# Visual Line Tracking

# Application Overview

# & Issues

## Machine Vision for
## Robot Guidance Workshop

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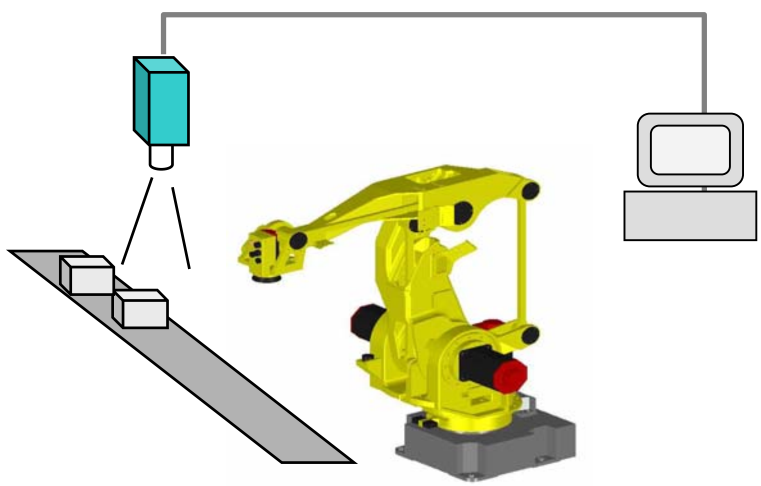
# 1 Background

Machine vision has been used with robots doing line tracking for several years.

Typical applications include:

- Pick and Place of non-fixtured parts
- Sorting of non-fixtured parts
- Placement of parts onto fixtures on a moving conveyor

The typical system is:



The typical system has the following components:

1. Conveyor system with parts
2. Fixed Camera and Vision system
3. Industrial Robot

The typical application in the manufacturing environment does not have a high throughput or performance requirement. Typically one robot with one camera can handle the line rates of 10 to 20 parts per minute.

Other markets (such as the distribution and packaging of consumer goods and food products) have significantly faster rates (100 to 300 parts per minute) and require higher performance. In the past, selected high speed or specialized robots were the only solutions available. The vision, robot, and computer hardware performance has been increasing where these applications are now achievable and justifiable with standard components.

But these applications present some different engineering problems and considerations.

This paper will present:

- Component requirements for Visual line tracking
- Considerations for the engineering and analysis of the high performance visual line tracking application.

The performance data that is presented is intended as a trend of what you might see. You must take the conditions of the any proposed project and solution into consideration when using these guidelines. Other aspects of vision and robot programming will have an impact on what can be expected from any cell.

The performance topics discussed include:

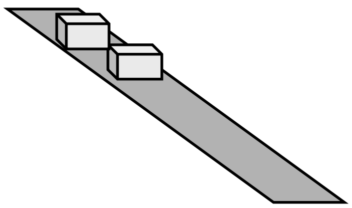
- Why scan time is Important
- Impact of # parts in Field of View (FOV)
- Impact of display/plot controls
- Impact of number of robots
- Impact of PC speed
- Considerations for FOV and conveyor speed
- Maximum Throughput discussion

# 1 System Components

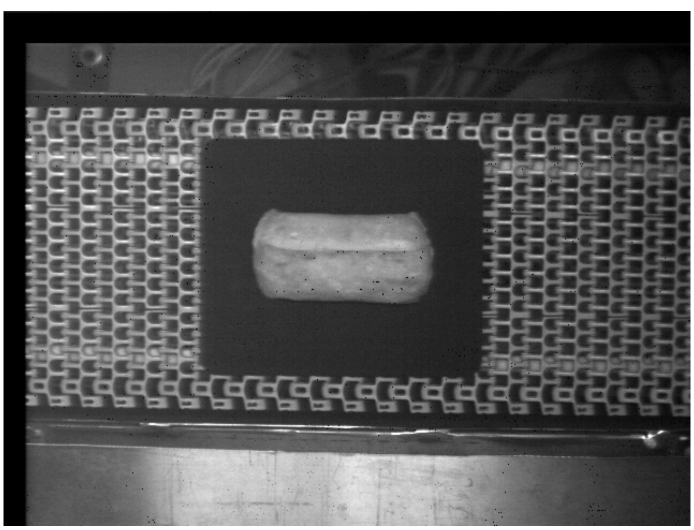
The typical system has the following components:

- Conveyor system
- Fixed Camera and Vision system
- Queuing System
- Industrial Robot

## 1.1 Conveyor System



The conveyor system must provide a good background for the vision system. Webbed conveyors (as shown in the picture) can present vision problem, especially if the conveyor and part colors are similar. In this example, the part had to be placed on a mouse-pad to achieve acceptable training results.



The conveyor must be reasonably consistent in the actual movement. That is to say, there should not be a lot of slack in the drive mechanism so that the conveyor jerks forward at times.

It must also provide an encoder input (motor position) so that the conveyor position of the time of the vision acquire can be recorded. This is critical to the accuracy of the part pickup.

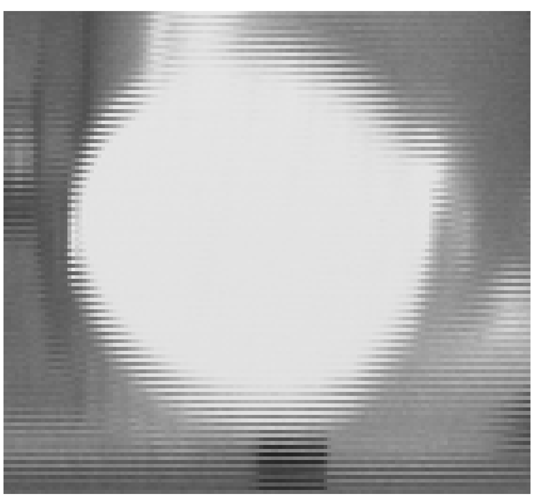
# 1.2 Fixed Camera and Vision system

The vision system has the following requirements:

- Progressive scan camera
- High speed communication method to robot
- Calibration software to match the vision frame with the tracking frame of the robot.
- Means to acquire conveyor position at time of vision acquire (1 of two methods)
    - Hardware pulse at the time of the vision acquire (to trigger a robot program)
    - Direct reading of encoder

A progressive scan camera is important to reduce the impact of a moving part. With a regular camera, the image can appear blurry due to the speed of the part. A higher shutter speed can reduce the impact, but will not totally eliminate it. Depending on the vision algorithm, the slewing of the part could impact accuracy and fit scores. It would be like trying to find an object in a blurry image.

See the image below (at high magnification) for the impact of not using a progressive scan camera.



# 1.3 Queuing System

A queuing system is critical to the operation of the system. It can be either on the vision system (though added software) or on the robot (in a multi tasking environment).

Without a queuing system, the robot and the vision system are limited to handling one part at a time, versus independent operation.

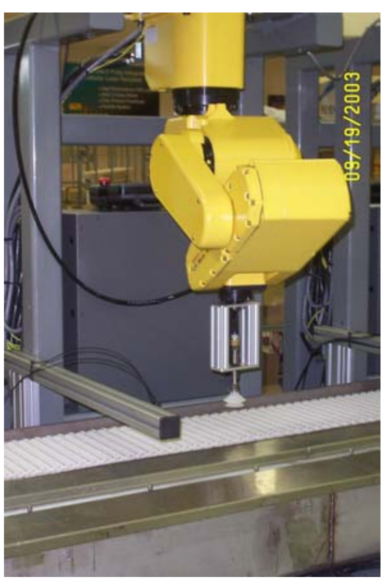
The following operations are required:

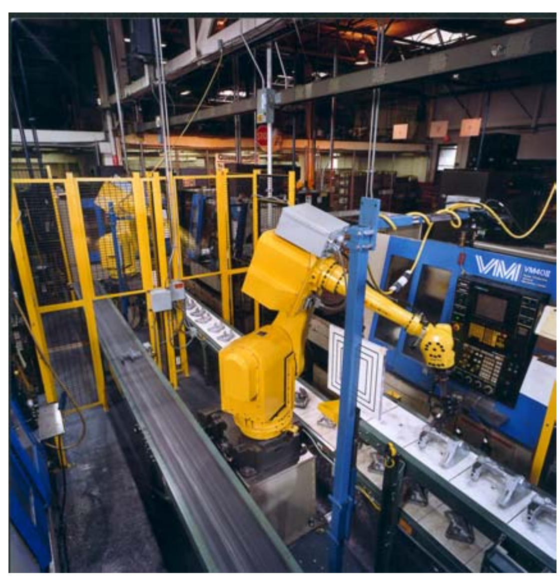
- Record the found position from the vision system for one or more parts
  (combined position of vision offset and conveyor position)
- Check for duplicates and keep the best one
- Provide the part offset to the robot when the part is within the tracking window of the robot.
- Provide for exception handling when a part is not picked up.

# 1.4 Industrial Robot

The robot has the following added requirements (from a standard system):

- Calibration software to match the vision frame with the tracking frame of the robot.
- High speed communication with the vision system
- Line tracking software and hardware
  - Separate encoder input
  - Tracking frames
  - Tracking boundaries
  - Adjustable Delay
- Multi tasking environment
  - One task to get the next offset
  - Another task to perform the part pickup and processing



# 2 Other Variations

Beyond the normal application of parts on linear conveyor, some interesting variations have been used for unique applications.

The first one is a rotary table with a Robot / Vision system doing circular tracking. The camera is in one quadrant, while the robot is picking parts in another quadrant.

The second one is where the camera is mounted on the robot (or picked up) and the robot scans the parts on a fixture. Once the scanning is complete, the camera is dropped off and all of the found parts are removed. In this example, a fixed camera presents problems because the distance to the parts will change per layer. The robot is ideally suited to move the camera at the correct focal length.

# 3 Why Scan Time is Important

Scan time is the driving force behind the timing and performance of a visual line tracking system.

The input side is typically running in a continuous loop trying to snap pictures and find parts at a user specified rate. But if the desired scan rate is too fast or the actual scan time is too long, the desired scan rate will not be achieved. The actual scan rate is inversely proportional to the scan time.

The vision scan time is dependent on various factors, such as number of objects in the field of view, what user options are enabled, etc. These will be discussed in later sections.

The system scan time for a typical system is more than the Image Acquire time plus the vision algorithm processing time. Depending on hardware configuration and assignment of tasks, it might include the following:

1. Queuing of parts
2. Robot communication
3. Conveyor Position reading
4. Sorting of parts
5. Saving of images
6. Results Logging
7. User interface

The other significant factor concerning scan time is that the relationship between Field of View (FOV) and conveyor speed is limited by the actual scan time. If the scan time is too long or the field of view is too small or the conveyor speed is too fast, parts may be missed because they are never seen by the vision system. See a later section of the detailed discussion.

In a typical system, the conveyor speed is fixed and the FOV must be large enough to cover the conveyor width. This defines what the maximum scan time can be.

The key factor is to try to get the scan time as small as possible. This lets you adjusted the desired scan rate so that the desired performance can be enhanced.

# 4 Impact of # Parts in FOV

The number of parts in the field of view will significantly increase the scan time. The typical process will perform a snap function and continuously find and queue parts until a part is not found. This means that the FIND algorithm is performed at least N+1 time, where N is the number of parts in the filed of view.

The penalty for increased number of parts will depend on the find algorithm and how the vision system is set up to find the parts.

In the typical application, the number of parts in the field of view cannot be controlled. The key item to consider is that the scan time will increase based on the number of parts and the increased scan time must be considered when selecting Camera Field of View with regard to conveyor speed.

Using a large circle with a single geometric locator, Chart 1 shows the impact on scan time for multiple targets in the Field of View.

