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Controlling Collimator Motion in Cobalt-60 Radiotherapy Machine by Converted Breathing Electrical Signal

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Abstract— The respiration (Inhalation and Expiration) as physiological mechanism causes the internal human organs displaced partially away from the field size boundary area during radiotherapy; as the collimator of radiotherapy machine is fixed, hence the aim of the following study was to convert the breathing physiological motion into electric signal and further to set the collimator in real dynamic synchronized with breathing mechanism. With usage of pressure sensor; the mechanical motion of abdomen due to breathing has been converted into analog electrical signal in a real time sinusoidal mode, then with usage of a microcontroller; the analog signal has been converted to digital discrete sequence signals form with (0-5) volts {1100,0110,0011,1001}and {1001, 0011, 0110, 1100}, then these signals connected to the stepper motor in sequence form; via the driver circuit (ULN2003A) which link and gives enough voltage (0-12) volts to turn the stepper motor in clock wise direction (CW), in respect to signal {1100,0110,0011,1001} or counter clock wise (CCW), in respect to signal {1001, 0011, 0110, 1100} which is corresponding to collimator motion of radiotherapy machine (Co-60) in synchronized pattern to abdominal motion induced by breathing mechanism.

Keywords— Breathing; Organs motion; Radiotherappy; Real-time; Collimator**.**

I. INTRODUCTION

Radiation therapy is a technique has been used to cure cancer patients beside surgery and chemotherapy, in which a localized ionizing radiation beam directed to deliver cancerous tissue a cancericidal dose while giving minimum dose to the adjacent normal structure [1]. One of the common known machines used in this field is the Cobalt-60 teletherapy machine which introduced to clinical usage in London-Ontario in 1951. It was adopted with tremendous enthusiasm in the treatment of malignant disease. Indeed, recently it considered as an old modality that is only useful for palliative treatments in a large department or for developing countries with limited technical resources [2, 3]. Co-60 is most commonly used because of its long half-life of the radioactive source, less complexity in view of electronics devices and friendly used, superior specific activity per gram (3000 to 5000 Curies) which is activity is limited by the physical size of the source, its greater beam intensity per curie, and higher average photon energy 1.25 megavolts (MV). A typical Co-60 source is 1 to 2 cm in diameter. Although of its advantages, however it has a conventional collimator in *x* and *y* pair jaws which is used to define the radiotherapy field with generous margin around the tumor i.e. implies wide target volume and more over no consideration to the organs movement caused by breathing.

In this realm, various authors demonstrated that: some organs are tend to mobile due to breathing mechanism or person position, such as prostatic motion of up to 3 cm can occur mostly in the anterior and/or superior direction [4, 5, 6]. Similarly, bladder treatments involve large changes in bladder and rectal diameters [7]. Thoracic studies have shown substantial tumor movement (1.5 cm) as a result of cardiac and respiratory cycles [8]. Similarly, in head and neck treatments, gross tumor volumes can change during a 6 week course of treatment. The net result is that our ability to reposition the involved tissues is severely limited by both a "moving target" within the patient as well as our ability to reposition the patient from day to day. Such motion during radiation therapy will degrade the efficiency of treatment as well as the prognosis, as the radiation therapy error will not exceeds ±5% [9, 10]. Some authors attempt to solve such physiological motion; as Neicu et al, [11] and George et al, [12] in which they attempted to

solve it by converting the infrared reflection to electric signal, however the signal generated is so week, noisy and distorted. Other attempt introduced by Sitharama et al, [13] to manage the organ motion problem in radiotherapy was the utilization of innovated real time diaphragm sensor excerpted from the fundamental of network sensor. On the other hand Seungwoo et al, [14] used a target-tracking radiation therapy (RT) system that tracks the movement of a treatment target resulting from internal organ movement.
While the aim of this work is to induce the dynamic synchronized motion to the fixed diaphragm of Co-60 radiotherapy machine with the breathing mechanism using microcontroller, so as to solve the problem arise due to organ motion during radiotherapy.

II. MATERIALS AND METHODS:

A. *The piezoelectric sensor:*

The following sensor used for voltage generation, it generates voltage when experience to pressed shown in Figure (1), the direction of arrows indicates the direction of pressure when attached to human abdominal wall.

