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# DESIGN OF GRAPHICAL USER INTERFACES FOR THE SYNTHESIS OF PLANAR RR DYADS

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## ABSTRACT

*This article discusses the design and implementation of two Matlab graphical user interfaces (GUIs) for mechanism synthesis. The first GUI addresses the four location Burmester synthesis problem. The designer specifies the 4 locations that are used to generate the Burmester curves for these prescribed locations. The GUI enables the designer to interact with these curves and choose a pair of moving and fixed pivots forming an RR dyad. The second GUI addresses dimensional synthesis of RR dyads for hybrid motion generation tasks. Given a hybrid motion generation task, the designer can either pick the fixed or moving pivots and the corresponding pivots of an RR dyad is determined. In both the interfaces, the designer is provided with tools to specify tasks. The GUIs were designed with an objective to provide the designer with a simple workflow. Design case studies that illustrate the features and capabilities of each GUI are included.*

## INTRODUCTION

Dimensional synthesis is the determination of the dimensions of parts such as lengths and angles necessary to create a mechanism that will effect a desired motion transformation [1]. Various graphical and analytical methods have been discussed by McCarthy [2] and Erdman and Sandor [3]. Using these methods, the dimensional parameters are determined and they can be used to model linkages using parametric modeling software such as Creo Parameteric [4], Solidworks [5], and CATIA [6]. There have also been academic research efforts to design systems for the synthesis of spherical, planar and spatial mechanisms namely Osiris [7, 8], SPHINX [9], Spades [10], SPHINXPC [11], SPASUR [12]. Bourelle et al. [13] introduced a graphical user interface that solves the five-pose problem based on an algorithm described in [18]. These software packages aim to integrate user input into the design process by providing interactive tools to select the desired solutions in the solution space. Ch Mechanism Toolkit [14] is another notable software that has been used for the analysis and simulation of planar linkages.

The GUIs have been developed in collaboration with Magna Seating by the Robotics and Spatial Systems Laboratory using Matlab [15]. The primary objective for designing the GUI is to provide end-users at Magna an interface to interact with our synthesis algorithms. As with any software, it is highly desirable that the interface be simple and intuitive. We adopt this design objective in our GUIs in order to ease the designer's workflow.

## GUI FOR FOUR LOCATION SYNTHESIS

A GUI which addresses the synthesis of planar RR dyads using 4 locations using the Burmester Theory is presented. The dimensional synthesis algorithm involved in this GUI utilizes

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the Burmester Theorem [2, 16] that solves the four location problem by computing the center-point curve and circle-point curve; collectively known as the Burmester curves. In brief, the center-point curve is the locus of the fixed pivots of an RR dyad and the circle-point curve is the locus of the moving pivots of the same RR dyads. Thus, the points on the center-point and circle-point curves have a one-to-one onto mapping with respect to each other. An RR dyad that moves a body through the four locations has fixed and moving pivots located on the Burmester curves. Practical considerations such as location of the pivots, link lengths, space limitations etc. limit the solutions that can be used. The GUI provides the designer with the capability to interact with the Burmester curves to find desirable solutions for their specific motion generation task.

We have a synthesis algorithm which takes in the four locations as input and returns discrete points on the center-point and circle-point curves associated with these four locations. The inputs to the GUI are provided as ($x$, $y$, $\theta$) of the 4 locations. Here locations include both the position (represented by $x$, $y$) and the orientation (represented by $\theta$) with respect to a fixed reference frame. Once the center-point and circle-point curves associated with these locations have been generated, the designer can then interact with these curves to synthesize an RR dyad.

## DESCRIPTION OF THE GUI

The GUI consists of two main panels; the Design Panel and the Solution Space, see Figure 1. The Design Panel consists of the Input Panel and the Output Panel. The coordinates ($x$, $y$, $\theta$) of the four locations to specify the guidance task are to be provided in the Input Panel. The Input Panel provides two methods for input; textboxes and loading a data file. We did consider alternative input methods such as a slider [17]. It is visually intuitive to choose the locations by sliding them across a visual workspace. We also considered using the mouse interactively to choose locations in the workspace. But in our experience, we found textboxes more quick and accurate to specify locations for a motion guidance task. When designers are modeling using a computer-aided software, they can transfer the parameters of their model by copy-pasting or typing them in the GUI to generate results. Similarly, the results generated in the GUI can be easily transferred to a modeling software by copy-pasting values from these textboxes.

