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Reconfigurable Automation of Carton Packaging with Robotic Technology

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1. Introduction

In the highly competitive food market, a wide variety of cartons is used for packaging with attractive forms, eye-catching shapes and various structures from a logistical and a marketing point of view. These frequent changes require innovative packaging. Hence, for some complex styles like origami cartons and cartons for small batch products, most confectionery companies have to resort to using manual efforts, a more expensive process adding cost to the final products, particularly when an expensive seasonal labor supply is required. This manual operating line must go through an expensive induction and training program to teach employees how to erect a carton.

Current machines are only used for the same general style or are specifically designed for a fixed type of cartons and all new cartons require development and manufacture of new tooling for this machinery. New tooling is also required for each different pack size and format. The development and manufacture of this tooling can be very expensive and increases the manufacturer's lead time for introducing new products to market, therefore reducing the manufacturer's ability to match changes in consumer demands. Tooling changeovers, when changing production from one packaging format to another, also adds cost to the manufacturer. It is uneconomical to produce a dedicated machine for a small batch production. Hence, in this high seasonal and competitive market, manufacturer needs a dexterous and reconfigurable machine for their variety and complexity in attracting customers.

The machines are expected to reconfigure themselves to adapt to different types of cartons and to follow different instructions for various closing methods. Rapid expansion of robotics and automation technology in recent years has led to development of robots in packaging industry. Though pick and place robots were extensively used, complex tasks for erecting and closing origami-type cartons still resort to manual operations. This presents a challenge to robotics.

Some related areas with carton folding on the problem of creating 3-D sheet metal parts from sheet metal blanks by bending are explored by some researchers to provide a starting point for exploration in this field when discussing folding sequences based on their objective function, consisting of a high-level planner that determines the sequence of bends, and a number of low level planners for individual actions. deVin (de Vin *et al.,1994)* described a computer-aided process planning system to determine bending sequences for sheet-metal manufacturing. Shpitalni and Saddan (Shpitalni & Saddan., 1994) described a system to

automatically generate bending sequences. The domain-specific costs for example the number of tool changes and part reorientations were used to guide the A* search algorithm. Radin *et al.,* (Radin *et al.,* 1997) presented a two-stage algorithm. This method generates a bending sequence using collision avoidance heuristics and then searches for lower cost solutions without violating time constrains. Inui *et al.* (Inui *et al., 1987)* developed a method to plan sheet metal parts and give a bending simulation. Gupta *et al.* (Gupta *et al., 1997*) described a fully automated process planning system with a state-space search approach. Wang and Bourne (Wang & Bourne, 1997) explored a way to shape symmetry to reduce planning complexity for sheet metal layout planning, bend planning, part stacking, and assembly, the geometric constraints in carton folding parallel those in assembly planning. Wang (Wang, 1997) developed methods to unfold 3-D products into 2-D patterns, and identified unfolding bend sequences that avoided collisions with tools.

In computational biology, protein folding is one of the most important outstanding problems that fold a one-dimensional amino acid chain into a three-dimensional protein structure. Song and Amato (Song & Amato, 2001a, 2001b) introduced a new method by modeling these foldable objects as tree-like multi-link objects to apply a motion planning technique to a folding problem. This motion planning approach is based on the successful *probabilistic roadmap* (PRM) method (Kavraki *et al.,* 2001a, 2001b) which has been used to study the related problem of ligands binding (Singh *et al.,* 1999, Bayazit *et al.,* 2001). Advantages of the PRM approach are that it efficiently covers a large portion of the planning space and it also provides an effective way to incorporate and study various initial conformations, which has been of interest in drug design. Molecular dynamics simulations are the other methods (Levitt *et al*, 1983, Duan. *et al*., 1993) which tried to simulate the true dynamics of the folding process using the classic Newton's equations of motion. They provided a means to study the underlying folding mechanism, to investigate folding pathways, and provided intermediate folding states.

Rapid expansion of robotics and automation technology in recent years has led to development of robots in packaging industry. Automation of the carton folding process involves several subtasks including automatic folding sequence generation, motion planning of carton folding, and development of robotic manipulators for reconfigurability. Though pick and place robots have been extensively used, complex tasks for erecting and closing origami-type cartons still resort to manual operations. This presents a challenge to robotics.

Investigating origami naturally leads to the study of folding machinery. This evolves to folding a carton. Lu and Akella (Lu & Akella, 1999, 2000) in 1999 by exploring a fixture technique to describe carton folding based on a conventional cubical carton using a SCARA-type robot and on the similarity between carton motion sequences with robot operation sequences. This approach uses the motion planner to aid the design of minimal complexity hardware by a human designer. But the technology only focused on rectangular cartons not on origami-type cartons which include spherical close chains on vertexes. Balkcom and Mason (Balkcom & Mason, 2004, Balkcom et al., 2004) investigated closed chain folding of origami and developed a machine designed to allow a 4DOF Adept SCARA robot arm to make simple folds. However for complex cartons including multi-closed chains the flexibility and reconfigurability of this method are limited. This requires a quantitative description of a carton, its folding motion and operations. Dai (Dai & Rees Jones, 2001, 2002, 2005, Liu & Dai, 2002, 2003, Dubey &Dai, 2006) and Yao (Yao & Dai, 2008, 2010, 2011) at King's College London developed a multi-fingered robotic system for carton folding.