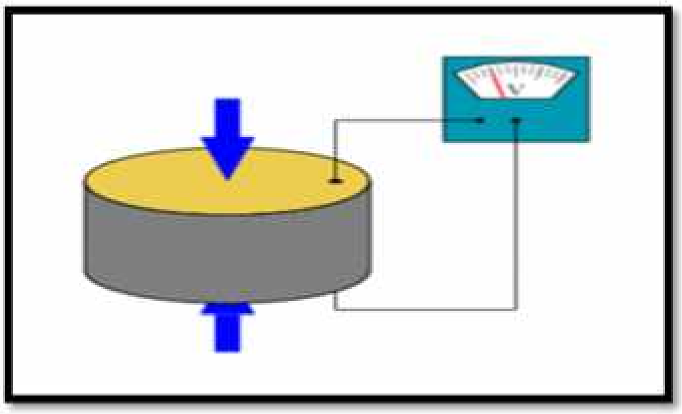

Figure (1): The piezoelectric sensor for voltage generator by pressure effects.

B. *Microcontroller At-Mega 16 (μC, uC or MCU):*

A microcontroller is the type of small computer on a single integrated circuit Figure (2), which contains a processor core, programmable Input/output and memory (Ram/Rom) in addition to a timer. It has the following features:

1. 16KB of Flash memory
2. 1KB of SRAM
3. 512 Bytes of EEPROM
4. Available in 40-Pin DIP
5. 8-Channel 10-bit ADC
6. Two 8-bit Timers/Counters
7. One 16-bit Timer/Counter
8. 4 PWM Channels
9. In System Programmer (ISP)
10. Serial USART
11. SPI Interface
12. Digital to Analog Comparator.

C. *Programming of microcontroller:*

The microcontroller has been programmed using assembly language, to be fit in the available on-chip program memory, and then compilers and assemblers are used to convert high-level language and assembler language codes into a compact machine code for storage in the microcontroller's memory and the code vision is the program used in this paper to simulate circuit operation.

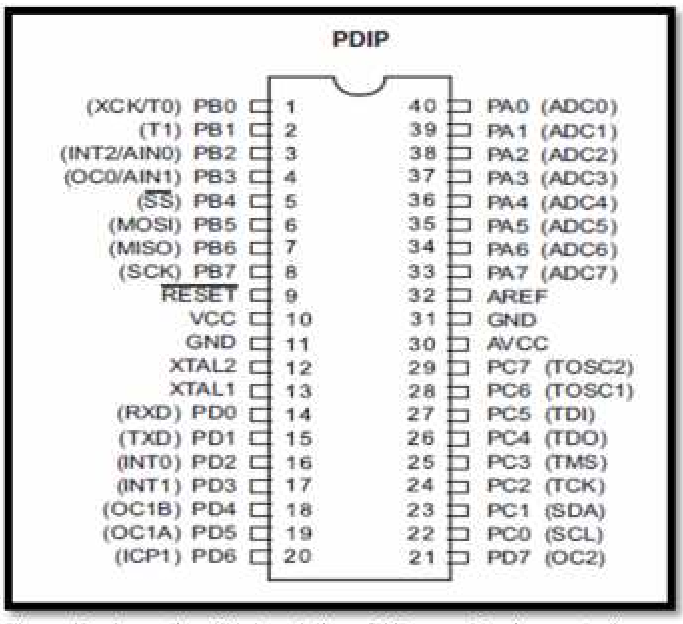

Figure (2) shows the PIN description of AT mega16 microcontroller

D. *Driver circuit ULN 2003A:*

In electronics, a driver is an electrical circuit or other electronic component used to synchronize another circuit or other component, such as a high-power transistor. The ULN2003A is a monolithic IC consists of seven NPN Darlington transistor pair's voltage and current capability. As shown in Figure (3).This design is used to synchronize between microcontroller (low power) and the stepper motor (high power) [15].

