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Applied Mathematical Modelling 32 (2008) 1017–1026

APPLIED MATHEMATICAL MODELLING

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# Sequence trajectory generation for garment handling systems

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Received 1 March 2005; received in revised form 1 February 2007; accepted 28 February 2007

## Abstract

This paper presents a novel generic approach to the planning strategy of garment handling systems. An assumption is proposed to separate the components of such systems into a component for intelligent gripper techniques and a component for handling planning strategies. Researchers can concentrate on one of the two components first, then merge the two problems together. An algorithm is addressed to generate the trajectory position and a clothes handling sequence of clothes partitions, which are outlined by garment folding creases. The trajectory positions are derived using configuration transformations. The handling sequence is calculated based on the analysis of the adjacency matrix of the graph description of the garment. A case study of the handling procedure of a female shirt is explained through the paper.

*Keywords:* Trajectory estimation; Textile material manipulation; Configuration transformation

## 1. Introduction

Automatic handling systems that can be reprogrammed to perform a different task in relation to rigid objects are readily available [1]. However, the use of robotics for automatic handling of textile materials brings serious difficulties for automation as their shape, position, orientation and other physical and mechanical properties can vary in unpredictable ways; depending on the dynamics of the material and the environmental conditions [2,3]. Moreover, the unique characteristics of floppy material and the complex interaction between the material properties and handling devices can make automated processes become inefficient if the processes are unable to adjust systematically to the changes of properties of the materials to be handled [4]. Therefore, intelligent control of handling textile material is indispensable if the handling system is to be effective. Intelligent control relies on a knowledge base and a suitable reasoning procedure for arriving at a control decision, which will in turn initiate a corresponding control action [5,6]. Intelligent control of handling limp materials involves multidisplinary knowledge and requires extensive study. There are several active research areas for the automated manipulation of a highly flexible and complex material such as cloth:

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doi:10.1016/j.apm.2007.02.026

(1) Sensing techniques.
(2) Handling mechanism performance.
(3) Material properties relevant for automated handling.
(4) Modelling and prediction of the interaction between material properties and handling devices.
(5) Intelligent planning strategy.

As to item 1, studies are active on applying vision and touch sensing techniques to textile material handling [7–9]. Sensing technology such as characteristic variable measurement, image processing, and discrimination play an important role in studies on intelligent handling systems. In Paraschidis' clothes folding system, vision sensing was used for the identification of the edge of the perimeter of a garment and for the identification of the folding edge [7]. Ono et al. [8] attempted to increase the effectiveness of a cooperative sensing of touch and vision for handling flexible and limp materials.

As to item 2, a variety of devices for handling cloth have been developed and invented [10,11] and gripping techniques for automatic cloth assembly such as robot hands is a popular topic [7,8,12]. Taylor comments on the nature of problems in developing a grasp system for handling cloth and provides a good reference in basic mechanisms in this field [13].

As to item 3, material properties relevant to automated handling are essential to optimise handling performance. Taylor and Pollet contributed their efforts to this area [14,15]. They investigated fabric low-force properties for fabric handling.

As to item 4, attempts have been made to theoretically analyse the relationship between material properties being handled and handling devices [16,17]. These attempts provided a fundamental understanding for the first step of grasping flexible materials by a robotic pinch gripper. An intelligent grasping system can systemically adjust grasping force based on these studies to adapt to the properties of the material to be grasped. Moreover, many computer simulation tools have been developed that allows modeling of fabric draping that occur during manufacturing. Fabric parts are modeled as very flexible elastic surfaces that can accommodate stretching, bending, and shear. The governing equilibrium equations are solved using either the finite element method or a particle system approach [18–21]. However, computational cost of the art of the state is too expensive to meet real-time requirement of packaging systems, which requires that feasible approaches have to be develop to balance computational cost and modelling precision.

