A method of meta-mechanism combination and replacement based on motion study

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Lacking the effective methods to reduce labor and cost, many small- and medium-sized assembly companies are facing with the problem of high cost for a long time. In order to reduce costs of manual operations, the method of meta-mechanism combination and replacement is studied. In this paper, we mainly discuss assembling motion analysis, workpieces position information acquisition, motion library construction, assembling motion analysis by Maynard’s operation sequence technique, meta-mechanism database establishment, and match of motion and mechanism. At the same time, the principle, process, and system realization framework of mechanism replacement are introduced. Lastly, problems for low-cost automation of the production line are basically resolved by operator motion analysis and meta-mechanism combination and match.

Keywords: production line; low-cost automation; motion analysis

1. Introduction

Motion Study, also known as motion research, element analysis, or work study, its main content is seeking the most economical and effective working method through a variety of analytical methods. It is an effective way to study and formulate correct and reasonable motion to shorten hours and improve efficiency by increasing valuable movement and shorten or eliminate waste motion (Du, 2013). Frank Bunker Gilbreth, an American engineer, established therbligs theory in 1912. The American Society of Mechanical Engineers added ‘Discovery’ motion and summarized 18 kinds of basic therbligs (Hua, 2012). In the process of analysis of therbligs, operation is observed and divided finely, and motion sequence is linked with hands, feet, eyes, and head movements in detail (Hirosea, Dokia, & Kondoa, 2013). Furthermore, operation is recorded and classified by therblig symbols, and the problems about operating sequence and method, such as single-hand waiting, unreasonable motion, and waste motion, are found and improved.

The application researches in the country about motion study are mainly focused on the following four aspects (Wang, 2010):

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• Motion analysis applied in production line balance.

Improvement measures based on motion analysis for production line in equipment or electronics manufacturing enterprise are proposed, and it improves the cycle time and balance ratio of production line (Gu & Zhou, 2009).

• Motion analysis applied in experimental teaching and assembly line study.

Wen Wei, Ding Wen-ying, and Dong Shao-hua choose reducer assembly line as the subject investigated, and eliminate bottleneck process of production line to improve its balance ratio. Gao Qi and Wang Shao-Hua research assembly line based on threbligs, and find out stasis, invalid, waste, imbalance, and disorder phenomenon in production process (Liao & Sun, 2009).

• Operation improvement and design by motion analysis.

Liu Shao-shan and Liu Feng-shan research therblig motion analysis and work improvement under lean production system to improve resource utilization rate. Lv Xiao-Ji and Chen Cang-ming take one automobile enterprises, for example, and eliminate various waste and imbalance problem in enterprise production process by motion analysis and line balance (Li & Gui, 2008).

• Operation process optimization by motion analysis.

Jiang De-yi and Liu Hong-xiao take snatch motion as instance, construct body mathematical model, and give optimal motion of snatch object in production activities. According to motion analysis for efficiency principle, Liu Hong-xiao optimizes male shirt shoulder sewing process (Yang, Wu, Zhu, Bao, & Wei, 2013).

However, there are few reports for the automation of the assembly line, especially the motion analysis and meta-mechanisms.

Since the automation technology appears, it develops crosswise with mathematics and computer technology. Increasingly mature hardware technologies, especially the rapidly developing computer technology, lay the foundations of automation technology (Wei, 1994). However, at the present stage, the automation technology not only solves the problems of production control for the single production cell, but also solves the problems of the entire production process as well as operation and management of business. The development of automation technology is divided into 4 stages, and it is shown in Table 1.

So far, for the automation of assembly enterprises all over the world, the four stages coexist, and they are information- and system-oriented (Jiang & Sui, 2012). But we know, at the fourth stage, computer-integrated manufacturing system (CIMS) costs too much, and the manufacturing period is too long; so in some small- and medium-sized enterprises, for the simple automation production lines, we can find a technology-intensive and low-cost way.