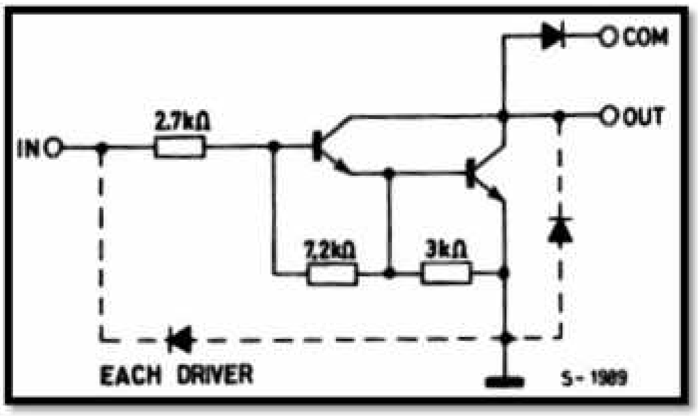

Fig. 3 shows the circuit of each Darlington Pair – ULN2003.

E. Stepper motor:

A stepper motor shown in Figure (4) is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence [16]. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied. The movement read by each pulse is precise and repeatable; hence the stepper motors are so effective for positioning applications, excellent solution for applications such as machine control, manufacturing test, semiconductor positioning, biomedical machines, and lab automation.
Figure 4 shows some of the physical details that characterize its operation. In a variable reluctance VR stepper motor, the surrounding coils that are physically located opposite to each other are energized to create opposite magnetic fields. As in Figure 4-a, coil C produces a south-pole magnetic field, and coil Ć produces a north-pole magnetic field. The magnetic fields produced by the coils pass through the air gap and through the metallic rotor. Because the magnetic fields attract each other, the metallic rotor spins in a direction that brings the nearest edges (2 and 4) of the rotor as close as possible to the pair of energized coils (C and Ć). The VR stepper rotor will remain aligned to the coils as long as coils C and Ć was energized and the magnetic fields are not changed. To move to the next state and continue this rotation, coils C and Ć must be de-energized, while coils A and Ā must be oppositely energized to attract rotor edges 1 and 3 respectively.
The same process occurs with coils B and Ḃ to attract rotor edges 2 and 4 respectively, and so on [17].

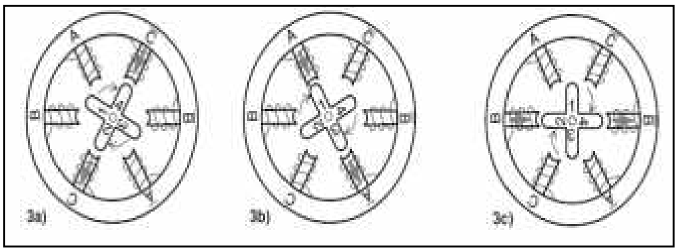

Figure 4 shows the position of the eight-pole rotor and Four-pole stator of a typical stepper motor, the signal initializing the magnet at No. 1 [17].

F. Gear Ratio:

Considering gear (A) as the one of the stepper motor and gear (B) is to be directly coupled to it to drive the collimator as shown in Figure (5) so as to increase the torque and reduce the speed [18], as we interest in torque rather than speed. This mechanical stage gear ratio is very important to make synchronization between stepper motor rotation numbers (A) and the desired displacement of the collimator (B).

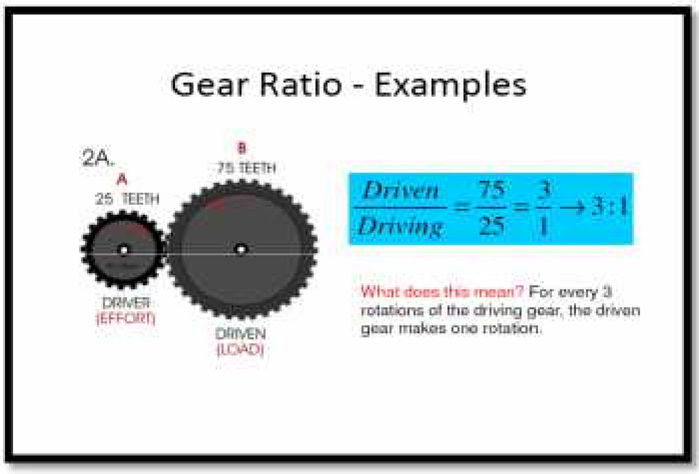

Figure (5) shows the gear ratio for controlling the displacement of of collimator in Co-60 teletherapy machine.

