# OPTIMAL SYNTHESIS OF ADJUSTABLE ROBOTIC MECHANISMS FOR LOW-COST AUTOMATION

**THATCHAI CHUENCHOM**
*Department of Mechanical Engineering, International Institute of Technology Thammasat University, Klongluang, Pathumthani 12121, Thailand.*

**SAN MYINT**
*Asian Institute of Technology, G.P.O. Box 2754 Pathumthani 12121, Thailand.*

**ABSTRACT**

This paper introduces an optimal design technique using Genetic Algorithm (GA)[1] for designing programmable and economical mechanisms called Adjustable Robotic Mechanisms (ARMs) for multiple pick and-place operations. For a few numbers of tasks, ARMs can outperform conventional robols with their simpler mechanical and control configurations, higher operational speed, and lower cost. Unfortunately, these programmable mechanisms are unpopular among manufacturing engineers primarily due to their difficulues in design and the lack of efficient design tools. To avoid the shortfall in ARMs' design, a convenient and effective approach to synthesize the mechanisms is proposed by incorporating a global optimization GA-based program called GENESIS[2] to the ARMs' synthesis procedures. A numerical example of an ARM design for two point-to-point operations using the proposed methodology are demonstrated with the verification of a global optimum solution.

## 1. Introduction

Although conventional hard automation, such as cams, gears, and linkage-based systems, provides cost effective, high speed capability, repeatability, and reliability, it can not deliver flexibility required in many industrial applications. Furthermore, designing an adjustable machine that can perform various tasks is extremely difficult and time consuming. Therefore manufacturing engineers typically employ available off-shelves robots in production lines instead. However, such robots are overly flexible, complicated, and expensive, so most of the time they are under -utilized, and cause unnecessarily high production cost. Clearly, having a method and a tool to design a simpler, low-cost adjustable machine would be beneficial to the manufacturers. A methodology and a computational tool presented in this paper for designing a spatial multi-tasking machine called the Adjustable Robotic Mechanism (ARM) may help manufacturing engineers in providing alternative cost-effective solutions to their production planing and design.

In an adjustable mechanism one or more members of the kinematic chain are adjusted so that the output member performs a "slightly" different function or a variation of the same function in response to the same input. Examples of adjustable mechanisms including; the lawn-sprinkler mechanism in which different dial settings result in corresponding sweep ranges of the sprinkler tube, and a variable-displacement engine mechanism whose stroke length of the piston is varied by adjusting the length of the control link. Other applications of adjustable mechanisms found in the literature survey include straight-line linkages for a leggd vehicle by Ryan and Hunt [3], and a quick-return mechanism for a packaging machine by Daadbin and Sadek [4].

Not until Bonnell and Cofer [5] introduced the use of the complex number method to synthesize an adjustable fourbar linkage, synthesis methods were primarily graphical [6-7]. McGovern and Sandor [8] then extended the complex number scheme further for analytical synthesis of adjustable mechanisms. Most of the studies in the area of adjustable mechanisms are restricted to, for example, two-dimensional problems of straight line paths, double points curves, or function generation. The focus of this paper, on the other hand, is the development of an optimal synthesis technique of an adjustable mechanism for three-dimensional motion generation. called Adjustable Robotic Mechanism (ARM) that inherits the advantages of both high speed, accurate, simple, low-cost mechanisms, and versatile, multi-degree-of-freedom manipulators such as serial robots.

