Testing and Analysis of a Flexible Feeding System
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Abstract
Flexible parts feeding techniques have recently begun to gain industry acceptance. However, one barrier to effective flexible feeding solutions is a dearth of knowledge of the underlying dynamics involved in flexible part feeders. This paper presents the results of testing the CWRU flexible parts feeder. Data was collected for extended periods while feeding a variety of parts. The data was examined to determine throughput and statistical properties. In addition, tests were performed to examine other aspects of the system. A new metric for specifying the throughput of vision-based flexible feeders is presented, interesting system phenomena is examined, and a statistical analysis of the data is performed.

1 Introduction

Automated manufacturing is undergoing a paradigm shift. Previously it was equated with dedicated systems producing large volumes of a single product at high speed. In the past few years it has changed to one which demands a flexible, reconfigurable system capable of producing a wide variety of products in small lot sizes as well as being capable of accepting the rapid introduction of new products. A major component of such a system is a flexible parts feeder.

![Schematic of the CWRU Flexible Feeder](image)

While a small number of reconfigurable parts feeders have been brought to market [1,2,3,4,5,6,7,8,9] or patented [10,11,12,13,14], there has been little research in the underlying principles governing the dynamics of such systems. Several papers have discussed methods of static and dynamic simulation [15,16,17]. All these efforts estimate throughput by simulating the tumbling of parts rather than gaining an understanding of why the system performs as it does. Goldberg and Gunmundsson [18] attempted to determine the best setting for relative conveyor speeds in an Adept FlexFeeder by examining a 2-D model of the system coupled with statistical part distribution. Goldberg et al. [19] outline how the throughput of a feeder may be estimated using the probability of stable part poses, conveyor speed, and robot cycle time. Again, their research did not examine the underlying dynamics governing the operation of the feeder.

This paper presents the results of testing the CWRU flexible parts feeder (shown schematically in Figure 1), whose design has been published previously [20,21,22,23]. First, a new metric for specifying the throughput of a flexible feeder is presented. Second, the throughput of the system for a variety of parts is presented. Next, interesting system behavior observed in the test data is discussed. Finally, a statistical analysis of the data is performed. For all following sections, see [23] for more details.

2 System Testing

During automated testing, the system was programmed to run continuously to allow data to be collected for extended, unattended periods. Parts which were retrieved from the feeder were simply dropped onto the return feeder and recirculated. Data collected included the time duration of all portions of the feeding cycle (feeder advance time, vision processing time, robot motion time), the total run time, the number of parts fed, and (when multiple parts were being fed at once) the type of part retrieved. The entire operation proceeded serially during testing. First the vision system would take a picture and identify a valid part. Next the robot would retrieve the part, then the vision system would look for another part. If a new part was not found, the feeder would advance and the vision system would again search for a part.

System throughput tests of six hour duration were performed on a variety of different parts. During this testing, no physical parameters of the feeder were altered. Control software was changed depending on the parts being fed. Angle dependence tests were performed to examine the effect of the angle of the inclined conveyor on the overall system throughput. A "slow robot" test was conducted to determine the effect of running one component of the feeder at a different rate. Lastly, an endurance test was performed to determine the reliability of the system over time and to determine the robustness of the system to mechanical jams.

Parts used for testing consisted of a mixture of 3/4" and 5/16" hex nuts, plastic snap rings (approximately...
$1\frac{3}{4}''$ in diameter and $\frac{3}{4}''$ in cross-section), plastic sockets (approximately $\frac{3}{4}''$ on a side by 1'' long), and clear plastic disks (approximately 2$\frac{3}{4}''$ in diameter and $\frac{3}{8}''$ thick) with black rims (see Figure 2).

After the data was collected, it was post-processed before further examination. The data was converted from a time per part to parts per minute (PPM). This was accomplished by moving a five-minute-wide window over the data and determining the average PPM inside that window. The act of converting the data from time per part to parts per time had a smoothing effect. Five minutes was chosen as a compromise window size so that short term system behavior would not be missed due to undue smoothing.