An alternative method to specify motion guidance task is to import the locations stored in *.txt* or *.csv* files using the *Import* button. The datafile follows a format wherein the first two columns correspond to the position co-ordinates ($x$, $y$) and the thrid column corresponds to the orientation ($\theta$). Figure 2 describes the sample input file containing a rigid body guidance task proposed by J.Michael McCarthy for the 2002 ASME International Design Engineering Technical Conferences held in Montreal, Quebec [18].

```
11.40   0.80    -5.00
11.30   2.90    10.00
10.50   5.40    62.00
 8.60   6.10   140.00
```

**FIGURE 2**. SAMPLE INPUT FILE FOR THE FOUR LOCATION GUI

**FIGURE 3**. TOOLBOX FOR THE FOUR LOCATION SYNTHESIS GUI FROM LEFT TO RIGHT: ZOOM-IN, ZOOM-OUT, PAN, DATA-TOOL

**TABLE 1**. FOUR PRESCRIBED LOCATIONS

| # | $x$ | $y$ | $\theta(deg)$ |
|---|---|---|---|
| 1 | 11.40 | 0.80 | -5.00 |
| 2 | 11.30 | 2.90 | 10.00 |
| 3 | 10.50 | 5.40 | 62.00 |
| 4 | 8.60 | 6.10 | 140.00 |

The *Execute* button calls upon a routine that generates the Burmester curves in the Solution Space. In the Solution Space, the designer can use the toolbox to interact with these curves to select an RR dyad, see Figure 3. The design parameters of the dyad selected in the Solution Space are updated in the Output Panel. Once the designer has selected the desired dyad, its parameters can be saved as a *.txt* or *.csv* file using the *Save* button.

## INTERACTION WITH SOLUTION SPACE

Once the Burmester curves have been generated, the designer can interact with the Solution Space to select the desired RR dyad that will pass through the four locations. The designer can utilize the tools shown in Figure 3 to interact with the Burmester curves. The Matlab datatool can be used to select points on the Burmester curves. The GUI detects whether the point selected by the user belongs to the center-point or circle-point curve. The corresponding pivot is calculated to yield a planar RR dyad that guides the moving body through the four locations. This dyad is plotted on top of the Burmester curves and the parameters of the selected dyads are updated in the Output Panel, see Figure 1. The user also has the option of changing the resolution of the Burmester curves using the buttons + and - positioned below the Solution Space, see Figure 1.

