MechAnalyzer: 3D Simulation Software to Teach Kinematics of Machines

Rakshith Lokesh, Rajeevlochana G. Chittawadigi and Subir K. Saha

Abstract

Theory of Machine course includes kinematics and dynamics of mechanisms and machines. Though it is an important part of Mechanical Engineering curriculum, it is often difficult for teachers to teach and students to learn the concepts related to mechanisms, by just following text-books. With physical prototypes or virtual mechanisms in a software environment, the course can be taught in a lucid and effective way. While several commericial and free software exist that can be used to compliment the teaching and learning, a significant amount of time is required to learn the software first, and then use it. In this paper, MechAnalyzer (Version 3) software is presented which has a very simple to use interface and an easy learning curve. An user can select from any of the available mechanism and change the input parameters. A 3D model of the selected mechanism with linkages and joints are generated and shown to the user in a 3D environment, whose motion can be animated and seen. The main advantage of MechAnalyzer is that it has been developed as a framework with modules making it easier for developers to add new mechanisms. The authors would like to include as many mechanisms as possible to make it a digital library of mechanism and perform analyses on them.

Keywords: mechanisms simulation, animation, kinematic analysis, education

1 Introduction

Mechanisms and linkages are the important components of a machine that move in a fully determined manner to perform a task. Thus understanding mechanisms is a vital step in the process of designing a machine. A study in Mechanical Engineering will be void without a course on mechanisms and linkages due to its immense application in industries and research. But visualizing a mechanism is a big hurdle for the students. To visualize different links moving relative to one another is indeed a demanding task for a student studying courses related to mechanisms. The teacher can overcome this difficulty by presenting working models of mechanisms but this would be a tedious approach and would limit the study to a few mechanisms. But again, how does one cater to the curiosity of a student who wants to experiment with various input parameters pertinent to the mechanism. It would be a lot easier if computer resources can be used to simulate mechanisms through a combination of

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Graphical and Analytical approach. The students need something that they can carry home, experiment with and apply these theories into projects. This will make the whole learning experience enjoyable and productive.

At present, there are commercially available software that can model and simulate mechanisms. But they are not directly aimed at teaching mechanisms to a student; being time consuming or complicated to use. For example, it can be done in CAD tools like ADAMS, RecurDyn, Autodesk Inventor, SOLIDWORKS, etc., but requires modeling the mechanism, defining constraints and then simulating the mechanism. Moreover the output parameters that can be observed are limited or require additional settings. Specific software for mechanisms have been developed by commercial software vendors as well as universities. Working Model 2D[1], SAM[2], Universal Mechanisms[3], Ch Mechanism Toolkit[4], etc. are such software that are commercially available. However, many Universities and Research Organizations have also developed software and resources that are available for free. MMTool[5] was developed as MS-DOS application with graphics. An user could sketch a generic mechanism and perform its kinematic analysis and see its animation. However, it is currently unavailable for download. Another software, Lincages 2000[6],is also not available for download. It had functionality related to synthesis of mechanisms. Of the recent software that are available for download and use, GIM[7] is a generic software related to mechanism modeling and simulation and requires users to develop mechanisms and simulate them. Linkage Mechanism Simulator[8] has an interface, similar to Working Model 2D, where mechanisms can be created from scratch by selecting links and joints and connecting them. It also has some example mechanisms to load and simulate. SOLVE[9] is an online platform to simulate and animate some of the commonly available mechanisms. Though, these freely available software are good to see the animation of mechanism motion, they do not have any option to plot kinematic or dynamic analyses data. The authors took this as an opportunity and started the development of MechAnalyzer, a 3D model based mechanism learning software.

MechAnalyzer is a Windows Desktop Application developed using Visual C# and OpenGL. The Version 2 of the software has been reported in [10], which had common planar mechanisms such as four-bar, slider crank and five-bar mechanisms. It could perform kinematic analysis and the results were shown as animation and graph plots. In this paper, updates made to MechAnalyzer in the form of Version 3 are presented. The software has been completely revamped on the lines of RoboAnalyzer[11], also developed by the authors, so that both the software have similar user interface and also have modularity to include more mechanisms in future. An overview of MechAnalyzer is given in Section 2. The mechanisms available in the software are discussed in Section 3, followed by the conclusions. Though the graph plot functionality is not available in Version 3 (as compared to Section 2), it will be implemented and will be reported in future.