Therefore, the replacement of assembly operation with meta-mechanism and LCA have great potential and extensive foreground. Besides, they meet the requirements currently with advantages of low-cost investment, short period, quick effectiveness, and high automation.
2. Common problems in the manual production lines

There are usually a lot of labor-intensive enterprises in the manufacturing production lines, in which the staffs are engaged in the simple and repetitive assembly motions, and easy to feel fatigued (Meng, 1994). Since the production efficiency and production quality are easily affected by workers, once lack of personnel or training, it will not be able to guarantee the delivery cycle (Son, 2005). In recent years, especially in the eastern coastal area, with the declining of the domestic manufacturing costs of parts and the increasing of the labor costs, reducing the costs of product’s assembly become more and more important and evident, particularly in the industries of household appliances and electronics industries. The economic benefits brought by improving assembly efficiency are far more obvious than that brought by simply reducing manufacturing costs of parts. The applications of low-cost automation will make some small- and medium-sized assembly enterprises (or some large enterprises) run their own business with lower costs, and in the process, it can almost get the same profits as the profits of advanced automation enterprises. If we combine the low-cost automation with each production line, which can realize the combined operation of machines and operators, and the achievements will be much more valuable than trying to carry out the pure automation in a short term.

Although many enterprises pay much attention to the development and application of low-cost automation all over the world in recent years, but the executing process of low-cost automation in the production line is still faced with many problems (Yang, 2010). Mostly, three issues must be considered: firstly, the effective analysis of assembly motions; secondly, the replacement of similar movements by automation; and thirdly, the mechanisms must be easily replaced and just need low costs. In general, low-cost automation should have the following features:

1. **Small investment**: The investment of computers and automation equipment generally accounts for 7–12% of all equipment investment, or less. The upper limit to the investment just likes this: the percentage of investment in a new factory should be lower than the general provisions. The percentage of some special projects should be far lower than the funds, which are approved by provinces and cities, and less than the enterprise’s affordability. However, this part should account for more than 40% in CIMS and computer-integrated process system (CIPS).

| The stage | Automatic level | Industrial mode of production | Technical means | Type of manufacturing |
|-----------|----------------|------------------------------|-----------------|----------------------|
| First stage | Manual control | Labor intensive              | Manual operation | Discrete manufacturing |
| Second stage | Unit automation | Equipment-intensive          | CNC technology  | Process manufacturing |
| Third stage | Information automation | Information intensive       | Computer-aided technology | |
| Fourth stage | Decision automation | Knowledge intensive          | Computer integrated technology | |
2. Targeted investment: Investment should increase output, improve quality, raise labor productivity, and reduce the consumption in the short term. Man should get benefits in a relatively short time (usually 1–2 years), and the lifetime of equipment should be 5–8 years.

3. The automation: The most necessary part is automation. It includes reasonable classification between men’s and machines’ functions, and compact structures. Besides, the rate of function should be above 95%.

4. Reliable and easy to maintain.

5. Low-cost automation should be gradually improved, eventually progressed in the direction of the CIM and CIP.

6. Use the mature technology as much as possible, invest least with quick effect, and reduce the investment risks.

7. The maintenance cost must be low; the work should be reliable, and the online rate should be above 95%.

3. The principle and process of meta-mechanism replacement

Assembly enterprises are usually faced with these problems: whether input low-cost automation equipment in production line or not; how much automation equipment should be input; and what kind of low-cost automation equipment should be input, etc. But, even if enterprises have the ability to put simple automation into effect, they do not; or they spent a lot on expensive automation equipment, but it is difficult to get benefits in a short time, which will cause huge losses. In this article, through the analysis of operator motion in production line, man can establish a matching relation between operator motions and meta-mechanism combinations or automation equipment, implement low-cost automation in a production line, and then save a large part of the expenses.

The principle and operating steps about motion analysis of assembly and mechanism replacement have shown in Figure 1.

The process to the motion analysis and the method of meta-mechanism replacement includes the following aspects:

1. Analyze the assembly motions. According to the category of products, use a video camera to do some real-time recording of the assembly operation, assembly operation is divided into parts by motion display devices, storage devices, and processing devices. At the same time, analyze the positional information about workpieces. Use the laser displacement sensor to collect the 3D data of workpieces in the assembling process from different positions.

2. Use the algorithm of point cloud reconstruction and registration to rebuild the 3D data model of the workpieces (Wang, 2012), and then obtain the positional information of the workpieces.

The algorithm of point cloud reconstruction is shown as following:

Step1: Point cloud data to be spliced is inputted.
Step2: Initial triangle is determined.

