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Microcontroller Based Sampling and Reagent Arm used for Batch Analyzer

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Abstract

In today's scenario, automation is being given high priorities as it requires less human labour and is faster. With this in context, a clinical batch analyzer can be automated to perform various tests with a higher accuracy and efficiency. Generally, a patient sample is reacted with proportionate amount of reagent in a reaction cell to perform a required test and then a new setup is used for next test. So a design with three robotics arms and a batch analyzer plate can be used to perform the mentioned operation. The two of the three arms will be operating for transferring the samples to the reaction cell present in the batch plate and the third for ensuring the mixing of the fluids with each other and transferring the content to the micro flow cell where the test results can be readout. This automation of the batch analyzer will reduce the amount of time taken to complete the entire process but also increase the efficiency of test results. The system proposed can be used to perform 38 different types of tests for 32 different patients.

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Keywords: Analytical Plate; Clinical Chemistry Analyzer; Random Access Algorithm (RAA); Reagent Arm; Sampling Arm.

Nomenclature

RAA	Random Access Algorithm
DOF	*Degree Of Freedom*
ΦD_{re}	*Diameter of Reaction Plate*
ΦD_r	*Diameter of Reagent Plate*
ΦD_s	*Diameter of Sample Plate*
R_{Arm}	*Distance of Sample/Reagent Arm from the centre of the batch plate.*
t_{ArmS}	*Time required for Sample Arm*
t_{ArmR}	*Time required for Reagent Arm*
t_{ArmC}	*Time required for Stirring Arm*
t_{PS}	*Time required for Sample plate motion*
t_{PR}	*Time required for Reagent plate motion*
t_{PRe}	*Time required for Reaction plate motion*
t_P	*Time required for Analytical plate motion*
t_{Cycle}	*Time required for one cycle of operation*
t_{Total}	*Total time required for all completing sequential tests*

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1. Introduction

This paper provides the complete information of clinical chemistry analyzer comprises of analytical plate which holds up the patient's samples, reagent containers and reaction cells where the reaction takes place. The six degrees of freedom of movement is controlled by PIC16F877A [1]. Avoiding the commercial software for the robot system, a virtual model has been developed in the MATLAB and tested with various positions [2]. The radius of the reaction cells is 4.4mm, when the cells spun around at 8000 rpm, this makes the liquid present inside to move upward at 1° draft angle and the parallel force acting upward with the reaction cell will be five times the force of the gravity [3]. In 2010 Dominguez *et al* proposed a automatic analytical system which gives very high accurate output based on the concept of sequential injection analysis technique, but it has the limitations of three channels to operate with three different reagents [4]. Clinical tests have been take care by Bio-robot platform with mobile agents and various robotic technology algorithms are proposed and validated [5]. The unique presentation in this paper is proposed the random access algorithm to access the samples and reagents. So that usage of regent is optimized and the system is validated with the RAA algorithm. The analytical plate, sampling arm and reagent arm are controlled by the micro controller AT Mega 2561 processor; the third arm is present for mixing the two fluids. Servo motors are present in the three arms and analytical plate where all of them are connected through the daisy chain link. The sampling arm and the reagent arm, each with four degrees of freedom, is used to transfer the samples and reagents to the reaction cells. By automating this unit with random access algorithm, it is not only saving the manpower but also the precise usage of reagents. This analytical plate contains 32 sample tubes, 36 reagent containers and 128 reaction cells. By implementing the random access algorithm, this unit is capable of performing the different type test for various patients. Thus we can perform 36 tests for 32 samples of patients in 9 cycles on the same batch plate. This setup along with random access algorithm will reduce the man power, time consumption and error percentage will be a major step in the field of clinical chemistry.

