Modelling and Simulation of a Dump Truck Tipping Mechanism using EdenLISP

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Abstract
The application and use of EdenLISP in mechanism design and analysis is demonstrated on the tipping mechanism of a dump truck. The foundation for mechanical engineering design is centred on mechanisms, their design operation and strength. Several design programs have been developed to assist the engineer in the product development cycle. This paper demonstrates how a complex mechanism of a typical machine can be broken down, modelled, simulated and analysed using a program developed using AutoLISP, an interface language as well as an integral part of the AutoCAD Design Software. The various links that make up the mechanism were initially modelled into simple lines for ease of display in AutoCAD. This was followed by timing of the various motions to enable the simulation and ultimately the analysis of the mechanism. Analysis of this nature are beneficial to the mechanical engineering designer in that potential areas of interference are detected before manufacture while at the same time, cutting down on potential costs incurred in prototyping.

Keywords: EdenLISP, AutoLISP, Mechanism Design and Analysis, Simulation

I. Introduction
Modelling is a very broad term like design, which is used rather loosely in everyday language to describe activities ranging from fashion and style to scale modelling. But, like all these, the activities have something in common. They are all trying to represent something. Fashion expresses an idea, fashion models project an image, scale modellers produce realistic renderings of full size objects etc., but modelling can be a much more formal activity as when a scientist, engineer or architect wishes to explore the nature of some physical process or understand how to construct or operate some physical object or system.

The latter is the sense in which the term, modelling is used in this paper. In fact modelling is used in an even more restrictive sense, that of computational modelling. There are several reasons that can be advanced for the use of computational modelling, such as the need to know more about the object, understand the process of constructing the object or to explore ways and improve on how the resultant system/mechanism behaves. But whatever the reason, the model is always a substitute or a representation for the real thing.

In the context of this paper, modelling entails the construction and investigation of a limited representation of a product or system in order to discover something about the characteristics of a fully developed version [1]. This implies that the dump truck, complex as it may be, can be broken down into a simple form that is easy to visualise and understand while the characteristics or behaviour required are maintained. The simple form can be studied and visualised easily to obtain the resultant behaviour of the mechanism in real life, i.e. simulation.

A modern designer or engineer is regarded as such because of the ability to use modelling techniques and this is what distinguishes them from a traditional craft-worker. Modifications in product design have traditionally been effected by a series of small evolutionary steps introduced by succeeding generations. Currently the trend has been that new products or systems are generated as a result of the use of models which allow them to be tailored in advance to the perceived user need. This ultimately leads to the performance prediction of complex systems.

Anthropometrics is a subject that concerns the mathematical modelling of humans. They are represented by statistical tables and graphs in order to aid the design process. Designers often find this an inadequate form in which to represent the models and consequently turn to 2 dimensional sketches in scaled down proportions or 2-D card models. Various advantages can be drawn from this, ranging from the simple display of the linkages to the ability to visualise and simulate the behaviour of the resulting mechanism.
2. Background to EdenLISP

When high level programming languages were developed in the early 1960’s, they followed two distinct routes, that of procedural or functional. One of the earliest functional languages developed was LISP (List Processing) from which there are several dialects such as MacLISP, InterLISP and AutoLISP. The latter is the one on which the widely used CAD software package, AutoCAD was developed. In fact it is still the interface language for the software.

AutoLISP allows AutoCAD users to write macro-programs to automate some of the routine tasks that are found in the software. It was developed by John McCarthy at MIT in 1960. While it is a very useful programming language, it requires one to have previous programming experience or training in LISP. Most functional programming languages are not as straight-forward and easy to learn like the procedural ones such as BASIC FORTRAN and C which are mostly used for mathematical modelling.

While making use of the graphic capabilities of AutoLISP, a simpler and more user-friendly programming environment was developed by Alan Cartwright at the University of Warwick in 1994 assisted by the author of this paper. This was done by combining aspects of the functional language, AutoLISP and that of the procedural language EDEN (Evaluator of Definitive Notations) to come up with EdenLISP, the language on which the mechanism in this paper is based. EdenLISP is a programming environment that contains straightforward English-like expressions while maintaining the graphic functionality from AutoLISP.

2. Geometric Model

The development and eventual launch of EdenLISP was accomplished by using several machines and mechanisms. One of those mechanisms used was the tipping mechanism employed by Wallpact Limited from Rugby in England.

Typically, the dump truck, as shown in figure 1 consists of a container or tray resting on a bell-crank, one arm of which is connected to a hydraulic cylinder and the other hinged to the container. A lever is connected to the hinge of the bell-crank.

The art of modelling in computer aided design is largely one of deciding how to partition objects into suitable discrete components in such a way that sufficient flexibility is retained to explore the behaviour of the resulting model in a wide enough range of situations.

