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A DC Actuator based elevation mechanism for Patient Positioner System

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Abstract -

Hydraulics based motion control has been used from many years in healthcare imaging and scanning applications like PET, CT, MRI etc. Achieving positional accuracy and repeatability is very crucial in medical imaging systems to get good scan reports. For scanner table elevation mechanism, a digital processor controlled hydraulic based methodology is used in existing systems. However hydraulic based design has its own disadvantages. So, this paper presents a new method of elevation mechanism for patient positioning system, which uses electrical DC actuator instead of hydraulics. Also, describes the use of optical encoders for table position tracking and PID controllers to control DC motor speed control

Keywords: **Digital Control Processor, H-Bridge Controller, MOSFETs, Actuator, Stepper motor, optical encoders.**

I. INTRODUCTION

In most of the healthcare imaging and scanning techniques, patient positioning on top of the scanner table bed plays an important role to acquire good quality scan images without large spatial error during overlapping to get 3D images for diagnosis. So, patient positioning system consists of a Digital motion control processor, which acts as heart of PPS. DCP accepts commands from the user and accordingly actuates the required motion of the table and continuously keep track of the table position, speed etc. to make the system to operate in a safer mode. Two important motions of the PPS are UPDOWN motion and TO-FRO motion of the table as shown in figure 1. Several methods are used to accomplish these motions. This paper mainly describes the methods used to control the table elevation mechanism and compare their performance with respect to speed, power, efficiency, cost etc.

Figure 1: Patient Positioner System of PET/ CT scanner

Abbreviations and Acronyms

- DCP- Digital Control Processor
- PPS- Patient Positioning System
- FPGA- Field Programmable Gate Array
- AEs- Absolute encoders
- IEs- Incremental Encoders
- PET-Positron Emission Tomography
- CT- Computed Tomography
- MRI-Magnetic Resonance Imaging
- PID- Proportional Integral Derivative

II. PRINCIPLE WORKING OF PPS

Patient Positioning system of any scanner system as shown in figure 2. basically, requires two types of motions to perform the required scanning and acquire the images. They are table Elevation Mechanism(Up-Down) and cradle In-Out motion. And a closed feedback mechanism to keep track of the table and cradle position.

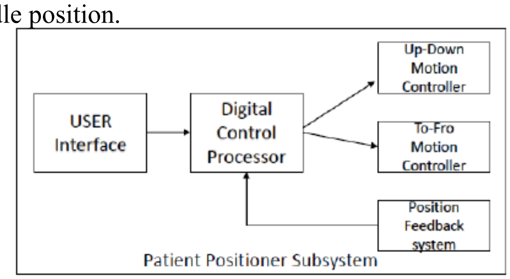

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Figure 2: Block Diagram of Patient Positioning System

Digital control processor is a microcontroller, which controls all the peripherals that are connected to it. Important peripheral blocks are table elevation controller, cradle motion controller and the feedback system.

III. METHODOLOGY

A. Table Elevation (Up-Down) Controller:

Most of the scanner systems uses hydraulic based mechanism for Up-Down motion of the table. Hydraulic based system uses oil pump in and out mechanism for elevation up and down. This methodology has some of the drawbacks like oil leakage, costlier, bulkier etc. One of the new method to overcome these drawbacks is to use an electrical DC actuator based mechanism for elevation as shown in figure 3.

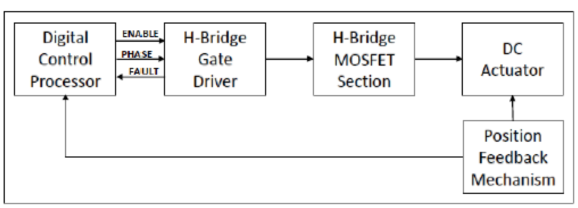

Figure 3: Block diagram of DC actuator based Elevation controller for PPS.

DC actuator assembly consists of a DC motor connected to a piston rod. As the motor shaft rotates forward the shaft connected to it moves upwards and as the motor shaft rotates backward the shaft connected to it moves downwards. Here no issues of oil pump in and out as in case of hydraulic based system. Forward and backward rotation of the motor is controlled by a H-Bridge controller. H-bridge controller consists of four gate driven power MOSFETs connected in a H bridge manner. During each motion of the motor, only two MOSFETs will be ON and other two will be OFF as shown in below figure 4.

