Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 12, No. 4, December : 2023

OPTIMIZATION THE PATH OF DRILLING OPERATION FOR THREE DEGREE OF FREEDOM CYLINDRICAL ROBOTIC ARM

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Abstract
This paper focuses on optimizing methods of a three degree of freedom robotic arm for drilling operation. Generally robotic arms are used in large scale industries. In Small scale industries and medium scale industries welding, drilling and other machining work have been done by the skilled workers. Although the machining work done by the skilled workers is satisfactory but there has been always some problems related to accuracy and machining time. As all of us know that there is no comparison between robotic arm and human in terms of accuracy. But robotic arms are not used for machining operations in small scale and medium scales industries because capital and maintenance cost of robotic arms are too high. This Robotic arm has been designed by taking two factors in mind. First cost of the robotic arm should be less in comparison of other robotic arm and second design of the robotic arm should be simple. Its mechanical structure has been finalized by solid works software. Arduino AT MEGA2560 I/O board is the main heart of this project which interfaces with the motors. Components of the robotic arm are designed according to the dimension of the work space. Simulation of robotic arm is performed by motion study in solid works. Optimization techniques are used to optimize the route of drilling for multi-point holes on an object such as Branch and Bound, Genetic algorithm, Simulated Annealing and Formulated Mathematical Approach. The optimum sequence has got by Formulated Mathematical Approach after comparing the all sequences calculated by the Branch and Bound, Genetic algorithm, Simulated Annealing optimization and Formulated Mathematical Approach techniques.

Keywords CAD software; Solid Works; Arduino Mega 2560, Degree of freedom, Drilling

Introduction
The robots play important roles in our lives and are able to perform the tasks which cannot be done by humans in terms of speed, accuracy and difficulty. Robots can be employed to imitate human behaviours and then apply these behaviours to the skills that lead the robot to achieve a certain task [1]. They do not get tired or face the commands emotionally, and since they are designed by humans. They can be programmed and expected to obey and perform some specific tasks. In some cases the use of a robotic hand becomes remarkable. Most of tools, vehicles, electronic devices and cuisine are built and prepared with the help of industrial robots.
Robotic arms play a pivotal role in automating various industrial operations, contributing to increased efficiency, precision, and safety. Among these, the three-degree-of-freedom (3-DOF) cylindrical robotic arm holds significance for its versatile applications, particularly in drilling operations. Drilling is a fundamental process in manufacturing and construction, and the optimization of a cylindrical robotic arm for this task represents a critical step towards achieving enhanced performance and cost-effectiveness.
The aim of this study is to explore and optimize a 3-DOF cylindrical robotic arm for drilling operations, addressing key challenges associated with accuracy, speed, and adaptability in diverse work environments. By incorporating advanced control strategies and design modifications, this research seeks to improve the overall performance of the robotic arm, making it a more efficient and reliable

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solution for drilling tasks.

1.1 Objectives:

1. **Enhanced Precision:** Achieving high precision in drilling operations is crucial for ensuring accuracy and minimizing errors. The optimization of the robotic arm will focus on refining its control algorithms to enhance positional accuracy and repeatability during drilling processes.
2. **Increased Speed:** Time efficiency is a critical factor in industrial operations. The study will explore ways to optimize the robotic arm's speed and movement coordination, reducing drilling cycle times without compromising accuracy.
3. **Adaptability to Varied Environments:** Industrial settings often present dynamic and diverse conditions. The robotic arm will be optimized to adapt seamlessly to different work environments, addressing challenges such as varying material properties and geometries.
4. **Cost-Effectiveness:** The optimization process will consider cost-efficient design modifications and control strategies to ensure that the enhanced robotic arm remains economically viable for industrial applications.

1.2 Scope of the Study: The scope of this research encompasses a detailed analysis of the current state-of-the-art in cylindrical robotic arms and drilling technologies. The study will investigate various control algorithms, kinematic configurations, and materials used in the construction of robotic arms. Furthermore, experimental testing and simulations will be conducted to validate the proposed optimizations and assess the performance improvements achieved.