2 Overview of MechAnalyzer

MechAnalyzer aims to be a software platform that can be used to teach and learn the concepts related to the kinematic and dynamic analyses of mechanisms and machines. As of now, only the kinematic analysis has been implemented in it. An overview of the software is presented in this section.

2.1 Earlier Versions

The first version of the software was an attempt to check the usefulness of the software. It contained forward kinematics of four-bar and slider crank mechanisms. Later five-bar mechanism and special mechanisms were included and released as Version 2. A screenshot of the 3D model of four-bar mechanism and plots for kinematic analysis in Version 2 is shown in Fig.(1).

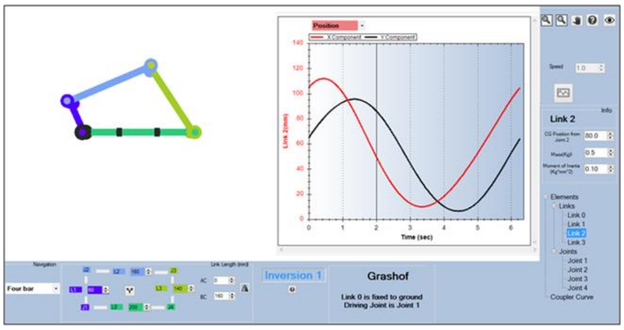


Figure 1: Kinematic analysis of four-bar mechanism in MechAnalyzer Version 2

2.2 Mechanalyzer Version 3

The idea behind developing the new version of Mechanalyzer was to make it easy to add new mechanisms through minimal input by the developers in the form of addition and/or modifications to the code-base. The concepts of Object Oriented Programming (OOP) were used extensively to make maximum reuse of code and also to ease out maintenance of the code base. The new framework of the code-base is modeled on lines similar to that of RoboAnalyzer software, developed by the authors of the paper.

As illustrated in Fig.(2), an user can select a mechanism from the list of available mechanisms and the corresponding user interface is displayed to the user. At the same time, the 3D model of the mechanism for the default values in the interface is generated and displayed. The range of motion of the input link is then determined from the position analysis and the limits of motion are set for the animation.The links of the mechanisms are modeled as a combination of various shapes like cylinder, cube, trapezoid, etc. For example, a four-bar link is made of a cuboid with a cylinder at each of the ends. The changes made in the user inputs are reflected as an updated 3D model of the mechanism and the forward kinematic analysis is performed.

To show the animation of the motion, the links are transformed in the 3D environment as per the kinematic analysis results. The animation can be played by using the play-back deck located in the user interface. The basic CAD viewing tools like zoom, pan and orbit have been implemented for easier navigation in the 3D model environment. Also, specific views such as front, top, side and isometric, have been enabled for quick navigation to a desired view. Another important feature is the output message box; it displays important messages related to the mechanism that a student can use to relate to what he/she has studied in a course on Theory of Mechanisms. As an example, whether a four-bar mechanism is of Grashof or Non-Grashof type is displayed based on the input parameters. An image window which describes the nomenclature of links and joints has also been provided for each mechanism.

