Design of a Reconfigurable Deployable Structure

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Summary: This paper introduces a reconfigurable mechanised structure design composed of planar linkage units. The alternative forms that a linkage can be constructed with the same links and connections are called configurations or assembly modes of the linkage. During its motion, the linkage may pass from one assembly mode to another, which is called reconfiguration or assembly mode change. The reconfigurable structure presented in this paper is a single DOF multi-loop mechanised structure which has more than two configurations. Design and position analysis of the mechanism are implemented in Microsoft Excel environment. The link lengths can be varied in this environment and the structure can be simulated by changing input joint parameters. The mechanised reconfigurable structure can be used as a multifunctional canopy which can take any form in a few minutes for urgent needs after disasters, military purpose or public needs.

Keywords: *Deployable, Reconfigurable Mechanisms, Canopy, Parallelogram Mechanisms*

INTRODUCTION

Gantes defines deployable structures as prefabricated structures that can be transformed from a closed compact configuration to a predetermined, expanded form, in which they are stable and can carry loads [1]. By using this definition, we define reconfigurable deployable structures as prefabricated structures that can be transformed from a closed compact configuration to multiple alternative expanded forms.

The aim of this study is to develop a multifunctional reconfigurable canopy which can fold and deploy in a few minutes for urgent needs after disasters, military purpose or public needs, so it is a kind of temporary building. Temporary means that it is intended to be used for only a limited period of time.

According to Kronenburg the buildings with variable location or mobility are classified into three specific types [2]:

1. Portable Buildings: They are transported whole an intact. Sometimes they include the means of transportation within their own structure and can be towed or carried.

2. Relocatable Buildings: They are transported in parts and are assembled at the site almost instantly into usable built form. These are almost always carried, but in a few limited cases may have part of their transportation system incorporated into their structure.

3. Demountable Buildings: They are transported in a number of parts for assembly on site. They are much more flexible in size and layout and can usually be transported in a relatively compact space.

Deployable structures can be counted as the fourth type in Kronenburg's classification.

Nowadays, it is preferred to use deployable systems for temporary buildings or shelters because they are set up rapidly when disaster occurs. There are many different types of deployable temporary shelter designs in the world. Design alternatives include classical tents, inflatable tents or structures comprising folded plates. Below are some of the specific designs.

The Rapid Deployable System (RDS) by Hoberman Associates [3] (Fig. 1) provides "quick-up" structures for modular expansion that are durable, efficient, and easy to assemble and disassemble. The RDS is made from extreme rugged materials and has a weather-proof surface, making it durable in the harshest environments and allowing it to be used as a long-term structure.

Fig. 01 Hoberman Associates' RDS [3]

Disaster victim shelter temporary house design such as Mount Merapi eruption disaster victim house design and Indonesia tsunami disaster victim shelter house is designed in order to protect victims [4] (Fig. 2).

Fig. 02 Disaster Victim Shelter [4].

The Life Bean is a rapidly deployable emergency shelter and life support system (Fig. 3). It can be easily transported to disaster sites to offer immediate protection and longer-term support mechanisms for people caught in circumstances of infrastructural crisis. It includes a number of discrete but interdependent building systems-structure, skin and plumbing. The Life Bean can be deployed in various climates, economies, and social environments. With simple material variations, it can adjust to local climatic requirements. The flexibility of its construction allows the Life Bean to reconfigure for individual isolated use, aggregated multi-unit formations, and to adapt too many topographical conditions [5].

Fig. 03 The Life Bean [5]

The first two examples comprise rigid elements, and they have only closed and expanded configurations. The last one is produced from flexible material. Thanks to this feature, it has more configurations and more application of area. So it is somewhat reconfigurable.

While deployable tents are used for a single function with a single form, proposed reconfigurable canopy concept is multifunctional to create closed and semi open spaces with reconfigurable mechanism design. These advantages of proposed mechanism for the reconfigurable canopy will provide public benefit especially at post-disaster situations.

The reconfigurable canopy design introduced in this paper consists of several planar linkage modules which are assembled parallel to each other. First the planar linkages are presented, and then the assemblies are explained.

PLANAR LINKAGE MODULE

The alternative forms that a linkage can be constructed with the same links and connections are called configurations or assembly modes of the linkage. During its motion, the linkage may pass from one assembly mode to another, which is called reconfiguration or assembly mode change.