1.3 Significance of the Study: The optimization of a 3-DOF cylindrical robotic arm for drilling operations holds immense potential for industries relying on automated manufacturing processes. The results of this study can lead to advancements in drilling technology, fostering increased productivity, reduced production costs, and improved overall operational efficiency.
As industries continue to embrace automation, the findings of this research are anticipated to contribute valuable insights and solutions to the challenges associated with drilling operations. The optimized robotic arm has the potential to become a standard solution for drilling tasks in manufacturing, construction, and related fields, thereby shaping the future landscape of industrial automation.

Methodology

Design of cylindrical robotic arm includes the following steps.

2.1. Programming Analysis Number of steps required for each stepper motors so that the end effector reached the drill point.

Number of steps required for stepper motor

The robot workspace is a collection of points that the end effector can reach. The workspace is dependent on the DOF angle/translation limitations, the arm link lengths, the angle at which something must be picked up at, etc. The workspace is highly dependent on the robot configuration.

Input from User ⟶ **x, y, h**

Where x & y are the coordinates of drill point in the Cartesian system whose origin point is o (refer to figure 2) h is the height from the base of work piece.

Step 1: Base motor 1 rotates angle θ.

The value of θ is

$$\theta = 90^0 - \left[\left\{\tan^{-1}\left(\frac{\sqrt{x^2+y^2-r^2}}{r}\right)\right\} - \left\{\tan^{-1}\left(\frac{y}{x}\right)\right\}\right]$$

Here, r = radius of circle= 12.5 cm

Step 2: Rotation of Motor 2 by angle α

The value of angle α is depends on L. Step angle of motor is 1.8^0 and pitch of lead screw is 8 mm.

So distance covered in rotation of 1.8^0 is $=\left(\frac{8\times1.8}{360}\right)$ mm

For L mm distance angle of rotation for motor 2 angle $\boldsymbol{\alpha} = \left(\frac{\mathbf{360\times L}}{\mathbf{8\times1.8}}\right)$ in degree

Here $\quad \mathbf{L}= \left\{\sqrt{(\boldsymbol{x^2+y^2-r^2})}\right\}-\boldsymbol{a}$

And a is distance of drill from starting point (see in figure 2) = 11.77 cm

Step 3: Motor 3 rotates the vertical lead screw rotates.

Due to this the horizontal plate moves up and down because nut is attached with this plate. Horizontal lead screw is placed on this plate. At this horizontal lead screw drill machine is attached on a plate. Motor 3 is used for vertical displacement H.

The value of H is

H= h_1 - h

Here, h_1 is distance of movement of plate between upper and lower limit & h is the height of work piece from base.

Limiting condition of workspace

$$\sqrt{x^2+y^2-r^2} > a$$

or, $\quad x^2+y^2-r^2 > a^2$

or, $\quad x^2+y^2 > a^2 + r^2$

So, a <x< (a+b) and r< y< (a+b)

Let, T_S = Total no of steps

Step angle of motor = 1.8^0

S_{m1} = Total steps by motor 1 for angular movement= (θ / 1.8)

S_{m2} = Total steps by motor 2 for linear movement = [(Lx200) / 0.8]

S_{m3} = Total steps by motor 3 for linear movement which is constant = (h x 200) / 0.8

Where, $\quad \theta=90^0-\left[\left\{\tan^{-1}\left(\frac{\sqrt{x^2+y^2-r^2}}{r}\right)\right\}-\left\{\tan^{-1}\left(\frac{y}{x}\right)\right\}\right]$

$L=\left\{\sqrt{(x^2+y^2-r^2)}\right\}-a$, and

h = Total vertical distance for drill a hole x and y are the coordinates of point.