2. Equivalent mechanism of an origami carton

A carton is formed with crease lines and various geometric shapes of panels. Folding and manipulating a carton is a process of changing the position of panels and their relationship. Taking creases as revolute joints and cardboard panels as links, a carton can be modeled as a mechanism. The kinematic model of this equivalent mechanism provides motion of carton folding.

Carton folding starts from a flat cardboard consisting of a set of panels with creases connecting adjacent panels. All the required motions involve carton panels folding about a crease-line through an angle. There are many ways to fold the carton box into its final state, which are based on the location and orientation of the folding. For the simple cartons the manipulation can be assumed to be at one joint between adjacent boards and each joint moves to its goal configuration. The motion path and sequence can be easily calculated by the joint angles of the carton. Folding sequence can be checked by following steps, including checking the reduced graph, which is checking the equivalent mechanism structures of cartons, to see if they are symmetric or have any other geometric characteristics; identifying independent branches which result in independent operations; searching folding layers in turn; and manipulating from the layer which is closest to the base, from the symmetric panels and from the node which is present in the shortest branch.

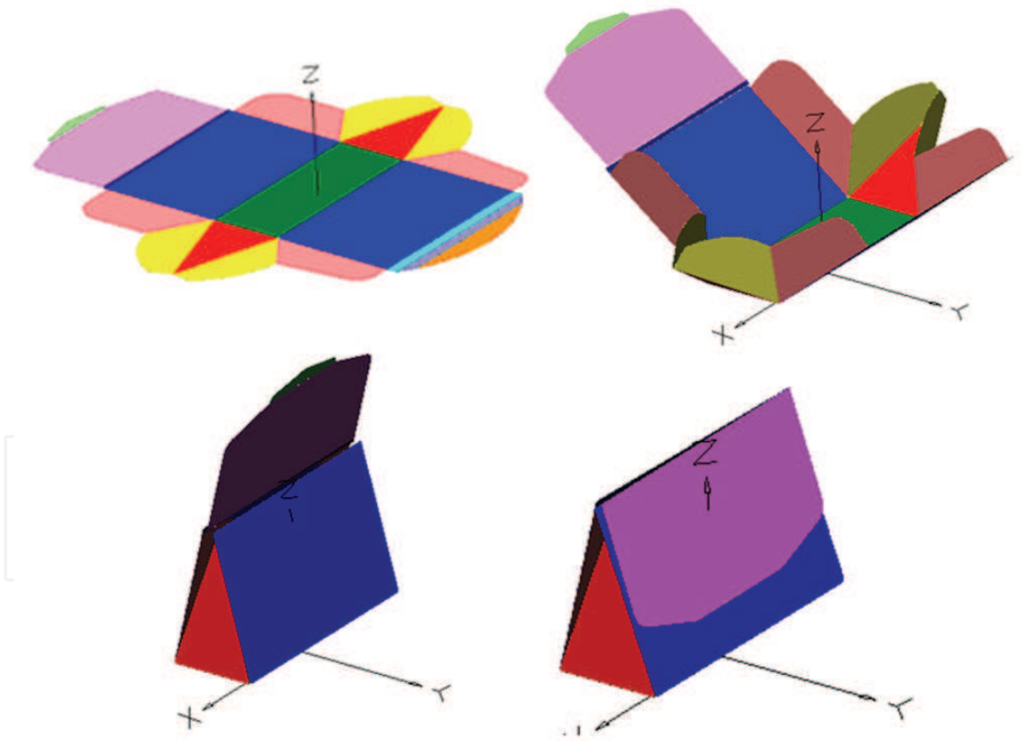


Fig. 1. A Carton Folding Sequence for an Origami Carton

During the process of the Origami carton folding the guiding joint can be identified. Four closed loops with four folding sub-mechanisms are found. For the sub-mechanism of a guiding joint, the mechanism can be described as a 5-Bar mechanism that the panels are described linkage and the creases are revolute joints. It is means that the reaction forces at

the joint of the box paper do not produce unexpected deformation. Five revolute joints axes that intersect in the point that is the intersection of the creases define the spherical linkage and their movement is defined.

Figure 2 gives a half-erected origami carton which consists of four sections at vertexes located at four corners of the carton labeled as O_1, O_2, O_3, and O_4Folding manipulation of the carton is dominated by these sections. The rectangular base of the carton is fixed on the ground. Four creases along the rectangular base are given by four vectors $\boldsymbol{b_1}$, $\boldsymbol{b_2}$, $\boldsymbol{b_3}$ and $\boldsymbol{b_4}$ Four centrally movable creases are given as $\boldsymbol{s}$, $\boldsymbol{s''}$, $\boldsymbol{s''}$ and $\boldsymbol{s'''}$ each of which is active in a gusset corner. The carton is symmetric along line AA′.