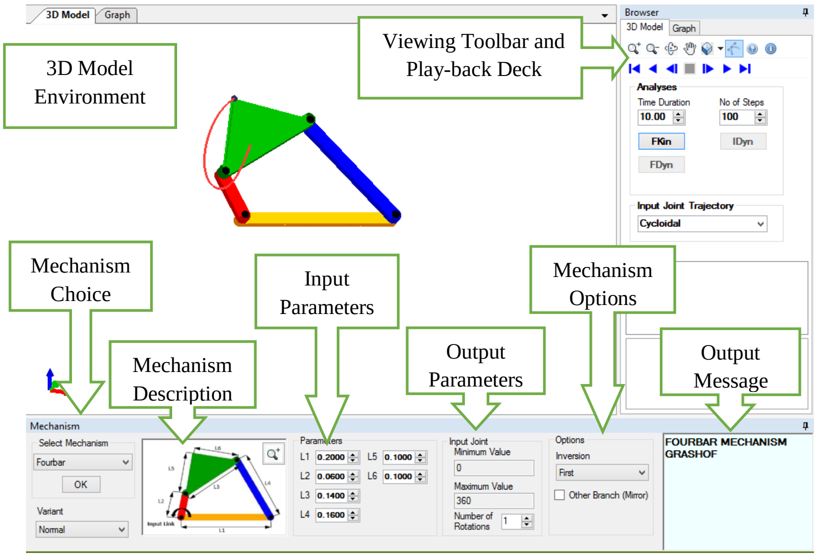


Figure 2: The interface of MechAnalyzer Version 3

3 Mechanisms in MechAnalyzer

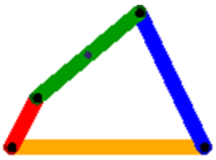
A list of mechanisms was prepared based on a survey of curriculums of undergraduate courses in mechanical engineering, renowned textbooks [12-13] and video lectures [14]. All these mechanisms are single degree-of-freedom (DOF) and are further classified as lower pair and higher pair mechanisms. The kinematic analysis formulations used in the software are primarily based on the geometric approach and is not presented in this paper, due to the space constraints. As of the current version, the mechanisms available in the software are listed in Table 1.

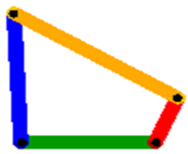
Table 1: Mechanisms available in MechAnalyzer Version 3

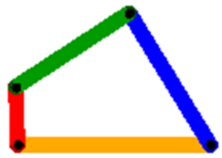
Lower Pair Mechanisms	*Higher Pair Mechanisms*
Four-bar mechanism	Spur gears
Slider crank mechanism	Compound gears
Double slider mechanism	Gear trains
Steering mechanisms	Cam-follower mechanisms
Quick return mechanisms	
Pantograph mechanism	

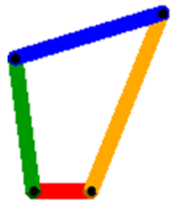
3.1 Four-bar Mechanism

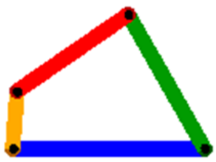
The highest emphasis is given to this mechanism as this is the most basic mechanism and is taught extensively at the undergraduate level. An user can select from any of the four inversions available for four-bar mechanism and observe the change of links from crank to rocker or vice versa. This is illustrated in Fig. (3a-d). The user can also toggle between the two configurations of the mechanism possible for a given crank angle, as shown in Fig. (3e-f).


(a) First inversion


(c) Third inversion


(e) Configuration 'One'


(a) Second inversion


(d) Fourth inversion

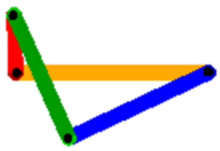
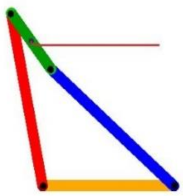
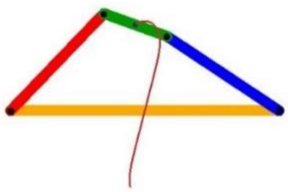
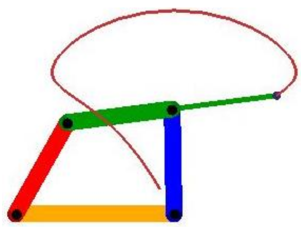

(f) Configuration 'Two'

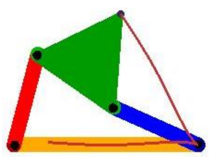
Figure 3: The inversions and configurations of a four-bar mechanism

The trace of the coupler point can also be drawn in the 3D environment and the user can observe the trace for different length of the links. Certain lengths of the links of four-bar mechanism also result in straight line mechanisms and these are preloaded in MechAnalyzer, so that user can readily observe its motion in the software. These special four-bar mechanisms are illustrated in Fig.(4).