3 Results

3.1 A Metric for Feeder Evaluation

Reporting results on the throughput of a flexible parts feeder requires a redefinition of the standard parameters used previously to qualify feeders. Unlike a bowl feeder, a typical flexible feeder is composed of several major components (a mechanism to present quasi-singulated parts, a vision system to determine the location of graspable parts, and a mechanism for removing those parts from the system). Simply stating a number as the throughput of the feeder doesn’t indicate the relative speed of each system component or pinpoint possible bottlenecks.

To report on the throughput of the feeder the following four different parameters will be used.

1. Overall throughput
2. Throughput of the parts presentation system
3. Throughput of the vision system
4. Throughput of the parts removal system

The overall throughput is the standard feeder parameter. This is a measure of how many parts are removed from the system in a certain amount of time. The throughput of the parts presentation system is a measure of the physical capability of the system to present singulated parts to the workcell. The throughput of the vision system is an indication of the speed of the vision system in locating candidate parts. The throughput of the part removal system is an indication of how fast the parts can be removed from the vision window.

3.2 Throughput Results

3.2.1 Snap Rings, Disks, Sockets

In the first three tests, snap rings, disks, and sockets were fed (individually) respectively. The average and standard deviation of each parts’ throughput is shown in Tables 1-3. All values are in parts per minute.

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>12.65</td>
<td>51.51</td>
<td>31.94</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.49</td>
<td>4.80</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Table 1: Throughput of Snap Rings

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>10.52</td>
<td>31.71</td>
<td>27.40</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.80</td>
<td>4.00</td>
<td>2.52</td>
</tr>
</tbody>
</table>

Table 2: Throughput of Plastic Disks

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>18.56</td>
<td>111.07</td>
<td>69.40</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.69</td>
<td>17.43</td>
<td>3.38</td>
</tr>
</tbody>
</table>

Table 3: Throughput of the Plastic Sockets

3.2.2 Nuts: $\frac{5}{16}''$ and $\frac{3}{8}''$

Two tests were performed using a combination of $\frac{5}{16}''$ and $\frac{3}{8}''$ hex nuts. Tables 4 and 5 show the results of the first and second test. Table 6 shows the results from the second test, broken out by individual part throughput (while still feeding both parts).

In Table 6, the overall and robot motion throughputs are shown. It was impossible to determine the throughput for the vision and conveyor sub-systems for individual parts. For example, while a single advance may have brought multiple parts into the vision window, only the first part retrieved was assigned the time for the conveyor advance.

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>19.50</td>
<td>189.34</td>
<td>59.73</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.95</td>
<td>48.46</td>
<td>5.67</td>
</tr>
</tbody>
</table>

Table 4: Throughput of Hex Nuts - Test 1

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>21.37</td>
<td>237.58</td>
<td>77.78</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.43</td>
<td>34.62</td>
<td>4.56</td>
</tr>
</tbody>
</table>

Table 5: Throughput of Hex Nuts - Test 2

Figure 3 shows the average throughput for the feeder and its sub-systems during the first test. Figure 4 shows the overall system throughput and the individual part throughput during the second test. The individual throughputs are shown for a shortened time period and were generated using a window of 30 minutes length to more clearly show the relationship between the feeding rates of the two parts.

An interesting feature can be seen in the overall throughput graph (Figure 3). A drastic drop in the throughput of the system can be seen at approximately 40 minutes. This was due to a lack of sufficient parts in the
system. Over time, the parts were distributed throughout the system more evenly, therefore the overall throughput of the system stabilized. This also had the effect of causing the throughput of the conveyor sub-system to vary, as seen in the upper right plot.