## 2. Configuration of Adjustable Robotic Mechanisms

ARMs were conceptually designed by incorporating a projection plane into a planar adjustable mechanism design. In Figure 1., a

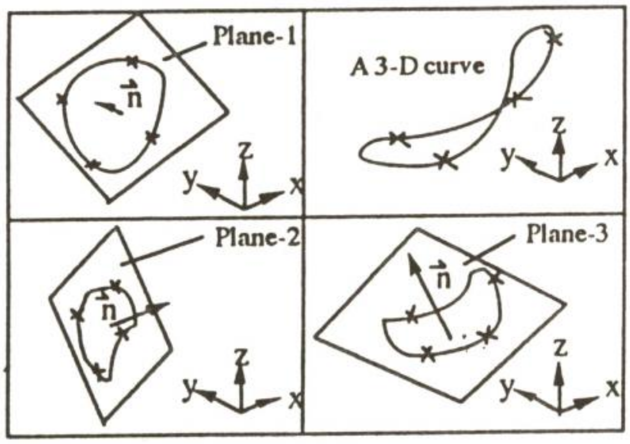


Figure 1. The projection planes

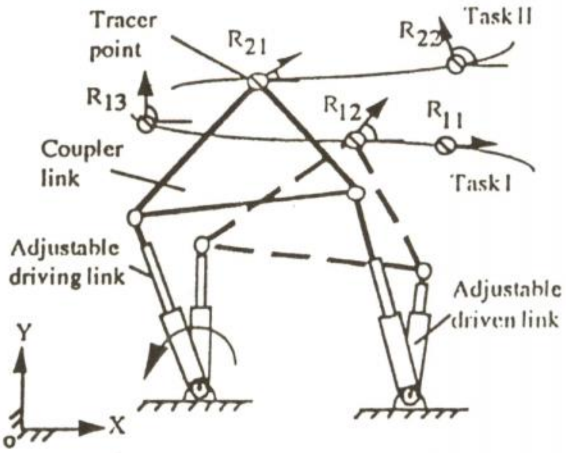


Figure 2. An adjustable four-bar

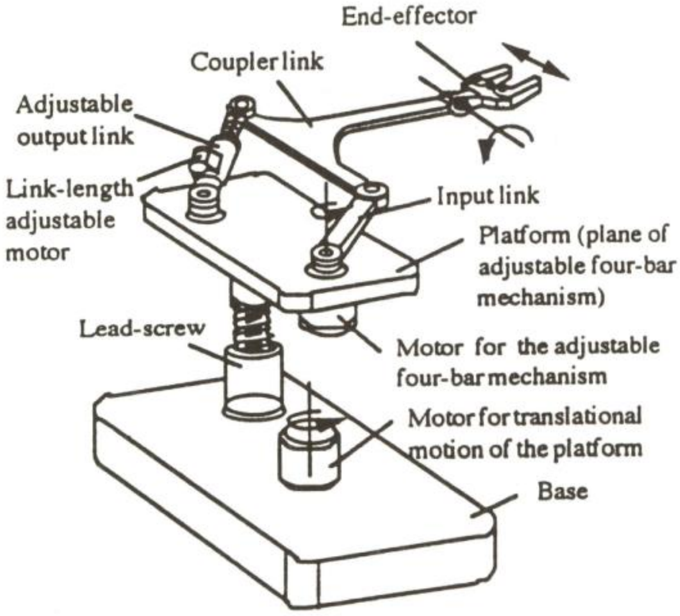


**Figure 3. Basic Configuration of an ARM**

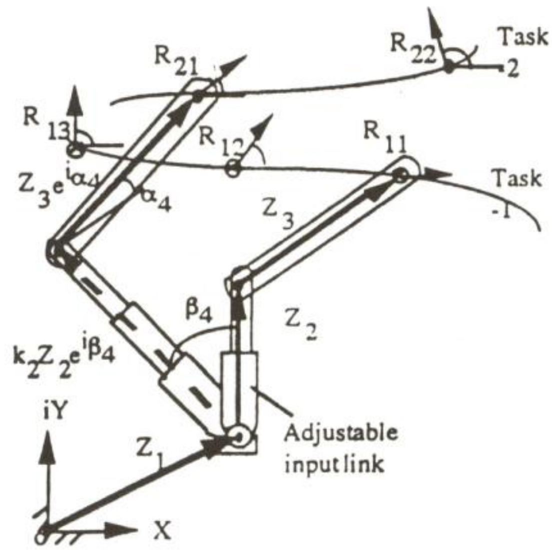


**Figure 4. An adjustable dyad with an adjustable input vector $Z_2$**

set of three-dimensional points are projected onto different oriented planes generating various sets of two-dimension points on the plane. The set of two-dimensional desired points may then be employed as specified set of precision points for an adjustable mechanism synthesis, e.g. an adjustable four-bar mechanism (Figure 2.). The integration of projection plane and an adjustable four-bar mechanism results in a semi-flexible mechanism, shown in Figure 3, with minimum numbers of active component but versatility.

The basic configuration of an ARM consists of a single-degree-of-freedom, kinematically closed-chain, planar mechanism with at least one electronically adjustable member. The adjustable mechanism traces a specific planar trajectory for a particular setting of the adjustable parameters. The same mechanism can trace different trajectories for different settings of the adjustable member. The entire assembly is mounted on a moveable platform. In one of its simpler embodiments, the platform with the attached mechanism simply translates perpendicularly to itself. The coordination of translational motion of the platform and nonlinear planar motion of the adjustable mechanism produces desired three-dimensional trajectories. The desired gross motions are thus obtained by the same ARM by simply adjusting a particular design parameter. An off-the-shelf end-effector attached to the path-tracer point of the mechanism provides precision motions that are typically needed to orient the gripper. Since the planar mechanism has one degree of freedom, it requires only one actuator to trace a planar trajectory. Thus, three-dimensional