2.1 Any point is selected randomly as first vertex \( P_1 \) of initial triangle.
2.2 Closet point \( P_2 \) from \( P_1 \) is searched, edge \( P_1P_2 \) is constructed.
2.3 Optimum point is searched by traversing other points.
The algorithm of point cloud registration is shown as following (Zhang, 2013):

2.4 If min(|P_1P_2|+|P_2P_3|), then goes to next step, else returns to 2.1.
2.5 If minimum interior angle of triangle ΔP_1P_2P_3 isn’t less than 35 degree, then goes to step 2.6, else returns to 2.1.
2.6 If maximum interior angle of triangle ΔP_1P_2P_3 isn’t more than 90 degree, then goes to next step, else returns to 2.1.
2.7 Initial triangle is determined, and point P_1, P_2 and P_3 are set as dead point. Besides, ΔP_1P_2P_3 and three edges of initial triangle are put into directly triangle table and edge table.

Step3: The process of triangulation is realized.
3.1 Any edge E_1 is selected randomly (point P_4 and P_5).
3.2 Minimum envelope rectangle for triangles including edge E_1 is solved.
3.3 Optimum point P_6 is searched from active point set in minimum envelope rectangle.
3.4 If min(|P_4P_5|+|P_4P_6|), then goes to next step, else returns to 3.1.
3.5 If minimum interior angle of triangle ΔP_4P_5P_6 isn’t less than 35 degree, then goes to step 2.6, else returns to 3.1.
3.6 If maximum interior angle of triangle ΔP_4P_5P_6 isn’t more than 90 degree, then goes to next step, else returns to 3.1.
3.6 P_6 is set as dead point, and P_4P_2 and P_4P_6 are added into edge table. Besides, edge E_1 is deleted, and ΔP_4P_5P_6 is put into triangle table.

The algorithm of point cloud registration is shown as following (Zhang, 2013):

Step1: Original point cloud data sampling.
1.1 Workpiece is scanned progressively by laser displacement sensor.
1.2 Reflected light of workpiece is collected by laser collection device.
1.3 Laser signal is converted into workpiece 3D data.
Step2: Bilateral filtering denoising of point cloud is realized.
Step3: Point cloud is simplified.
3.1 Minimum enveloping hexahedron of point cloud is calculated.
3.2 By data traversing point, grid cell is divided, and data points are classified as grid cell.
3.3 Grid cell spatial location is set as mean value of data point set, and point cloud quantity and coordinate are reset.
Step4: Corresponding closest point of reference point cloud set X_1 is calculated, according to registration point cloud set X_2 to be matched.
Step5: Minimum optimal model for corresponding point mean distance is constructed.
Step6: Translation transformation and rotation transformation matrix are determined, and registration point coordinate value X_3 in new coordinate system are calculated.
Step7: If condition of convergence is satisfied, then point cloud registration is finished, else X_2 = X_3, and returns to 4.

(3) Set up the motion database. According to the products’ category, store each motion of the operating personnel who assembles a product, the required time, and the variation of position of ready-to-assemble parts.

(4) Express the motion with Maynard’s operation sequence technique (MOST). After each motion has been divided into therbligs, we can express the assembling operations by MOST. Then, classify and integrate it, such as moving, grabbing, body movements, pressure, pull, and rotation. We can inspect strictly, delete redundant motion, and change the existing procedure by canceling, merging, rearrangement, and simplification. Last, we can adjust the working methods to get the optimal operation.

(5) Set up the meta-mechanism repository. Sort the application of the existing meta-mechanism of assembly production line and automation equipment. Forming the meta-mechanism repository of the assembly line, such as object-clamping
mechanism, moving mechanism, fixture-clamping mechanism, switches, positioning mechanism, locking mechanism, automatic halt mechanism, overload protecting mechanism, and so on, which usually includes 2D diagrams, key parameters, suitable operation, serial number, etc. The mechanism repository requires a lot of mechanisms and their combinations. The simple mechanisms and combinations which are commonly used can be divided into forms just like Figure 2.

(6) Match assembly motions with specific mechanisms. In view of each motion expressed by MOST in motion repository, search meta-mechanism repository and calculate the semantic similarity. If the similarity ratio is less than the setting threshold, combine mechanisms to form the project that can meet the requirements of assembly motion, which can contribute to evaluating and decision-making, and refer to the positional information about workpieces in the Step 2, then get the key technical parameters of mechanisms. The system interface has shown in Figure 3.
The realization of the above functions is based on the J2EE (Java 2 Platform Enterprise Edition) framework. Figure 4 shows that the system is divided into five layers: client layer, request to accept layer, application service layer, perception layer, and data storage layer from top to bottom. The function and effect of each layer are shown.