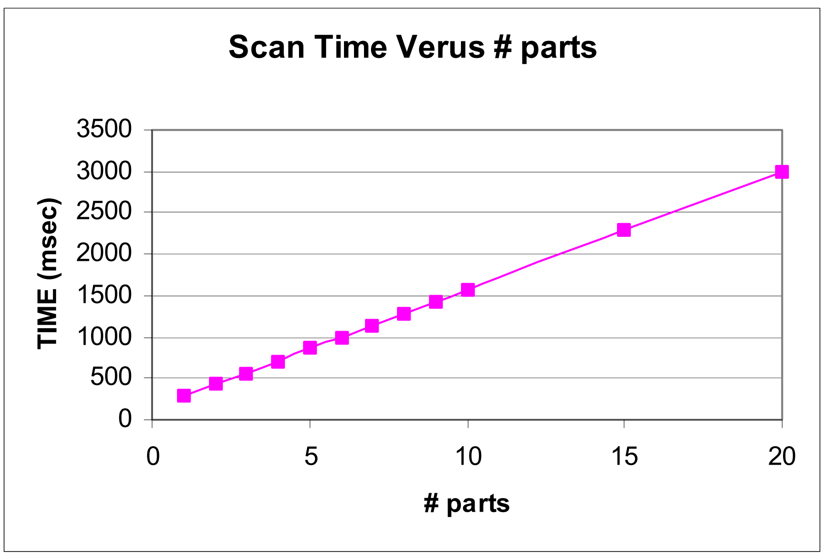



Chart 1 – Scan time impact of multiple parts

# 5 Impact of Display/Plot controls

Enabling the user interface to provide more information and plot images and found points for every part will increase the amount of work that the scan task has to do and will increase the cycle time.

On the FANUC Robotics VISTRAC system, the user has two main options:

1. Display the part queue and update automatically whenever it changes
2. Plot the found images on the "Run Mode Images" tab.

Both of these will increase the scan time.

The best performance will happen when both of these are turned off on the Run Mode screen.

Chart 2 shows the impact of scan time when various combinations are used.

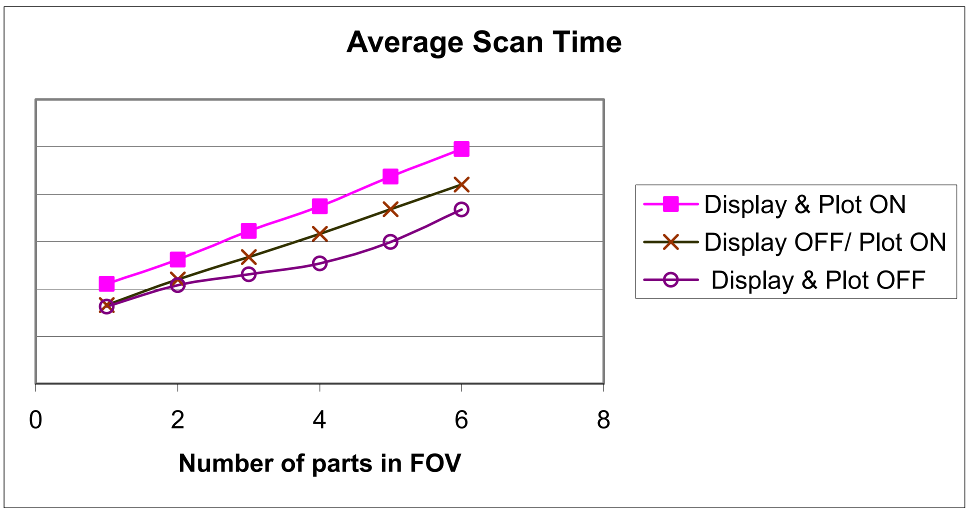



Chart 2 – Impact of User Display Options

Another potential impact is the saving of images and data logging. Both of these features will increase the system scan time.

Careful attention must be paid to the User Interface and data capture & logging.

# 6 Impact of Number of Robots

The number of robots in the system will increase the scan time due to the extra overhead and extra communications with the added robots. The extra robots do not have a direct impact on the scan processing, because only one camera is being used. The impact will be the extra PC processing required for multiple robots and potential delays at key time in the vision process due to the communication overhead.