We make use of parallelogram loops in the planar linkage modules of the reconfigurable canopy design. Parallelogram mechanism is a special kind of four bar mechanism with equidimensional and parallel reciprocal links.

Fig. 4 shows the parallelogram and anti-parallelogram configurations. Parallelogram mechanism may change the configuration through the dead-center position [6].

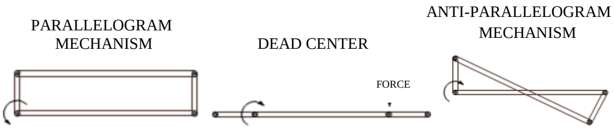


Fig. 04 Assembly mode change through the dead center

The reconfigurable mechanism comprises two parallelogram loops (Fig. 5). It has single degree-of-freedom with 2 ternary, 4 binary links and 7 joints. It has 4 alternative configurations. Thanks to this feature, the reconfigurable canopy concept is multifunctional to create closed and semi open space. Moreover, it is deployable, i.e. it can be folded into compact form and moved to another place.

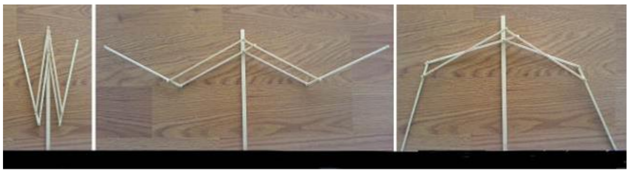


Fig. 05 Planar linkage unit in compact, open and closed form.

POSITION ANALYSIS

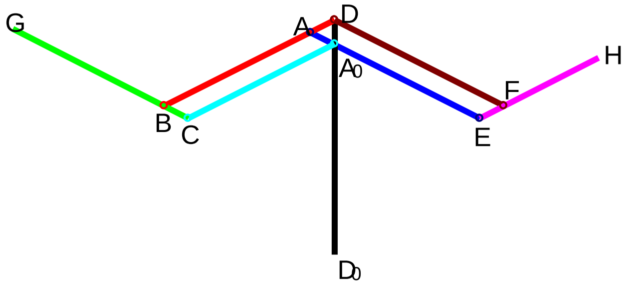


Fig. 06 Links and joints of the planar mechanism

In order to understand the kinematic analysis of this mechanism, first mobility of the system should be found. In this study, Gruebler equation is used. According to this formula,

$$M = 3(L-1) - 2j$$

where;

