Design of Flexible Loading Module for a Connector Assembly

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ABSTRACT
In most recent years, particularly due to the globalization, companies strive to supply their customers with high-quality products with a delivery time as short as possible and at a lower cost. On the other hand, manufacturing systems are switching from mass production to high-variety low-volume products to follow the needs of the customers. Due to such trends, flexibility in manufacturing is critical to accomplish these goals as well as to be quicker to adapt to future changes in customers’ demands. The present work addresses how to introduce flexibility into an existing manufacturing system. Particularly, in the electronics industry, in a robotic connector assembly system. Furthermore, this work not only addresses this problem conceptually but also offers a solution and test it against current machines. A concept for a flexible robotic assembly machine, its design, building and test are outcomes of this work. The flexible robotic assembly module presented makes use of an integrated vision system to load connectors both in loose pieces and trays. Doing so, the proposed module is not only very flexible but also economically more viable than single individual solutions.

Keywords: Flexible Robotic Assembly, Vision Guided Robotics, Flexible Feeding, Conveyor tracking, Connector Assembly;

1 INTRODUCTION
There is nowadays a clear need for flexibility all over in production however, the robotic assembly loading machines were not able yet to follow this need. The problem is that loading machines only process some products or a single product for which they were designed for. The use of conventional feeding methods such as bowl feeders, which are by nature very specialized, makes practically impossible to have flexible loading machines (Causey, Quinn, Barendt, Sargent, & Newman, 1997).

Furthermore, the feeder regardless of its form, can only provide a single product to a conveyor. When the objective is to produce several products instead of just one, different mechanical guidings have to be installed on the feeder each time a different product is produced. This approach results on additional costs in changeover kits and additional time spent for the changeover.

This unproductive time, the fact the current loading modules only process a limited range of products as well as the high costs with changeover kits are the main motivations for this work.

2 RELATED WORK AND FLEXIBLE FEEDING SYSTEM

2.1 FLEXIBLE FEEDING SYSTEM
A typical assembly work cell has the following components:

On the other hand, a flexible robotic assembly work cell:
Nevertheless, the differences are not only on the vision system itself, as mentioned in the introduction, parts feeders are on the most specialized components in the system. Thus, even when employing a modular approach which could make easier to change dedicated feeders in the work cell, several difficulties arise with this approach:

1. Storing space for the feeders;
2. Higher costs, since a specialized feeder is already an expensive component;
3. Higher lead time, i.e., nowadays the delivery time of current feeders is very high, minimum 8 to 10 weeks, making impossible for the work cell to be rapidly adapted to produce new products.

Thus, using current feeding technology behind a generic, modular interface is not a feasible solution because any change to the design of a part requires that the feeder be either reTooled or completely replaced (Gupta & Arora, 2009). With today’s product life cycles as short as a few months for many products, this no longer acceptable.

Therefore, this greater need for flexibility, low cost automation and faster changeover time leads to new approach called “flexible feeding”. So, having a flexible feeder, articulated with a robot which by itself is “flexible” and vision system to “help” the robot taking decisions is what is needed to create a flexible loading system.

### 3 Methodology Used

#### 3.1 Product Portfolio

The Assembly department of Wört produces many different products approximately 1000, between current and old products. It is practically impossible to test all the products due to time, money and human resources that these tests would require.

Thus, there is a clear need to divide these products into suitable categories. As a result, one can test only a few representative products and nevertheless extract useful insights to infer the viability of the future machine.

To achieve this goal, two weeks were spent in the assembly department to gather as many products as possible to make a product portfolio benchmark. Below, can be a summarizing table:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Small</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Small-Medium</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td>Large</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1 - Product Portfolio summarizing table

As a result two products were chosen to make the tests:

1. Product A (Small Category 3)

   Photo not available due to confidential agreement

2. Product B (Large Category 7)

   Photo not available due to confidential agreement

#### 3.2 Target Specifications

The core objectives of this module are:

- Decrease the changeover time;
- Produce different PN’s;
- Increase quality.

