1 Background

- Business globalizations of Hitachi
  - Other Asian Countries
  - Europe
  - North America
  - Japan
  - Offshore over 50%
  - South Korea Thermal power plant
  - India Power control systems manufacturing site

- Subjects in globalization of market and manufacturing sites:
  - Employ un experienced workers in the fields
  - Quality control on local sites

Clear and Quick Understandable Work Instructions are Essential

2 Problems of 2D drawings work instructions

- Conventional work instructions based on 2D drawings are:
  - Time consuming understanding what to do
  - Misunderstands of what to do
  - Different understanding from persons
  - Uncertainty of work preparations

Assembly Animation and 3D work instruction sheets are effective

3 Design review with assembly animation

- Assembly animation

- Bottleneck in creation time of animations
  - 1 Man Month (160hr)
  - for a power plant machine (1,000 parts) assembly

© Hitachi, Ltd. 2013. All rights reserved.
4 Assembly operations with work instruction viewer

3D work instruction sheets

Video of assembly operations with 3D work instruction viewer

Bottle neck of creation time of work instruction sheets
7 Men * 6 Months for 119 Work Instructions (200 pages for each)

6 Subjects of assembly sequence generation

Definition: Assembly sequence consists of an assembly order and each part's assembly motions

1. If one part order changes the network status changes
   • Collision space changes
   • Non collide motion and the next part to assemble changes

2. What is optimal assembly operation?
   • Difficulty of numerical estimation of assemblability
   • Difficulty of numerical estimation of efficiency of assembly operation

3. NP problem
   • Computation order is N! where N is number of parts in assembly.

5 Subjects of creation of assembly animations and work instruction sheets

Digital engineering tools

3D-CAD Model

Ratios of user operations
• Assembly sequence 60%
• Assembly motion 30%
• Camera setting 10%

Manual setting items in WIS
• Select and paste 3D models
• Highlighting object parts
• BOM
• Annotations

Time consuming manual operations

Development of Assembly sequence generation system

7 Application of Assembly sequence generation system

Applicable condition:
sequences of assembly and disassembly are reversible
assembly order ⇔ disassembly order
assemble motion ⇔ disassembly motion

Power plant machines
Power plant control systems
Trains

ATMs
Manufacturing control systems
Semi conductor inspection systems
**8 Benchmark**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Developer</th>
<th>Dissassemble sequence</th>
<th>Disassemble motions</th>
<th>WIS out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>Lattice Technologies (XLV Studio)</td>
<td>−</td>
<td>−</td>
<td>Auto.</td>
</tr>
<tr>
<td>Commercial</td>
<td>Fujitsu (VPS)</td>
<td>Large area part prior, one sequence</td>
<td>Normal direction of large area</td>
<td>Auto.</td>
</tr>
<tr>
<td>Develop</td>
<td>Tokyo U. of science* Fuji Xerox</td>
<td>All sequences generation</td>
<td>6 orthogonal directions collision check</td>
<td>−</td>
</tr>
</tbody>
</table>

NP problem of all sequences generation:

→ O(N!): 10^{100} sequences for 100 parts assembly and collision check for each part

→ No practical computation time

**9 Dynamic exchange order algorithm**

Disassembly sequence which satisfies on site rule with minimum change to prevent collision

Initial disassembly order based on disassembly rules

Disassemble rules on site

Collision avoidance disassembly motions generation based on geometrical constraints btw parts

Minimum change for initial disassemble sequence

Is there disassemble motion?

No: Exchange the order of the part to the next order part

Yes: The part order is decided

**10 Generation of initial disassembly order**

Assembly rules:
1. Base part first
2. Lower part first

Disassembly rules:
1. Base part last
2. Upper part first

**11 Generation of disassembly motion avoiding collision**

Geometrical constraints (cylinder, plane)

→ Collision avoidance motion

Collision (2 disassy vectors)

Plane (1 disassy motion collides with plane)

= 1 collision avoidance disassy motion
12 Disassembly vector candidates

Disassembly vector candidates between 2 parts
\[ V_a = \{e_1, -e_1, e_2, -e_2, e_3\} \]
\[ V_C = \{e_3, -e_3\} \]

Disassembly vector candidates in multiple parts:
\[ E_a = \bigcup_i V_a(i) \quad (V_a = \phi) \]
\[ E_a = \bigcup_j V_a(j) = V_c \quad (V_c \neq \phi) \]

