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# A Simulation Study Of Energy Utilisation In A Variable Link Length 3 DOF Revolute Articulated Manipulator

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**Graphical abstract**

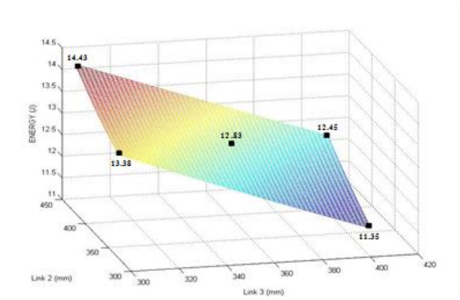


Figure 4.3: Total average energy for the trajectory 1

**Abstract**

Determination of manipulator link lengths is one of the important criteria in robotic design. The purpose of this study is to find the minimum energy utilization for a 3 DOF revolute articulated manipulator to perform certain point-to-point task by varying the link lengths of the manipulator. The lengths of the second and third link of the developed manipulator can be varied accordingly. The investigation of energy for different link length combinations is carried out theoretically. In the simulation, the work-energy method is constituted in order to determine the average mechanical energy of the manipulator. The simulation shows that, different trajectory of motions results in different link length combinations that could give optimum average energy utilization. Results of the simulations shows that, improvement of mechanical energy utilization could be achieved by having variable link length of manipulator rather than having fixed length of manipulator's arms.

*Keywords*: Robotics, manipulator, energy, trajectory, articulator



## 1.0 INTRODUCTION

The main study area generally centers on improvement of robot manipulator. Over years, a lot of improvement of manipulators has been done by many researchers. The improvement types are countless. Some of them were keen to study on trajectory improvement, torque and energy optimizations. However, the priority of this study was more towards minimization of energy of the robot manipulator by having variable link length.

Some of researches focused on the study of trajectory planning [1, 2, 3, 4, and 5]. They proposed methods and techniques on how to optimize the motion in a trajectory planner. Finally, the improved solutions were applied to the manipulator controllers. As a result, the proposed solutions presented by them could minimize the cycle time and minimize the energy consumption of the manipulators' actuators.

Torque has been extensively studied in order to improve the manipulator's performance [6, 7, 8, and 9]. Garg *et al*. (2002) presented a method of improving the controller performance by studying the torque and path planning. H. Merkel (1998) examined where to place a robot base in order to perform a predefined task. The suitable placement of robot base could minimize the joint effort or torque of actuators. This method actually might disturb the flow of production line should the best location of robot base disrupt the view of operators or it might harm the safety of the workplace. Guillaume *et al*. (1999) found that the joint friction gravity effects could be the factors that lead to the inaccurate precision of a robot. Finally, Guillaume *et al*. (1999) introduced new measurement-based joint friction compensator in which it gave high-precision motion control. Apart from that, Berner *et al*. (1998) minimized the average torque by having the optimal link lengths of the manipulator. The optimized link lengths were for design purpose only. That means, the geometry of links is the same irrespective of the task given. Herman (2008) proposed a method for evaluation and reduction of dynamical couplings between the links of a rigid serial manipulator. The method claimed that the torque as well as the kinetic energy could be minimized.

In terms of energy optimization, Banga *et al*. (2007) optimized the movement of robotic arm with the help of Genetic Algorithm so that the minimum energy consumption criteria can be achieved. Banga *et al*. (2007) considered three factors namely movement, friction and least settling time in order to find the fitness function. Other than that, in 2004, Hossain *et al*. experimented 2- link revolute joint manipulator by varying different parameters like mass, angular speed, length and angular positions. The method of experimentation did not provide the best optimum parameter for any given trajectory. It was just a matter of analysis.

All studies made by the researchers mentioned above were looking for minimum cycle time, minimum torque, minimum joint friction and minimum energy consumption. However, they did not take into consideration the factor involving the trajectory change. Trajectory is an assigned motion of the end-effector of a robot manipulator. Changing the trajectory could not give the optimum performance improvement of a robot manipulator. For instance, the optimal geometry links could not give the minimum average torque should the design manipulator are assigned to various points of different distance [7, 10].

On the other side, if the trajectory changes, the studies done [1, 2, 3, 4 and 5] can still offer improvement to the manipulators. But, the degree of optimization could be maximized further if proper length geometry links is constituted according to the task assigned. In some sense, the links of manipulators could be played with accordingly.

In mass-production manufacturing, a robot is used to perform work not only to a single product. It might be many products. Commonly, an industrial product differs to each other causing the processes to perform work might also be different. Therefore the task assigned to a robot to finish a process will also be different to each other. Having fixed-length link does not give optimal energy utilization should the improvement done by some researchers mentioned above are practiced. The degree of optimizations depends on the trajectory. To compensate for the change of trajectory the best solution in giving the optimum energy utilization is by having the variable link lengths.

This study investigated the energy consumption of the manipulator for some different link length combination under a given task.

## 2.0 METHODOLOGY

The research embarked on with the development of the variable link length of the 3 DOF articulated manipulator as shown in Figure 1.