However, intelligent planning strategies for textile material handling are scarce in the literature. Our interest is to develop an intelligent planning strategy for garment handling systems. Though not much literature exists in garment manipulation, similar concepts can be found in the sequence problems of handling other material such as carton folding, sheet metal bending and even protein folding. A computer-aided process planning (CAPP) [22] was used based on a tolerance tree to generate bending sequences. Gupta and Guo [23] proposed an automated robotic system for planning and executing bending on sheet metal blanks. There is also a need to generate a sound and straightforward algorithm based on the intricate geometry properties of a carton to generate a trajectory in carton packaging. Liu and Dai [24,6] proposed a generic approach to carton-folding applications. One of the main characteristics of garment handling is symmetry, which could lead to simplification of the design of handling mechanisms. The aims of this study are to investigate and understand the handling characteristics of a garment, to derive a generic handling sequence in order to reduce the design complexity of an intelligent gripper.

Two major issues of the handling problem of textile materials are handling mechanisms, e.g., robotic grippers, and planning strategies, e.g., handling sequences [25–27]. It is too difficult to solve the two issues at the same time so that we make an assumption to separate them. The assumption is that a handled part of materials retains a virtual plane during materials operation. This assumption meets both development requirements of handling mechanisms and planning strategies. Handling systems have to keep the handled material, e.g., clothes partitions, in a virtual plane as the systems can avoid their shape and posture vary in such predictable ways as dynamics of the materials, and the output of previous handling. It also is one of the design requirements for handling mechanisms, e.g., an intelligent gripper.

The paper is organised as follows; Section 2 derives a generic representation of a clothes based on the standards of clothes industries so that a variety of clothes can be mathematically described. Section 3 presents the analysis of clothes handling operation. Finally conclusions are presented.

## 2. Generic representation of clothes

There has been huge growing trend of producing as many varieties of clothes as possible in both quantity and quality to meet the need of the consumer market. Generally speaking, clothes are classified into several major types such as mens' suits, women's trousers, women's shirts, childrens' coats, etc. Though each type of garment has different fashion styles, for both convenience of clothes manufacturing and the market, it can be denoted and selected by industrial standards such as size intervals. In order to generate a handling sequence of clothes, a generic clothes description has to be developed to bridge the gap between the clothes manufacturing industry and clothes handling. Such a mathematical description is an urgent requirement to improve the efficiency of the clothes industry.

The development of a generic garment model has been inspired by a garment lifecycle, which can be described as a closed loop: textile manufacturing, garment design, garment manufacturing, marketing, customers and recycle or reuse. Due to the fact that the garment handling concerned herein is an internal link between clothes manufacturing and marketing. It is a natural starting point to build a generic garment models based on the standards of clothes design and manufacturing industries. Fig. 1 provides the example of a female

Fig. 1. A unfolded and folded female shirt.

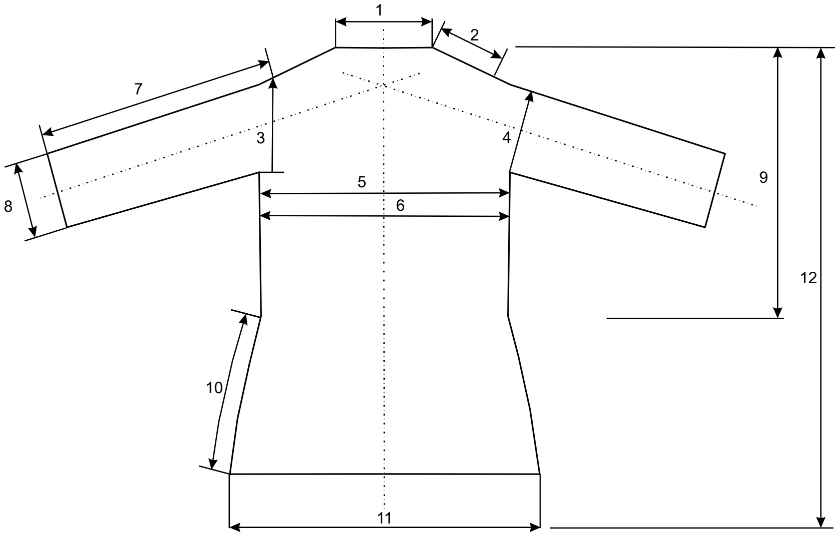

Fig. 2. A diagram for the example in Fig. 1.