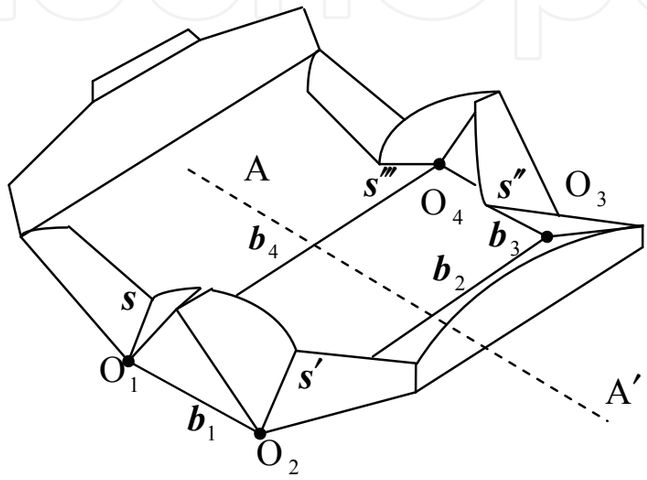


Fig. 2. A half-erected origami

Thus an equivalent mechanism is modeled in figure 3.4. The five bar mechanism's centres are located at four corners of the carton base O_1, O_2, O_3, and O_4.From the equivalent mechanism and folding process, the five-bar spherical mechanism can determine the configuration of the carton.

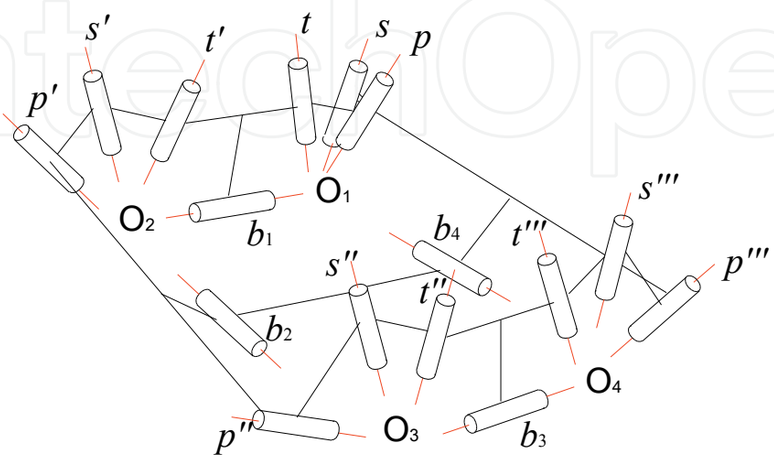


Fig. 3. The equivalent mechanism of the base of a double wall tray

One of the corners located at O_1 formed one spherical mechanism. When its folding joint ***s*** moves and controls the configuration of the mechanism and drives joints ***t***, and ***p***. When the two joints attached the mobility of the mechanism reduces from 2 to 1 and the mechanism gets its singularity. The joint ***s*** is active and called control joint. During the manually folding of this origami carton human fingers attaches the control joints and drives them into goal positions.

3.Geometry analysis of the mechanism

The geometric arrangement is defined in figure 4.

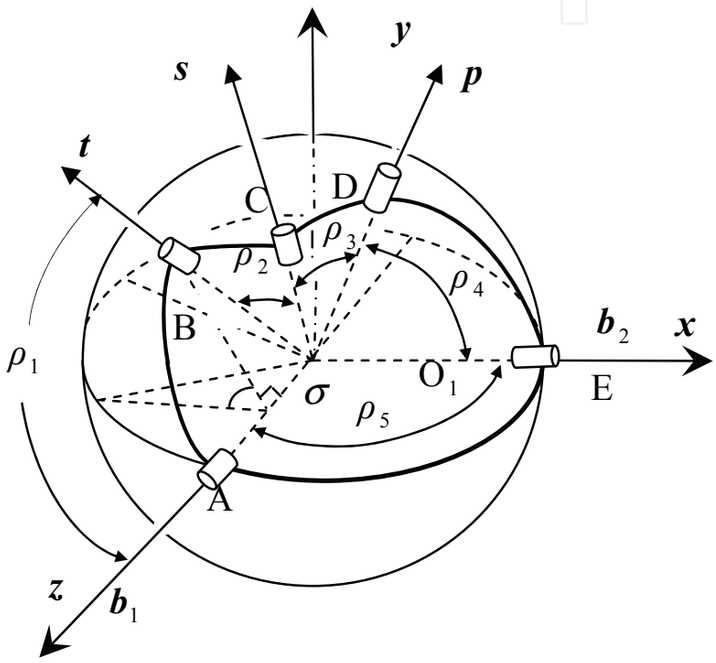


Fig. 4. Geometry of spherical five-bar mechanism

Among joint axes ***t, s, p*** and fixed axes $\boldsymbol{b_1}$ and $\boldsymbol{b_2}$ configuration control vector ***s*** provides the guiding joint axis that controls the carton section configuration. The spherical links between joint axes are labeled as AB, BC, CD, DE, and EA. Since angles $\boldsymbol{\rho_i}$ between revolute joints are constant throughout the movement of the linkage, the coordinates of the joint axes ***t, s,*** and ***p*** can be obtained by matrix operation from original joint axis $\boldsymbol{b_1}$ which is a unit vector. This relationship of the axes can be given in terms of geometric constraints as,