The impact is minimal for 2 to 4 robots. Greater than 4 robots was not tested.

For multiple robots, it is assumed that the hardware configuration is as follows:

- 1 camera
- 1 conveyor
- 1 PC running the vision system
- 1 robot (master) with sync hardware and cable
- N robots (slaves)
- 1 encoder on conveyor multiplexed to all robots

Chart 3 shows the impact of multiple robots.

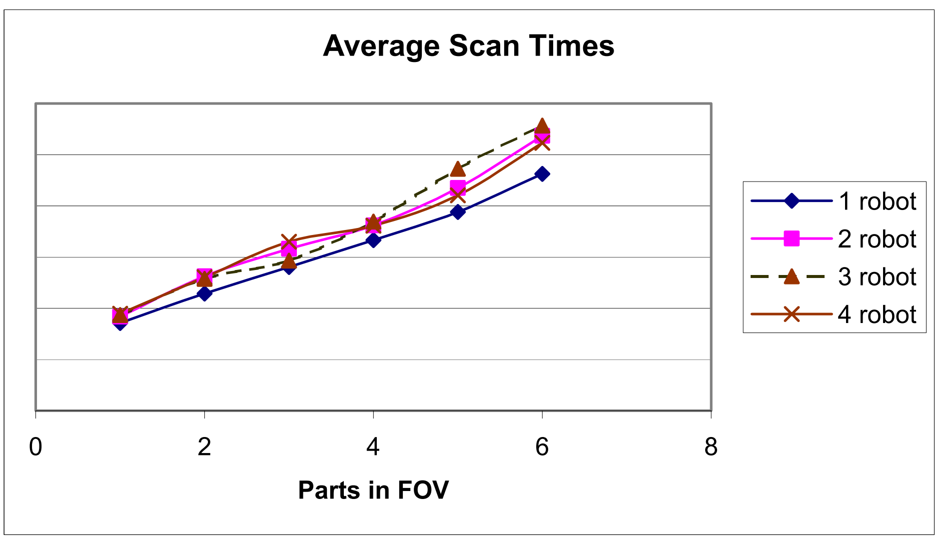



Chart 3 – Impact due to number of robots

The key item to remember is that the number of robots is not unlimited. Adding a robot to meet throughput requirements will have an impact on the performance for the rest of the system.

# 7 Impact of PC speed

The speed of the PC will significantly impact the cycle time. The PC speed will drastically impact the vision processing and queuing function.

For single parts in the field of view with low expected throughput, a slower PC is probably good enough. For high performance systems with multiple parts in the FOV, a high performance PC will probably be required.

Getting as fast a PC as you can afford is the best approach.