Table 1
Manufacturing parameters of a female shirt shown in Fig. 1 (Metric size chart, cm)

| | *Size*($i$) | 38 | 40 | 42 | 44 | 46 |
|---|---|---|---|---|---|---|
| | *To fit*($j$) | 10 | 12 | 14 | 16 | 18 |
| 1 | *Neck girth* (*ng*) | 37 | 37.6 | 38.2 | 39.4 | 40.6 |
| 2 | *Should length* (*sl*) | 12 | 12.5 | 13 | 13.6 | 14.2 |
| 3 | *Armhole circumference* (*ac*) | 41 | 42 | 43 | 44.5 | 46 |
| 4 | *Upper arm girth* (*ua*) | 33 | 34.2 | 35.5 | 37 | 38 |
| 5 | *Across back* (*ab*) | 34.5 | 35.5 | 37 | 38 | 39.5 |
| 6 | *Across chest* (*ah*) | 34.5 | 35.5 | 36.5 | 37.5 | 38.5 |
| 7 | *Sleeve length* (*ll*) | 57.2 | 57.2 | 58.4 | 59 | 59.7 |
| 8 | *Wrist* (*wr*) | 18.5 | 19 | 19.5 | 20.5 | 21 |
| 9 | *Nape to waist* (*nw*) | 40 | 40.5 | 41.2 | 41.8 | 42.5 |
| 10 | *Body rise from waist* (*bw*) | 27.5 | 28 | 28.5 | 29 | 29.5 |
| 11 | *Hem circumference* (*hc*) | 92 | 97 | 102 | 107 | 112 |
| 12 | *full length* (*fl*) | 79 | 79.5 | 80.2 | 80.8 | 81.5 |

shirt in both flat and folded situations. The design model and corresponding manufacturing parameters of the shirt are shown in Fig. 2 and Table 1.

A study of Fig. 2 and Table 1 clearly indicates that the geometric model of each type of garment can be extracted and described by its metric size chart, which includes its own sizing and size intervals. Consequently the general length of a garment $\mathbf{r}_s^d$ is introduced in Eq. (1) to mathematically describe a garment's dimensions

$$\mathbf{r}_s^d = \mathbf{r}_b + \Delta\mathbf{r}, \tag{1}$$

where $d$ denotes an identity constant, which is used to identify a garment in both clothes manufacturing and marketing, herein parameter $d$ is replaced by a barcode. $s$ denotes the size of a garment, parameter $s$ also helps to search the size interval, $\mathbf{r}_b$ is the base vector of the garment's dimensions, size 38 is defined as the base vector in this paper. $\Delta\mathbf{r}$ is a size interval vector. For example, the shirt shown in Fig. 1 is size 38, based on which the representation of size 42 can be given as $\mathbf{r}_{42}^d = \mathbf{r}_{38} + \Delta\mathbf{r}$. The description of the representation is naturally adopted from the standards of both the clothes design industry and marketing. Not only does such a representation of clothes fit into the clothes lifecycle very well, but it also provides a solid basis for clothes-parameter representation for developing intelligent clothes handling systems.

## 3. Analysis of garment handling motion

In accordance with the assumption of a virtual plane of each partition of a garment, which is decomposed by its folding creases. A virtual plane is further simplified as a position of the plane and its relation to its base garment partition in three dimension. Consequently the connection between gripper techniques and handling sequences are the trajectory positions of the virtual planes. That is to say, the aim of a garment-handling gripper design has to meet the fact that the gripper must keep each partition of a garment within a virtual plane as much as it can, its handling positions can be fixed by those which are relevant to the 3D trajectories, which are generated from a garment planning strategy. In other words, the garment handling task can be viewed as that of articulated objects, each of which is a rigid plane. Hence the handling motion can be described as the combination of position trajectories and their operational sequence.