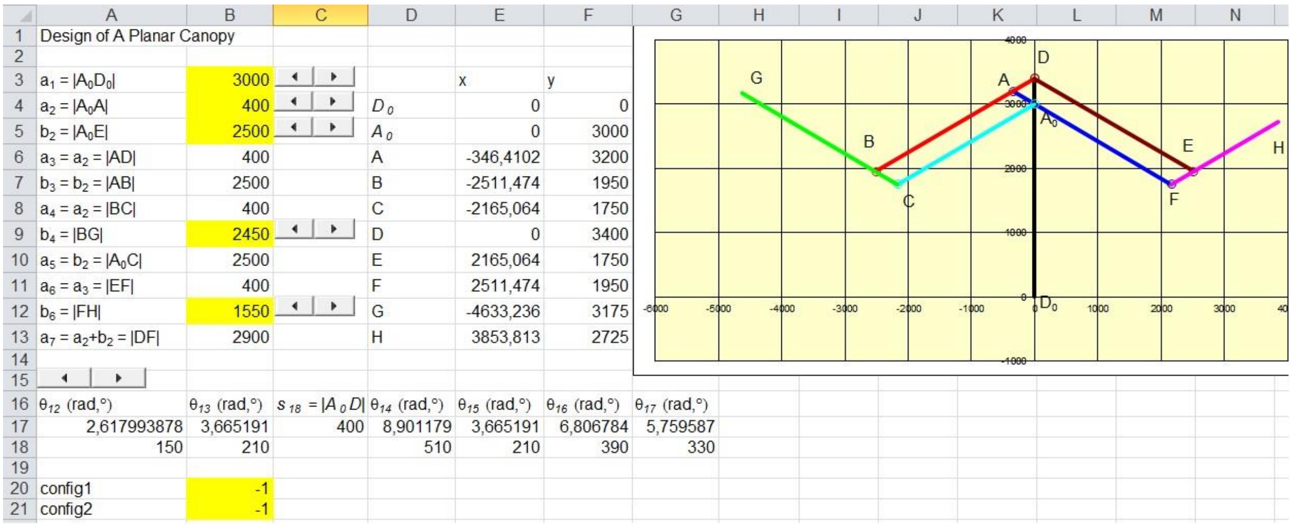
M= degree of freedom or mobility

L= number of links

j= number of joints

$$M = 3(6-1) - 2 * 7 = 1$$

We use Microsoft Excel® in order to perform the position analysis of this mechanism. The analysis is mainly based on triangulation. The link lengths can be varied in this environment and the structure can be simulated by changing input joint parameters. Fig. 7 illustrates the design environment in Excel.



	A	B	C	D	E	F	G
1	Design of A Planar Canopy						
2							
3	$a_1 = \|A_0D_0\|$	3000			x	y	
4	$a_2 = \|A_0A\|$	400		D_0	0	0	
5	$b_2 = \|A_0E\|$	2500		A_0	0	3000	
6	$a_3 = a_2 = \|AD\|$	400		A	-346,4102	3200	
7	$b_3 = b_2 = \|AB\|$	2500		B	-2511,474	1950	
8	$a_4 = a_2 = \|BC\|$	400		C	-2165,064	1750	
9	$b_4 = \|BG\|$	2450		D	0	3400	
10	$a_5 = b_2 = \|A_0C\|$	2500		E	2165,064	1750	
11	$a_6 = a_3 = \|EF\|$	400		F	2511,474	1950	
12	$b_6 = \|FH\|$	1550		G	-4633,236	3175	
13	$a_7 = a_2 + b_2 = \|DF\|$	2900		H	3853,813	2725	
14							
15							
16	θ_{12} (rad,°)	θ_{13} (rad,°)	$s_{18} = \|A_0D\|$	θ_{14} (rad,°)	θ_{15} (rad,°)	θ_{16} (rad,°)	θ_{17} (rad,°)
17	2,617993878	3,665191	400	8,901179	3,665191	6,806784	5,759587
18	150	210		510	210	390	330
19							
20	config1	-1					
21	config2	-1					