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot; Nuts</td>
<td>11.48</td>
<td>33.84</td>
</tr>
<tr>
<td>Average</td>
<td>9.89</td>
<td>33.95</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.46</td>
<td>0.21</td>
</tr>
<tr>
<td>5/16&quot; Nuts</td>
<td>11.48</td>
<td>33.84</td>
</tr>
<tr>
<td>Average</td>
<td>9.89</td>
<td>33.95</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.46</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Table 6: Individual Throughput when Feeding Mixed Hex Nuts

The second test occurred approximately 60 hours of operation after the first, which had the effect of further reducing the variation in system throughput. The right hand graph of Figure 4 shows the interaction of the two different-sized parts (top line: 5/16" nuts, bottom line: 3/8" nuts). As one of the part’s throughput increases, the corresponding throughput of the other part decreases. Since the size of the presentation window is constant, it follows that if more of one part is present then less of the other part will be present.

Since there were an equal number of parts placed in the bin, it was expected that the average feed rate for each part would be the same. However, as seen in the right-hand plot of Figure 4, this was not the case. A possible explanation for this behavior is the relative stability of each part (nuts resting on their sides are undesirable). So, a third test was conducted using the same parameters with the addition of a pause programmed into the controller to halt the system after each part was retrieved which allowed the number of parts on the horizontal conveyor and the number of parts retrieved to be manually counted.

<table>
<thead>
<tr>
<th>Mixed Nuts</th>
<th>Overall</th>
<th>3/8&quot;</th>
<th>5/16&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Parts on Edge</td>
<td>15.6%</td>
<td>21.0%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Percentage Parts Fed</td>
<td>73.4%</td>
<td>69.5%</td>
<td>77.1%</td>
</tr>
</tbody>
</table>

Table 7: Statistical Data from Manual Nut Test

From the data, it is clear that the 3/8" nuts are more prone to standing on edge (21% vs. 10.4%) and that the percentage of parts removed by the robot is higher for the 5/16" nuts (77.1% vs. 69.5%).

Figure 3: Feeder Throughput for the 5/16" and 3/8" Hex Nuts

3.2.3 Mixed Nuts and Plastic Sockets

Finally, two tests were performed using a combination of hex nuts and plastic sockets. These tests were interesting because the parts themselves were of different material and geometry; the nuts were steel and relatively flat while the sockets were plastic and more box-like.

Table 9 shows overall system throughput and Table 10 shows individual part throughput. Figure 5 shows the

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>20.82</td>
<td>254.85</td>
<td>68.90</td>
<td>34.03</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.52</td>
<td>33.61</td>
<td>4.70</td>
<td>0.35</td>
</tr>
<tr>
<td>TEST 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>20.79</td>
<td>291.74</td>
<td>66.98</td>
<td>33.87</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.55</td>
<td>35.68</td>
<td>5.14</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 9: Throughput of the System Feeding All Parts

The lower plots show that further mixing of the parts occurred between the tests (performed about a week apart).

Figure 4: Feeder Throughput for the 5/16" and 3/8" Hex Nuts overall system and individual part throughputs for the two tests. As with the previous test, a 30-minute window was used to generate the individual throughput plots (top line: 5/16" nuts, middle line: 3/8" nuts, bottom line: sockets).

From this table, it is clear that approximately the same number of parts are being spilled onto the horizontal conveyor from the inclined conveyor (48.3% vs. 51.7%). The percentages of parts fed during both the manual test and test 2 correlate well. Therefore, the differences in the throughput of each size nut can be attributed to their relative stability.

Table 8: Percentage of Each Type of Nut
To reflect a typical assembly requirement, two tests were conducted: one in which the parts were fed in a particular order (in this case, \( \frac{3}{8}\)" nut, \( \frac{1}{16}\)" nut, socket, \( 36^\circ\) nut, etc.) and another in which only one part was fed with all the parts in the bin. Tables 11 and 12 show the respective results.