(a) Chebychev's linkage


(c) Watt's linkage


(d) Evan's linkage


(b) Robert's linkage

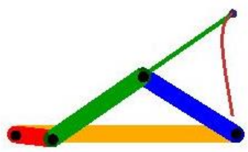
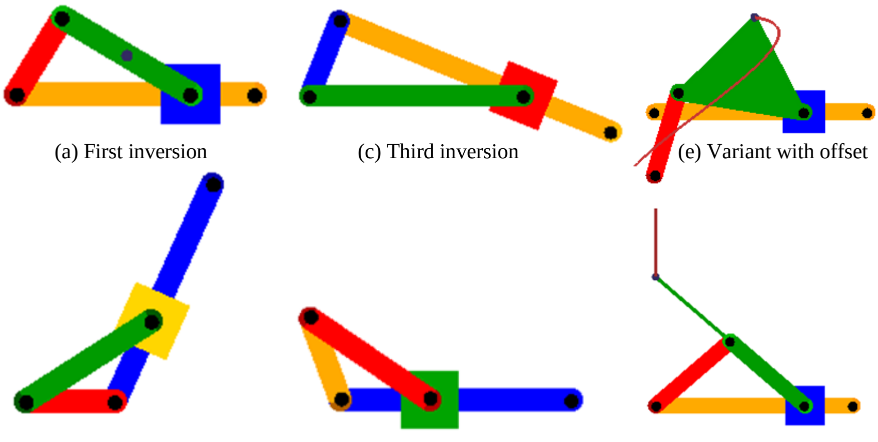

(e) Hoeken's linkage

Figure 4: Straight line drawing four-bar mechanisms

3.2 Slider Crank Mechanism

Slider crank mechanism is also one of the basic and important mechanism studied extensively. It also finds its use in the internal combustion engines. Understanding the conversion of rotary motion of the crank to the translation of the slider is an important aspect, which can be easily full-filled using MechAnalzer. The inversions of slider crank motion find interesting applications and they are illustrated in Fig. (5a-d). The variation with offset also can be studied as shown in Fig. (5e). Another variant with specific link lengths results in Scott-Russel's straight line mechanism shown in Fig. (5f).



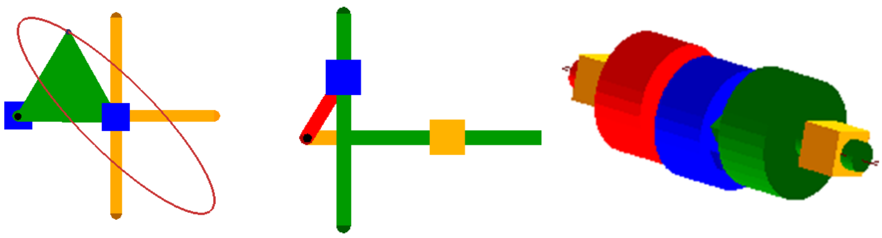
(a) First inversion (c) Third inversion (e) Variant with offset

(b) Second inversion (d) Fourth inversion (f) Scott-Russel Mechanism

Figure 5: Inversions and variants of slider crank mechanism

3.3 Double Slider Mechanism

A double slider mechanism is formed when four links are connected using two revolute and two prismatic/translation joints. The rotation of one of the joints results in the rotation of another revolute joint through a sliding motion by the intermediate joint. As in four-bar and slider crank, inversions of double sliders are also implemented in MechAnalyzer. These have good applications as well. Elliptical trammel can be used to trace an ellipse, Scotch Yoke mechanism is used in window regulators in automobiles and Oldham's coupling is used to transmit motion in shafts with an axial offset. These are illustrated in Fig. (6).



(a) Elliptical trammel (b) Scotch Yoke mechanism (c) Oldham's coupling

Figure 6: Inversions of double slider mechanism

3.4 Steering Mechanism

The two major steering mechanisms, Ackermann and Davis, which are a part of most curriculums, have been implemented in the software. In both the steering mechanisms, the translation motion of a link (rack), is caused due to the rotation of the steering wheel and is converted into the rotation of the steering arm connected to the wheels. The difference in rotation of the wheels about the instantaneous turning centre is responsible for the steering of the vehicle. This is illustrated in Fig. (7).