Fig. 07 The design environment in the Excel

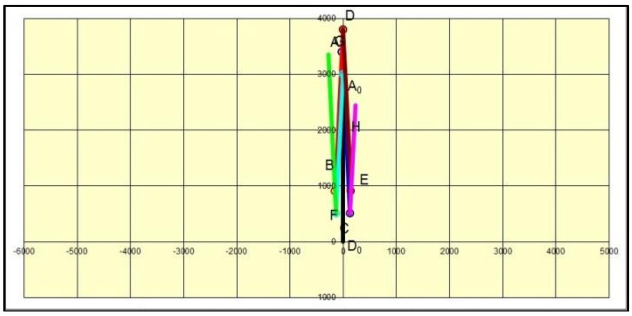


Fig. 08 Compact form

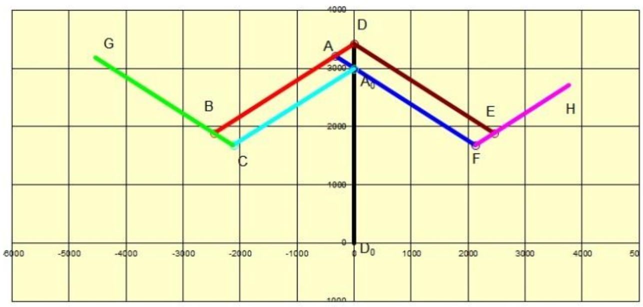


Fig. 09 Mid deployment stage

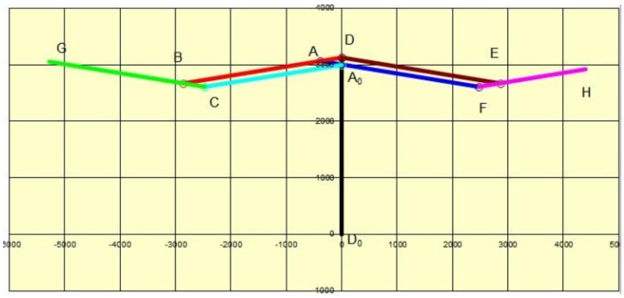


Fig. 10 Fully open form

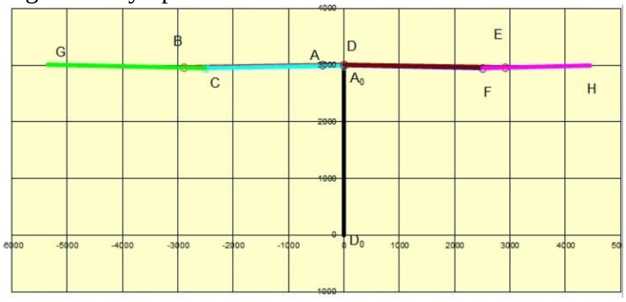


Fig. 11 Dead center

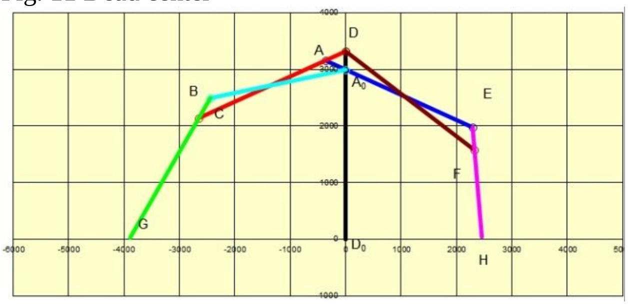


Fig. 12 Closed form

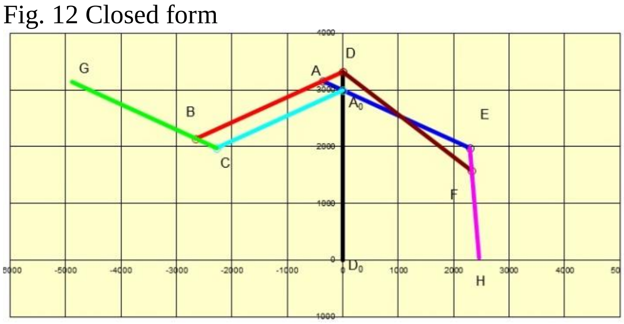


Fig. 13 Semi-open form

There are two different configurations called config 1 and config 2. If config 1 and 2 are both equal to -1, the mechanism has two parallelograms. Therefore, an open area is acquired (Figs. 8-10).

When all links become inline, the mechanism reaches the so-called dead-center position (Fig 11). At this point config 1 and 2 can be changed. If config 1 and 2 are equal to +1, the mechanism has two anti-parallelograms and closed form is obtained (Fig. 12).

If different values are used for config 1 and 2, it has parallelogram and anti-parallelogram (Fig. 13)

ASSEMBLING PLANAR LINKAGES

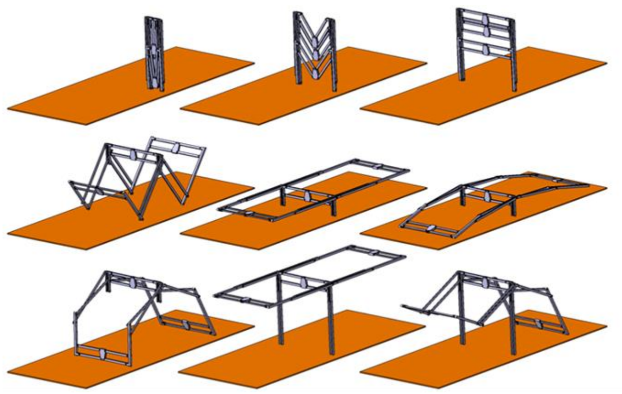


Fig. 14 Special reconfigurable mechanism.

Fig.14 illustrates an assembly of 2 planar modules. The planar reconfigurable mechanisms are positioned in parallel planes. These two planar modules are connected to each other by parallelogram loops on the perpendicular plane. The assembly constitutes a spatial module. One can use as many spatial modules as necessary to obtain wider canopies.

CONCLUSION

Reconfigurable mechanisms are used in many areas in machinery. This paper has exposed a reconfigurable deployable mechanism and proposed their use as temporary shelters. For architectural applications, another problem is the cover material which has sufficient features. A membrane covering can be tied from various points to the reconfigurable structure. Inasmuch as, there are plenty of examples of canopies which are covered with membrane. For instance Hoberman's rapidly deployable shelter is covered with a weather-proof membrane. They preferred to use a membrane because this material supplies flexibility, slightness and mobility.

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