Of primary concern during the modelling process were the tipping mechanism and the container although this did not totally ignore the rest of the dump truck. The simplified geometric model is as shown in Figure 2, where links, 2-3-4 represent the bell-crank, links 6-7-8-9 represent the container, 4-6 the hydraulic cylinder and 1-5 the frame between the 2 wheels of the dump truck.

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Fig. 1 Dump Truck

Fig. 2 Simplified Model of the Dump Truck

Typically the container is loaded with rubbish and to empty this, the hydraulic cylinder is activated. As the ram opens, it pushes the lower arm of the bell-crank (4) that rotates about the hinge (2). In turn the upper arm (3) pushes the container and tips towards the right. The lower right corner of the container (8) is fixed but can rotate about this point.

The design involved modelling the mechanism, by initially coming up with the right geometry at each instant that the ram pushes the bell-crank until the lower arm is level with the lever. At this point both the lever and the arm are pushed together. Apart from opening up and pushing the bell-crank, the ram also oscillates about point 5. Two arcs, one centred at 5 and the other at 2, intersecting at 4 are thus formed as the ram opens up. Points 1, 2, 5 and 7 are initially fixed and hence can be defined by the respective (x, y) coordinates. The other points depend on these four. However when length 4-5 changes, the points 3, 4, 6, 7, 8 and 9 also change.

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3. Mathematical Model

The specifications for the dumping truck for Wallpact limited were as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Lever</td>
<td>2800 mm</td>
</tr>
<tr>
<td>arm-length of the bell-crank</td>
<td>500 mm</td>
</tr>
<tr>
<td>Container dimensions</td>
<td>4400 x 100</td>
</tr>
<tr>
<td>Angle of lever to the horizontal</td>
<td>23°</td>
</tr>
</tbody>
</table>

**Table 1: Specifications of the Dumping Truck**

The initial task in developing the mathematical model was to determine the coordinates of point 4 as this is the intersection point for the 2 circles. To simplify the model further, point 5 was chosen as the origin of the mechanism.

Looking back at figure 4, it should be noticed that there are two intersection points and the one required (point 4) would be the one with the lowest value (more negative) of \( x \).

The intersection of two circles is given by

\[
\begin{align*}
    x^2 + y^2 &= -c_1 \\
    x^2 + y^2 - 2a_2 x - 2b_2 y + c_2 &= 0
\end{align*}
\]  

Where \((a_1, b_1)\) is the centre for circle 1 and \((a_2, b_2)\) is the centre for circle 2.

\[
\begin{align*}
    c_1 &= a_1^2 + b_1^2 - r_1^2 \\
    c_2 &= a_2^2 + b_2^2 - r_2^2
\end{align*}
\]

\( r_1 \) and \( r_2 \) are the respective radii of the 2 circles. Since point 5 has been chosen as the origin or \((0, 0)\) then

\[
a_1 = b_1 = 0
\]

and equation (1) thus reduces to

\[
x^2 + y^2 = -c_1
\]  

and

\[
y^2 = -c_1 - x^2
\]

\[
y = \sqrt{c_1^2 - x^2}
\]

Equation (8) can be simplified and reduced to a quadratic equation in \( x \):

\[
(4a_2^2 + 4b_2^2)x^2 + (4a_2c_1 - 4a_2c_2)x + (c_2^2 + c_1^2 + 4b_2^2 - 2c_1c_2) = 0
\]

the solution of which is:

\[
x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}
\]

Looking back at figure 4, it should be noticed that there are two intersection points and the one required (point 4) would be the one with the lowest value (more negative) of \( x \).

Hence

\[
x = \frac{-B - \sqrt{B^2 - 4AC}}{2A}
\]  

and from equation (7)

\[
y = \frac{c_2^2 - c_1^2 - 2a_2x}{2b_2}
\]

Equations (10) and (11) give the \((x,y)\) co-ordinates for points 4 as the ram opens outwards. At the starting point, the end of the ram would be at a distance equivalent to the stroke from the base of the cylinder.
stroke = \sqrt{a^2 + (b - \text{armlength})^2} \quad (12)

Using the specifications of the Wallpact Dumping Truck, the stroke would thus be 1917 mm at the initial position. When the lower arm of the bell-crank comes in line with the lever, both links move outwards together. Hence from this point, apart from varying the ram length or stroke, the angle of inclination of the lever would also change. As a result this changes the relationship of point 3 from point 4. At this point, conditions are included in the design program to use a different formula for determining the position of point 3 that will in turn affect points 6 to 9.

4. Simulation of the Mechanism

The complete simulation of the mechanism was achieved by modelling and displaying the links at the initial position where the stroke was 1917 mm and angle of inclination of the lever at 23° followed erasing the display and move on to 2 new variables of stroke and angle of inclination. This repetitive task can be automated in the program by looping and changing the 2 variables at each stage. The calculations for the new positions, erasing and redisplaying happens so fast that what appears on the CAD screen is a simple animation of the mechanism.