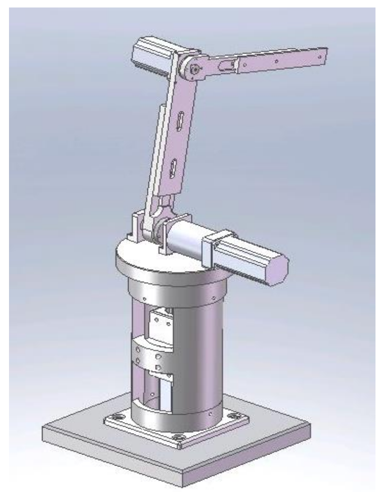

**Figure 1** The configuration of the variable link length 3 DOF revolute articulated Manipulator

The energy then was calculated according to the different link lengths of the manipulator. Table 1 summarizes the combination length of different links for link 2 and link 3.

**Table 1** Length of some link's combinations and their values

| Link combination | Link length in mm | |
|---|---|---|
| | Link 2 | Link 3 |
| **Shortest $L_2$-Shortest $L_3$** | 327 | 300 |
| **Fixed-length** | 373.5 | 352.5 |
| **Shortest $L_2$-Longest $L_3$** | 327 | 405 |
| **Longest $L_2$-Shortest $L_3$** | 420 | 300 |
| **Longest $L_2$-Longest $L_3$** | 420 | 405 |

The end-effector of the manipulator was assigned to travel from the home position to the three different points and got back to the home position. The trajectory of the manipulator from point to point was based on *Linear Segment Parabolic Blending* (LSPB). Table 2 shows the points to be travelled by the end-effector of the manipulator. The payload carried by the manipulator was 1 kg.

**Table 2** Trajectories motion of the manipulator

| Trajectory of Motion (end-effector motion) | Coordinates to be reached by the end-effector (mm) referred to Inertial Frame | | |
|---|---|---|---|
| | ***P*₁** | ***P*₂** | ***P*₃** |
| 1 | [400, -300, -200] | [400, 200, 0] | [200, 400, 400] |
| 2 | [200, -100, 0] | [100, 0, 100] | [100, 100, 200] |

In order to compute the energy, the kinematics and kinetics analyses were carried out. The energy for a system is given by:

$$E = \sum_i^t T_i + \sum_i^t P_i \qquad (1)$$

Where $\sum_i^t K_i$ is the summation of kinetic energy at each interval of time for each body mass and $\sum_i P_i$ is the summation of potential energy for each body mass.

The kinetics and potential energy of a system is given respectively by by:

$$T = \frac{1}{2} m V_G{}^2 + \frac{1}{2}\left[I_{\bar{X}}\omega_{\bar{X}}^2 + I_{\bar{Y}}\omega_{\bar{Y}}^2 + I_{\bar{Z}}\omega_{\bar{Z}}^2\right] - \left[I_{\overline{XY}}\omega_{\bar{X}}\omega_{\bar{Y}} + I_{\overline{YZ}}\omega_{\bar{Z}}\omega_{\bar{Y}} + I_{\overline{XZ}}\omega_{\bar{X}}\omega_{\bar{Z}}\right] \qquad (2)$$

$$P = mg(\Delta h) \qquad (3)$$

All the computations were carried out using MATLAB® R2007b version 7.5.0.342.

## 3.0 RESULT AND DISCUSSION

Figure 2 and Figure 3 depict the average energy required by the manipulator to complete the trajectory 1 and 2 respectively.