$$\rho_1 = \arccos(\boldsymbol{b} \cdot \boldsymbol{t})$$

$$\rho_2 = \arccos(\boldsymbol{t} \cdot \boldsymbol{s})$$

$$\rho_3 = \arccos(\boldsymbol{s} \cdot \boldsymbol{p})$$

$$\rho_4 = \arccos(\boldsymbol{p} \cdot \boldsymbol{d})$$

$$\rho_5 = \arccos(\boldsymbol{d} \cdot \boldsymbol{b}) \tag{1}$$

Further, the configuration control vector $\boldsymbol{s}$ can be determined as,

$$\begin{aligned} s &= \mathrm{R}(-^1\boldsymbol{y}, 90^0 + \phi)\mathrm{R}(-^1\boldsymbol{x}', \xi)\boldsymbol{b}_1 = \\ &= \begin{bmatrix} \mathrm{c}(90^0+\phi & 0 & -\mathrm{s}(90^0+\phi) \\ 0 & 1 & 0 \\ \mathrm{s}(90^0+\phi) & 0 & \mathrm{c}(90^0+\phi) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \mathrm{c}\xi & \mathrm{s}\xi \\ 0 & -\mathrm{s}\xi & \mathrm{c}\xi \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} -\mathrm{c}\phi\,\mathrm{c}\xi \\ \mathrm{s}\xi \\ -\mathrm{s}\phi\,\mathrm{c}\xi \end{bmatrix} \end{aligned} \tag{2}$$

The side elevation vector $\boldsymbol{t}$ is given as,

$$\begin{aligned} \boldsymbol{t} &= \mathrm{R}(-^1z, \sigma)\mathrm{R}(-^1\boldsymbol{y}', \rho_1)\boldsymbol{b}_1 = \\ &= \begin{bmatrix} \mathrm{c}\sigma & \mathrm{s}\sigma & 0 \\ -\mathrm{s}\sigma & \mathrm{c}\sigma & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathrm{c}\rho_1 & 0 & -\mathrm{s}\rho_1 \\ 0 & 1 & 0 \\ \mathrm{s}\rho_1 & 0 & \mathrm{c}\rho_1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} -\mathrm{c}\sigma\mathrm{s}\rho_1 \\ \mathrm{s}\sigma\mathrm{s}\rho_1 \\ \mathrm{c}\rho_1 \end{bmatrix} \end{aligned} \tag{3}$$

Further the geometric constraint gives,

$$\boldsymbol{t} \cdot \boldsymbol{s} = \mathrm{c}\,\rho_2 \tag{4}$$

Substituting $\boldsymbol{t}$ of equation (2) and $\boldsymbol{s}$ of equation (3) into above yields

$$\mathrm{c}\,\rho_2 = c\phi\ c\xi\ c\sigma\ s\rho_1 + s\xi\ s\sigma\ s\rho_1 - s\phi\ c\rho_1\ c\xi \tag{5}$$

Collecting the same terms with $\mathrm{c}\sigma$ and $\mathrm{s}\sigma$, the above equation can be rewritten as,

$$A(\phi,\xi)\,\mathrm{c}\sigma + B(\phi,\xi)\,\mathrm{s}\sigma - C(\phi,\xi) = 0, \tag{6}$$

Where

$$\begin{aligned} A(\phi,\xi) &= s\rho_1\ c\xi\ \mathrm{c}\phi, \\ B(\phi,\xi) &= s\xi\ s\rho_1, \\ C(\phi,\xi) &= -s\phi\ c\rho_1\ c\xi - \mathrm{c}\,\rho_2. \end{aligned} \tag{7}$$

The side elevation angle σ varying with the transmission angles ϕ and ξ can hence be given:

$$\sigma(\phi,\xi) = \tan^{-1}\left(\frac{A}{B}\right) \pm \cos^{-1}\left(\frac{C}{\sqrt{A^2+B^2}}\right) \tag{8}$$

Further, the main elevation vector $\boldsymbol{p}$ can be obtain as,

$$\boldsymbol{p} = \mathrm{R}(^1\boldsymbol{y}, \rho_5)\mathrm{R}(^1\boldsymbol{z}', \varsigma)\mathrm{R}(^1\boldsymbol{y}', \rho_4)\boldsymbol{b}_1 \tag{9}$$

Hence,

$$\boldsymbol{p}=\begin{bmatrix} \mathrm{c}\rho_5 & 0 & \mathrm{s}\rho_5 \\ 0 & 1 & 0 \\ -\mathrm{s}\rho_5 & 0 & \mathrm{c}\rho_5 \end{bmatrix}\begin{bmatrix} \mathrm{c}\varsigma & -\mathrm{s}\varsigma & 0 \\ \mathrm{s}\varsigma & \mathrm{c}\varsigma & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \mathrm{c}\rho_4 & 0 & \mathrm{s}\rho_4 \\ 0 & 1 & 0 \\ -\mathrm{s}\rho_4 & 0 & \mathrm{c}\rho_4 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{10}$$

Since $\rho_4 = \rho_5 = \pi / 2$, the above becomes,

$$\boldsymbol{p}=\begin{bmatrix} 0 \\ \mathrm{s}\varsigma \\ -\mathrm{c}\varsigma \end{bmatrix} \tag{11}$$