<table>
<thead>
<tr>
<th>Overall</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST 1</td>
<td>TEST 2</td>
</tr>
</tbody>
</table>

Table 10: Individual Part Throughput When All Parts Fed

Intuitively, it would be expected that altering the angle of the inclined conveyor would cause system throughput to range from 0 (the conveyor too steep for any parts to advance) to some nominal value (the conveyor set to an angle of \( 0^\circ \)) with the maximum at some angle between these two extremes. If the conveyor is at too shallow of an angle, too many parts will be spilled onto the presentation conveyor, thereby reducing part singulation. A mixture of nuts and sockets were fed and data was collected for 2.5 hours per angle.

The angles tested were \( 32^\circ \), \( 34^\circ \), \( 36^\circ \), and \( 38^\circ \). Testing of other angles was not straightforward due to mechanical limitations of the construction of the current feeder. Table 13 shows system throughput for the tests.

![Graphs showing overall and individual throughput with multiple parts in the feeder](image)

Figure 5: Overall and Individual Throughput with Multiple Parts in the Feeder

3.3 Angle Dependence Test

One of the many parameters that contribute to the overall throughput of the system is the angle of the inclined conveyor with respect to the horizontal.

![Graphs showing overall and individual throughput with multiple parts in the feeder](image)

Table 12: System Throughput Feeding Individual Parts

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST 1</td>
<td>TEST 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11: System Throughput Feeding Parts in a Specific Order

The test was identical to the one described in Section 3.2.3. The only change was in the speed of the robot (from 130% to 10% of its nominal speed).

Table 14: Throughput of the System with the Robot Slow

3.5 Endurance Test

An endurance test was performed to determine the ability of the system to feed parts for a long period of time without jamming or human intervention. Data was
analyzed in discrete 30-minute windows to reduce computation time.

A mixture of nuts and plastic sockets were fed. Total run time for the test was about 3 days 9 hours. During that time the system fed over 150,000 parts without intervention. Table 15 shows the throughput of the system and its components.

<table>
<thead>
<tr>
<th>Overall</th>
<th>Conveyor</th>
<th>Vision System</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>31.38</td>
<td>424.60</td>
<td>107.80</td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.20</td>
<td>22.10</td>
<td>2.07</td>
</tr>
</tbody>
</table>

Table 15: Throughput of the System During Extended Testing

When comparing the results with those reported in Table 9, a major increase (about a 60% increase) in the throughput of the system can be seen, which was obtained by altering system parameters and control code.

3.6 Other Observations

3.6.1 Effects of Part Size on Throughput

System throughput versus part size is examined in Table 16.

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Major Dimension</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuts and Sockets</td>
<td>0.850**</td>
<td>20.7 ppm</td>
</tr>
<tr>
<td>Mixed Nuts</td>
<td>0.640**</td>
<td>19.4 ppm</td>
</tr>
<tr>
<td>Plastic Sockets</td>
<td>0.850**</td>
<td>18.5 ppm</td>
</tr>
<tr>
<td>Plastic Snap Rings</td>
<td>1.700**</td>
<td>12.6 ppm</td>
</tr>
<tr>
<td>Clear Plastic Disks</td>
<td>2.100**</td>
<td>10.5 ppm</td>
</tr>
</tbody>
</table>

Table 16: Major Part Dimension and System Throughput

Clearly, higher throughputs can be expected for smaller parts. A better indicator of the effect of part size on the throughput of the system may be to examine the number of conveyor increments made during operation. Figure 6 shows this for plastic disks and mixed nuts and sockets. A zero indicates that no conveyor move was necessary to acquire the next part (i.e., it was already in the vision window). When examining the graph for the mixed nuts and retainer, it can be seen that no conveyor move was necessary when retrieving over 5000 parts and only a single move was necessary when retrieving approximately 2000 additional parts.

