Chapter 9

Material Handling System for a Hybrid Machine

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## Organization of the presentation

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4. Process for loading of the machining center
5. Measurement of pose accuracy
6. Material handling system integration using a terminal control protocol (Command protocol, Data flow)
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Introduction

- Material handling is the movement, protection, storage and control of materials and products throughout manufacturing, warehousing, distribution, consumption, and disposal.

- Material handling can be done by four number of ways as shown in the figure.

- Manual handling system has the highest flexibility, and on the other hand, special purpose automation is just stuck to a fixed action.

Figure: Pathway from manual assembly system to fixed special purpose automated system \[1\]
System specification

• The material handling system is required to manipulate a wide range of parts in the millimeter range.

• The figure shows the range of dimensions of (a) lenses, (b) casing, and (c) Erowa chuck.

• The lenses and casing must be manipulated with as little gripping force as possible.

• Accuracy will be critical when determining the position of the small components and the placement accuracy must be 0.1 mm or greater.
System components

• Figure presents an image of the assembled and functional system.

• It includes following components:
  ➢ SCARA (Selective Compliance Assembly Robot Arm) robot
  ➢ Robotiq gripper
  ➢ vision system (camera, motorized lens and ring light)
  ➢ Workpiece fastening system.
SCARA Manipulator

- It is clear from the system requirements that a four-DOF system will be required.
- A SCARA would be an appropriate choice as it can translate along three axes; rotate about the Z-axis and has a cylindrical work envelope.
- Most SCARA robots are based on serial architectures, which means that the first motor should carry all other motors.

Fig. (A) schematic diagram of the SCARA robot\cite{2,3,4,5}

Fig. (B) kinematic diagrams of the SCARA robot\cite{2,3,4,5}
Robotiq Gripper

- Most reported grippers fall into three categories, parallel, three fingered and angled.

- In many applications, to grip a large range of components robots must be fitted with tool change technology and different end effectors.

- This gripper has two modes of operation, encompassing grip and parallel grip.

Figure: Robotiq 2 finger-85 gripper (A) holding a work piece holder, and (B) holding a precision machined lens casing[6].
Vision System

- The developed vision system incorporates a Baumer 2.8 Mp 1/1.2 inch CMOS mono camera, motorized zoom and focus Navitar 7000 lens (182 108 mm focal length), and red ($\lambda = 625$ nm) ring light.

- This system will allow for the imaging of parts as small as 54 $\mu$m (using 2 pixels for detection, with 108 mm focal length) and field of views as large as $270 \times 169$ mm, with 18 mm focal length.

Figure: Assembled and function vision system, mounted above the SCARA’s end effector[13]
Vision System

• The vision system was calibrated by imaging a Thorlabs calibration standard, which consists of concentric squares from 0.1×0.1 mm to 50×50 mm.

• A processed image of the calibration standard is presented in Figure.

• The calibration was then determined using following equation:

\[
\text{Calibration} = \frac{\text{pixels}}{\text{mm}} = \frac{d(\text{pixels}) \cos \theta}{50}
\]

Where \( \theta \) is the rotation angle of the calibration standard relative to the image frame and \( d \) is the lateral distance between the edges of the outer square.

FIGURE 9.8 Image of the processed Thorlabs calibration standard
Vision System

• The following figure presents the calibration of the vision system

➢ (A) When maintaining the zoom at 18 mm and changing focus.

➢ (B) When focusing on the calibration standard and changing the zoom.

• The equation for each line was determined using curve fitting techniques and ensuring that the Person Product-Moment correlation coefficient ($R^2$) was in all cases 0.99.

Figure: Vision system calibration results[13]
Vision System

- A schematic diagram used to determine the position of the part relative to the base coordinate system is presented in Figure.

- The following equations are used to determine the center of the camera relative to the base coordinate system:

\[
P_{c_x} = l_1 \cos \theta_1 + l_2 \cos(\theta_1 + \theta_2) + l_3 \cos(\theta_1 + \theta_2 + \theta_3)
\]

\[
P_{c_y} = l_1 \sin \theta_1 + l_2 \sin(\theta_1 + \theta_2) + l_3 \sin(\theta_1 + \theta_2 + \theta_3)
\]

Where the values for \( \theta_3 \) and \( l_3 \) consider the spatial offset of the camera.
Vision System

- The already explained calibration and equations were employed in the process detailed in Figure to determine and record the position of the part.
- The same process will later be used to determine the pose accuracy of the SCARA and vision system.

Figure: Flow chart presenting the outline of the process used in the detection of part and determination of its position[13]
Work piece Fastening System

• Figure presents the assembled system, which consists of two stacked Newmark system eTrack linear stages to form an XY cartesian stage, with an accuracy of 60 µm and a travel range of 100 mm.

• Mounted on the XY stage is a stepper motor and 25:1 reduction gearbox which provides actuation and a torque of up to 5.8 Nm to a hex bar, which is used to fasten the screws on the workpiece holder.