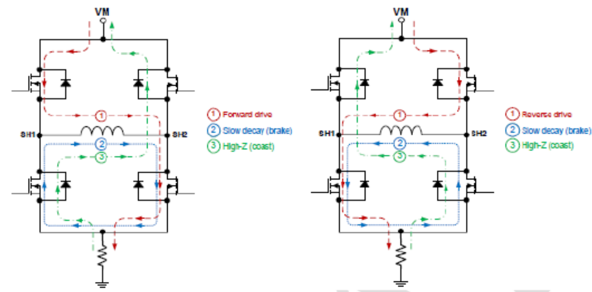

Figure 4: Working of H-Bridge MOSFETS

H- Bridge Gate driver chip is used to provide the required gate drive voltage and current for the MOSFETs. Also, it consists of several protection circuits like to indicate overcurrent, over voltage, over temperature etc. During these conditions the driver will turns off the power supply to the MOSFETs and hence system goes to sleep mode. Important signals that are given from DCP to gate driver are Enable and Phase. Enable signal is the one which is used to control ON and OFF the MOSFETs. Phase signal is used to control the direction of motor motion. H-Bridge gate driver consists of inbuilt LDOs (Low Drop Out) Voltage regulators which gives required voltage supply to the internal circuits.

B. Cradle IN-OUT motion Controller:

Stepper motor is used for cradle IN-OUT motion control of PPS as shown in figure 5. Control signals from the user are given to DCP. DCP will decide the required action to be carried out and gives the appropriate control signals to the stepper motor driver. Stepper motor driver will control the current and voltage supply required to drive the stepper motor. Direction of the stepper motor rotation will be changed as per the user command, which in turn changes the direction of current flow in the stepper motor circuit. Also, Stepper motor driver is use to monitor the motor current, voltage etc. and to shut down the power supply when there are over current, over voltage condition occurs.

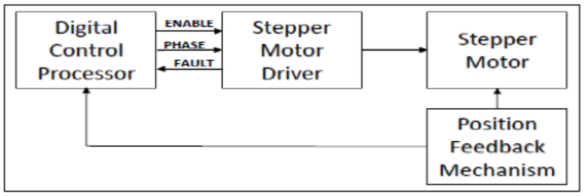

Figure 5: Block diagram of Stepper motor based Cradle motion controller for PPS.

C. Position Feedback System:

It is very important to keep track of the table and cradle position continuously to achieve good positioning of the patient. For this purpose, potentiometers and optical encodersare used. Optical encoders are used in position sensing and estimation of velocity and acceleration of a rotating shaft. Optical encoders are of two types: Absolute encoders(AEs) and Incremental encoders(IEs). Absolute encoders output a coded data that uniquely identifies the current position of the shaft to which it is coupled. Although position data is available instantaneously after every system power-up, but wraps back after every complete revolution. Hence continuous data acquisition is not possible. Incremental encoders give a pair of pulse trains in quadrature, each pulse representing an incremental rotation of the shaft.By counting the number of pulses, one measures the total incremental motion from the starting point. However, every time the system is powered up, a zero reference needs to be established as the last sensed data will be lost. Commercial IEs implements a third channel called Index channel which outputs a single pulse per every revolution, which can be used to establish zero position every time the system is switched on. Absolute encoders are costlier than incremental encoders. The position data received from the encoder will be amplified and given to ADC. ADC will give a digital value for each position data received and it will be compared with the data stored in DCP. After this comparison, DCP will decides the direction of the motion and velocity as per the required actions from the user.

D. DC motor speed control using PID control feedback system:

DC motor consists of a stator and an armature. Speed of the motor can be controlled by two methods. One by varying the stator field current and second by varying the armature supply voltage. The transfer function of a DC motor is given by

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{Km}{sT+1} \ldots\ldots(1)$$

Where (s) =motor speed in rpm.

(s)=armature supply voltage in Volts

$K\,m$ = motor gain constant in rpm/V

T =motor time constant in secs.

PID (Proportional Integral Derivative) Controller is used to control the motor speed. It is used to regulate the time behavior of a closed loop system. PID controller, DC motor, Optical switch(encoder), F/V(frequency to voltage)block and the error estimator block forms a closed loop system as shown in Fig 6 below.