The program was designed to stop the simulation at the point when the container is fully tipped, but can be modified to stop by an interruption from the user. Visualisation of the resultant mechanism can be improved by using different colour displays for the different segments of the mechanism.

5. Discussion

The EdenLISP program code for modelling and eventually simulating the dump truck tipping mechanism is shown in the appendix. The program is based on the mathematical model in the previous section. As can be seen from the program the expressions are in simple English statements unlike the use of parenthesis as in normal LISP programs.

Just like in any other programming language, the first part of the EdenLISP program consists of the declaration of whether or not, the variables used such as points and absolute distances are reals or integers. This is followed by defining the variables, first by putting the formulae for calculating x and y, followed by the definitions of their dependent variables. In this design program the dependent variables of x and y were used before they were defined, a useful aspect of the EdenLISP programming environment.

The two values for x and y define the coordinates for point 4, and then the rest of the points are calculated by referring to this point using the polar function. At this stage the conditions are also put in to enable the lever and bell-crank to move together once the two are on the same level. The mechanism geometry is then displayed at the initial position with the stroke at 1917 mm.

The great diversity of design activity has often been noted with all design represented as compromising two broad functions, that of decision and information processing.

Decision making would include development of the most satisfactory solution to a problem i.e. optimisation. The optimisation requirement leads to a need for iteration and sometimes visualisation (display). Hence the need for iterative methods and graphics facilities, especially interactive graphics when the frequency of decision making is high and time compression is important. Although the modelling and simulation of this mechanism was done for an existing machine, tools of this nature are often necessary when designing a machine from scratch to predict their behaviour.

Processing of information is also another vital function for design. This can also be aided by use of interactive graphics. There have been problems in developing the types of information processing that are needed for design purposes.

Computer aided design has been depicted as comprising two distinct disciplines, graphics and modelling. Looking back at modelling and simulation of the dump truck, the links for the various parts of the mechanism can be displayed graphically while modelling consists of the use of the program accessing a database to compute the position of links when one of them is varied. In general, interactive graphics are used in the design environment to optimise the design of parts, components, assemblies, etc., before the manufacturing phase commences. This can be useful for reducing expensive work associated with such activities as prototyping and introducing modifications to items after manufacturing has begun.

Linkage analysis, for example, was intended for the design of mechanical linkages and to investigate their properties. It is possible to enter the input data in a matter of a few minutes and the user can perform a complete geometrical and motion analysis in even less time.

Parametric analysis can be carried out for the different forms of engineering design problems, e.g. in structural design. Engineering structures generally fail, depending on the materials used, the kinds of loads in operation and conditions of support. They can be modelled mathematically and the critical loading conditions and factors of safety calculated.

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6. Conclusions

There has been an increased development of either new design software or the improvement of the existing ones. This has been largely due to increased awareness of the benefits of CAD software. The development of a new programming environment that made use of aspects of functional as well as procedural attributes of high level languages culminated in EdenLISP. This environment can be used for various forms of design including the foregoing, modelling and simulation of a dump truck tipping mechanism.

Although the processing files were written in AutoLISP, they can be easily modified to suit ones own needs. The user also has more control over the design program. In AutoLISP, if one is using a program written by someone else, then there is less control. All this makes design easier and can be handled by personnel with little or no practical experience.

The increased awareness of the benefits of good engineering design software and the need for such software capable of solving design problems by use of interactive graphics, to a large extent influenced the need for research in the development of EdenLISP.

Companies who have invested in CAD systems such as AutoCAD could realise more return on their investment if the package were fully utilised. This can easily be achieved by sending their technical personal for professional training which the University's Department of Mechanical Engineering is offering.

Improved interaction can be achieved by using EdenLISP for geometrical modelling and general design analysis. Most engineering problems are solved by the use of mathematical models that consist of variable constraints. EdenLISP can also be used for optimisation and simulation analysis to assist designers in the decision-making process of design.

7. References

pt8 = polar (pt3, boxang, baser)
pt9 = polar (pt3, ( atan(boxh/baser) + boxang), sqrt((boxh*boxh)+(baser*baser)))

size = [1, 1]
origin = [-440.0, 0.0]

a2 = projn(1, pt2)
b2 = projn(2, pt2)
a3 = projn(1, pt3)
b3 = projn(2, pt3)
a4 = projn(1, pt4)
b4 = projn(2, pt4)

tipp = object(tipper, origin, size)

baser = 440 - basel

b7 = projn(2, pt7)
boxang = atan ((b3-b7)/(a3-a7))

motion = ploop ('stroke', 191.7, 5.0, 245.0)

beta = 25.0
beta = 30.0
beta = 35.0
beta = 40.0