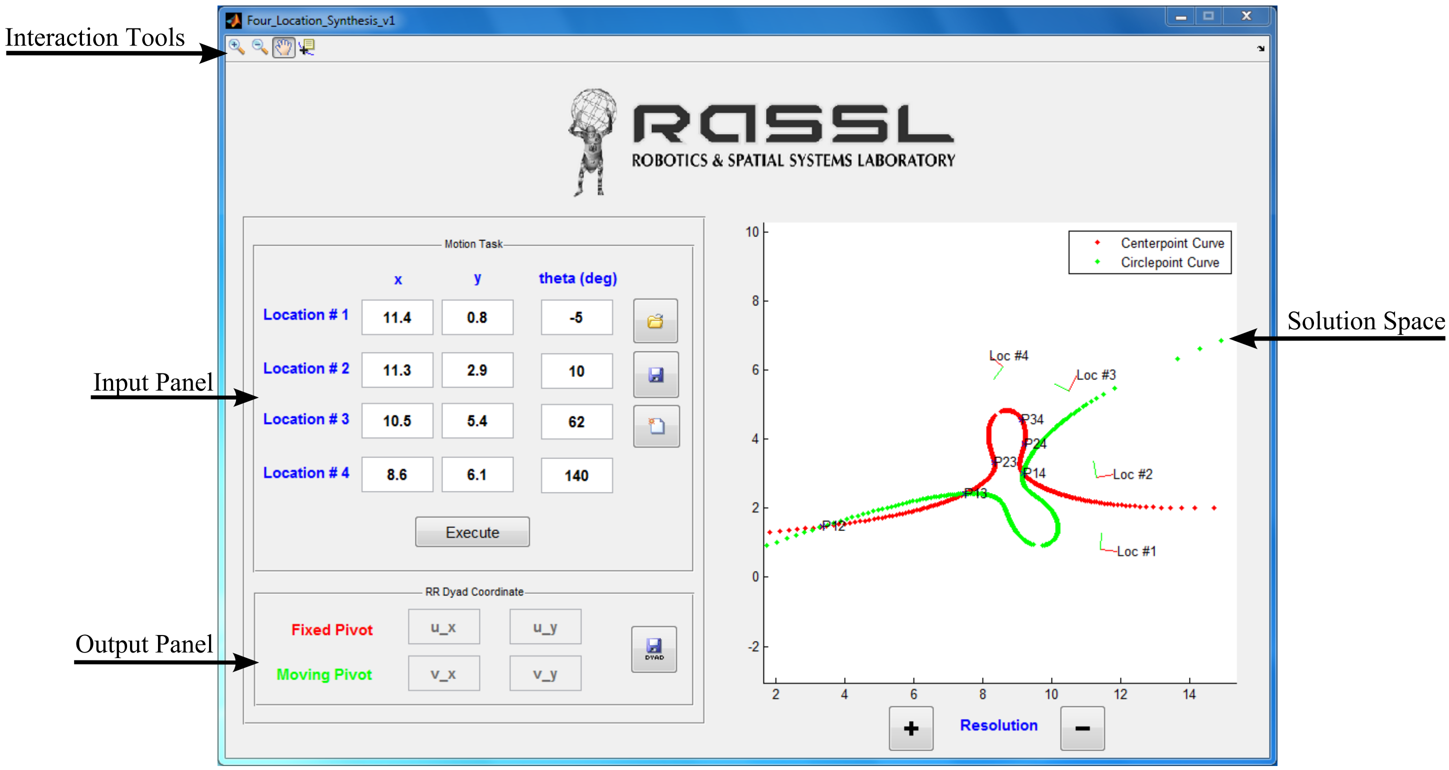


**FIGURE 1**. GUI FOR FOUR LOCATION SYNTHESIS

## CASE STUDY

We now present a step-by-step procedure to synthesize an RR dyad using the GUI for four location synthesis.

1. Input the 4 locations ($x$, $y$, $\theta$) using the input panel. The data is provided Table 1.
2. Click on *Execute* to generate the center-point and circle-point curves in the Solution Space.
3. Use the interaction tools such as *Zoom* and *Pan* to interact with the generated Burmester curves.
4. Use the datapick tool to select either a fixed or moving pivot. The corresponding pivot is determined and both the pivots are updated in the Output Panel.
5. The designer may iterate the above steps and re-generate the curves using *Execute*.
6. If the dyad meets the designer's requirements, the pivot information can be saved to a *.txt* file using *Save Dyad*.

## GUI FOR PICK-AND-PLACE TASKS

A GUI for the dimensional synthesis of planar four-bar (4R) mechanisms for rigid-body motion with mixed exact-approximate locations is presented. The dimensional synthesis algorithm implemented in this GUI is discussed in