3.1. The client layer

When engineering technicians need data interaction, they use the server interface, which is provided by world web service and JavaBean (Enterprise Java Beans, EJB), to visit the system, and start the functions. The client layer includes two kinds of clients. One client is the thin client of Web service; the other is the specific client, which is based on Java and downloaded from the platform.
Figure 3. The interface of assembling motion analysis and meta-mechanisms.

Figure 4. The framework of assembling motion analysis and meta-mechanisms.
3.2. **Response layer**
Response layer is used to receive the requests from the browser and give it to the bottom layer to handle, and send the result to the browser. The progress is made up of Java Server Page and Servlet that shows the information about the client layer. The request to accept layer can handle the data logically, for example, data calibration and the check of client browser. This layer cannot deal with complicated logical processing.

3.3. **The business logic layer**
The business logic layer is the core of the platform. It runs on the application server of Java and all logical processes are sealed in the EJB elements. The application server provides EJB elements with an optimized execution environment. The business processes are: engineering technicians use video cameras to record the assembling operation. They get 3D data of workpieces with a laser displacement sensor. Then, they use the algorithm of 3D reconstruction to reconstruct the 3D model of workpieces and get the changed information about positions of instruments. Changed positional information and the video files are synchronous. They utilize the classification of motions Bean to determine the sort of operations. They define and disassemble the assembly operations by the means of motion analysis. Then, get the standard database of MOST-elements. They use human–computer interaction to get the corresponding MOST-expression and its validity, and optimize the assembly operations. The standard database of MOST-elements can be controlled by the maintenance of therbligs. The information management module of meta-mechanism is in charge of the information maintenance of meta-mechanism in general assembling lines. Of course, this information is saved in meta-mechanism repository. The meta-mechanism combination and replacement are responsible for calculating the matched-degree between assembly operations and the typical meta-mechanisms. If the matched-degree meets the requirements, the mechanism will be replaced. After that, the operator will get changed positional 3D information of workpieces and the technical parameters. Otherwise, the operator will analyze XML, which is the rule of meta-mechanism combination, then the manual assembling operation is substituted by the valid combination of meta-mechanisms. Basic data management is responsible for personnel management, role management, user management, organizational management, and management of video files. The analytic and statistical model gets information of the assembly motion repository, foundation database, and meta-mechanism repository, so that it can analyze the operation of the assembling line and get reports and statistics of meta-mechanism replacement.

3.4. **Sensing layer**
The sensing layer involves two kinds of hardware: the video camera and laser displacement sensor. Video cameras record the assembly operation and send it to the database by Wi-Fi. The laser displacement sensor sends the collected 3D data to the server synchronously and stores the positional information of workpieces by the means of the reconstruction of a 3D model.
3.5. The data storage layer

The data storage layer provides the assembling motion analysis and the meta-mechanism combination and replacement with infrastructural support. It comprises assembling motion repository, MOST-element repository, 3D database of workpieces, foundation database, meta-mechanism repository, and XML files (the rule of meta-mechanism combination). The data storage layer is responsible for the storage of data, inquiring data, and backups. It maintains consistency and safety and provides the application service layer with data services. Assembling motion repository stores the motions’ classifications, names, numbers, operating time, MOST-expressions, and therbligs. MOST-element repository stores the basic data table and consists of general motion table, controlling motion table, and instrument table. The 3D database of workpieces stores the changed positional information of workpieces. Fundamental database stores users, staff, roles, and motion video files. Meta-mechanism repository stores types, names, application, key parameters, and 2D images of the meta-mechanism that assembly line usually uses.

4. The mechanism replacement of a station in PS4 handles assembly line

There are some preconditions to realize meta-mechanism replacement of ‘Installing R1/R2 buttons’ workstation in PS4 handles line:

1. Realize arrangement and classification of the meta-mechanism repository of productive operation in assembly line.

   The meta-mechanism combination in an assembly line can be divided into five categories according to different ways of working: feeding mechanism, selecting mechanism, carrying mechanism, grasping mechanism, and assembly mechanism. The letters in parentheses express the corresponding acronym of each mechanism.