Substituting $\boldsymbol{p}$ of equation (4.15) and $\boldsymbol{s}$ of equation (4.6) into equation (4.3) gives,

$$\mathrm{c}\,\rho_3 = \mathrm{c}\varsigma\ \mathrm{s}\phi\ \mathrm{c}\xi + \mathrm{s}\varsigma\ \mathrm{s}\xi \tag{12}$$

Assembling the same terms of $\mathrm{c}\varsigma$ and $\mathrm{s}\varsigma$, the above can be rearranged as,

$$D(\sigma,\xi)\,\mathrm{c}\varsigma + E(\sigma,\xi)\,\mathrm{s}\varsigma + F = 0 \tag{13}$$

Where,

$$\begin{aligned} D(\sigma,\xi) &= \mathrm{s}\phi\ \mathrm{c}\xi \\ E(\sigma,\xi) &= \mathrm{s}\xi \\ F &= -\mathrm{c}\,\rho_3 \end{aligned} \tag{14}$$

The main elevation angle ς varying with the transmission angles ϕ and ξ can hence be obtained,

$$\varsigma(\phi,\xi) = \tan^{-1}(\frac{D}{E}) \pm \cos^{-1}(\frac{F}{\sqrt{D^2+E^2}}) \tag{15}$$

The control vector $\boldsymbol{s}$ also can be gotten from the transformation:

$$s = \boldsymbol{R}({}^1z',\sigma)\boldsymbol{R}({}^1y',\rho_1)\boldsymbol{R}({}^1z',\mu)\boldsymbol{R}({}^1y',\rho_2)b_1 \tag{16}$$

The vector can be expressed,

$$s=\begin{bmatrix} -\mathrm{c}\rho_1\mathrm{s}\rho_2\mathrm{c}\mu\mathrm{c}\sigma - \mathrm{c}\rho_2\mathrm{s}\rho_1\mathrm{c}\sigma + \mathrm{s}\sigma\mathrm{s}\mu\mathrm{s}\rho_2 \\ -\mathrm{s}\sigma\mathrm{s}\mu\mathrm{s}\rho_2 + \mathrm{c}\sigma\mathrm{s}\mu\mathrm{s}\rho_2 \\ -\mathrm{s}\rho_2\mathrm{s}\rho_2\mathrm{c}\mu + \mathrm{c}\rho_2\mathrm{c}\rho_1 \end{bmatrix} \tag{17}$$

Two columns are equal and can be easily got,

$$\mathrm{c}\mu = \frac{\mathrm{c}\rho_3\mathrm{c}\varsigma - \mathrm{c}\rho_2\mathrm{c}\rho_1}{\mathrm{s}\rho_2^2} \tag{18}$$

$$\mu(\sigma,\varsigma)=\arccos\frac{\mathrm{c}\rho_3\mathrm{c}\varsigma - \mathrm{c}\rho_2\mathrm{c}\rho_1}{\mathrm{s}\rho_2^2} \tag{19}$$

Hence, the elevation angles are related to the transmission angles that control the configuration vector ***s***. Both sets of angles feature the carton configuration. The following Figure 5 shows the end-point trajectories of four configuration control vector.

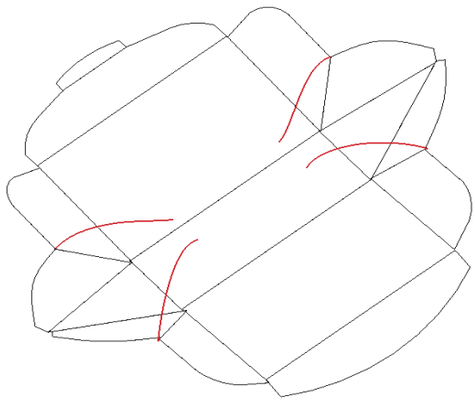


Fig. 5. End-point trajectories of four configuration control vectors

4. Velocity-control formulation of the single-vertex on the origami carton

The kinematic representation of the spherical mechanism is showed an above figure which is in the Cartesian space