3.6.2 System Throughput Oscillations

While examining the extended test data, interesting oscillations in individual part throughput were noticed. Figure 7 shows the individual part throughput for two 6 1/2 hour windows during the test (3-3/4" nuts, 1-3/4" nuts, \* - sockets). The top plot begins by showing a strong anti-phase relationship between the two sizes of nuts. By the end of the window, however, the phase between the two sizes of nuts is beginning to align while the sockets have begun oscillating out of phase with the 3/4" nuts. Examining the bottom plot shows the 3/4" nuts and sockets are anti-phase while the 3/8" nuts are feeding at a consistent rate. However, by the end of the window, the 3/8" nuts are beginning to oscillate out of phase with the 3/4" nuts and the amplitude of the oscillations of the sockets seems to be diminishing.

3.6.3 Jumps in the Variation of System Throughput

Another phenomenon noticed while examining the test data from Sections 3.2.2 and 3.2.3 was sudden jumps in the variation of system throughput. Figure 8 shows the throughput of each part versus time for the extended test (Section 3.2.3). There is a jump in the magnitude of the oscillations of the 3/8" nuts at approximately 2200 minutes and a jump in the oscillations of the 3/4" nuts at approximately 1500 minute, however, no jump was seen in socket throughput.
Next, the data from Section 3.2.2, second test was further examined as shown in Figure 9. Again, a reduction in the oscillations of the throughput of each part is seen (at about 500 minutes). In this case, however, both the parts display the jump at the same time.

The phenomena of jumping between two seemingly stable operating regions is a characteristic of a nonlinear system. It is important to determine the underlying dynamics which are causing this to happen so that the variation in the throughput of the system may be reduced.

![Figure 9: Individual Part Throughput - Second Mixed Nut Test](image)

3.7 Statistical Properties of the Feeder

Statistical distributions associated with the test data are first examined followed by a discussion of determining system properties when only sub-system properties are known. Lastly, the correlation between the sub-systems is investigated. In all statistical distribution figures, a solid line represents the ideal distribution while a dashed line or histogram represents experimental data.

3.7.1 Statistical Distribution

The Poisson distribution is a common model of discrete arrival processes. Hence, it (shifted from 0 by the minimum part retrieval time) appears a logical choice for modeling the Overall System Throughput. In this case, the times between retrievals (also called interarrival times) are exponentially distributed. Therefore, a test of the fit of an exponential distribution to these interarrival times must be examined. Figure 12 shows the cumulative distribution function (CDF) for several test parts.

Examining the graphs, it is clear that the exponential distribution does fit the data, which can therefore be modeled by a time-shifted Poisson process. This agrees with the distribution used in [18].

The Conveyor Sub-system is unique in that its data is very discrete. It takes a repeatable amount of time to advance the conveyor, therefore the possible move intervals can only be combinations of those times. Again, an exponential distribution was fit to the data. In this case, there was no minimum part retrieval time since it was possible for the next part which was removed from the system to require no conveyor advance. Figure 10 shows an exponential distribution fit to the mixed nuts and plastic snap rings. As with the overall system case, the data fit an exponential well. Therefore the throughput of the conveyor can also be modeled as a Poisson process.

The Vision Sub-system is unique in that there is a minimum process time (for an empty window), to which is added the time required to find a part. The vision processing time depends on many factors including the complexity of the part and associated vision algorithms, the number of parts in the window, the location of the part in the window, and the speed of the vision system. An exponential distribution was fit to the data to see if the process could be modeled as Poisson. Figure 11 shows the mixed nuts and plastic snap rings fit with this distribution. As can be seen, the exponential again fits the data well. It can therefore be concluded that the vision system may also be modeled as a time-shifted Poisson process.