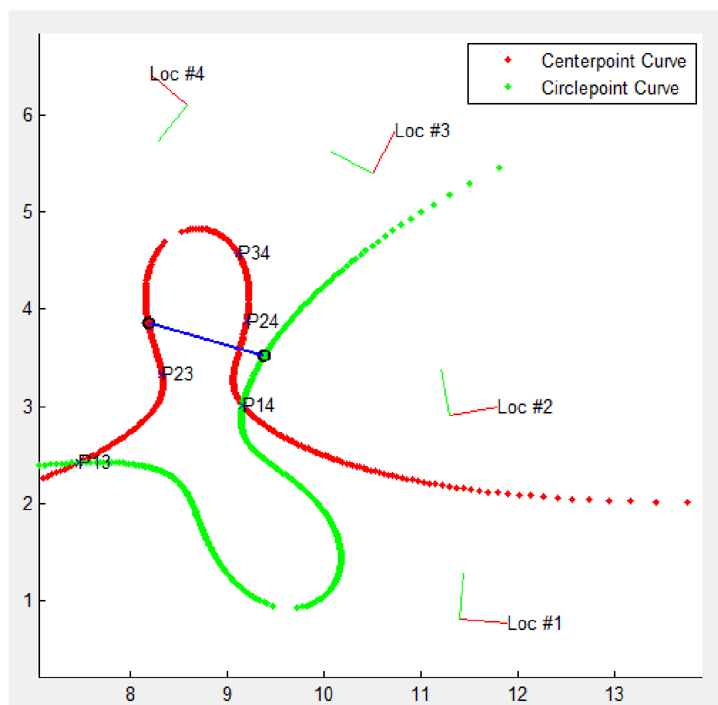


**FIGURE 4**. SELECTED PLANAR RR DYAD

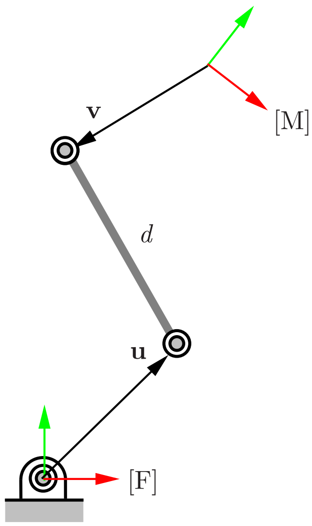


**FIGURE 5**. PLANAR RR DYAD

Larochelle [19]. The synthesis objective is to generate a planar four-bar mechanism that guides a moving body exactly through two locations and approximately through $n$ guiding locations given either a fixed pivot $\mathbf{u}$ or a moving pivot $\mathbf{v}$.

The notations used here is as follows. A planar RR dyad is characterized by it's fixed pivot $\mathbf{u}$ and moving pivot $\mathbf{v}$ and a planar 4R mechanism consists of a pair of RR dyads. Thus, in order to design a planar 4-bar mechanism, the designer needs to provide either a pair of fixed ($\mathbf{u}_a$, $\mathbf{u}_b$) or moving-pivots ($\mathbf{v}_a$, $\mathbf{v}_b$) and the synthesis algorithm is used to compute the corresponding pivots.

## DESCRIPTION OF THE GUI

The GUI includes two sub-panels; the Input panel and the Output panel, see Figure 6. The designer can input more than 3 locations of a motion guidance task by specifying the parameters ($x$, $y$, $\theta$) in a tabular form inside the Motion Task panel. The locations could also be imported from a *.txt* or *.csv* file containing these parameters using the *Import* button. The format of the datafile is the same as presented in the previous GUI. The use of a table in Matlab facilitated change in the number of locations of the motion guidance task which otherwise wouldn't have been possible with a fixed number of textboxes. The *Add* and *Remove* buttons are used to add and remove rows (locations) respectively from the input table, see Figure 7. The designer also can decide upon the order of guiding locations by moving rows (locations) above and below existing locations using the *Up* and *Down* button, see Figure 7.

In the Solve panel inside the Output panel, the designer can select between computing either the fixed pivots ($\mathbf{u}_a$, $\mathbf{u}_b$) given the moving pivot ($\mathbf{v}_a$, $\mathbf{v}_b$) or the moving pivot ($\mathbf{v}_a$, $\mathbf{v}_b$) given the