14 Disassemble vectors

Disassembly vector candidates:
\[ E_a = \{e_3, -e_3\} \]

Colliding space with part c:
\[ D = \{-e_3\} \]

Elimination of colliding vector from disassembly vector candidates
Disassembly vector:
\[ V_a = \{e_3\} \]

13 Colliding space

Colliding space is spanned by normal vectors of adjacent parts

Disassembly vector
Disassembly part a
adjacent part b
Disassembly vector
Collliding part c
Colliding vector
Colliding vector
Colliding space
Colliding vector

Colliding space of part a spanning by colliding vector:
\[ D = \{-e_3\} \]

15 Example of collision avoidance vectors calculation

Disassembly vector candidates:
\[ \{m_1, \ldots, m_{15}\} \]

Colliding space:
\[ \begin{cases} \quad d_1 = -z \\ \quad d_2 = -\left(1/\sqrt{2}\right)(x + z) \\ \quad d_3 = z \end{cases} \]

Elimination of colliding vectors
\[ m_i^1 = m_i \quad (i = 1, \ldots, 15) \]
\[ m_j^j = m_j^t - F(m_i, d_j) \quad (j = 2, 3) \]
\[ m_j^j = \frac{m_j^t - F(m_i, d_j)}{|m_j^t - F(m_i, d_j)|} \]
\[ F(m_i, d_j) = \begin{cases} \quad (m_i, d_j) > 0 \\ \quad 0 \quad (m_i, d_j) \leq 0 \end{cases} \]

Disassembly vectors:
\[ m_1 = m_3 = m_4 = y, \quad m_2 = m_7 = m_8 = -y, \quad m_9 = m_10 = m_11 = m_12 = x \]
16 Dynamic exchange order algorithm

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial disassembly order generation</td>
</tr>
<tr>
<td>2</td>
<td>Insert an empty exchange list L into /+1 order</td>
</tr>
<tr>
<td>3</td>
<td>Calculate disassembly vectors of /+1 order part</td>
</tr>
<tr>
<td>4</td>
<td>Decide the part order as</td>
</tr>
<tr>
<td>5</td>
<td>End disassembly order</td>
</tr>
</tbody>
</table>

17 Computation times of dynamic exchange order algorithm

Applicable for thousands parts assembly

<table>
<thead>
<tr>
<th>Part number</th>
<th>10°</th>
<th>10¹</th>
<th>10²</th>
<th>10³</th>
<th>10⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computation time (s)</td>
<td>0.2</td>
<td>0.4</td>
<td>1.0</td>
<td>1.2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Control system

18 Computation times

Maximum number of exchange times

Number of exchange times of actual models

Validities of order

<table>
<thead>
<tr>
<th>Parts number of assembly</th>
<th>Editing time after generation [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>316</td>
</tr>
<tr>
<td>2</td>
<td>221</td>
</tr>
<tr>
<td>3</td>
<td>498</td>
</tr>
</tbody>
</table>

19 Application effects

This technology shortens time of creation of assembly animations and work instruction sheets and applied to products manufacturing in Hitachi group.

<table>
<thead>
<tr>
<th>Application</th>
<th>Manual time</th>
<th>Applied time</th>
<th>Effect</th>
<th>Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Creation of assembly animation</td>
<td>-Power plant machines 1 Man Month (160 hr)</td>
<td>2.5 hr</td>
<td>1/60</td>
<td>Japan, Germany, India, China, Iraq, etc.</td>
</tr>
<tr>
<td>2. Instruction of work</td>
<td>-Semi conductor inspection machines (1,000 parts)</td>
<td>18 Man Month 1 Man Month</td>
<td>1/18</td>
<td></td>
</tr>
<tr>
<td>3. Creation of work instruction</td>
<td>-Control panels of power plant (1,000~2,700 parts)</td>
<td>20~40 hr 3 hr</td>
<td>1/7~1/13</td>
<td>Japan, India</td>
</tr>
</tbody>
</table>
Fast automatic generation system of assembly animation and work instruction sheets has been developed to assure product quality and meet short production date of diversified products in globalized manufacturing environment.

The developed assembly sequence generation system is characterized as follows:
(1) Dynamic exchange order algorithm based on on-site assembly rules.
(2) Collision avoid assembly motion vector generation based on geometrical constraints.

This technology is contributing to globalization of manufacturing in Hitachi group.