Chart 4 shows the range that might be expected due to CPU Speeds

SLOW = 400 Mhz Pentium II

FAST = 2.2GHZ Pentium IV

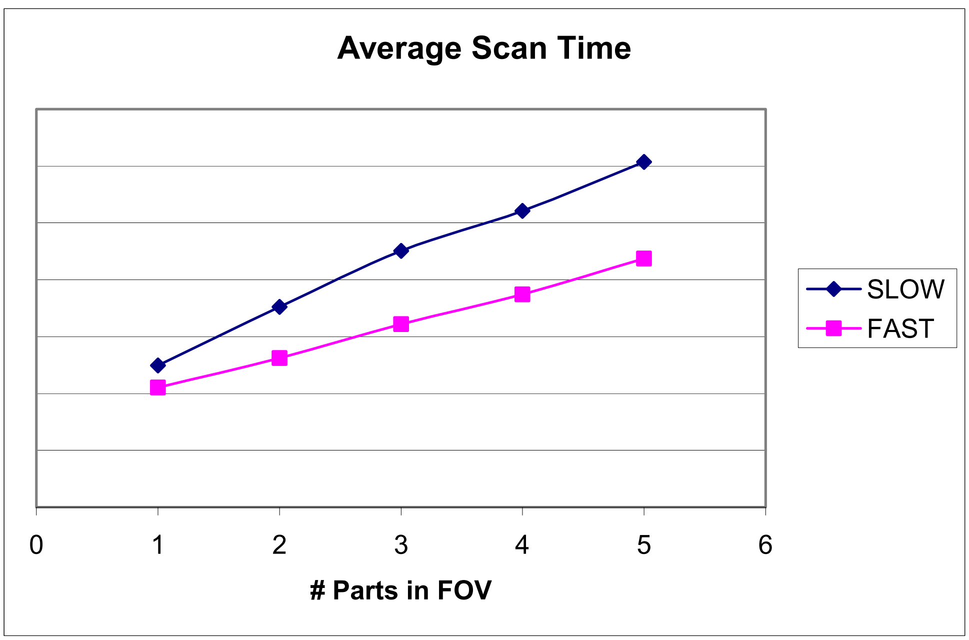



Chart 4 – Impact of PC Speed

# 8 Discussion of FOV and Conveyor Speed

The relationship between the scan time, the Field of View and the conveyor speed must be carefully considered.

In many applications, this relationship is adequate so that it is not even considered.
In high performance applications, this must be considered up front in the design process.

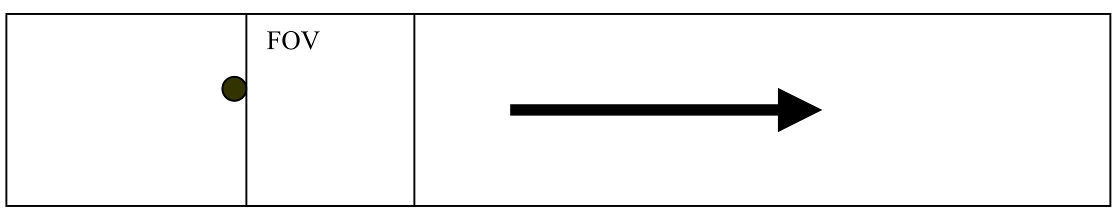
The minimum Field of View is defined as the conveyor speed times the scan time. Past application experience has shown that each part should be seen at least twice. So this number (conveyor speed * scan time) should be 50 % of the field of view.

FOR EXAMPLE:

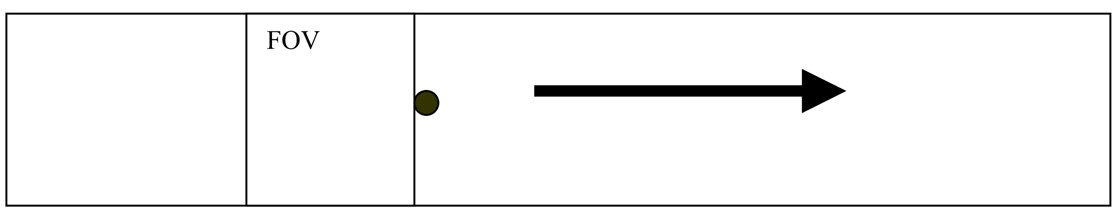
> Average scan time = 300 msec. ( 1 part in FOV)
> Field of view = 10 inches
> Conveyor speed = 75 feet per minute
>
> 300 msec * 75 feet per minute = 4.5 inches which is 45 % of field of view (acceptable).
>
> At 100 feet per minute:
> 300 mec * 100 feet per minute = 6.0 inches which is 60 % of the field of view (marginal).
> Some parts may only be seen once.
>
> This application would be considered marginal from past experience.
> If more than 1 part could be in the FOV occasionally, then there is a risk of missed parts due to the increase snap times.

The parts would be missed because the parts have moved farther downstream and may not have been seen by the camera due to the timing of the snaps. For example,

At time of the first snap




At time of next snap




At slow speeds, the impact is not seen because the conveyor does not move far enough to move a part out of the FOV. At higher speeds, significant sections of conveyor (and parts) could be missed.

# 9 Maximum Throughput Discussion

The number of parts in the FOV limits the maximum throughput of the system. If a more complex find algorithm (multi locator, histogram, etc.) is used, the scan time will increase and decrease the max throughput. This max throughput is defined as the maximum parts that the vision system can process. It does NOT include any robot motion or IO times.