2. Methodology:

Random Access Clinical Chemistry Analyzer comprises of Analytical Plate, Sampling Arm, Reagent Arm, Stirrer Arm, and Controlling Unit. Analytical plate comprises of three circular plates which is patient samples tray contains 32 sample tubes, reagent container tray contains 36 reagent bottles and reaction cells array contains 128 reaction cells where the reaction and incubation takes place. Sampling and Reagent arm are having 4 degrees of freedom each. Transferring of samples from sample tubes to reaction cells is carried out by sampler arm; likewise the reagent is done by reagent arm. Each arm has four Dynamixel – MX 28 servo motors and connected through the daisy chain link. Stirrer arm does the stirring of the content of reaction cell as well as transferring the content from reaction cell to micro flow cell. In the micro flow cell the results are readout and stored in the memory.

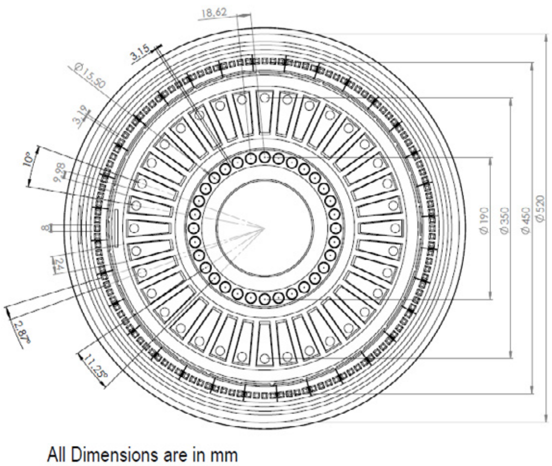


Fig 1: CAD Drawing of Analytical Plate topview with it's dimensions

2.1. Analytical Plate:

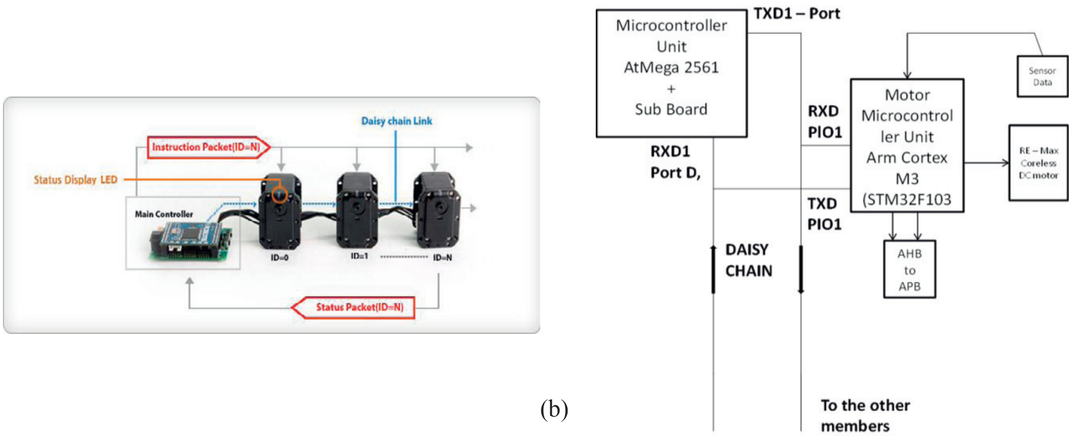
Analytical plate has three turntable circular plates has its different rotating speed, each plate is able to rotate with a separate Dynamixel 28 servo motor and it is controlled by the ATMega 2561 MCU. Fig 1. shows the top view of analytical plate which is drawn in 3D CAD design software SolidWorks. The total diameter of the analytical plate is 520mm. specifications of the analytical plate are given in the Table 1.

2.2. Control Unit:

The control module type controller is used with an AT Mega 2561 Micro Controller Unit (MCU) installed on it. The operating voltage range is + 7 to + 35 Volts with an overall maximum current rating is 10 Amps, with this temperature and voltage sensors added to the circuit to provide data about the working atmosphere and prevent thermal shutdown. It has a working temperature range of – 5° C to + 70° C. The motors connected with this controller board are Dynamixel Servo motors by Robotis which provides no load speed of 54 rpm and holding torque of 24kgf.cm at a 12 Volts DC supply.