So, $\quad \mathbf{T_S = S_{m1} + S_{m2} + S_{m3}}$

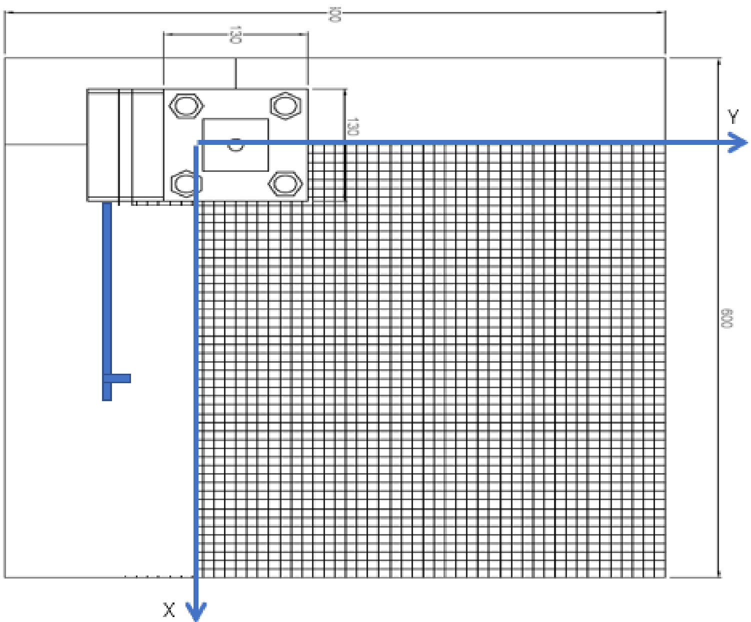

Fig. 1 Workspace

X

Industrial Engineering Journal
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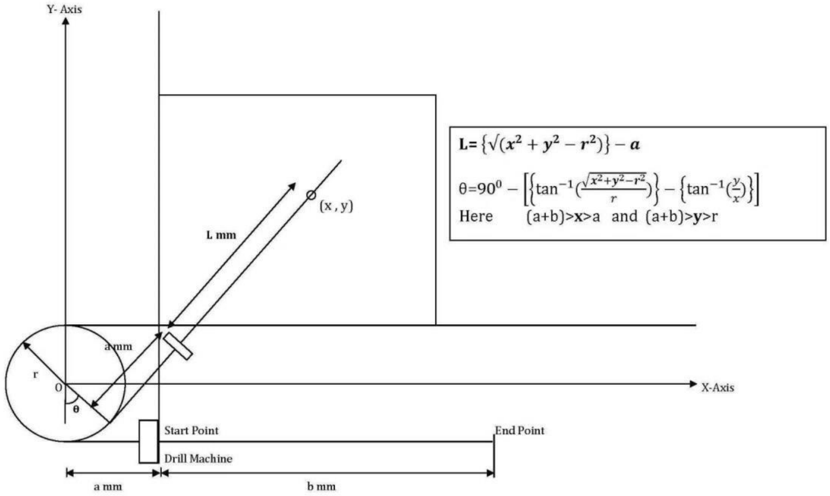

Fig. 2 Mathematical formulation of rotation of motor 1 (θ) andlinear displacement of motor 2 (L)

Design of robotic arm:

Cylindrical robots have two prismatic joints: one rotary joint for positioning task and the end-effector of the robot forms a cylindrical workspace. The main idea of the cylindrical robots is to mount a horizontal arm which moves in forward and backward directions. The horizontal arm is linked to a carriage which goes up and down and is connected to the rotary base. Solidworks software is used for designing this cylindrical robotic arm. The basic design of cylindrical robotic arm is shown in figure 3.

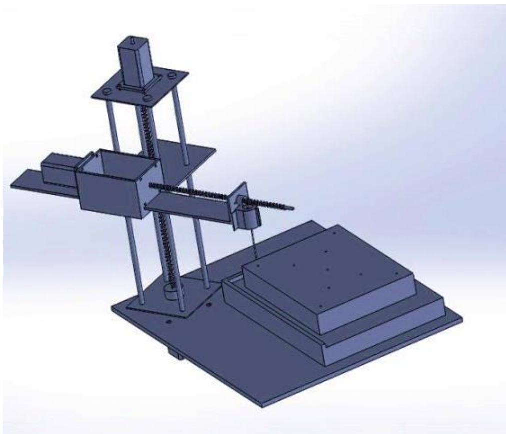

Fig. 3 Design of cylindrical robotic arm

3.1 Electronic circuit and Software

This section is divided into two parts one is electronic component and second is software used for programming the arduino at mega 2560 microcontroller.