The typical throughput of the system is a balancing act between putting more parts in the field of view (which causes the scan time to increase) and spreading out the parts on the conveyor (which will cause you to run the conveyor faster).

With a faster conveyor speed, the larger field of view may have to be increased to cover the distance moved during each snap. This in turn leads to the potential of multiple parts in the FOV, which increases the scan time.

With a slower conveyor speed, the field of view may be smaller, but parts will be spaced closer together. Again this causes an increase in scan time.

Any communication overhead must also be considered. When the vision processing is done on one system and the results communicated to another system, the message transfer time must be considered as part of the typical cycle. In most cases this is not significant, but for high performance systems with part pick times approaching 1 second, this should be considered.

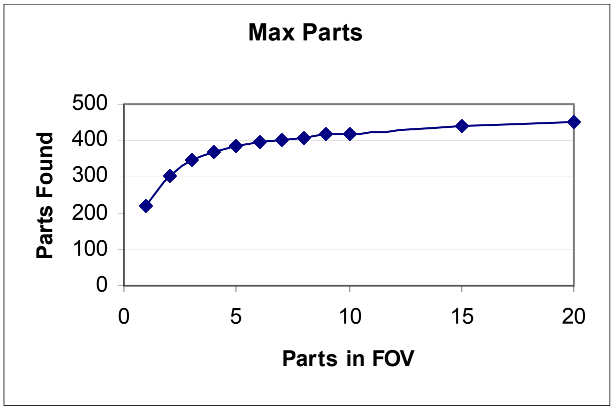
For estimating purposes, consider the minimum, average, and maximum number of parts in the FOV.

If multiple parts in the FOV are assumed, but only 1 shows up but on a fast conveyor, the max throughput will be limited. In that case, parts may be missed at a later time for apparently unknown reasons (because later an increased number of parts will be in the field of view causing an increased scan time).

The system design must consider that a user may change the display options and cause the system to behave differently than originally installed.

The system throughput is dependent on the following factors:

1. System Scan time
2. Field Of View
3. Conveyor Speed
4. Number of robots
5. Robot Part transfer time
6. User Interface



# 10 Performance Estimator

To help in determining various aspects of a visual line tracking application, a performance estimator was developed for the FANUC Robotics VISTRAC SYSTEM..

The user will input suggested field of view, part throughput, conveyor speed, and #parts in FOV.

The estimator will calculate average and worst case estimates for scan time and field of view.
Also an accuracy estimate is given.

See the example below. In this case, the original FOV was 12 inches, but that is not adequate based on part throughput and conveyor speed and parts in the FOV. The suggested FOV value is shown in red to alert the operator.

## visTRAC Performance Estimator

**Project Data**

| | | |
|---|---|---|
| Number of robots | 3 | |
| Estimated Field of View (in Convyer Direction) | 12 | inches |
| Part throughput | 120 | Part per minute |
| Conveyor Speed | 61 | Feet per minute |
| Parts in FOV (typical) | 2 | |
| Parts in FOV (MAX CASE) | 2 | |
| Part Size (in Conveyor Direction) | 4 | inches |

**CALCULATED**

| | | | |
|---|---|---|---|
| Average parts in Field Of view | 2 | | Calculated based on part throughtput and conveyor speed |
| PARTS in FOV (typical) | 2 | | |
| average scan time (msec) | 500 | msec | Based on basic locator algorithm |
| PARTS IN FOV (MAX CASE) | 2 | | |
| Scan time (MAX CASE) | 500 | | based on basic locator algorithm |
| Suggested FOV (minimum size) | 12.2 | inches | For 2 views of each part assuming average parts in FOV |
| Suggested FOV (Max case condition) | 6.1 | inches | For 1 view of each part, assuming worst case parts in FOV |

**ACCURACY (After adjustment)**

| | | |
|---|---|---|
| Typical Accuracy error | 0.098 | inches |
| | 2.48 | mm |
| Worst Case Accuracy | 0.195 | inches |
| | 4.96 | mm |