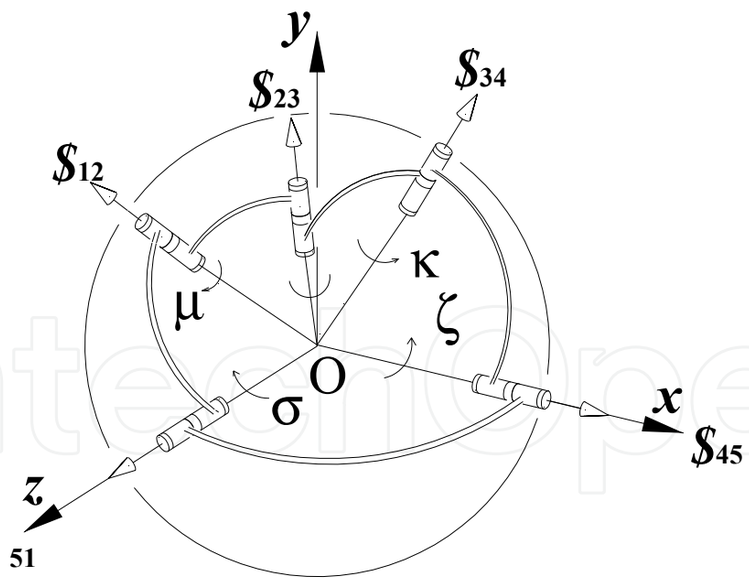


Fig. 6. Screw of the spherical five-bar mechanism

Since the system is spherical the fixed point o can be selected as represent point and the system only have 3 rotation parts in Plücker coordinates the infinitesimal screw are given by, $\$_{51} = (0,0,1;\vec{0})$, $\$_{12} = (-c\sigma s\rho_1, s\sigma s\rho_1, c\rho_1;\vec{0})$, $\$_{45} = (1,0,0;\vec{0})$, $\$_{34} = (0, s\varsigma, -c\varsigma;\vec{0})$, $\$_{23} = (\vec{s};\vec{0})$. $\$_{23} = (\vec{s};\vec{0})$.

Where, ***s*** is control vector that got from last section
Assume that a velocity of control vector ***v*** is,

$$\boldsymbol{v} = \dot{\varsigma}\$_{45} + \dot{\kappa}\$_{34} = \dot{\sigma}\$_{15} + \dot{\mu}\$_{21} + \omega_s\$_{32} \tag{20}$$

Thus after canceling the dual parts of the infinitesimal screw the joint speeds can be computed as,

$$\begin{bmatrix} -\$_{34} & \$_{21} & \$_{32} \end{bmatrix} \begin{bmatrix} \dot{\kappa} \\ \dot{\mu} \\ \omega_s \end{bmatrix} = -\dot{\varsigma}\$_{45} + \dot{\sigma}\$_{15} \tag{21}$$

With the application of Cramer's rule,

$$\dot{\kappa} = \frac{\left| -\dot{\varsigma}\boldsymbol{b}_2 + \dot{\sigma}\boldsymbol{b}_1 \;\; \boldsymbol{t} \;\; \boldsymbol{p} \right|}{\left| \boldsymbol{t} \;\; \boldsymbol{p} \;\; \boldsymbol{s} \right|} \tag{22}$$

For the coefficients can be gotten,

$$\begin{aligned} G_1 = & \frac{-s\kappa s\varsigma + s\rho_3 c\kappa c\varsigma + s\varsigma}{c\sigma c\varsigma s\rho_1 s\kappa s\rho_3 c\rho_3 - c\sigma c\varsigma s\rho_1 c\kappa s\varsigma} \\ & -s\kappa s\varsigma + s\rho_3 c\kappa c\varsigma + s\varsigma c\rho_1 - s\varsigma c\varsigma s\rho_1 \end{aligned} \tag{23}$$

then,

$$\begin{aligned} G_2 = & \frac{c\kappa c\varsigma s\varsigma - s\rho_3 s\kappa c\varsigma c\rho_3 + s\varsigma c\varsigma c\rho_3}{c\sigma c\varsigma s\rho_1 s\kappa s\rho_3 c\rho_3 - c\sigma c\varsigma s\rho_1 c\kappa s\varsigma} \\ & -s\kappa s\varsigma + s\rho_3 c\kappa c\varsigma + s\varsigma c\rho_1 - s\varsigma c\varsigma s\rho_1 \end{aligned} \tag{24}$$

So, the velocity of the control joint ***s*** can be obtained,

$$\boldsymbol{v} = \dot{\varsigma}\boldsymbol{b}_2 + \dot{\varsigma} G_1 + \dot{\sigma} G_2 \tag{25}$$

Where,

$$\omega_s \begin{bmatrix} s\kappa s\varsigma - s\rho_3 c\kappa c\varsigma \\ c\kappa s\varsigma - s\rho_3 s\kappa c\rho_3 \\ -c\rho_3 c\varsigma \end{bmatrix} = \begin{bmatrix} -c\sigma s\rho_1 & 1 & 0 & 0 \\ s\sigma s\rho_1 & 0 & 0 & s\varsigma \\ c\rho_1 & 0 & 1 & -c\varsigma \end{bmatrix} \begin{bmatrix} \omega_t \\ \omega_{b_1} \\ \omega_{b_2} \\ \omega_p \end{bmatrix} \tag{26}$$

where, the matrix $\begin{bmatrix} -c\sigma s\rho_1 & 1 & 0 & 0 \\ s\sigma s\rho_1 & 0 & 0 & s\varsigma \\ c\rho_1 & 0 & 1 & -c\varsigma \end{bmatrix}$ is the Jacobean matrix for the control of the system.

5. Simulation of automatically folding origami carton using a multi-fingered robotic system

The robot has been designed based on the analysis of common motion and manipulation, which has four fingers in the following figure 7, two with three degrees of freedom noted finger 1 and finger 2, and two noted with finger 3 and finger4 with two degrees of freedom each. These fingers design are able to offer required folding trajectories by changing the control programs of the fingers' motors. Two horizontal jaws are arranged with the pushing direction parallel to the fingers' horizontal tracks. The joints of the fingers are actuated directly by motors and the whole system requires 14 controlled axes. This design is considered specifically based on providing high degree of reconfigurability with minimum number of motors to be controlled.