III. Result and Discussion:

The piezoelectric pressure sensor (Figure 1) responses to mechanical pressure (Kilo Pascal) by abdominal motion, hence will generates a voltage in direct proportional to the pressure applied from abdomen or a chest movement during breathing process at inhalation and exhalation state. The generated voltage by pressure sensor as output (Figure 6) has been connected and fed to the programmed Microcontroller (At mega 16, Figure 2) to convert the analog signal samples from Figure (6) as {12,6,3,9} and {9,3,6,12} seen in Figure (7, 8) into digital sequence form in the port (A) pin number 40 (ADC 8 bit conversion) seen in Figure (2) to be in digital discrete sequence signals form with (0-5) volts {1100,0110,0011,1001}and {1001, 0011, 0110, 1100}, then these signals connected to the stepper motor in sequence form; via the driver circuit (ULN2003A) Figure (3) which link and gives enough voltage (0-12) volts to turn the stepper motor in clock wise direction (CW), in respect to signal shown in Figure 7) or counter clock wise (CCW), in respect to signal shown in Figure 8). And the final system for conversion of abdominal motion into electric signal could be highlighted in Figure (9) in a simulation schematic diagram using the pressure sensor; from which to microcontroller (ADC) to convert the signal into digital in sequence form, then to driver circuit for more voltage to drive the collimator motor in radiotherapy system in clock wise and counter clock wise to mimic the movement of abdomen in real time.

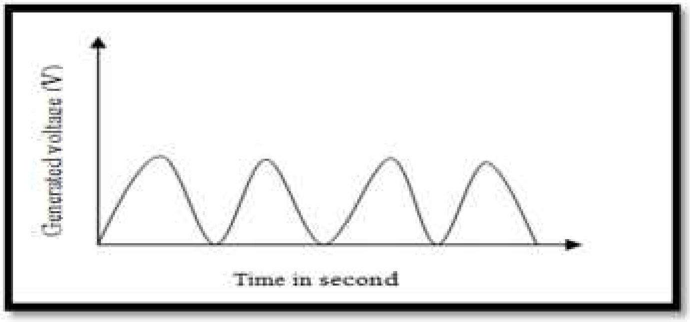

Fig. 6. Shows the microcontroller input signal.

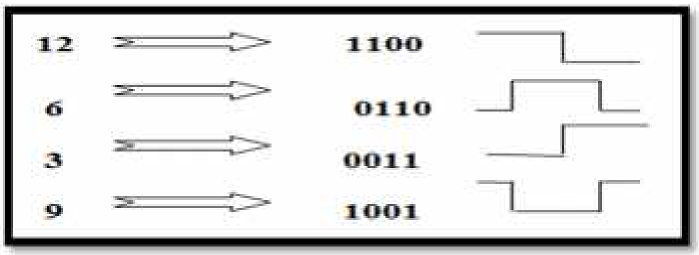

Figure: (7) shows microcontroller output (CW) signals

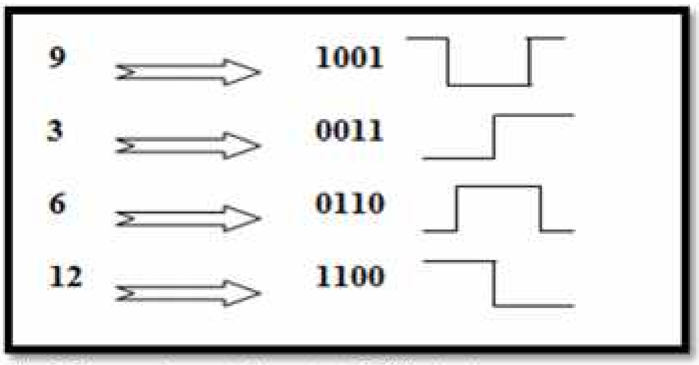

Fig. 8. Shows microcontroller output (CCW) signals.