Table 1: Specification of Analytical Plate

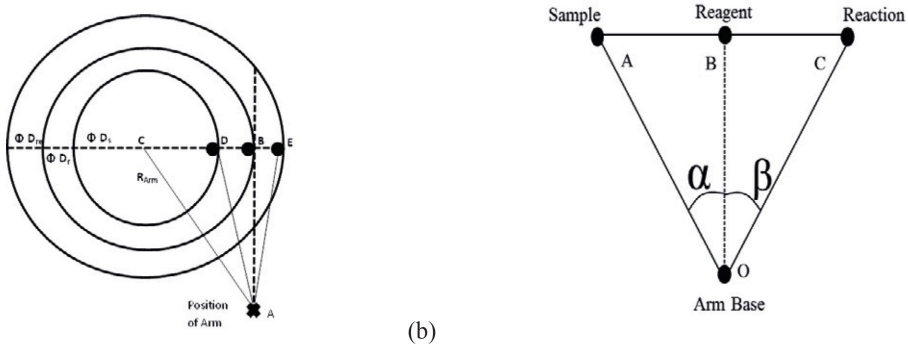
Name	Size
Number of Sample tubes	32
Capacity for each sample tube	0.8ml
Total Size of samples tray	190mm
Diameter of each sample tube	15.5mm
Distance between each sample tube	3.15mm
Number of Reagent container	38
Capacity for each reagent container	25ml
Total Size of reagent tray	350mm
Size of each reagent container	10mm
Distance between each reagent container	9.98mm
Number of reaction cells	128
Capacity for each reaction cell	1.2ml
Total Size of reaction cells tray	450mm
Size of each reaction cell	8mm
Distance between each reaction cell	3.19mm
Total Diameter of Analytical plate	520mm



(a) (b)

Fig.2. (a) The daisy chain link connection between servos and (b) Interfacing of Microcontroller with the Servo motor

The Dynamixel – MX 28 motors have an in-built STM32 series MCU which has the ARM Cortex M3 architecture. This motor has almost 0° to 360° full sweep. It also has a 12-bit position sensor to depict the shaft position, providing a feedback path for errors. It works on PID control algorithm to enhance the precision. PID control actually helps in considering the current error (P), integrate the previous errors (I) and derive the value for future errors (D). Other than position feedback, it also gives temperature and load values to prevent from overheating and overloading. Also it has an analog resolution of 4096 for total 360° giving the accurate 0.08789° angle resolution. It has a standby current of 100 milliamps and operating current around 1.5 Amps, this reduces the power consumption during no operation. It uses TTL/RS485 communication protocol for communicating with Dynamixel – MX 28 servo motors. RS485 is a standard serial communication and its standards are fixed by Electronic Industries Alliance (EIA), which should meet out the requirements for a multi-point communications network.



(a) (b)

Fig.3. (a) Position with the analytical plate and (b) Triangle formed by the sampling and reagent arm motion over the batch analyzer

2.3. Interface of Robotic Arm:

RS485 serial communication suits for the common mode range data transfer of drivers and receivers in the tri-state logic, power off mode; it can withstand data collisions and address to bus fault detections. The communication between the STM32 (32-bit ARM Cortex MCU's) which is present in the Dynamixel – MX 28 and AT Mega 2561 (present on CM700); it's a Half-Duplex Asynchronous serial communication. All the motors are connected in a Daisy chain physical link with the help of a daisy chain type connector. Then each motor is assigned a specific ID to be identified in the chain. This ID number can vary from 0x00 to 0xFD giving us total 254 options. This ID can be saved in the EEPROM of the motor MCU. Along with this data the zero position, maximum temperature limit and other necessary data about the motor are saved in the EEPROM of STM32. Now whenever a specific angle is to be obtained, AT Mega 2561 board is programmed to send the analog value along with the ID of motor where shaft movement has to take place as a digital data packet to STM32 MCU. The target motor controller interprets the data packet and instructs DC motor to move. With the help of the position sensor installed inside the motor, the high precision movement of DC motor can be achieved and hence completing the motion.