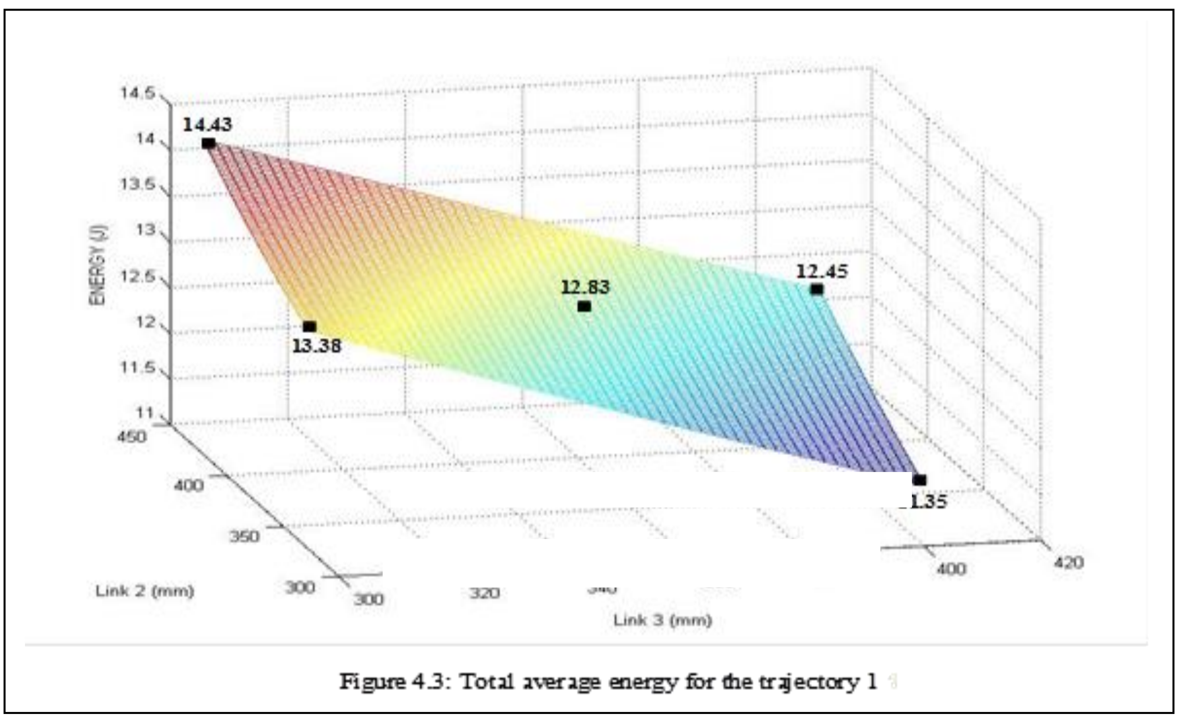


**Figure 2** Energy utilization for the trajectory 1

The total average energy simulated for the *trajectory 1* in Figure 2 shows that the *optimized link* length for this trajectory occurred at $L_2$ = 327.0 mm and $L_3$ = 405.0 mm (*Shortest* $L_2$*-Longest* $L_3$). The corresponding average energy for the optimized link is 11.35 J and that for *Fixed-Length* is 12.83 J. The energy saving obtained by constituting the optimized link is 11.5 **%**. The highest energy consumption for this trajectory is at *Longest* $L_2$*-Shortest* $L_3$ link combination with the value of 14.43 J. The *Shortest* $L_2$*-Shortest* $L_3$ and *Longest* $L_2$*-Longest* $L_3$ consumed 13.38 J and 12.45 J respectively.

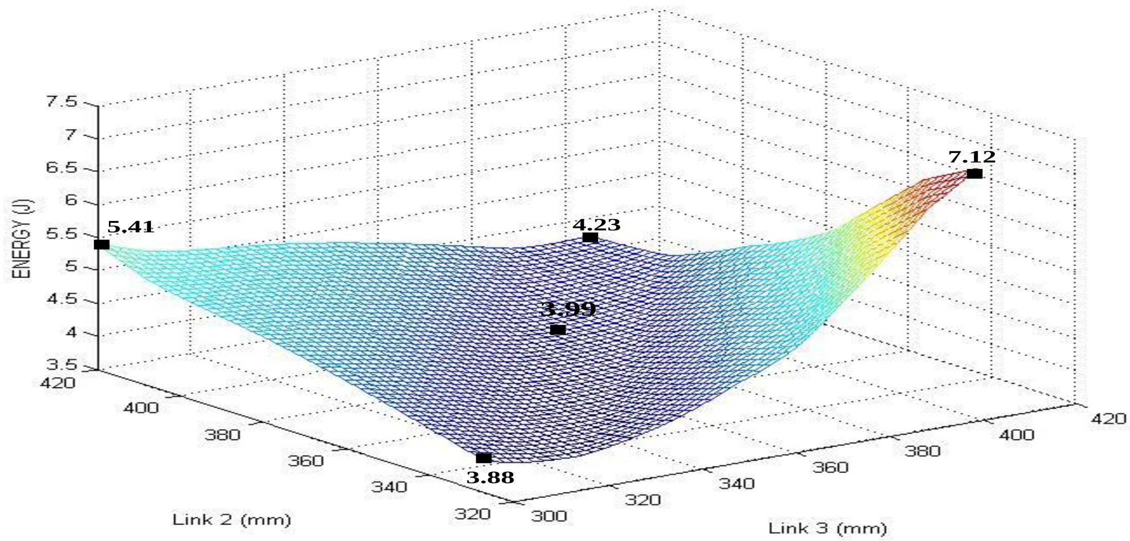


**Figure 3** Energy utilization for the trajectory 2

For the trajectory 2, the total average energy of each link combination can be depicted in Figure 3. From Figure 3, the minimum energy occurs at $L_2$ = 327.0 mm and $L_3$ =321.0 mm. The simulated energy for the trajectory 2 is merely different from what was obtained in trajectory 2. In this trajectory, the preferred link's combination based on the variable link combination is *Shortest* $L_2$*-Shortest* $L_3$. Constituting the *Shortest* $L_2$ *-Shortest* $L_3$ link combination will offer 2.8 **%** of energy saving. The highest energy consumption for this trajectory is at *Shortest*$L_2$*-Longest*$L_3$ link followed by *Longest* $L_2$*-Shortest* $L_3$, *Longest* $L_2$*-Longest* $L_3$, *Fixed-Length* and *Shortest* $L_2$*-Shortest* $L_3$ combination with the values of 7.12 J, 5.41 J, 4.23 J, 3.99 J and 3.88 J respectively.

## 4.0 CONCLUSION AND RECOMMENDATION

The study has successfully determined the energy utilization of the developed manipulator for various link length combinations. The optimized link length for each trajectory has also been identified.

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