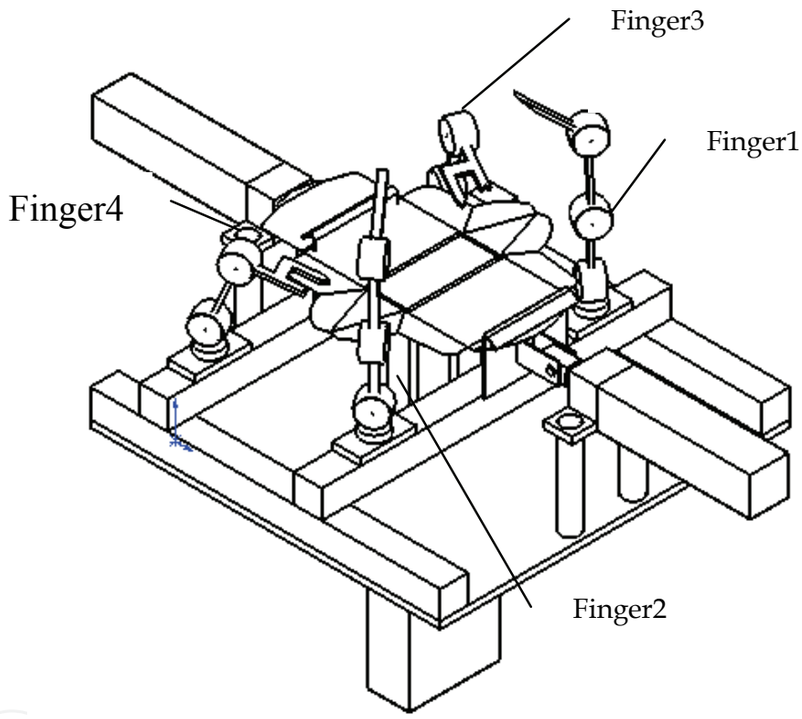


Fig. 7. A Multi-fingered robot for origami carton folding

To determine the control setting and speeds of the actuated joints for the multi-finger robotic system when fingertips are in special location and twists the *Jacobian* [**J**] need to be identified as.

$$[\$_s] = [J][\omega_i] \tag{27}$$

For corner1 which located in O_1 in configuration space the main parts of the screw is shown in equation 25.

Expanding to the four fingers robotic system, each finger related one Conner manipulation which their velocities is got from four five bar's control joints twist.

While ,

$$\begin{bmatrix} \nu_1 & \nu_2 & \nu_3 & \nu_4 \end{bmatrix} \tag{28}$$

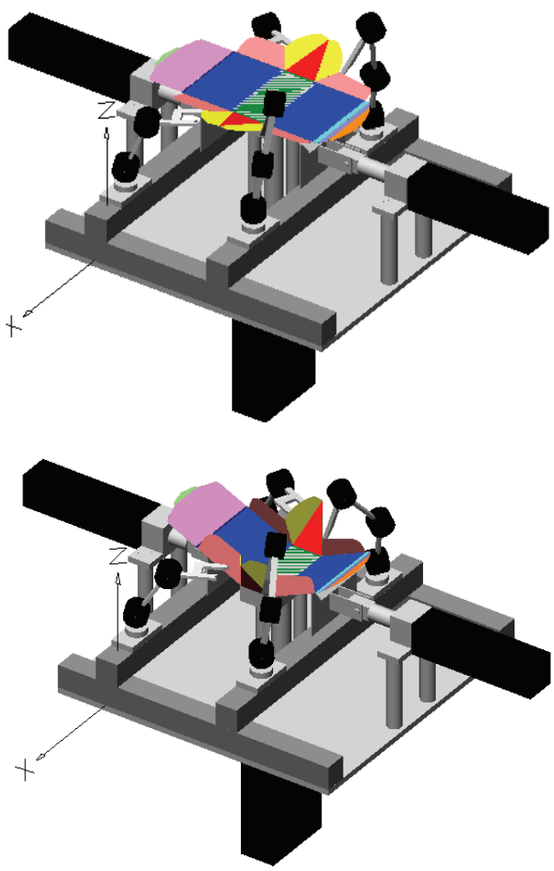
Then the Jacobean matrix of the robotic system is determined as $\left[\$_{ij}\right]$, where i for finger's number and j for motors number.

$$\left[\omega_{ij}\right] = [J]^{-1}[\nu_i] \tag{29}$$

Then every motor's speeds and control can be set.

The whole folding process can be simulated by the multi-fingered robotic system in the following figure 8.

This methodology of multi-robotic manipulations using configuration space transformation in interactive configuration space is the theoretical base for the further development of multi-finger reconfigurable systems. This test rig has given experimental knowledge and information for further reconfigurable systems in packaging industry. In this robotic system, all motors of the robotic fingers and the two horizontal jaws are controlled by a computer. For different types of cartons, the system just need be changed the programs based on their folding trajectories without readjusting the hardwires of the system.