R_{Arm} – Distance of Sample/Reagent Arm from the center of the batch plate. From Fig.3 (b) it is seen that there are three right angled triangles: ΔABC, ΔABD & ΔABE. By Pythagoras theorem in ΔABC,

$$AC^2 = BC^2 + AB^2 \tag{1}$$

Placing values in the equation,

$$R_{Arm}{}^2 = (D_r/2)^2 + AB^2 \tag{2}$$

$$AB^2 = R_{Arm}{}^2 - (D_r/2)^2 \tag{3}$$

Similarly from ΔABD,

$$AD^2 = BD^2 + AB^2 \tag{4}$$

Placing values in the equation,

$$AD^2 = (D_r - D_s)^2/4 + R_{Arm}{}^2 - (D_r/2)^2 \tag{5}$$

$$AD^2 = \left(D_s{}^2 - 2D_rD_s\right)/4 + R_{Arm}{}^2 \tag{6}$$

Also from triangle ΔABE,

$$AE^2 = BE^2 + AB^2 \tag{7}$$

Placing values in the equation,

$$AD^2 = (D_{re} - D_r)^2/4 + R_{Arm}{}^2 - (D_s/2)^2 \tag{8}$$

$$AD^2 = \left(D_r{}^2 + D_{re}{}^2 - 2D_{re}D_r - D_s\right)/4 + R_{Arm}{}^2 \tag{9}$$

From the above three equations, the maximum length of arm in various modes of operation is obtained. Eq. (3) gives the length when the arm is picks up the reagent; Eq. (6) gives the length when the arm is picks up the sample and Eq. (9) gives the length when the arm drops the fluid into the reagent cell. On placing the numerical values of the respective diameters, the maximum length required in its various modes of operation is obtained. Hence the length of the arm should be greater than the maximum length required. In this case, maximum length required is 22 cms and hence the total arm length is around 25 cms.

2.4. Arm Model

The proposed arm is a combination of three parts: Base, Elbow and wrist. It is a 4 joint Cartesian robotic arm with each joint having 2 degrees of freedom which is shown in figs 4 a) and 4b). As formulated earlier, the length of the arm should be of minimum 25cms from the base From this condition we obtain that,

$$L_{2eff} + L_{3eff} \geq 22\ cms$$

Now if there is a rotation of θ_1 andθ_2 then L_{2eff} and L_{3eff} can be given by:
$L_{2eff} = L_2 \cos\theta_1$ &$L_{3eff} = L_3 \cos\theta_2$
On substituting into the main inequality,$L_3 = L_2 = 20cms$ we have: $\cos\theta_1 + \cos\theta_2 \geq 1.1$
This is the angular constraints on the rotation for the M_2 and M_3 in the XY plane.
Now for the motion in the XZ Plane (Z is the axis coming out of the plane), M_1 actuates to provide it.
As the arm has to pick from sample cell and drop in reaction cell and same action for reagent cell, the following equations are obtained:

$$\tan\alpha = (AB/OB)$$
$$\tan\beta = (BC/OB)$$

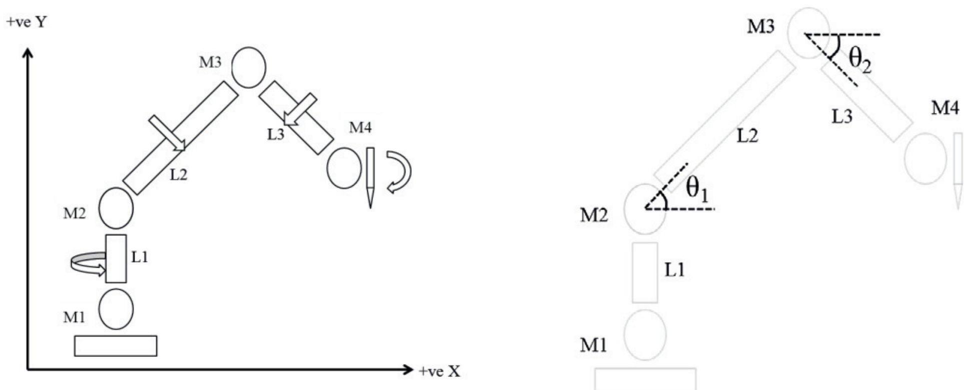
Since:$AB = (D_r - D_s)/2\ and\ BC = (D_{re} - D_r)/2$
Also $OB = Arm\ Length\ \approx 22cms$
$\alpha = \tan^{-1}(D_r - D_s)/44$ And $\beta = \tan^{-1}(D_{Re} - D_R)/44$
Adding α and β,

