Automated Manufacturing

Automation is the use of control systems such as numerical control, programmable logic control, and other industrial control systems and information technology including computer-aided technologies, to control industrial machinery and processes, reducing the need for human intervention.
Two Types of Automation

- Fixed systems and
- Flexible systems
Reasons for Automation in the Factory Include

• Reduced labor costs
• Sales growth
• Better quality
• Reduced inventory
• Increased worker productivity
Chapter 8: Industrial Robotics

Sections:
1. Robot Anatomy and Related Attributes
2. Robot Control Systems
3. End Effectors
4. Applications of Industrial Robots
5. Robot Programming
6. Robot Accuracy and Repeatability
Industrial Robot Defined

An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place of mobile for use in industrial automation applications (ISO 8373)

• Why industrial robots are important:
  – Robots can substitute for humans in hazardous work environments
  – Consistency and accuracy not attainable by humans
  – Can be reprogrammed
  – Robots are controlled by computers and can therefore be connected to other computer systems
Industrial Robot at Work
Industrial Robot Terminologies

- The basic robot system consists of manipulator, power supply, controller, end effectors, interfacing or required equipment such as devices and sensors and any communications interface that is operating and monitoring the robot, equipment and sensors.
- The mechanical arm is driven by electric motors, pneumatic devices, or hydraulic actuators.
- Six motions are identified: Arm sweep, shoulder swivel, elbow extension, pitch, yaw, and roll.
Robot Anatomy

• Manipulator consists of joints and links
  – Joints provide relative motion
  – Links are rigid members between joints
  – Various joint types: linear and rotary
  – Each joint provides a “degree-of-freedom”
  – Most robots possess five or six degrees-of-freedom

• Robot manipulator consists of two sections:
  – Body-and-arm – for positioning objects in the robot's work volume
  – Wrist assembly – for orienting objects
Robot Anatomy

Robot manipulator - a series of joint-link combinations
Robot Body-and-Arm Configurations

- Five common body-and-arm configurations for industrial robots:
  1. Articulated robot (aka jointed-arm robot)
  2. Polar configuration
  3. Selective Compliance Arm for Robotic Assembly (SCARA)
  4. Cartesian coordinate robot
  5. Delta robot

- Function of body-and-arm assembly is to position an end effector (e.g., gripper, tool) in space
Articulated Robot (Jointed-Arm)

- General configuration of a human arm
Polar Configuration

• Consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and horizontal axis (R joint)
SCARA Robot

• SCARA = Selectively Compliant Assembly Robot Arm

• Similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks
 Cartesian Coordinate Robot

• Consists of three sliding joints, two of which are orthogonal

• Other names include gantry robot, rectilinear robot, and x-y-z robot
Delta Robot

- Consists of three arms attached to an overhead base
- Each arm consists of two rotational joints (type R), the first of which is powered and the second is unpowered
- All three arms are connected to a small platform below, to which an end effector is attached
Wrist Configurations

- Wrist assembly is attached to end-of-arm
- End effector is attached to wrist assembly
- Function of wrist assembly is to orient end effector
  - Body-and-arm determines global position of end effector
- Two or three degrees of freedom:
  - Roll
  - Pitch
  - Yaw
Wrist Configuration

- Typical wrist assembly has two or three degrees-of-freedom (shown is a three degree-of-freedom wrist)
Work Volume

Defined as the three-dimensional space within which the robot can manipulate the end of its wrist

• Also known as work envelope

• Determined by:
  – Number and types of joints
  – Ranges of joints
  – Physical sizes of links
Joint Drive Systems

• Electric
  – Uses electric motors to actuate individual joints
  – Preferred drive system in today's robots

• Hydraulic
  – Uses hydraulic pistons and rotary vane actuators
  – Noted for their high power and lift capacity

• Pneumatic
  – Typically limited to smaller robots and simple material transfer applications
End Effectors
The special tooling for a robot that enables it to perform a specific task

- Two types:
  - Grippers – to grasp and manipulate objects (e.g., parts) during work cycle
  - Tools – to perform a process, e.g., spot welding, spray painting
Robot Mechanical Gripper