### *3.1. Motion trajectory formulation*

Each partition, modelled as a virtual plane, of a garment is mathematically denoted by a linear vector and its relation to its base, which is randomly defined from all partitions. The center partition is usually selected as a base partition since it is fixed during handling procedure. It indicates that only a linear vector $pq$ of the $s$th partition $\mathbf{G}^s$ needs to be defined, because the geometric center of its base defaults to the origin of the Cartesian coordinates. The linear vector $pq$ is described at its $j$th time instant as

$$
\begin{aligned}
G_j^s = {}^s\mathbf{H}_{i,j}(\mathbf{p}_i - \mathbf{q}_i) = {}^s\mathbf{h}^p_{i,j}\mathbf{p}_j - {}^s\mathbf{h}^q_{i,j}\mathbf{q}_j &= T^p_{i,k}(u_x, u_y, u_z) \cdot R^p_k(\phi, \theta, \psi) \cdot T^p_{k,j}(v_x, v_y, v_z)\mathbf{p}_j - T^q_{i,k}(u_x, u_y, u_z) \\
&\quad \cdot R^q_k(\phi, \theta, \psi) \cdot T^q_{k,j}(v_x, v_y, v_z)\mathbf{q}_j
\end{aligned}
\tag{2}
$$

where

$$
T^p_{i,j}(v_x, v_y, v_z) = \begin{bmatrix} 1 & 0 & 0 & v_x \\ 0 & 1 & 0 & v_y \\ 0 & 0 & 1 & v_z \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

and $R_k(\phi, \theta, \psi) = \mathbf{R}_x(\phi) \cdot \mathbf{R}_y(\theta) \cdot \mathbf{R}_z(\psi)$, and $\mathbf{p}_i$, $\mathbf{q}_i$ are positions in the $i$th folding procedure. $T$, $R$ stand for a translation transformation and orientation. $v_x$, $v_y$, $v_z$ represent a linear displacement from virtual panel $j$ to joint $k$ , and $u_x$, $u_y$, $u_z$ represent a linear displacement from joint $k$ to virtual panel $i$. The mapping of the linear vector $pq$ from $i$th trajectory position to $j$th is represented as

$$
{}^s\mathbf{H}_{i,j} : p_i q_i \to p_j q_j.
$$

With the relationship between the linear vector and its base, the above mapping is also that of the virtual plane $s$ from $i$th trajectory position to $j$th. Concerning all partitions of a garment, a concise description of the garment handling configurations' mapping can be derived as

$$
[\mathbf{G}_{\text{goal}}]_{n\times 1} = [\mathbf{H}]_{n\times n} \cdot [\mathbf{G}_{\text{ini}}]_{n\times 1} \tag{3}
$$

and

$$
\mathbf{H}_{n\times n} : [\mathbf{G}_{\text{ini}}]_{n\times 1} \to [\mathbf{G}_{\text{goal}}]_{n\times 1},
$$

where $[\mathbf{G}_{\text{ini}}]_{n\times 1}$ denotes the initial configuration of a garment, $[\mathbf{G}_{\text{goal}}]_{n\times 1}$ denotes the final configuration. Though Eq. (3) represents the mapping of the folding procedure from an initial configuration of a garment to its final configuration, it mixes folding positions of garment partitions and sequences together so that it cannot provide feasible trajectories for intelligent grippers or garment handling systems due to existence of motion collisions. The method of Liu and Dai [24] in carton-folding applications has been adapted to solve this problem. They extracted a folding sequence from the simplified graph model of a carton, then combined with carton-folding trajectory positions to generate the carton-folding trajectories. It inspires one to decompose Eq. (3) into a composite description of garment folding trajectory positions and their handling sequences. In order to solve the problem, Eq. (3) has been rearranged as another description, which comprises of separated trajectory positions of garment partitions and their sequences. Consequently the trajectory positions can be supervised by their sequence to be fed into the effectors of garment handling systems such as intelligent grippers. Due to the fact that the number of partitions of a garment is limited, a final configuration of $[\mathbf{G}_{\text{goal}}]$ can be represented and calculated by $\text{Diag}[\mathbf{H} \cdot \mathbf{G}] \cdot [\mathbf{I}]$ in a matrix, and the folding sequence can be achieved heuristically by the adjacency matrix of a graph $[\mathbf{A}] \cdot [\mathbf{I}]$ [24], Eq. (3) is rewritten as