$$\theta = \alpha + \beta = \tan^{-1}((D_r - D_S)/44) + \tan^{-1}((D_{re} - D_r)/44) \quad (10)$$

Rearranging Eq (10),

$$\theta = \tan^{-1}(\mu/(\mu + 1936)) \quad (11)$$

Where $\mu = (D_r - D_s)(D_{re} - D_r)$
The value of θ, Eq(11) gives us the total rotation in the XZ Plane, which will obtained with the help of M_1 actuation. At last for the positioning of the nip, M_4 is used.



a) b)

Fig. 4. (a) Four DOF Robotic Arm and (b) The Motion of Servo Motors to achieve the desired motion in 4 DOF

Table 2: Movement of Sampling Arm

Analogue Values of Motors			Stages of Sample Arm
M1	M2	M3	
1365	2048	2048	1
1365	1536	2389	2
1365	2048	2048	3
1707	2048	2048	4
1707	1536	2389	5
1707	2048	2048	6
2048	2048	2048	7
2048	1536	2389	8
2048	2048	2048	9

Table 3: Movement of Reagent Arm

Analogue Values of Motors			Stages of Reagent Arm
M1	M2	M3	
1024	2048	2048	1
1024	1536	2389	2
1024	2048	2048	3
1707	2048	2048	4
1707	1536	2389	5
1707	2048	2048	6
2048	2048	2048	7
2048	1536	2389	8
2048	2048	2048	9

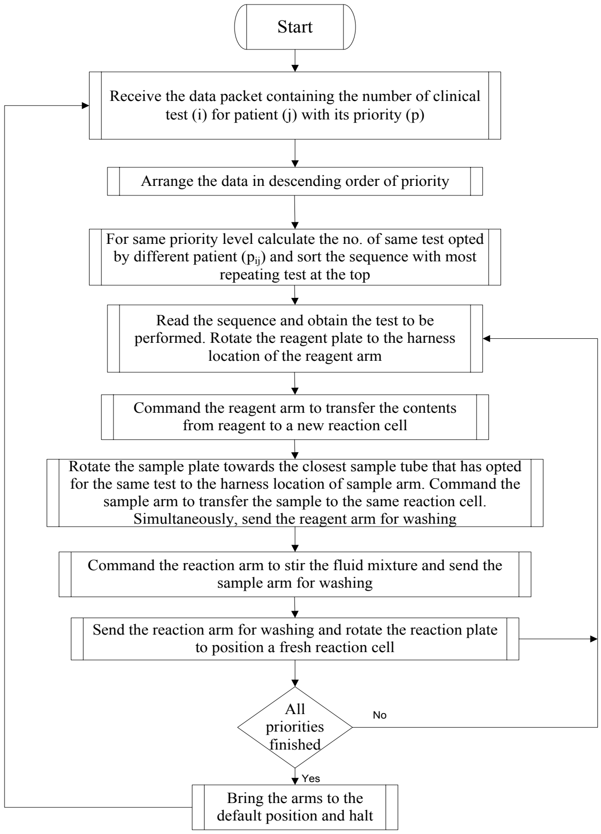


Fig 5. Flowchart for Random Access Algorithm implemented in Sampling and Reagent Arm with analytical plate