Electronic components

The brain and muscles of any robotic arm is electronic part. The input given by the user is read by the microcontroller and converted into useful electronic signals which are given to the actuators like stepper motors. In this paper the main electronic components used for designing the cylindrical robotic arm are following

a) Stepper Motors
b) Microcontroller
c) Driver for stepper motor
d) LCD & Keypad

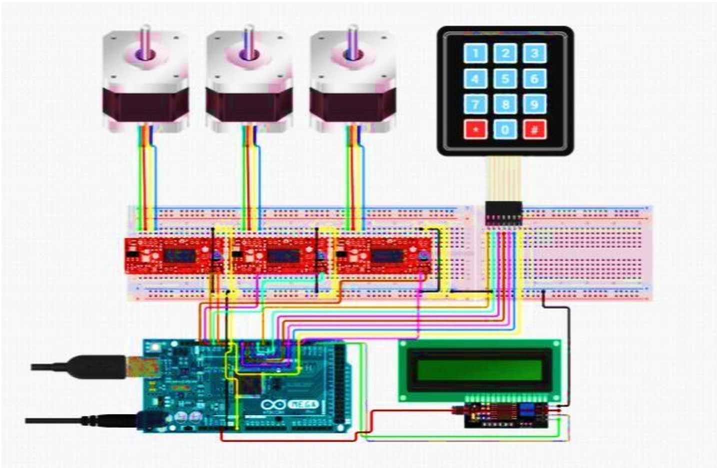

Fig. 4 Electronic Circuit

Software

Arduino Integrated Development Environment (IDE) software is used for programming the arduino at mega 2560 microcontroller. Firstly a programme is written for the drilling operation according to the dimensions of the mechanical component and electronic component used in the robotic arm in this IDE software. This programme is a set of general instructions for the microcontroller on the basis of which when an input is given to the microcontroller than according to that programme microcontroller gives the output signals to the stepper motors. And after writing programme it is send to the microcontroller with this Arduino IDE software.

The solidworks software is used for designing and motion analysis of the robotic arm. This software is used for the designing the mechanical components and assembly of the components. After assembling the mechanical components motion analysis of robotic arm is also done in this software.

Optimization method for optimum sequence of drilling

Consider a multi-point drilling operation on a workpiece which is shown in figure 5. Here is a number of sequences are possible for completing the drilling job. But only one sequence will be the optimum sequence among these sequences. So there is a need to find out the best possible solution so that the process becomes more efficient and less time consuming. For this following optimization techniques are applied for determining the optimum sequence for drilling in minimum time.

1. Branch and Bound
2. Simulated annealing
3. Genetic Algorithm
4. Mathematical approach for optimization

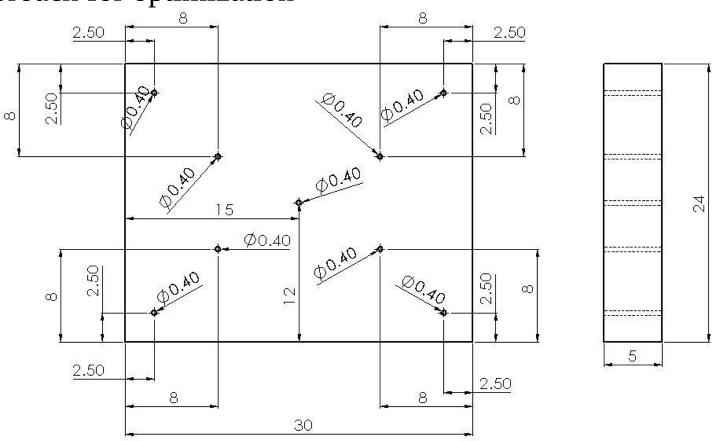

Fig. 5 Drawing of Work piece

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 12, No. 4, December : 2023

After applying the above optimization techniques we get the following optimum sequence for drilling operation.