The following targets were imposed by management:

1. Loading of loose pieces and trays;
2. Changeover time ≤ 5 min;
3. Cycle time ≤ 10 s (loose piece) and ≤ 10s (product delivered in tray);
4. Increase Quality;
5. Changeover kits Costs ≤ 16.000 € (50 % reduction);
6. Total Cost of module ≤ 200.000 € (loose piece) and ≤ 260.000 € (trays).

### 3.3 Possible Concepts

There might be more concepts for a flexible loading machine, the four presented below are the ones the author thinks makes more sense. In the following diagrams, the blocks show the needed components and the arrows, illustrates the path which the part follows:

**Concept A:**
![Figure 3.3 - Concept A Scheme](image)

**Concept B:**
![Figure 3.4 - Concept B Scheme](image)

**Concept C:**
- Option 1:
![Figure 3.5 - Concept C.1 Scheme](image)
- Option 2:
![Figure 3.6 - Concept C.2 Scheme](image)

**Concept D:**

![Figure 3.7 - Concept D Scheme](image)

### 3.4 Cause and Effect Matrix

Below it is presented a Cause and Effect Matrix (C&E Matrix), where all specifications (i.e. rating to the customer) are given the same importance.

The notes used to classify the different concepts regarding to their importance to the customer are:

- 10 – Best in class
- 3 – Not the best in class, but satisfy the specification
- 1 – Does not satisfy the specification

The reason why the notes are so different is to clearly distinguish which is the best concept among the others.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Changeover time</th>
<th>Cycle time</th>
<th>Quality</th>
<th>Total Cost</th>
<th>Overall Score</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>31</td>
<td>2°</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>31</td>
<td>3°</td>
</tr>
<tr>
<td>C1</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>3</td>
<td>17</td>
<td>4°</td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>22</td>
<td>3°</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>15</td>
<td>5°</td>
</tr>
</tbody>
</table>

*Table 2 - Cause and Effect Matrix from several concepts*

From the C&E Matrix, the concept B surges as the most suitable for our application.

### 3.5 Concept Chosen

The layout of the concept chosen (without the feeder) is below:

*Photo not available due to confidential agreement*
The following table summarizes the choices of each component:

<table>
<thead>
<tr>
<th>Component</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeder</td>
<td>Step Feeder</td>
</tr>
<tr>
<td>Conveyor</td>
<td>Belt Conveyor</td>
</tr>
<tr>
<td>Gripper Unit</td>
<td>Pneumatic Gripper Unit</td>
</tr>
<tr>
<td>Robot</td>
<td>6 axis</td>
</tr>
<tr>
<td>Vision System</td>
<td>Integrated Vision System</td>
</tr>
</tbody>
</table>

Table 3 - Concept chosen components

A step feeder with a width of 200 mm was chosen because it can feed all the parts of the product portfolio and it is a cheaper solution since this is a standard step feeder.

The disadvantage of using a step feeder is that the parts are fed with no particular orientation.

A standard belt conveyor was used instead of a flipping band to reduce the cycle time. Since when using a flipping band, the Robot has always to wait, i.e., at least the robot must wait when the band is shaking to get the parts in the right orientation. Furthermore, the cost of standard belt conveyor is 4x lower than a flipping band.

Concerning the gripper, a pneumatic one was chosen over an electric one. Below are listed several reasons to use a pneumatic gripper unit rather than an electric one:

1. Reliability;
2. Faster actuation times;
3. Force generated vs. gripper’s footprint higher;
4. Less weight;
5. Cheaper (≈ 5x).

Regarding the Robot choice, a 6 axis Robot was preferred to a SCARA Robot, since the parts come to the conveyor in any orientation possible. Thus, the Robot must be able to rotate the parts to correct their orientation which is only possible with a 6 axis Robot.

The final Robot choice was a FANUC LR Mate 200iD because it had a higher payload, horizontal reach, an integrated vision system and financial aspects.

An integrated vision system was chosen instead of conventional one from a known supplier (e.g. Cognex) for the following reasons:

1. No additional work needed to program communication programs;
2. Cheaper solution;
3. Faster cycle time.

A final remark, IR Vision (the integrated vision system from FANUC) was used in this work because it pledged all the application’s requirements. However, it will not always be the best vision solution. It has some limitations and this is why independent vision suppliers, with their experience and high quality products continue to be used in robotic assembly systems.