$$
[\mathbf{G}_{\text{goal}}]_{n\times 1} = (\text{Diag}[\mathbf{H} \cdot \mathbf{G}]_{n\times n} + [\mathbf{A}]_{n\times n}) \cdot [\mathbf{I}]_{n\times 1}, \tag{4}
$$

where $\text{Diag}[\mathbf{H} \cdot \mathbf{G}]$ is a diagonal matrix whose description is replaced by Eq. (2), $[\mathbf{I}]$ is a $n \times n$ unit matrix, $\mathbf{A}$ is an adjacency matrix of the graph of a garment.

For instance, the graph version of the shirt in Fig. 1 is given in Fig. 3, where the graph partitions are outlined by its folding crease. The partitions are labelled by numbers, partitions labelled with $i$ and $i^*$ means that they are geometrically symmetric, and partition labelled as 1 is its base partition since it does not have motion during such a handling process. The mathematical description of the initial configuration of the shirt is given in Eq. (5),

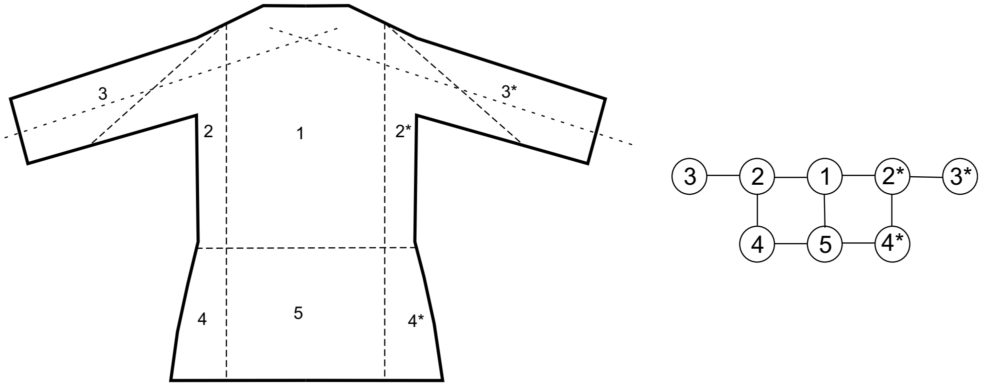

Fig. 3. Graph version of the example in Fig. 1.

$$[G]=\begin{bmatrix} IG_{10} & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & H_{2,1}G_{20} & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & H_{3,2}G_{30} & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & H_{4,(2,5)}G_{40} & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & H_{5,1}G_{50} & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & H_{2^*,1}G_{2^*0} & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & H_{3^*,2^*}G_{3^*0} & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & H_{4^*,(2^*,5)}G_{4^*0} \end{bmatrix}. \tag{5}$$

Eq. (5) combines the garment handling sequence of the partitions and their corresponding trajectory positions. Its diagonal entries are configuration positions and changes of garment partition, For example, entry $G(5,5) = H_{5,1}G_{50}$ denotes the trajectory position of partition 4 in Fig. 3 at the initial configuration. The states of the other partitions in the column and row of a diagonal entry determine the position of the corresponding partitions in handling sequence of a garment. Hence the value of a garment partition is calculated using Eq. (2) while its folding state changes are determined by a heuristic algorithm to work out the garment handling sequence based on its graph representation.