1. By Branch and Bound technique the optimum sequence is [1-3-5-4-2-6-8-9-7-1].
2. By Simulated annealing technique the optimum sequence is [1-3-4-5-2-7-8-6-9-1].
3. By Genetic Algorithm technique the optimum sequence is [8-6-7-9-5-4-2-3-1].
4. By Mathematical approach technique the optimum sequence is [1-3-4-5-2-6-8-7-1].

Here table 1 shows the total number of steps taken by different motors by Branch and Bound optimum sequence.

Table 1 Total no of steps by Branch and Bound optimum sequence

Points	x	y	θ^0	θ_{Final}- $\theta_{Initial}$	Steps by motor 1	L(cm)	L_{Final}- $L_{Initial}$	Steps by motor 2	Total h	Steps by motor 3
1	12.5	12.5	90.00	90.00	50	0.73	0.73	183	44	11000
3	18	18	74.40	15.60	9	10.41	9.68	2419	12	3000
5	25	22	63.38	11.02	6	19.10	8.69	2173	12	3000
4	18	26	78.58	15.20	8	17.28	1.82	455	12	3000
2	12.5	31.5	90.00	11.42	6	19.73	2.45	613	12	3000
6	32	18	49.24	40.76	23	22.75	3.02	755	12	3000
8	37.5	12.5	36.84	12.40	7	25.73	2.98	745	12	3000
9	37.5	31.5	54.80	17.96	10	35.58	9.85	2463	12	3000
7	32	26	56.73	1.93	1	27.52	8.06	2015	12	3000
Total Steps					**120**			**11821**		**35000**

Here table 2 shows the total number of steps taken by different motors by Simulated annealing optimum sequence.

Table 2 Total no of steps by Simulated annealing optimum sequence

Points	x	y	θ^0	θ_{Final}- $\theta_{Initial}$	Steps by motor 1	L(cm)	L_{Final}- $L_{Initial}$	Steps by motor 2	Total h	Steps by motor 3
1	12.5	12.5	90.00	90.00	50	0.73	0.73	183	44	11000
3	18	18	74.40	15.60	9	10.41	9.68	2419	12	3000
5	25	22	78.58	4.18	2	17.28	6.87	1718	12	3000
4	18	26	63.38	15.20	8	19.10	1.82	455	12	3000
2	12.5	31.5	90.00	26.62	15	19.73	0.63	158	12	3000
6	32	18	56.73	33.27	18	27.52	7.79	1948	12	3000
8	37.5	12.5	36.84	19.88	11	25.73	1.79	448	12	3000
9	37.5	31.5	49.24	12.40	7	22.75	2.98	745	12	3000
7	32	26	54.80	5.56	3	35.58	12.83	3208	12	3000
Total Steps					**120**			**11280**		**35000**

Here table 3 shows the total number of steps taken by different motors by Genetic Algorithm optimum sequence.

Table 3 Total no of steps by Genetic Algorithm optimum sequence

Points	x	y	θ^0	θ_{Final}- $\theta_{Initial}$	Steps by motor 1	L(cm)	L_{Final}- $L_{Initial}$	Steps by motor 2	Total h	Steps by motor 3
1	12.5	12.5	36.84	36.84	20	25.73	25.73	6433	44	11000
3	18	18	49.24	12.40	7	22.75	2.98	745	12	3000
5	25	22	56.73	7.48	4	27.52	4.77	1192	12	3000
4	18	26	54.80	1.93	1	35.58	8.06	2015	12	3000
2	12.5	31.5	63.38	8.58	5	19.10	16.49	4121	12	3000
6	32	18	78.58	15.20	8	17.28	1.82	455	12	3000
8	37.5	12.5	90.00	11.42	6	19.73	2.45	613	12	3000
9	37.5	31.5	74.40	15.60	9	10.41	9.32	2331	12	3000
7	32	26	90.00	15.60	9	0.73	9.68	2419	12	3000
Total Steps					**69**			**20324**		**35000**

Here table 4 shows the total number of steps taken by different motors by Mathematical approach technique optimum sequence.