2. Analyze the scope of application about meta-mechanism combination.

   Analyze and research the way of motion and applicable object of meta-mechanism combination, thereby mainly confirm the range of application of meta-mechanism.

3. Complete the matching process in MOST of commonly used productive mechanism.

   Achieve the matching of MOST expression to each of the operating mechanism.

4. The MOST expression of key motions.

   Extract key motions of MOST from the each mechanism, and delete invalid motions, which can be easy to filtrate the meta-mechanism combination later.

5. The index extracting of key motion of the operation mechanism.

   Extract the key motion from the MOST expression (or MOST formula), which can be easy to improve the accuracy of matching.
After the above procedures, we can begin to replace the motion of ‘Install R1/R2 buttons’ workstation with corresponding meta-mechanism. The process can be achieved according to Table 2, and its detail description is shown as following steps:

(1) Observe the movement of objects.

Observing the operator’s working process on ‘Install R1/R2 buttons’ workstation, and analyze the motion of the workpieces carefully, which can narrow down the range of selected mechanisms.

(2) Express by MOST.

The ‘R1/R2 buttons’ station is mainly composed of six motions, whose specific names and the MOST formulas are shown in Table 3.

(3) Select the key motions from MOST formulas.

The method of selecting key motions from MOST formulas is deleting the invalid motion sequences, and selecting the key motions, then we will get the key MOST motions as shown in Table 4.

(4) Extract the index from the key motions.

When the process of selecting key motions is finished, we can begin to extract the key index from these key motions. The results are shown in Table 5.

(5) Select the meta-mechanism.

When the above steps are completed, we can find the corresponding meta-mechanism or its combinations to replace the motions. Through the analysis we can obtain that six motions can be replaced by four different mechanisms, and the specific results are shown in Table 6.

Table 2. The replacement process of ‘Install R1/R2 buttons’ station.

| Steps | Step name                          | Operation process                                                                 |
|-------|------------------------------------|-----------------------------------------------------------------------------------|
| 1     | Observe the movement of objects    | Observe the movement of objects, then grasp the mode of motion                     |
| 2     | Express by MOST                    | Analyze the operator’s MOST motion on the ‘Install R1/R2 buttons’ workstation, and write down the working process |
| 3     | Select key motions from MOST formulas | Select key motions from MOST formulas, and must ensure they are effective ones     |
| 4     | Extract the index from the key motion | Extract the index from the key motion which has got from the MOST formulas        |
| 5     | Select the meta-mechanism          | According to the MOST formulas, key MOST motion, its index and the motion-object, consult the corresponding meta-mechanism combination, then select the suitable mechanism-combination to replace them |
| 6     | Sort the mechanism combination     | More than one motions often correspond to the different sets of mechanisms, so sometimes need to combine the multiple mechanisms to reduce input costs |
It is observed that there are four different replacing mechanisms, and two of them are repeated, which can be achieved through a simple transformation on the primary mechanisms.

(6) Sort the mechanism combination.

Because the mechanism replacement involves four mechanisms, therefore, we can renew to combine and simplify them.

Table 3. Express the motions of ‘Install R1/R2 buttons’ by MOST formulas.

| Station name     | No. | Motion name                                                                 | MOST formula                  |
|------------------|-----|------------------------------------------------------------------------------|-------------------------------|
| Install R1/R2    | 1   | Get a qualified product from the front workstation                          | A1B0G1T3A1B0P1A0              |
| buttons          |     | Install the button ‘R1’ (right)                                             | A1B0G1A1B0P3A0B0G0M1X0I3A0    |
|                  | 2   | Get the button ‘R2’ and install a button spring in it (right)                | A1B0G1(A1B0G3)A1B0P3A0        |
|                  | 3   | Install the button ‘R2’ in the main holder (right)                           | A0B0G1A0B0P3A0B0G0M1X0I3A0    |
|                  | 4   | Use adsorption-fixure to absorb a loudspeaker and install it                 | A1B0G1A1B0P1A1B0G3A1B0P3A1B0P1A1 |
|                  | 5   | Push the product to the next workstation                                    | A1B0G1M1X0I1A1(A1B0G1A1B0P1A1) |

Table 4. Select the key motions of ‘Install R1/R2 buttons’ workstation.