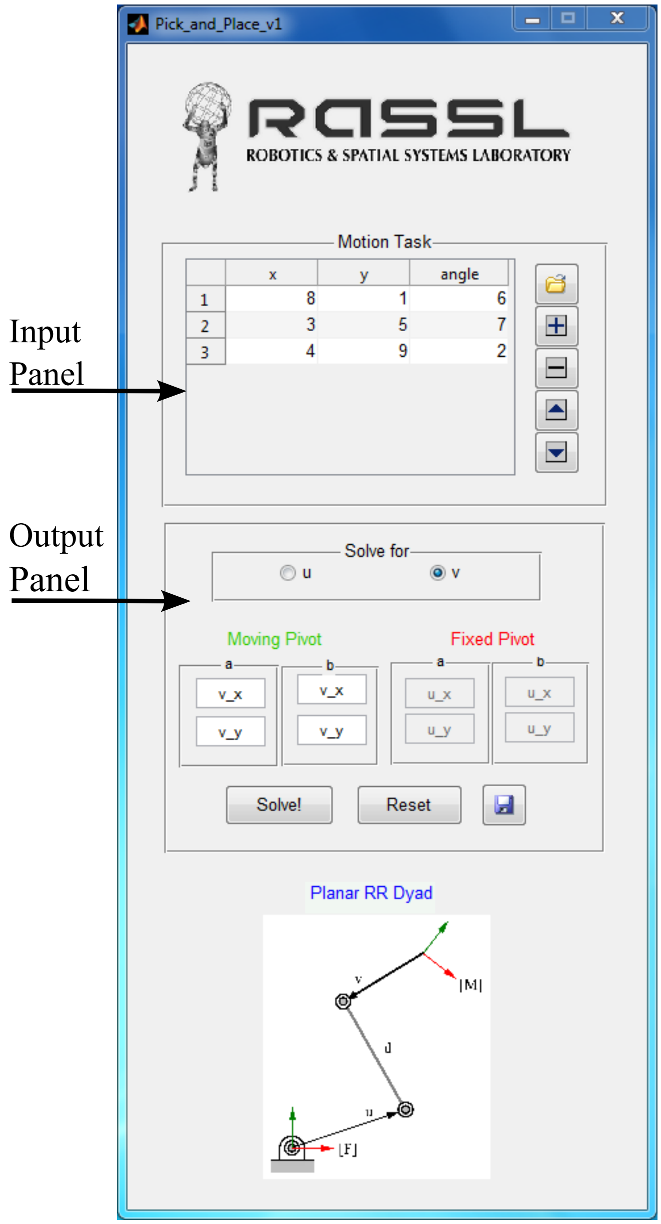


**FIGURE 6**. GUI FOR PICK-AND-PLACE

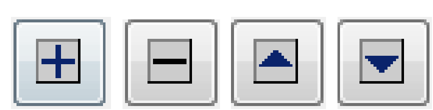

**FIGURE 7**. TOOLBOX FOR THE PICK AND PLACE GUI FROM LEFT TO RIGHT: ADD, REMOVE, UP, DOWN

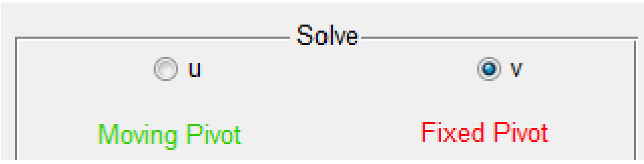


**FIGURE 8.** SOLVE PANEL

**TABLE 2.** FIVE PRESCRIBED LOCATIONS

| # | $x$ | $y$ | $\theta(deg)$ |
|---|---|---|---|
| 1 | 0.00 | 0.00 | 0.00 |
| 2 | 1.00 | 2.00 | 30.00 |
| 3 | 2.00 | 3.00 | 45.00 |
| 4 | 4.00 | 3.50 | 70.00 |
| 5 | 5.00 | 5.00 | 90.00 |

fixed pivot ($\mathbf{u}_a$, $\mathbf{u}_b$), see Figure 8. The pivots are displayed in textboxes for the same reason as stated for the previous GUI. Designers modeling in computer-aided software packages can copy-paste or type parameters into the GUI and retrieve the results from the GUI the same way and use them in their models. The pivots can later be saved into a *.txt* format using the *Save* button.

## CASE STUDY

We will now proceed to design a planar 4R mechanism for 5 locations; 2 exact and 3 guiding locations. Larochelle [19] uses the pick-and-place motion task shown in Table 2 and the moving pivots $\mathbf{v}_a = [0-1]^T$ and $\mathbf{v}_b = [1-1]^T$ to compute the fixed pivots $\mathbf{u}$:

1. Input the pick-and-place locations ($x$, $y$, $\theta$) in the Input panel, see Figure 8. The data is provided Table 2.
2. Select either to solve for $\mathbf{u}$ or $\mathbf{v}$:
   (a) If solving for $\mathbf{u}_a$ and $\mathbf{u}_b$, input $\mathbf{v}_a$ and $\mathbf{v}_b$
   (b) If solving for $\mathbf{v}_a$ and $\mathbf{v}_b$, input $\mathbf{u}_a$, and $\mathbf{u}_b$
3. Generate solution using *Solve*.
4. Computed pivots are updated in Output panel.
5. The designer can iterate the above steps to change locations and pivots to obtain the desired pivots.
6. If the pair of RR dyads meet the designer's requirements, the pivot information can be saved to a *.txt* file using *Save*.

## CONCLUSION AND FUTURE WORK

This paper presents the design and implementation of two GUIs for mechanism synthesis. Both GUIs were designed to facilitate end-user interaction. A GUI which addresses the four location Burmester synthesis problem is discussed. The GUI facilitated the user to interact with the solution space to design an RR dyad. The second GUI addresses dimensional synthesis of RR dyads for hybrid motion generation tasks. After the designer specifies a hybrid motion generation task, they can either pick the fixed or moving pivots to determine the corresponding pivots of an RR dyad. Both GUIs enable designers to interact with the solutions at will and save the results. These results could be utilized in a CAD/CAM/CAE software package for further development. Future work would entail integrating these GUIs into a single comprehensive package for designing planar RR dyads.

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