Table 4 Total no of steps by Mathematical approach technique optimum sequence

Points	x	y	θ^0	θ_{Final}- $\theta_{Initial}$	Steps by motor 1	L(cm)	L_{Final}- $L_{Initial}$	Steps by motor 2	Total h	Steps by motor 3
1	12.5	12.5	90.00	90.00	50	0.73	0.73	183	44	11000
3	18	18	74.40	15.60	9	10.41	9.68	2419	12	3000
5	25	22	78.58	4.18	2	17.28	6.87	1718	12	3000
4	18	26	63.38	15.20	8	19.10	1.82	455	12	3000
2	12.5	31.5	90.00	26.62	15	19.73	0.63	158	12	3000
6	32	18	49.24	40.76	23	22.75	3.02	755	12	3000
8	37.5	12.5	36.84	12.40	7	25.73	2.98	745	12	3000
9	37.5	31.5	56.73	19.88	11	27.52	1.79	448	12	3000
7	32	26	54.80	54.80	30	35.58	8.06	2015	12	3000
Total Steps					**155**			**8896**		**35000**

Result and discussion

The sequences which have been determined by the different optimization techniques, one of them will be the optimum sequence. Here which sequence takes the minimum number of steps for completing the drilling operation that sequence will be the optimum sequence for the given drilling operation at multi point. So that number of steps required for motors have been calculated by applying the above sequences which have been determined by the different optimization techniques.

Now the optimum sequence will be determine by comparing the total number of steps required for motors by different method.

Table 5 Total number of steps required for motors by different method

	Branch and Bound	Simulated annealing	Genetic Algorithm	Mathematical approach
Steps by motor 1	120	124	69	155
Steps by motor 2	11821	11280	20324	8896
Steps by motor 3	35000	35000	35000	35000
Total No of Steps	**46941**	**46404**	**55393**	**44051**

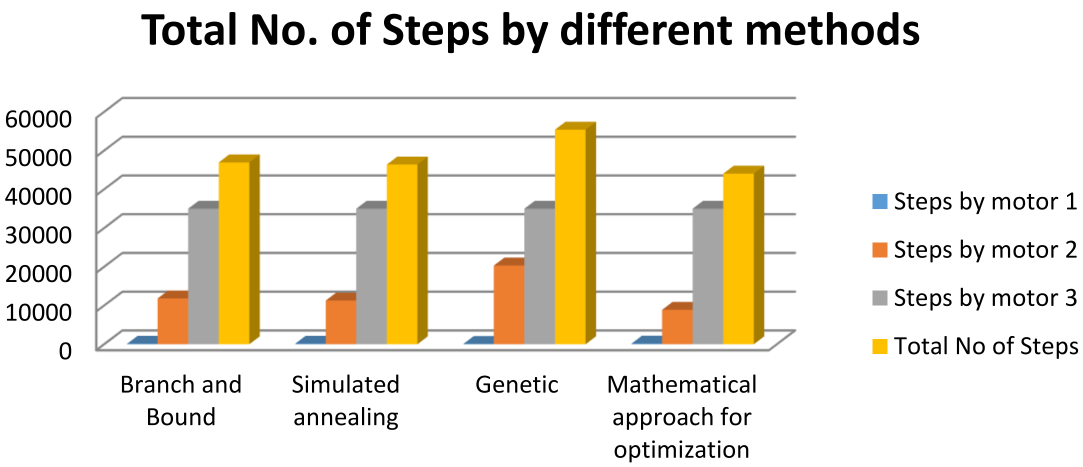

Fig. 6 Comparison of number of steps by different method

The total numbers of steps taken by the motors are shown in figure 6. Here total number of steps taken by the motors is less when robotic arm follows the sequence of mathematical approach.
So that mathematical approach gives the optimum sequence for drilling operation.
Mathematical approach < Simulated Annealing < Branch and Bound < Genetic

Total time taken for drilling operation by robotic arm
As already discuss that which sequence takes the minimum number of steps for completing the drilling operation that sequence will be the optimum sequence for the given drilling operation at multi point. Total time taken for drilling at multipoint is directly proportional to total number of steps.
Total time = (Total steps) / (200 x N)
Where N = Speed of motor in rpm = 30 rpm
Table 6 shows the total time taken for drilling operation by robotic arm.