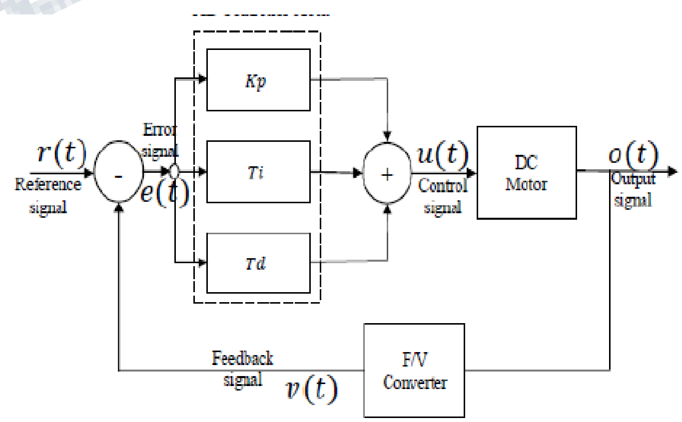

Figure 6:Closed loop Speed Control of DC motor using PID controller

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DC motor is considered as plant of the closed loop system. PID controller is placed in the forward path before the plant. Speed of the motor is sensed through an optical switch. This speed frequency is converted to voltage by F/V (frequency to voltage) converter and this voltage v(t) is fed as input to the error block through feedback path. This feedback input is subtracted from the reference input r(t) to get the error voltage e(t). Error voltage is fed to PID controller block, which generates the required control voltage u(t) to be given to motor to reduce the error and make the output o(t) of the motor sustained.

The transfer function of a PID controller is given by

$$C(s) = Kp(1 + \frac{1}{s*Ti} + (s*Td))\text{.......}(2)$$

Where Kp - Proportional Gain Constant

Ti - Integral reset time

Td -Derivative time or rate time

Proportional control Kp is used to make the control signal (t) to respond to the error signal immediately. Here error will not be reduced and still offset error will be present.

Integral control Ti is used to remove the offset error. Derivative control Td is used to dampen out the oscillations in the plant response and to reduce the requirement of large Kp to achieve high stability.

These PID constants are tuned to achieve the desired response. One method of PID constants tuning is Ziegler-Nichols Rules ultimate cycle method. As per this rule:

- Connect the controller behind the plant.
- Initially disconnect the Ti and Td controller and set Kp at small value.
- Increase Kp till system gives sustained oscillations. And find the period of oscillations Pu and the ultimate gain Kpu.
- Use the below table to fine the PID constants using Pu and Kpu.

Table 1 : PID constants relationship for different control modes

Control Mode	Constants Relationship
P control	Kp =0.5 Kpu
PI control	Kp =0.45 $KpuTi$ =0.83 Pu
PID control	Kp =0.6 $KpuTi$ =0.5 $KpuTd$ =0.125 Pu

IV. RESULTS

This section gives the performance comparison between hydraulic based and DC actuator based table elevation mechanism used in PPS.

Speed Accuracy: It is possible to achieve high speed in case of Actuator based design compared to hydraulic based design.

Cost and Size: Actuator based design elevation mechanism is cheaper and sleeker compared to hydraulic based design elevation mechanism. Hydraulic based mechanism is bulkier and requires more space for assembly.

Power and Efficiency: Actuator based design requires less DC electrical power as it requires less current to drive the motor. Hydraulics based system require high AC voltage since there are many mechanical components need to be powered up. Efficiency of actuator based design is better than hydraulic base design with respect to its lifecycles, robustness etc.

Maintenance and Reliability: Maintenance cost for hydraulic based system is higher and complex compared to actuator based design. Reliability of actuator based system is better than the hydraulics based system since there is a two-level protection provided by the actuator system against the piston snag or rollback due to the weight.

System safety: actuator based system is simpler and safer to replace in case of any system failure compared to hydraulic based design.

Oil Leakage: No issue of oil spill or leakages in actuator based system as in case of hydraulic based system.

Table 2 : Comparison between DC Actuator and Hydraulics based PPS

Factors	Actuator based PPS	Hydraulics based PPS
Speed accuracy	High 28 to 55mm/sec	Medium 24 to 50mm/sec
Power required	Less DC power	High AC power
Efficiency	High	Medium
System size	Sleeker	Bulkier
Maintenance	Simple and cheaper	Complex and costlier
Reliability	Better	Good
System safety	High	Medium
Oil leakage	No	Yes
Piston snag	No	Yes
System cost	Low (300 dollars)	High (1500 dollars)
Repeatability	Better	Good
System Complexity	Less	High

V. CONCLUSION

DC actuator based elevation mechanism for PPS is advantageous than the hydraulic based design. Position feedback mechanism used in PPS should be very accurate, precise and robust as the PPS is used for healthcare applications. PPS using actuator based design has been found to be cheap, sleeker, high speed accuracy etc. Hence the cost per each scan is reduced compared to previous hydraulic based design.

FUTURE SCOPE

This paper presents an DC actuator based elevation mechanism for PPS of imaging scanner systems in which entire table mechanism is controlled and monitored by a digital control processor nothing but a microcontroller. Since microcontrollers are application specific, non-reconfigurable, they have limited performance since upgradation is not easy. So, Field Programmable Gate Arrays (FPGAs) can be used in place of microcontroller, which are easily reconfigurable, cheaper than microcontrollers.

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