trajectories can be controlled by using at most two controllers -- the first controller would be in conjunction with the actuator driving the planar mechanism, and the second controller in conjunction with the actuator driving the platform. Both actuators can be mounted on a fixed base to reduce moving masses. Alernately, a linear actuator can be made integral with the endeffector thus eliminating the need to translate the entire mechanism and its platform vertically up and down. Since all links of mechanism are simply connected together by passive joints in contrast to employing actuators at every joint as is done in an open-loop serial robot, ARMs possess desirable characteristics such as low weight, low inertia forces, and high speed capabilities.

## 3. Analytical Synthesis Method

After the set of two-dimensional prescribed points are translated from a set of desired three-dimensional points via the projection plane, the planar synthesis technique is then utilized to design the adjustable

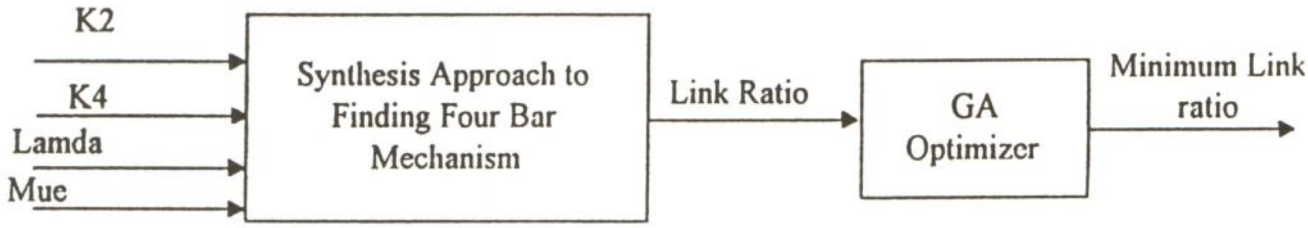


**Figure 5. - Overall structure of optimization model**

mechanisms. In the adjustable four-bar mechanism synthesis, the mechanism is modeled with two adjustable dyads (Figure 4.) that are connected at the end of both coupler vectors. The point on the coupler link is the tracer point that will pass through the two specified sets of precision points. The adjustable dyad may have a ground pivot location change, an input vector change, or a coupler angle change for the adjustment between tasks. Figure 2. illustrates an adjustable four -bar linkage whose input vectors of both driving and driven dyads can be adjusted between tasks. The two adjustable dyads are synthesized separately using the synthesis technique provided in Chuenchom and Kota [9]. The synthesis equations of each adjustable dyad are formulated using the complex notations to represent all link parameters and the adjustable factors called "stretch-ratios." The simultaneous solutions are obtained from solving an eight-degree polynomial equation of an angular displacement of the input-vector from the first position. This equation is expressed as follow:

$$a_8(k_2)T_2^8 + a_7(k_2)T_2^7 + \dots\dots\dots$$

$$+ a_1(k_2)T_2 + a_0(k_2) \quad = \; 0 \qquad (1)$$

where coefficients $a_j(k_2)$ are functions of precision points and stretch-ratio $k_2$. The non-trivial solutions of $T_2$ are substituted back to the synthesis equations yielding a set of solution vectors $Z_1$, $Z_2$, $Z_3$ in Figure 4.

## 4. Opimization Using Genetic Algorithm

Although Holland introduced the concept of Genetic Algorithm in the 60ies, the real application of GA became popular in early 1980s. The genetic algorithm, which is a probabilistic heuristic-based search technique, and which the main idea is derived from Darwinian reproduction theory and the power of binary representation, has three major fields of research; the basic algorithm, optimization using GA, and machine learning with classifier systems [1], [10-12]. Due to its independence of the functional structure requirement in approaching the global optimum, GA has proven to be a very powerful tool in functional optimization when the problem is very complex and could not be expressed with mathematical expression as mostly seen in many design problems. GA has mainly six parameters in which the performance and stability of the algorithm depend on how the parameters are set and adjusted during the optimization [13]. The prime reason to employ GA for ARMs' synthesis is due to the very complex nature of the dyad synthesis equations whose solution spaces sporadically scatter. The overall structure of the optimization model can be expressed as in Figure 5. The objective is to minimize the link-length ratio of the adjustable four-bar mechanism to obtain the most compact mechanism. The four input variables to the optimization program are (i) two direction cosine parameters Lamda and Mue, (ii) the stretch-ratio of the driving dyad, K2, and (iii) the stretch-ratio of the driven dyad, K4.

The systematic approaches to the use of GA to obtain the optimal solution can be summarized as follows:

1. Solving the problem with simple GA with default parameter values, such as cross over rate as 0.6 and mutation rate as 0.01, window size as 5 and using elitist strategy for selection. For

this case, we applied simple GA package called GENESIS version 5.0 and implemented in PC 486 model. After running the program with 5 experiment based on 100 population size. it still gave the infeasible solutions in the final population. In this case, we found out that the simple GA algorithm could not seek the proper solution due to the discontinuous structure of the problem when running with 5 experiments based on 100 population size.

2. Solving the problem again with simple GA by changing selection strategy from elitist to ranking. However, the ranking strategy generated more inferior population than elitist strategy in which it gave all genes in population become infeasible solutions. Therefore, we conclude that the elitist strategy is better than ranking strategy and we must input the initial population which include feasible solutions of the problem.
3. Based on the previous runs, we made the third run by giving an input file containing 25 percent feasible solutions. However, we again found out