### 3.2. Garment handling sequence

The analysis of a garment handling sequence is performed to, firstly, produce a graph model of the garment based on its folding creases and its adjacency matrix, second it is to generate its folding sequence based on heuristic rules and finally it is to produce folding trajectories of the garment by merging its folding sequence and trajectory positions together. A heuristic algorithm is presented for the calculation of a garment folding sequence. The sequence is calculated based on the combination of graph theory, particular to adjacency matrix analysis and empirical rules from clothes designers and clothes manufacturers. With the adaptation of Liu and Dai's approach to carton-folding applications, heuristic rules for generation of a garment folding sequence are as

(1) Identify if there are close loops in a garment graph, if yes, removing them from the graph because a partition positioned as a close loop usually is passively handled.
(2) Detect if there are symmetric garment partitions, if yes merging the folding actions of symmetric partitions together because empirical indicates that symmetric partitions always are handled by similar actions.
(3) The longer branch of the graph, the later the partition positioned are handled.

For the convenient description, $S_i$ is introduced to denote a garment handling procedure. $\{S_i\}$ and $[S_i]$ denote a garment partition set and handling sequence, respectively. Entries of $S_i$ is the column vectors of the handling configuration **G**. For example, a garment consisting of twelve partitions can be described as a garment set, $S_{12}=\{\eta_1,\eta_2,\ldots,\eta_{12}\}$, its handling sequence can be described by $S_{12}=[\eta_1,\eta_2,\ldots,\eta_{12}]$. The difference of $\{S_i\}$ and $[S_i]$ is that entries of the former have sequence, those of the latter do not have. The algorithm is explained with the above example in Fig. 1, whose graph version is given in Fig. 3. The adjacency matrix $\mathbf{A}_{8\times 8}$ of the initial configuration of the shirt is derived in Eq. (6). It mathematically denotes the relation of the eight garment partitions

$$[\mathbf{A}]_{8\times 8}=\begin{bmatrix}0&1&0&0&1&1&0&0\\1&0&1&1&0&0&0&0\\0&1&0&0&0&0&0&0\\0&1&0&0&1&0&0&0\\1&0&0&1&0&0&0&1\\1&0&0&0&0&0&1&1\\0&1&0&0&0&0&0&0\\0&0&0&0&1&1&0&0\end{bmatrix}. \tag{6}$$

The set of the garment partitions, $S_8$, can be denoted as $\{\eta_1,\eta_2,\eta_3,\eta_4,\eta_5,\eta_{2^*},\eta_{3^*},\eta_{4^*}\}$, whose elements correspond to column vectors of **G** in Eq. (5) and the numbered partitions in Fig. 3 as well. Graph version of the explanation of the shirt handling procedure is given in Fig. 4, where solid-line circles denote unfolded garment partitions, dashed-line circles denote folded partitions. Fig. 4a illustrates the graph version of the initial configuration of the female shirt. Heuristic rule 1 is used to identify and remove passive garment partitions in order to reduce the complexity of the handling process. This rule is mainly derived from empirical knowledge of practical garment handling. These sorts of garment partitions are those partitions handled passively as the other partitions are in operation. That is to say, it is not necessary to provide extra stages to handle such partitions because those partitions are folded passively when the other partitions are handled by a garment handling system. Such garment partitions can be identified as those positioned with closed loops in the graph analysis. The number of the partitions with closed loops can be calculated by Euler's formula [28]

$$l=e-n+1, \tag{7}$$

where $l$ is the number of closed loops, $e$ is the number of edges in the graph version of a garment, $n$ is the number of nodes representing garment partitions. Applying Eq. (7) to the case study here, it shows that there are two passive partitions. The passive partitions are located by checking whether or not elements of a closed

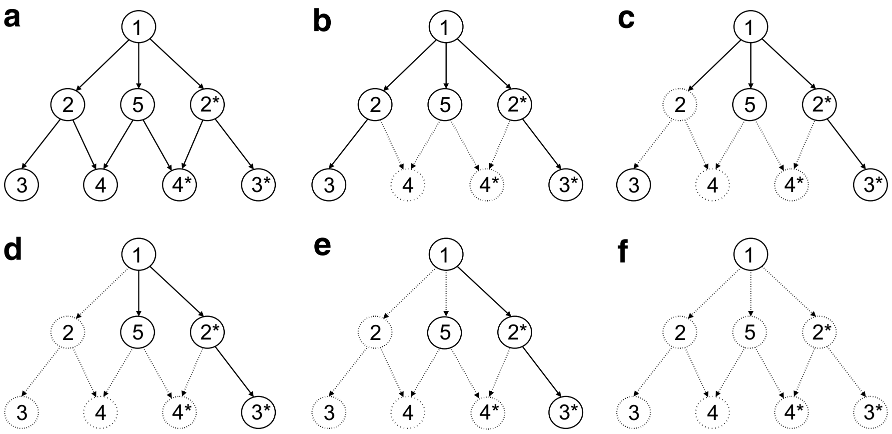

Fig. 4. Graph representation of a folding process.