3. Results:

Table 2 and 3 shows the analogue values of position for each motor and with respect to stages of sampling and reagent arm. Resolution of the motor is 0.08°, for total 360° it takes 4096 steps. Based on the present motor position, the analogous values are calculated and listed in the table 2 and table 3. Table 2 reflects the data for intial stage of the sample arm positioned over sample tubes which then moves to the reaction cell and finally goes for wash cycles. Similarly in table 3 the data provided is for Reagent arm with starting position over the reagent container and it follows the same sequence. Fig 6 a) shows the response of moving the sampling arm from its original position to pick up the sample, placing it in reaction cell and washing the sampling arm. Each position is considered as stages of the sampling arm movement. Fig 6 b) shows the response of reagent arm, which picks up the reagent and puts it in the reaction cell. It goes for washing only after it transfers the reagents into the required number of reaction cells based on random access algorithm.
The model proposeed in this paper was designed and following output information were obtained :

Arm Motion:

Time Required for sample arm motion (t_{ArmS}) = 4.4 seconds
Time Required for reagent arm motion (t_{ArmR}) = 4.4 seconds
Time Required for stirring arm motion (t_{ArmC}) = 0.8 seconds
Hence the total time consumed in arm motion is (t_{Arm})= $t_{ArmS} + t_{ArmC} + t_{ArmR}$ = 9.6 seconds

Analytical Plate Motion:

Now we consider the sequential motion of the plate, then
Total time consumed in Sample plate motion (t_{PS})= 25.6 seconds
Total time consumed in Reagent plate motion (t_{PR}) = 28.8 seconds
Total time consumed in Reaction plate motion (t_{PRe}) = 102.4 seconds
Hence total time consumed in Analytical Plate motion (t_P) = $t_{PRe} + t_{PR} + t_{PRe}$ = 156.8 seconds

Total time required for both armsand analytical plate :

Now, time required for transfering fluids in to 128 reaction cells (t_A) = 128 x (t_{Arm}) = 1,228.8 seconds

Total time consumed in one complete cycle (t_{cycle}) = t_P + t_A = 1,385.6 seconds

Thus total time for completing (t_{Total}) = 9 x (t_{Cycle}) = 12,470.4 seconds = 3 hrs 27 mins and 50 secs

The time obtained above is for reacting each sample with each reagent separately in 128 different reaction cells. This assumption will differ on the basis of the reagent requirements for a particular test but for general analysis, such an assumption was made and results were obtained.

a) b)

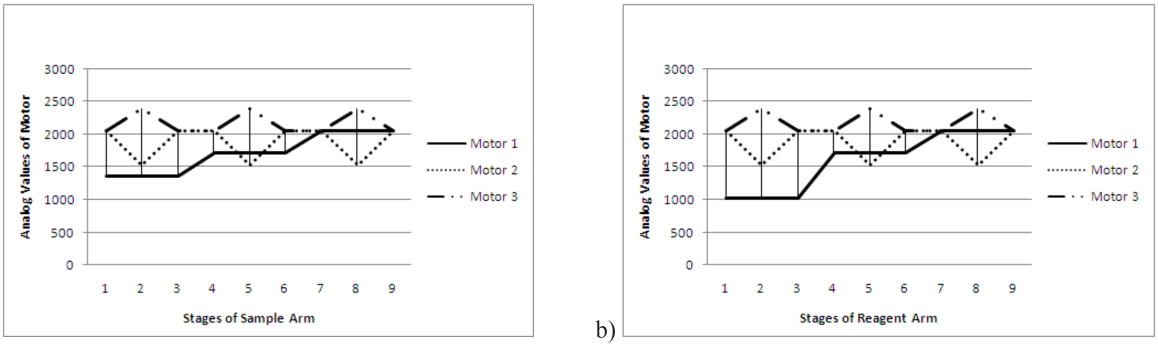


Fig 6. (a) Response of Sample Arm with respect to analytical plate (b) Response of Reagent Arm with respect to analytical plate.

4. Conclusion:

This paper presents the synchronization of microcontroller based sampling and reagent arm with analytical plate which is used in clinical chemistry analyzer. The prototype model has been made and movements of sampling and reagent arm have been programmed. The prototype's arm motion and design can be customized according to the test required to be performed. The random access sequence along with the movement of sampling and reagent arm is verified and tested.

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