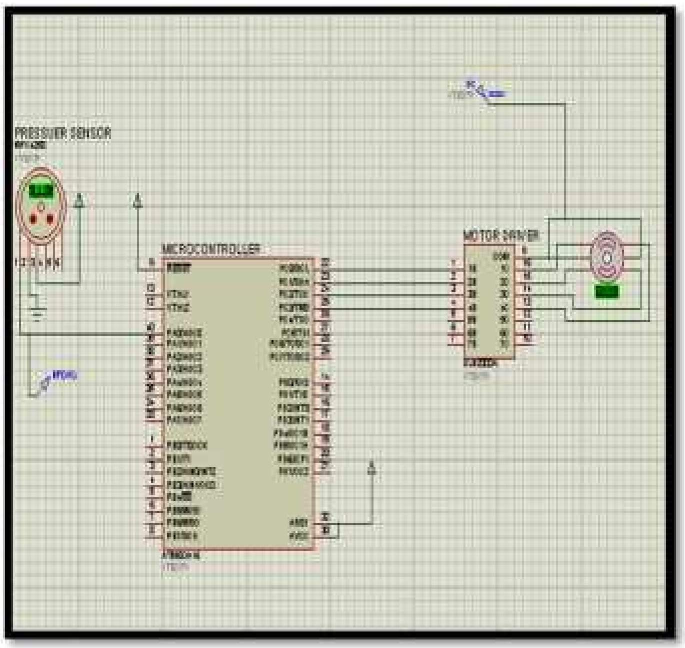

Fig. 9 represents the schematic diagram of the designed circuit.

Figure 10 shows the digital signal connected to stepper motor via driver circuit (ULN2003A) and showing the position of motor at different angles (a = 0^0; corresponding to 19Kpa) (b =90^0; corresponding to 20 Kpa). Same position of motor could be achieved by decreasing the pressure to 19 Kpa.

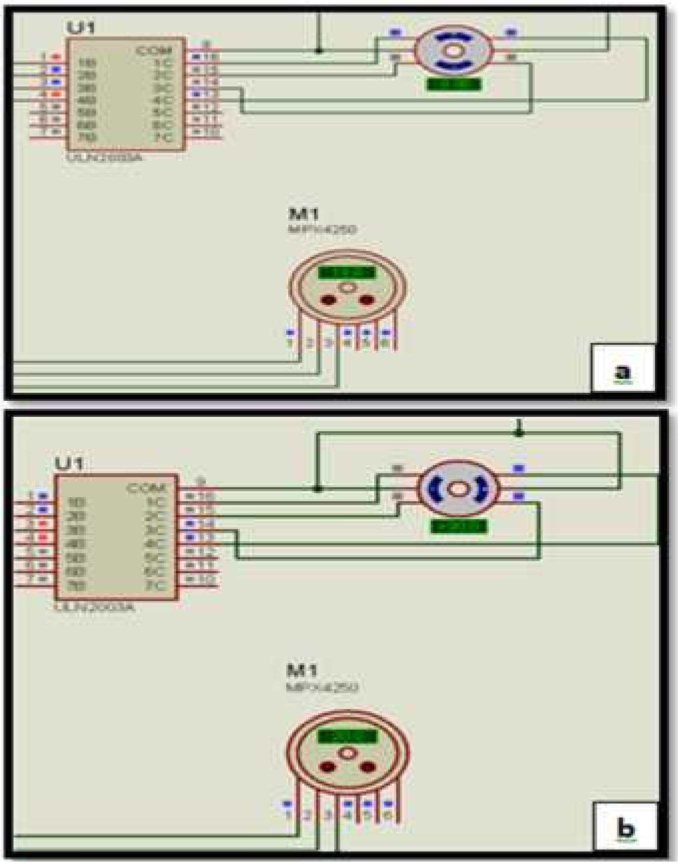

Fig.10. shows the digital signal connected to stepper motor via driver circuit (ULN2003A), and showing the position of motor at different angles (a = 00; corresponding to 19 Kpa) (b =900; corresponding to 20 Kpa). Same position of motor could be achieved by decreasing the pressure to 19 Kpa.

IV. CONLUSION:

With enhancement of pressure sensor, the microcontroller, driver circuit and the gear box, the mechanical motion of abdomen due to breathing has been converted into electrical signal in a real time to synchronize the movement of radiotherapy machine diaphragm with target volume motion.

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