Table 6 Comparison of time taken by different method

	Branch and Bound	Simulated annealing	Genetic Algorithm	Mathematical approach
Time by motor 1	0.02	0.02	0.01	0.03
Time by motor 2	1.97	1.88	3.39	1.48
Time by motor 3	5.83	5.83	5.83	5.83

Total Time For operation	**7.82**	**7.73**	**9.23**	**7.34**

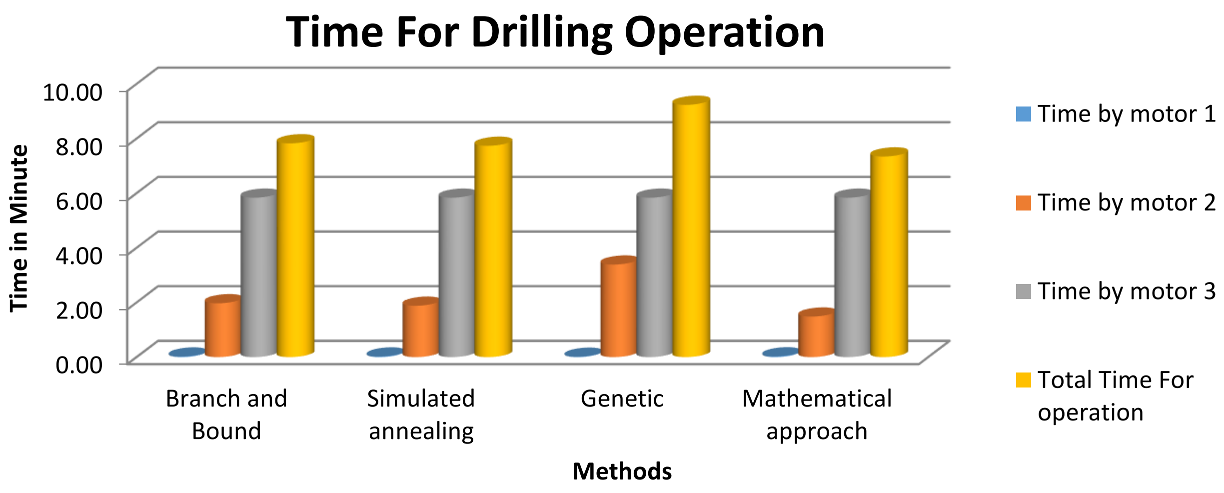

Fig. 7 Comparison of time taken by different method for drilling

The total time taken by the motors is shown in figure 7. Here total time taken by the motors is less when robotic arm follows the sequence of mathematical approach.
So that mathematical approach gives the optimum sequence for drilling operation.

Mathematical approach < Simulated Annealing < Branch and Bound < Genetic

Conclusion and Future work

After design, simulation of cylindrical robotic arm and applying optimization technique for sequencing of 9 holes in a mild steel object having dimension of 30 cm x 25 cm x 40 cm. Following conclusions have been drawn.

- Cylindrical robotic arm is made of Al 7056 – T6 which is light weighted and high strength.
- It is very simple to operate for drilling operation because only three inputs (x, y and h) are needed for drilling.
- No skilled worker is required for operation of drilling because it is fully automatic.
- Design and programming of this robotic arm is simple compared to other robotic arms.
- The optimum sequence of cylindrical robotic arm for drilling operation is [1-3-4-5-2-6-8-7-9] by using formulated mathematical optimization.
- Total steps required for drilling 9 holes is to be minimizing using mathematical approach as compare to GA, SA and Branch and Bound.
- Total time required for drilling 9 holes is to be minimizing using mathematical approach as compare to GA, SA and Branch and Bound.
- By increasing the DOF of cylindrical robotic arm to increase the flexibility of robotic arm.
- Rotating end effector can be used for drilling at any angle and any plane.
- This cylindrical robotic arm can be used for welding by Peaucellier mechanism.
- Position correction method (bi- linear interpolation) can be used to increase the drilling accuracy.

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