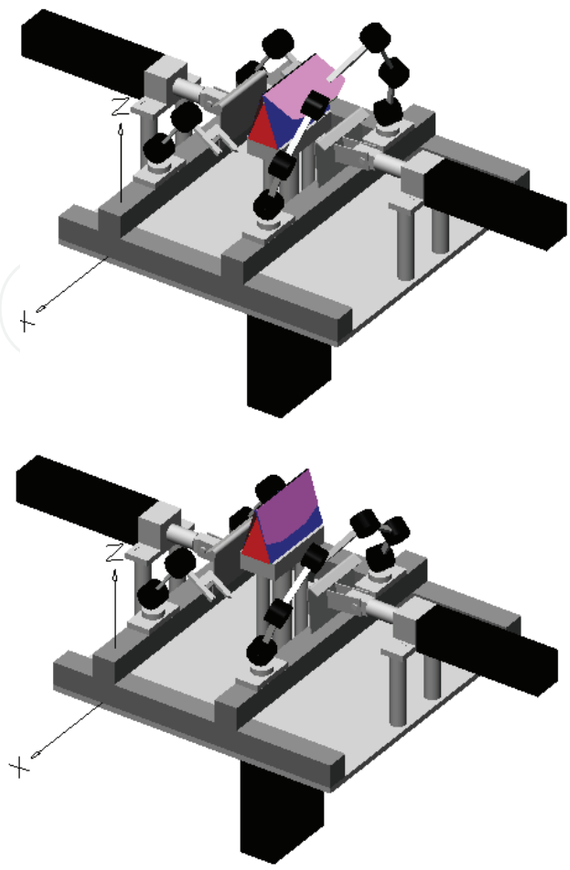


Fig. 8. Simulation of a multi-fingered manipulation on an origami carton

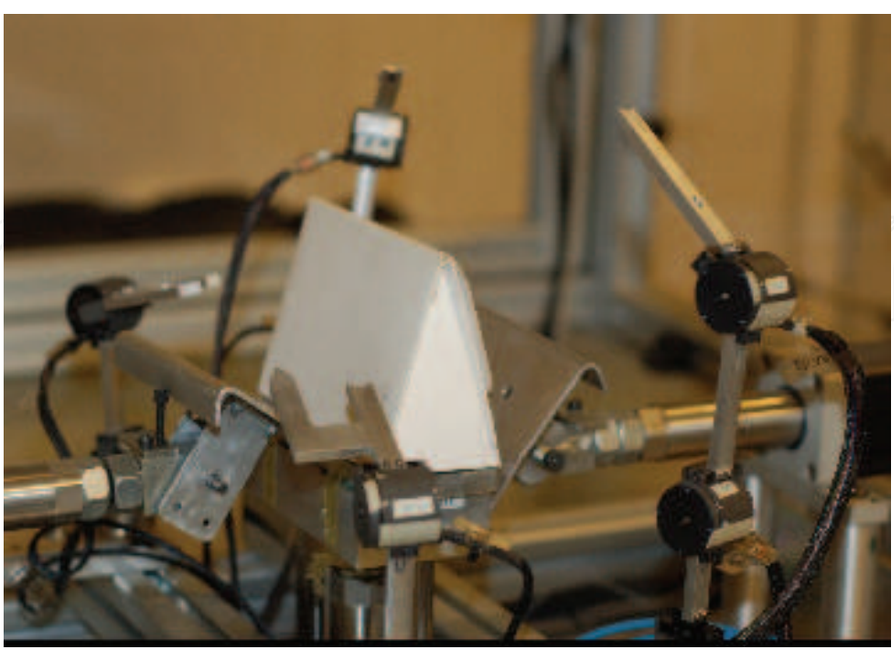


Fig. 9. A multi-fingered robotic system

6. Conclusion

This paper has presented new approaches to carton modelling and carton folding analysis. By investigating carton examples, with an analysis of the equivalent mechanism, the gusset vertexes of the cartons - being a common structure of cartons - were extracted and analyzed based on their equivalent spherical linkages and were identified as guiding linkages that determine folding.

A reconfigurable robotic system was designed based on the algorithms for multi-fingered manipulation and the principle of reconfigurability was demonstrated. The simulation results for the folding of an origami carton were given to prove the theory of the multi-fingered manipulation strategy and the concept of reconfigurable robotic systems. Test rigs were developed to demonstrate the principles of the reconfigurable packaging technology.

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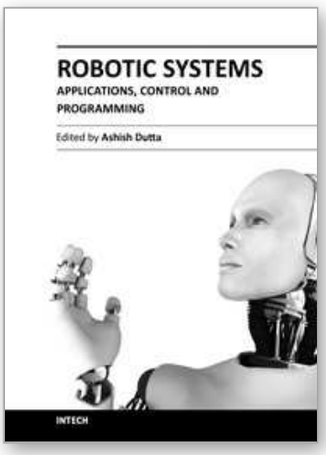
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This book brings together some of the latest research in robot applications, control, modeling, sensors and algorithms. Consisting of three main sections, the first section of the book has a focus on robotic surgery, rehabilitation, self-assembly, while the second section offers an insight into the area of control with discussions on exoskeleton control and robot learning among others. The third section is on vision and ultrasonic sensors which is followed by a series of chapters which include a focus on the programming of intelligent service robots and systems adaptations.

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