3.6 MECHANICAL DESIGN

3.6.1 Objectives and Requirements

After the target specifications were set and a concept was chosen, a prototype was designed.

The goals in making this prototype were to:

1. Test the loading process with a 6 axis Robot and Vision System;
2. Test various products;
3. Record cycle times;
4. Draw conclusions on the feasibility of making a final module for future usage in production.

The requirements were:

1. Space available: use of an existing structure place restricted the layout design;
2. Work envelope from the robot;
3. Being able to recognize part’s features (e.g. dome).

3.6.2 Layout Design

There are some general constraints when designing a robotic assembly cell:

1. The Robot Envelope: area where the Robot can operate;
2. Vision Requirements:
   a. Magnification needed;
   b. Camera Resolution;
   c. Field of View;
   d. Working Distance necessary.
3. Lighting used.

Regarding to Vision, there are several parameters which dictate the success of a vision application. Thus, the author created the scheme below for better understanding of how a vision system works and to make better decisions when facing problems in a real application.
Figure 3.9 - Decision scheme designed by the author to choose suitable parameters for a vision system

To illustrate the use of this diagram and assuming that lighting is not a problem, let us suppose that we cannot recognize a feature in a part in our application. In principle one of two things can occur, either:

1. The magnification is not sufficient;
2. There is too much distortion in the parts on the corners of the Field of View;

The possible solutions are:

1. Increase the magnification: which can be done either by changing the camera (increasing resolution) or reducing the FOV;
2. Reducing distortion: that can be done by reducing the FOV (reducing the working distance) or increasing the focal length (changing the objective).

In this application since it is a conveyor tracking application, one need to take into account that the FOV should be at least 2x the largest dimension of the part. This happens because the trigger is given by encoder counts (then converted to mm). This fact is illustrated in the picture below:

Concerning the objective, its choice was done taken into consideration the working distance, lighting intensity, and the distortion effects.

3.6.3 Gripper Design
The following factors should be taken into consideration when designing gripper fingers (guidelines adapted from (Causey & Quinn, 1998)):

1. Minimize Gripper Footprint: the three dimensional space which must be free of obstructions for a gripper to successfully grasp a part;
2. Chamfer the Exterior of the Fingers: this enables the gripper to grasp a part, even when there are parts nearby. As a result, when approaching the part it will move the nearby parts away;
3. Minimize Gripper Weight: minimizing the gripper’s weight, minimizes also the payload on the wrist of the robot, which leads to the Robot to accelerate more quickly;
4. Minimize Finger Length: the longer the fingers, more are they going to deflect. Thus, the face of the finger which is contact with the part, is no longer properly aligned and so the quality of the gripping is deteriorated.

Moreover, when designing a gripper, first one must look at the part and what is the function that the Robot has to perform with it:

- Function: to load the part onto a product carrier;
- Part Configuration: the part can appear under the Robot in two possible configurations (face up or face down).

As a result it was decided to choose an area which was possible to grip in both directions, so that only one gripper is used. The following pictures illustrate exactly the gripping area chosen:

Photo not available due to confidential agreement

Figure 3.10 - Part seen by the camera in two different time instances

Figure 3.11 - Part’s Top View (Correct orientation)

Photo not available due to confidential agreement

Figure 3.12 - Part’s Bottom View (Wrong orientation)
3.7 PROGRAMMING LANGUAGE

FANUC robots are teaching-playback robots, i.e., specific tasks are taught to robots in advance, which then are executed exactly as they were taught.

The Fanuc programming language is known by a Teach Pendant Programming (TPP), however it is also possible to program in a high-level language known as Karel. Although, this high level language is also provided by FANUC, on more than 90% of the applications, the customers still use the Teach Pendant to write their Robot’s programs.