loop have two or more edge connections to the other partitions. At the graph analysis level, the localisation is calculated by checking whether or not the addition of the entries in a row vector or column is more than 2. Using rule 1, Eq. (6) can be rewritten without passive garment partitions, the handling task reduces to that with six partitions, i.e., $S_6 = \{\eta_1, \eta_2, \eta_3, \eta_5, \eta_{2^*}, \eta_{3^*}\}$. It indicates that the handling procedure is a set of six garment partitions without a sequence yet, and its corresponding graph version is given in Fig. 4b, in which circles labelled with number 4 and 4* are removed from the garment graph.

Graph symmetry plays a key role in the calculation of a garment handling sequence. Heuristic rule 2 indicates that symmetric garment partitions have similar "being folded" actions, and it helps that those have a casual handling sequence. The algorithm in [24] is applied to identical symmetric garment partitions, For example, Eq. (6) can be reduced to Eq. (8) by identifying symmetric partitions

$$[\mathbf{A}]_{4\times 4} = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}. \qquad (8)$$

The updated garment handling set is $S_4 = \{\eta_1, \{\eta_2, \eta_{2^*}\}, \{\eta_3, \eta_{3^*}\}, \eta_5\}$. Though there are six elements in $S_4$, $S_4$ can be assumed as a four-partition procedure due to the fact that $\{\eta_2, \eta_{2^*}\}$ and $\{\eta_3, \eta_{3^*}\}$ occupy one handling sequence each. It should be noted that there is no handling sequence working out yet since $\{S_i\}$ denotes a set of garment partitions only as defined before. Heuristic rule 3 is the brain behind the sequence calculation. Concerning partitions 1, 2, 3, 5 with heuristic rule 3, it leads to the sequence $S_4$ as $[\eta_3 \quad \eta_2 \quad \eta_5 \quad \eta_1]$. Each action of the handling sequence is calculated by the diagonal elements of Eq. (9). Its handling procedure in graph version is given from Fig. 4c to e. Finally Consider heuristic rules 2 and 3 together, the handling procedure can be described as $S_4 = [\eta_3 \quad \eta_2], [\eta_{3^*} \quad \eta_{2^*}], [\eta_5 \quad \eta_1]$. It demonstrates that there are four elements in the sequence as