| Station name     | No. | Motion name                                                                 | Key motions                  |
|------------------|-----|------------------------------------------------------------------------------|-------------------------------|
| Install R1/R2    | 1   | Get a qualified product from the front workstation                          | ABG/ABP                      |
| buttons          |     | Install the button ‘R1’ (right)                                             | ABG/MXI                      |
|                  | 2   | Get the button ‘R2’ and install a button spring in it (right)                | ABG/ABP                      |
|                  | 3   | Install the button ‘R2’ in the main holder (right)                           | ABG/MXI                      |
|                  | 4   | Use adsorption-fixure to absorb a loudspeaker and install it                 | ABG/ABP                      |
|                  | 5   | Push the product to the next workstation                                    | ABG/MXI                      |

Table 5. Extract the index from key motions of ‘Install R1/R2 buttons’ workstation.

| Station name     | No. | Motion name                                                                 | Index of key motions         |
|------------------|-----|------------------------------------------------------------------------------|-------------------------------|
| Install R1/R2    | 1   | Get a qualified product from the front workstation                          | G1/T3                        |
| buttons          |     | Install the button ‘R1’ (right)                                             | M1/X0/I3                     |
|                  | 2   | Get the button ‘R2’ and install a button spring in it (right)                | G1/P3                        |
|                  | 3   | Install the button ‘R2’ in the main holder (right)                           | M1/X0/I3                     |
|                  | 4   | Use adsorption-fixure to absorb a loudspeaker and install it                 | G1/G3/P1/P3                  |
|                  | 5   | Push the product to the next workstation                                    | M1/X0/I1                     |
5. Conclusions

Though the motion analysis is increasingly applied in enterprise production lines, it is still limited in follow aspects: relieving operational fatigue, improving operating process, measuring, and controlling the labor-hour. The motion analysis and the meta-mechanism replacement will improve the theory of motion analysis, expand the ranges of application of motion analysis, and find a good way to save manpower and costs.

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References
Du, Z. (2013). Motion analysis of application research in China. Journal of Mechanical Management Development, 1 (1), 1–2.
Gu, T., & Zhou, B. (2009). The application of motion analysis in cylinder production line. Journal of Mechanical Manufacturing, 8 (540), 1–2, 47.
Hirosea, K., Dokia, H., & Kondoa, A. (2013). Dynamic analysis and motion measurement of ski turns using inertial and force sensors. Procedia Engineering, 60, 355–360. Retrieved from http://www.sciencedirect.com/science/article/pii/S1877705813011338
Hua, J. (2012). Optimization in the idea of lean production to the fixed telephone Bit Electronics. Shandong province: Shandong University of Science and Technology.
Jiang, J., & Sui, R. (2012). Automatic assembly of combined checking fixture for auto-body components based on fixture elements libraries. College of Mechanical and Electrical Engineering, 6 (30), 2–6.
Li, J., & Gui, W. (2008). The applications of methods research in G company operating standards decision. *Journal of Guilin University of Electronic Science and Technology, 28*, 2–10.

Liao, Y., & Sun, H. (2009). The application research of drug packaging assistive technology. *Journal of Packaging Engineering, 30*, 199–201.

Meng, X. (1994). *The modern mechanism manual* (pp. 152–229). Beijing: The Press of Mechanical Industry.

Son, C. (2005). Comparison of intelligent control planning algorithms for robot’s part micro-assembly task. *Engineering Applications of Artificial Intelligence, 7*(19), 1–4.

Wang, F. (2010). *The technology and prospect of low cost automation concept*. Beijing: Tsinghua University.

Wang, J. (2012). *Technology research to the splicing and fusion of mass point-clouds model* (p. 10). Zhejiang: Zhejiang University of Technology.

Wei, C. (1994). Intelligent machine design with object-oriented design and constraints satisfaction mechanism. In *Proceedings of the third international conference on automation technology*, Taipei, China.

Yang, P. (2010). Drug packaging operation process analysis and optimization on the basis of motion research. *Journal of Packaging Engineering, 7*, 31.

Yang, Q., Wu, D. L., Zhu, H. M., Bao, J. S., & Wei, Z. H. (2013). Assembly operation process planning by mapping a virtual assembly simulation to real operation. *Computers in Industry, 64*, 869–879.

Zhang, F. (2013). *Research of point-clouds data processing with geometric method*. Xian: Northwestern University.