It was expected that the times for the Part Manipulator (robot) to retrieve parts would be normally distributed. Figure 13 shows the mixed nuts and sockets

![Figure 10: Conveyor System CDF's](image)

![Figure 11: Vision System CDF's](image)

![Figure 12: CDF for Overall throughput vs. Exponential Dist.](image)
Average System Throughput: First, the mean of the overall system in terms of the 1st order interarrival times (in PPM) can be expressed as

\[
\mu_{F_{\text{rev}}} = n / \sum_{i=0}^{n} F_i
\]  

(3)

After writing the average throughput of each sub-system and substituting these and (1) into (3), the equation for the average system throughput in terms of the average sub-system throughputs is

\[
\mu_{F_{\text{rev}}} = 1 / (\mu_{C_{\text{rev}}}^{-1} + \mu_{V_{\text{rev}}}^{-1} + \mu_{R_{\text{rev}}}^{-1})
\]  

(4)

Variance of the 1st Order Interarrival Time: The population variance of the system is determined using the standard formula [24]. Substituting (1) and (2) into the standard formula and rearranging yields the system variance in terms of the sub-system variances:

\[
\sigma_{F_{\text{rev}}}^2 = \sigma_{C_{\text{rev}}}^2 + \sigma_{V_{\text{rev}}}^2 + \sigma_{R_{\text{rev}}}^2 - 2 \left[ \text{Cov}(C,F) + \text{Cov}(C,R) + \text{Cov}(V,F) \right]
\]  

(5)

Variance of the Average Throughput: In this case, one can write an equation for the system variance, but it cannot be partitioned into an equation depending only on the sub-system variances and covariances (as in (5)).

3.7.3 Correlation Between Sub-systems of the Feeder

There are three sub-systems in the feeder (conveyor, vision system, robot) and therefore there are three possible sub-system interactions. A correlation coefficient is determined for each, shown in Table 17.

It is clear that there is a fairly strong relationship between the conveyor and the vision system while there is very little correlation between the robot and either the conveyor or vision system.
<table>
<thead>
<tr>
<th></th>
<th>Snap Rings</th>
<th>Disks</th>
<th>Sockets</th>
<th>Mixed Nuts</th>
<th>Mixed Nuts and Sockets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vision vs. Feeder</td>
<td>0.8210</td>
<td>0.8841</td>
<td>0.8696</td>
<td>0.5696</td>
<td>0.4494</td>
</tr>
<tr>
<td>Vision vs. Robot</td>
<td>-0.0205</td>
<td>-0.0460</td>
<td>-0.1257</td>
<td>-0.1452</td>
<td>-0.1329</td>
</tr>
<tr>
<td>Feeder vs. Robot</td>
<td>0.0139</td>
<td>-0.0555</td>
<td>-0.1297</td>
<td>-0.1435</td>
<td>-0.1102</td>
</tr>
</tbody>
</table>

Table 17: Correlation Coefficients from Feeder Tests

By examining the serial mode of operation of the feeder, shown in pseudo code:

While (Part Found == False) [Advance the Feeder]
Return the Part Location

an explanation of the dependence between the feeder and the vision system is possible. The advancement of the feeder is signaled by the vision system, but to determine if an advance is necessary, the vision system must take a picture. This leads to two pictures for each conveyor advance. Hence, in general, when the vision time is large, the conveyor advance time will also be large.

4 Conclusions

Preliminary testing has been performed on the CWRU flexible feeder using several different parts. A new metric has been constructed to better describe the throughput of a vision-based flexible parts feeder. Testing has shown throughputs between 10 to 30 parts per minute for a variety of parts. The system was shown to be nonlinear and it displayed jump phenomena. A statistical analysis was also performed. An exponential distribution fit the overall system, conveyor sub-system, and vision processing sub-system while a normal distribution fit the robot sub-system. When the data was converted into average parts per minute, all the data was fit by a normal distribution. It was shown that the average throughput and 1st order interarrival times could be determined from knowing the properties of the subsystems. However, the variances of the average throughput and 1st order interarrival times could not be determined from knowing the properties of the subsystems. Finally, it was determined that the conveyor and vision sub-systems are inter-related while the robot is mostly independent of other sub-systems.

Acknowledgments

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References