TPP was the language used to program the FANUC Robot. At first, one could argue that programming in a high-level language like Karel would be better than in a low-level language as TPP but there are also other factors which should be taken into account:

1. Karel was not designed to program directly the Robot, i.e., the motion controls are exactly the same as in TPP;
2. Karel has no advantage comparing to the TPP language besides the fact that it allows to make communication with external devices easier. No external components were used in the module that required the use of Karel, so Karel was not used to program the robot;
3. Karel is a high-level language like C++, Java among others so it requires more time to learn than the TPP language;
4. When programming a robot for a pick and place application, the robot programmer needs to teach the pick and place positions, part’s reference positions and Robot frames locally, i.e. at the module, because there are always differences between a CAD Module and its physical module. So, there is no advantage of writing a program offline and then loaded onto the Robot controller because it will simply not work and one will need again to teach the positions with the Teach Pendant.

3.8 PSEUDO CODE

Example of a pseudo code for a Conveyor Tracking application:

```
// declaration of variables
Speed = constant; // % of maximum possible speed used
Payload [constant]
Digital_Output[constant]=ON; // open gripper
Parts_counter = 0; // R[constant:parts_counter]=0;
Cycle_stop=0; // R[constant:cycle_stop]=0;

// program
Call PKSGETID // checks if the conveyor is running
Standby position // move to standby position
Call PKWCSTART // starts the vision process

LBL [100]
Standby position // move to standby position
Call Picks
if (cycle_stop==1)
    JMP LBL [900]
if (Model_ID==1)
    Call Places
else
    JMP LBL [900]
if (cycle_stop==1)
    JMP LBL [900]
JMP LBL [100]

LBL [900]
Call PKWCEND // ends the vision process
```

4 RESULTS AND DISCUSSION

4.1 CONVEYOR TRACKING

4.1.1 Objectives and Parameters used
The objectives for this stage of tests were:

1. Prove that the conveyor tracking works;
2. Meet a cycle time of 10s;
3. Make the loading process robust.

In the table below are described the parameters used:

| Objective focal length | 35 mm |
| Field Resolution       | 1.3 MP (sensor size: 1/2”) |
| Field of View          | 160 x 128 mm |
| Working distance       | 910 mm |
| Magnification          | 0.125 mm/pixel |
| Lighting               | Direct illumination |
| Filter                 | None |
| Average conveyor speed | 300 mm/s (18 m/min) |

*Table 4 - Parameters used for the conveyor tracking application*
4.1.2 Layout

*Photo not available due to confidential agreement*

4.1.3 Lessons Learned

After the tests lessons learned were taken and the chart below describes the list of problems identified and solutions suggested:

*Table not available due to confidential agreement*

The major problem was really the first one since there was not much which could have been done to try to solve it using the same motor. To sum up, there are three types of error in a conveyor tracking application:

1. Calibration error: the calibration has always an error, as minimum as it can be;
2. Reference error: when one teaches the reference part position under the camera;
3. Dynamic error: is originated because of speed of the conveyor is not constant.

4.1.4 Results and Costs

As result from tests the cycle time required (≤ 10s) was achieved. Below are described the components of the cycle time:

| Camera detection time: 0.9-1 s | Movement from the Robot: 4.5 to 5 s | Total Cycle Time: 5.5 to 6 s |

The differences in the cycle time are justifiable since the part can lay down in both orientations. When the part lays in the wrong orientation, the robot has to rotate on the 6 axis 180° to correct its orientation for placing onto the product carrier.

Regarding costs, the objective was also achieved since the final cost of the module is approximately 200.000 € below than the target of 180.000€. In the table below, the costs are explained:

*Table 6 - Module Costs for loading loosepieces*

4.2 Static Vision with Trays

4.2.1 Objectives and Parameters Used

In the second stage of tests, several modifications were done to the module so that it allowed loading trays.

Having a modular loading machine which can load both trays and single pieces is a great advantage to a company, since there is more flexibility in the products it can load and additional it is economically more viable.

The objectives for the second stage of tests were:

1. Check if the gripper works properly;
2. Test to load the trays with different roll angles;
3. Meet a cycle time of 10s or less;
4. Make the loading process robust.