• Encoders connected to the stepper motors provide feedback.
Work piece Fastening System

• The placement of the chuck into this subsystem is like the “peg and hole problem” and the placement accuracy must be ±0.25 mm or greater.

• Process used to tighten the four screws on the Erowa chuck using the workpiece fastening system is shown in the figure[13].
Process for loading of the machining center

Figure highlights the basic steps required for loading of machine center.

1. The position of the Erowa chuck is determined using the vision system.

2. The chuck is picked using the Robotiq gripper.

3. The chuck is placed in the workpiece fastening system.

Figure: Basic outline of the process used to assemble the raw material with the Erowa chuck and load this into the machining center[13].
Process for loading of the machining center

4. The SCARA returns to its initial position and the vision system is used to determine the position of the raw material.

5. The raw material is picked using the Robotiq gripper.

6. The raw material is positioned inside the Erowa chuck and the workpiece fastening system is used to tighten the screws thus securing the raw material.

7. The assembled chuck and raw material are picked from the workpiece fastening system and placed on the machining center emulator.
Process for loading of the machining center

• A more detailed outline of the process is presented in the following Figure, which details the flow chart used for the loading process, including error reporting.

Figure: Flow chart of the established process used to assemble the raw material with the Erowa chuck and load this into the machining center\textsuperscript{[13]}
Measurement of pose accuracy

• To measure this the Erowa chuck was imaged at five points within the workspace.

• The aim of this process is to position the SCARA such that the part is centered in the image frame.

• Hence the positioning error is defined from the offset of the part from the center of the frame.

• Fig. (A) presents a schematic representation of how the parts were positioned.
Measurement of pose accuracy

• While (B) presents a scatter plot of the positioning offset in the XY plane.

• It is clear from this plot that the points are positioned in tight clearly defined clusters. Hence, the repeatability of the system is observably high.

• The following equation was used to determine the pose accuracy (AP)

\[
AP = \sqrt{(\bar{x} - x_c)^2 + (\bar{y} - y_c)^2}
\]

• Where \(\bar{x}\) and \(\bar{y}\) are the barycenters of the cluster of points obtained after repeating the pose \(n\) times and are given by

\[
\bar{x} = \frac{1}{n} \sum_{j=1}^{n} x_j, \quad \bar{y} = \frac{1}{n} \sum_{j=1}^{n} y_j
\]
Material handling system integration using a terminal control protocol

• The integration of the material handling system with the advanced machining center is essential.

• However, for logistical reasons it is not possible to have full integration at this stage.

• Hence, to confirm the capability of the systems to be integrated, a terminal control protocol (TCP) was used to send data packets between the two systems.

• It will also send the input parameters to the handling system such as the dimensions and material of the part to be machined.
Material handling system integration using a terminal control protocol

Command protocol

- The command and acknowledge code formats are detailed in the figure.
- When a system initiates a new command to the opposite system, the new command starts with a US dollar sign, followed by a decimal number as the command code.
- If the command requires additional parameters, they are specified after a semicolon and separated by another semicolon.
- All commands are terminated by a Carriage Return.

Figure: Command and acknowledge data formats[13]
Material handling system integration using a terminal control protocol

Data flow

- The following table shows the data flow between the machining center and the material handling system[13].

<table>
<thead>
<tr>
<th>Step no.</th>
<th>Process</th>
<th>Communication Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CNC to Handling System</td>
</tr>
<tr>
<td>1</td>
<td>Send ready command</td>
<td>$1;(CR)</td>
</tr>
<tr>
<td>2</td>
<td>Send acknowledge command</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Send three dimensional part and material type data</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2;XSize;YSize;ZSize;Material;3(CR)</td>
</tr>
<tr>
<td>4</td>
<td>Send acknowledge command</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Send activate handling system command</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Send acknowledge command</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Handling system conducts required process and moves part to CNC machining center</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Send complete command</td>
<td>✓</td>
</tr>
<tr>
<td>9</td>
<td>Send acknowledge command</td>
<td>✓</td>
</tr>
<tr>
<td>10</td>
<td>CNC machining center conducts machining process</td>
<td>-</td>
</tr>
</tbody>
</table>
Summary and future work

• This chapter has detailed the development of a flexible automated material handling system for use with an ultraprecision hybrid machining center.

• The chapter has discussed each component or subsystem in detail along with justification for its use.

• Interpolated equations of calibration have been determined and in all cases a correlation coefficient ($R^2$) of 0.99 was established.

• Processes to detect and determine the position of a part in the workspace, tighten the screws on the Erowa chuck, and load the machining center have been developed and effectively implemented.
Summary and future work

• The pose accuracy has been determined as 0.125 mm. This value is 25 µm greater than that required by the system specification.

• There is a future work point to determine a suitable nonlinear or feed-forward control method to improve this accuracy.

• Finally, a TCP protocol has been developed and implemented to integrate the handling system and machining center.

• Integration of these two systems in future.
References


References


Thank you