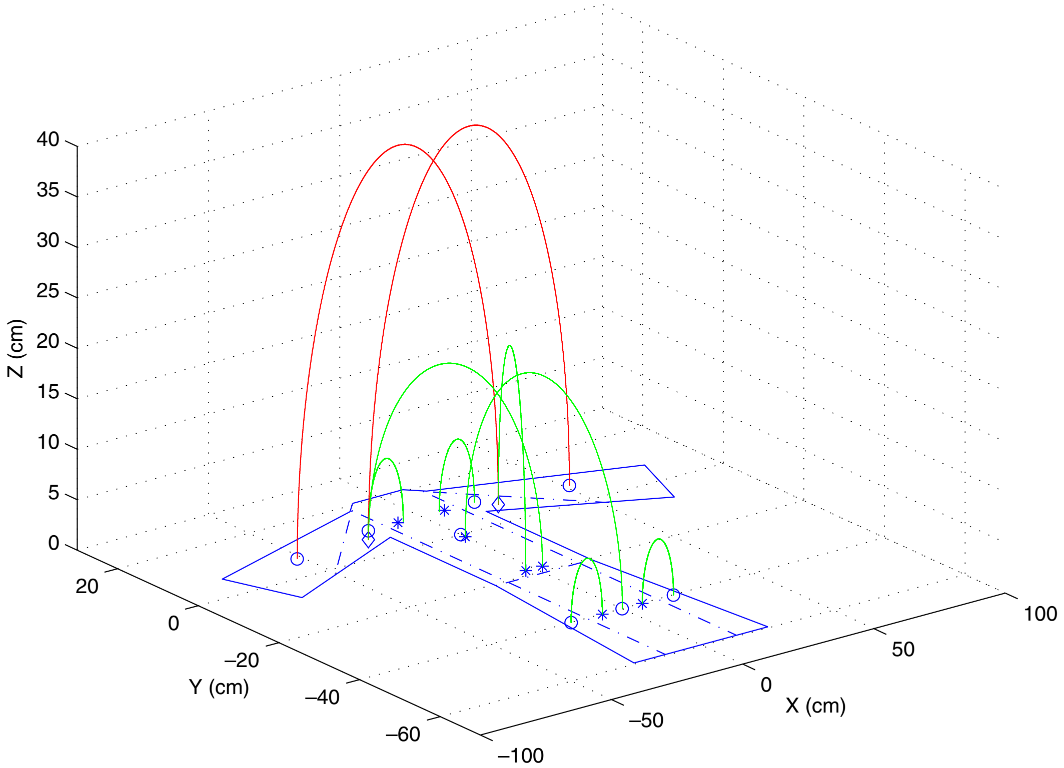

Fig. 5. The handling trajectory sequence of the example in Fig. 1.

given by $S_4$, the first two elements include two actions due to the geometric symmetry of garment partitions, respectively. The folded female shirt in graph description is shown in Fig. 4f.

$$[G] = \begin{bmatrix} IG_{10} & 1 & 0 & 1 \\ 1 & H_{2,1}G_{20} & 1 & 0 \\ 0 & 1 & H_{3,2}H_{2,1}G_{30} & 0 \\ 1 & 0 & 0 & H_{5,1}G_{50} \end{bmatrix}. \tag{9}$$

Consider the example in Fig. 1 again and merging the results from Sections 3.1 and 3.2 leads to the simulation result in Fig. 5, in which the trajectory in solid lines gives the active folding process actuated by a clothes handling system such as a intelligent robotic arm with a gripper. The trajectory in dashed lines gives the passive folding process actuated by adjacent clothes partitions. Symbols $\circ$ represent initial configurations of the geometric centres of the clothes partitions, symbols $\diamondsuit$ represent the folding process of these clothes partitions, symbols $*$ represent the folded positions of these clothes panels. The handling trajectory in the simulation represents the configuration transformation between the initial configuration, process configurations and folded configuration. For example, the trajectory of clothes partition 3 is given from the start position $(-51.82, 6.8, 0)$ cm to the processing position $(24.72, 6.8, 0)$ cm, then the final position $(-3.17, -18.2, 0)$ cm.

## 4. Concluding remarks

A heuristic algorithm has been proposed for the folding procedures of intelligent garment handling systems in this paper. First, a generic model is constructed for general clothes based on standards of clothes designers and the clothes manufacturing industry. Then, the handling procedure has been described as trajectory positions and the handling sequence of garment partitions. Finally three heuristic rules were defined to help generate a feasible handling procedure based on graph theory. This work assumes each garment partition as a virtual plane, which is described by a linear vector and its relation to its base. It indicates that a robotic mechanism with a gripper having the capability to hold a garment partition approximately in a virtual plane during handling processes, can combine the proposed handling strategies together to develop an intelligent garment handling systems. This work has addressed a novel path to the development of intelligent flexible material handling systems. Future work aims at integrate the proposed approach with existing computational models in order to achieve a feasible approach which practically handles computational cost and modelling precision for real-time packaging systems.

## Acknowledgements

The authors thank Prof. Paul M. Taylor, Dr. Jian Dai and Dr. Frank Guerin for their discussions. The author also would like to express their thanks to the Journal Editor-in-Chief Prof Mark Cross and referees for their valuable comments.

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