In the table below are described the parameters used:

<table>
<thead>
<tr>
<th>Objective</th>
<th>35 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera Resolution</td>
<td>1.3 MP (sensor size: 1/2&quot;)</td>
</tr>
<tr>
<td>Field of View</td>
<td>320 x 256 mm</td>
</tr>
<tr>
<td>Working distance</td>
<td>1785 mm</td>
</tr>
<tr>
<td>Magnification</td>
<td>0.250 mm/pixel</td>
</tr>
<tr>
<td>Lighting</td>
<td>Black field illumination</td>
</tr>
<tr>
<td>Filter</td>
<td>None</td>
</tr>
</tbody>
</table>

*Table 7 - Parameters used for the 2nd phase of tests*

4.2.2 Layout

*Photo not available due to confidential agreement*
4.2.3 Lessons learned
Lessons learned were taken on how to load parts from trays. The chart below describes the list of problems identified and solutions suggested:

Table not available due to confidential agreement

Table 8 - Summarizing table of problems and solutions from the 2nd phase of tests

In the first problem, nothing can be done to change the working distance needed between the camera and the object. However, the conveyor can be at lower level and as result the camera will also be at a lower height.

Regarding the second problem, in the tests it was not possible to see the reference pins which would have helped to teach the reference part position. So, when teaching the part, lines were drawn so that it would be possible to grip it.

4.2.4 Results and Costs
As result from tests the cycle time required ($\leq 10$ s) was achieved. Below are described the components of the cycle time:

![Figure 4.5 - Cycle time components](image)

The costs are explained in the table below:

Table not available due to confidential agreement

Table 10 - Module Costs for trays

5 Conclusions and Future Developments

5.1 Conclusions
This work’s objective of building a testing flexible loading module was fulfilled. Not only it was proved that conveyor tracking works enabling the module to load loose pieces with almost zero changeover time but also it was proved that the same module could handle both single pieces and trays.

Key business goals and technical specifications were fulfilled as shown in the table below:

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Flexible Loading Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>$2^{nd}$ Quarter of 2015 (till June)</td>
</tr>
<tr>
<td>Average changeover time</td>
<td>$\leq 50$ min</td>
</tr>
<tr>
<td>Changeover kits costs</td>
<td>32.000 €</td>
</tr>
<tr>
<td>Total module costs</td>
<td>200.000 €</td>
</tr>
<tr>
<td>Cycle time (loose piece)</td>
<td>10 s</td>
</tr>
</tbody>
</table>

Table 11 - Comparison table

Increasing the current quality was also a requirement and this will be accomplished because the robot will always load the parts onto the product carrier in the correct orientation. No matter the orientation parts have when entering the conveyor, they will always be loaded in the correct way.

At the beginning of this study, loading trays was not an objective but, designing a modular flexible loading module made it also possible. Furthermore, the growing need for cheaper palletizing modules was the main motivation for its implementation.

So, in the case of loading trays, both costs and cycle time were also fulfilled:

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Flexible Loading Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>260.000 €</td>
</tr>
<tr>
<td>Cycle time (loose piece)</td>
<td>10 s</td>
</tr>
</tbody>
</table>

Table 12 - Comparison table

This module has some great advantages which cannot be undervalued:

- Great flexibility: loads both loose pieces and trays;
- Modular Concept: starting with one version of the module (either loose pieces or trays) is always possible to upgrade for a complete version which loads both type of products;
5.2 **FUTURE DEVELOPMENTS**

A flexible loading module was developed and tested for both single pieces and trays, nevertheless there are still improvements which can be done for accelerating the designing process, evaluating the full capabilities of the module within product portfolio range and to increase its reliability.

The following points are suggestions for future work:

1. **Gripper Design:**
   a. Test Schunk eGrip Design Software;
   b. Test designing grippers for 3D Printers;
2. **Feeder and Conveyor System:** Access the possibility of designing a conveyor with a flipping area and a backlight;
3. **Module Capabilities and Reliability:** Test more products to create a product portfolio with:
   a. Which products can be produced?
   b. Respective cycle time.

**REFERENCES**


