figure 5(a)-5(d). Red LED indicate low level, yellow/orange LED indicate medium level, green LED indicate high level. The LED turns OFF to indicate empty canister (200 puffs have been used).



(b)



(c)

(d)

Figure 5. Picture showing the (a) 120 puffs of salbutamol had been used and the indicator show green colour (b) 160 puffs of salbutamol had been used and the indicator show yellow/orange colour (c) 199 puffs of salbutamol had been used and the indicator show red (d) 200 puffs of salbutamol had been used ("Empty Canister") and there was no indicator indicate

The percentage of battery measured through the output voltage of the voltage divider were achieved. Figure 6 presents the percentage of battery displayed on the LCD as 95%.

Figure 6. Battery percentage display

Figure 7 present the level of salbutamol versus used puffs in the MDI canister. When the used puff increase then the level of salbutamol will change to the next level and the indicator would show different colour on the RGB LED. Green LED represents high level of salbutamol in the MDI canister (0 to 120 puffs), yellow/orange LED represents medium level of salbutamol in the MDI canister (121 to 160 puffs) and red LED represents low level of salbutamol in the MDI canister (161 to 199 puffs). The RGB LED is turned OFF to indicate the MDI canister is empty (200 puffs).

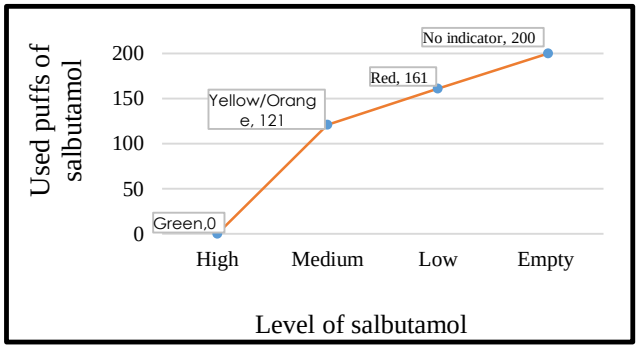


Figure 7. The level of salbutamol versus used puffs in the MDI canister

The MDI press is designed as a tip to press the limit switch and act an input for microcontroller. While the limit switch is pressed, it is not counted unless the switch is released because some users will press the MDI canister for a long time and will continuously counted. The counter value will be counted or stored after the switch is been released. In this application, one address of the EEPROM (ATmega328P) has been selected to store the counted value of used salbutamol puff. ATmega328P is an 8-bits microcontroller which have 256 addresses in this chipset. In one address, it can store value until 255 since this chipset is 8-bit microcontroller. Hence, only one address has been selected because one MDI canister contained 200 puffs and one address is capable to memory the counted value. The EEPROM for this chipset had write/erase cycle up to 100,000 times and it can be used up to 500 of MDI canister.

The RGB LED is designed as visualization to indicate the level of salbutamol for MDI canister and it encompassed pulse width modulation (PWM) in ATmega328P to function. In this application, the RGB LED encompassed PWM to function because PWM can control the output voltage where it can control the brightness or intensity of each colour of RGB LED. Hence, by controlling the intensity of each colour of the RGB LED which is red, green and blue, RGB LED would produce different colour at one time. After the used puffs reaches “200”, users should replace a new MDI canister and press the reset button for 5 seconds or more. The reset button for counter is required to be pressed for 5 seconds or more because it act as security in case users accidently presses it. The percentage of battery is an indicator to remind the user to charge the battery for better working performance. The input voltage from battery connected with two resistors to form a voltage divider proposed to reduce voltage lower than 5VDC. The voltage required to be reduced because the analogue pin for the Arduino UNO could only work with a maximum voltage of 5VDC. The voltage divider output is read by the microcontroller and this signal will be converted into actual voltage. The minimum voltage refers to the minimum voltage required by the Arduino UNO and the maximum voltage refers to the voltage of the battery after it is fully charged.

4. Conclusion

A non-volatile counter with battery indicator for metered dose inhaler (MDI) has been developed and is capable of counting the used salbutamol puff inside the MDI canister. The MDI counter successfully store memory of the last counting value even when there is power failure. The RGB LED function well as visualization to indicate the salbutamol level inside the MDI canister. This device could remind the user to prepare a new MDI canister since it had indicated of low level of salbutamol in the MDI canister. Besides this, it also could reduce the deaths from asthma due to the user would prepare a new MDI canister before attacked by asthma. In addition, this device could reduce the population of discard unwanted electronic device since this device is using rechargeable battery.

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