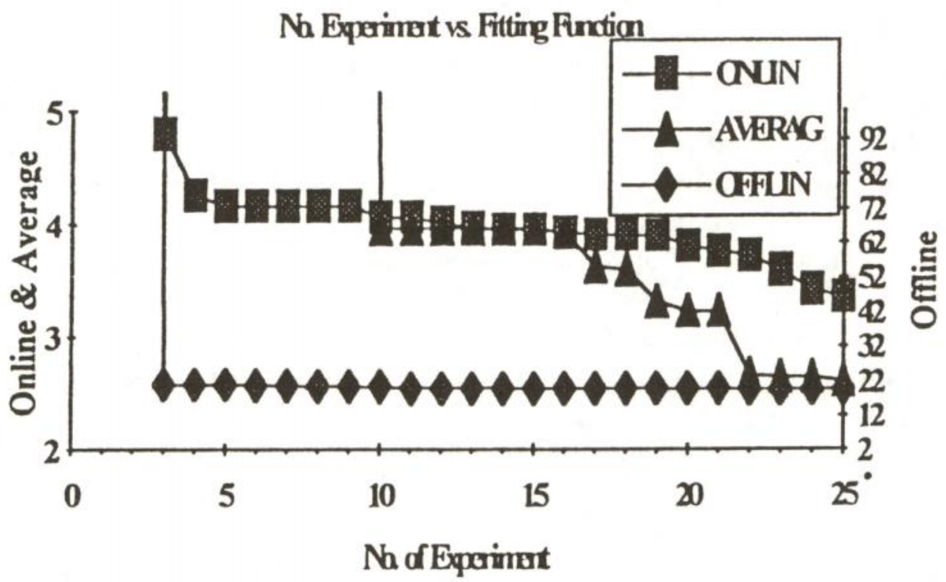


**Figure 6. Graph of No. Experiment vs. Fitting Function (Linkage Ratio)**

| Linkage | Value |
|---|---|
| L1 | 1.76686432 |
| L2 | 2.80954312 |
| L3 | 1.28517378 |
| L4 | 2.67436896 |
| L5 | 2.7740862 |
| L6 | 3.34303972 |
| Stretch Ratio K2 | 0.93665 |
| Stretch ration K4 | 1.007499 |
| Lamda | 0.04007 |
| Mue | 1.007499 |
| Nue | 0.18756785 |

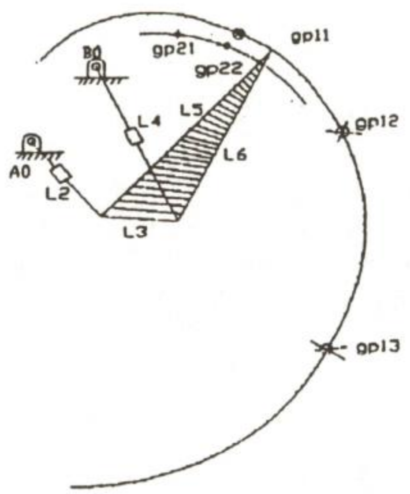


**Figure 7. An Adjustable four-bar mechanism with the minimum link-length ratio.**

that this approach could not give faster solution.

4. Based on the first two tests, we made the forth attempt by giving initial population with 100 percent feasible solutions and ran the program based on 10 experiments with different population size as 100 and 500 members. The result was that smaller population size gave better solution by comparing the percentage of infeasible solutions in the final population. Therefore, we conclude that the small population size with large amount of experiments can give better solution to our problem. However, at the end of the run there were still some infeasible solutions appeared in final population.

5. Finally, we developed one strategy to eliminate the infeasible solutions during mutation by assuming that the genes were not the completed genes to become the children of next population. By so doing, we obtain the optimal solution with considerable reduction in computational time.

Figure 6. illustrates the numerical results in terms of the on-line, off-line and average values of the final fitting function versus the number of experiments using the modified GA technique described above. The program gave the optimal link-length ratio of 2.601235 within 25 experiments as the 400 population size was set. Figure 7. demonstrates the synthesized adjustable mechanism.

## 5. Conclusions

This paper introduces an automated synthesis technique for designing a semi -flexible, low-cost material handling machine called Adjustable Robotic Mechanism or ARM by integrating the modified GA programming technique into the mechanism synthesis procedure. The result from the numerical example illustrates the near global optimal searching capability of the technique. The current approach to eliminate the defect genes during mutation, however requires higher running time to reach the near global optimum solution. This could be a serious hindrance in practice. Therefore, as the authors gain more experience with GA and insight characteristics of the problem, we hope to improve the performance of the techniques by finding, for example, good mutation rate and cross over rate which can generate feasible solution into the synthesis stage much quicker.

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