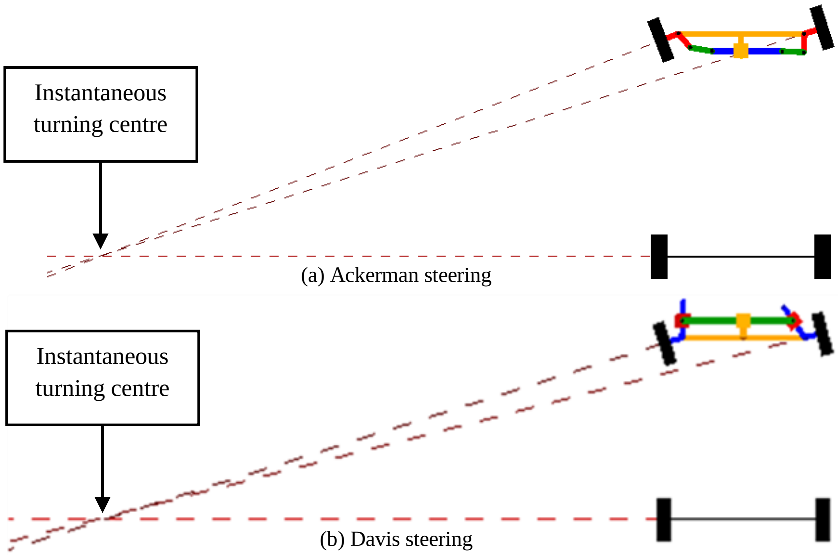


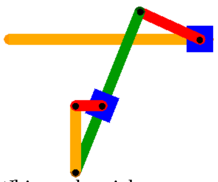
Figure 7: Steering mechanisms

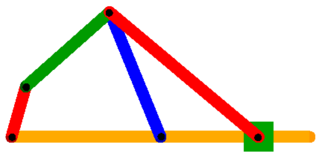
3.5 Other Lower Pair Mechanisms

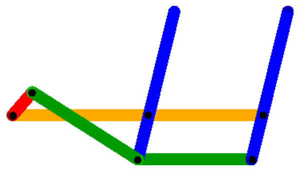
Mechanisms which have real life applications have been included in the software so that a student can relate the theory to practical applications. These are Whitworth quick return mechanism which is widely used in machines, Four-bar quick return mechanism illustrating how quick return motion can be achieved using a four-bar, wiper mechanism showing basic version of a car windshield wiper and a pantograph which can draw scaled versions of input drawing. All of these are illustrated in Fig. (8).

3.6 Higher Pair Mechanisms

Higher pair mechanisms have a line or point of contact between the links, as compared to lower pair which have a surface contact. Some of the common higher pair mechanisms such as gears, simple gear train, complex gear train, cam-followers, etc. Some of these are implemented in MechAnalyzer and they are illustrated in Fig. (9).


(a) Whitworth quick return mechanism


(b) Four-bar quick return mechanism


(c) Wiper mechanism

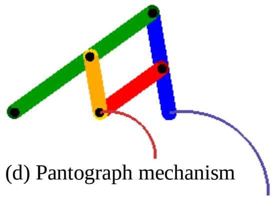
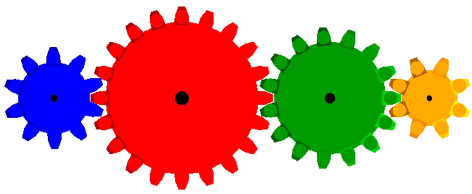
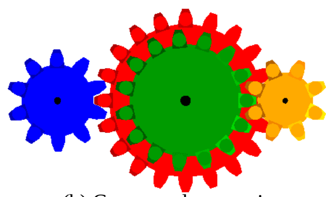
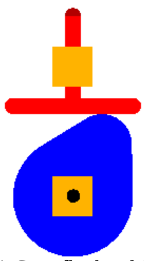

(d) Pantograph mechanism

Figure 8: Other lower pair mechanisms in MechAnalyzer


(a) Simple gear train


(b) Compound gear train


(c) Cam-flat head follower

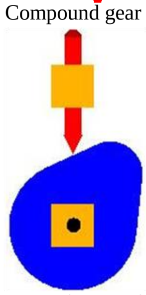

(d) Cam-knife point follower

Figure 9: Gear trains and cam-follower mechanisms in MechAnalyzer

4 Conclusion

For effective learning of concepts in Theory of Machines course, a simulation environment with very minimal learning curve is desired. In this paper, Version 3 of MechAnalyzer software is presented which aims to help in the effective learning and teaching of mechanisms. It uses templates of common mechanisms and users can easily vary the length of the links and other parameters and the 3D model of the mechanism gets updated instantly. The animation of the mechanism can be seen for the range of motion possible, which would help the user to understand the mechanisms motion and how it could be used in any application. Several special mechanisms are also made available as templates, for easy visualization.

MechAnalyzer Version 3 is freely available and readily used from http://www.roboanalyzer.com/mechanalyzer.html.

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