- A two-finger mechanical gripper for grasping rotational parts
Industrial Robot Applications

1. Material handling applications
   - Material transfer – pick-and-place, palletizing
   - Machine loading and/or unloading

2. Processing operations
   - Spot welding and continuous arc welding
   - Spray coating
   - Other – waterjet cutting, laser cutting, grinding

3. Assembly and inspection
Robot Application Characteristics

General characteristics of industrial work situations that promote the use of industrial robots

1. Hazardous work environment for humans
2. Repetitive work cycle
3. Difficult handling task for humans
4. Multishift operations
5. Infrequent changeovers
6. Part position and orientation are established in the work cell
Robot Programming

A robot program can be defined as a path in space to be followed by a manipulator, combined with peripheral actions that support the work cycle.

- Examples of peripheral actions:
  - Opening and closing a gripper
  - Performing logical decision making
  - Communicating with other piece of equipment in the cell
Types of Robot Programming

- **Leadthrough programming** - work cycle is taught to robot by moving the manipulator through the required motion cycle and simultaneously entering the program into controller memory for later playback.

- **Robot programming languages** - uses textual programming language to enter commands into robot controller.

- **Simulation and off-line programming** – program is prepared at a remote computer terminal and downloaded to robot controller for execution without need for leadthrough methods.
Leadthrough Programming

Two types:

1. Powered leadthrough
   - Common for point-to-point robots
   - Uses teach pendant to move joints to desired position and record that position into memory

2. Manual leadthrough
   - Convenient for continuous path control robots
   - Human programmer physical moves manipulator through motion cycle and records cycle into memory
Robot Programming
YASKAWA Industrial Robot
Enable switch
Located on the back of the programming pendant. When you lightly squeeze it, the power turns ON. When you firmly squeeze it, the power turns OFF.

Insertion slot for Compact Flash

Start button
Hold button

Emergency stop button

Page key

Select key

Cursor key

Menu area

General-purpose display area

Mode switch

Manual speed keys

Axis keys

Enter key

Enable switch (option)

Motion Type key

Numeric keys / Function keys

Press to input numbers. These keys are also used as function keys to input instructions, etc. Key's function is automatically switched when function keys are available.
AC servomotor motors are used in the six axes of manipulators.

The controller controls the complex motion of manipulators in a comprehensive manner.
Sample Program

<table>
<thead>
<tr>
<th>LINE</th>
<th>INSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>NOP</td>
</tr>
<tr>
<td>0001</td>
<td>MOVJ VJ=0.78</td>
</tr>
<tr>
<td>0002</td>
<td>MOVJ VJ=100.00</td>
</tr>
<tr>
<td>0003</td>
<td>MOVJ VJ=25.00</td>
</tr>
<tr>
<td>0004</td>
<td>MOVJ VJ=276</td>
</tr>
<tr>
<td>0005</td>
<td>MOVJ VJ=50.00</td>
</tr>
<tr>
<td>0006</td>
<td>MOVJ VJ=100.00</td>
</tr>
<tr>
<td>0007</td>
<td>END</td>
</tr>
</tbody>
</table>
Given the Following Information, Interpret the Following Program:

- MOVJ = Joint speed and is a percent of maximum ranging from 0.01 to 100.00. Speed can be upwards of 9000 centimeters per minute.
- VJ stands for joint speed
- Move J stands for motion type
- Linear motion is specified as MOVL
- 0000 NOP stands for No Operation, top of program
Justification of Industrial Robots

• Selecting and justifying robot application requires a detailed design process and cost analysis.

• Justifying a robotic system is performed using this model:

\[ P = \frac{I}{S - E} \]

where:

- \( P \) = # of years for pay back
- \( I \) = Investment in robot
- \( S \) = Savings in robot
- \( E \) = Cost of servicing the robot
Chapter 10: Material Transport Systems

Sections:
1. Overview of Material Handling
2. Material Transport Equipment
3. Analysis of Material Transport Systems
Material Handling Defined

“The movement, protection, storage and control of materials and products throughout the process of manufacture and distribution, consumption and disposal” (The Material Handling Industry of America)

• Estimated to represent 20-25% of total manufacturing labor cost in US
  – The proportion varies depending on type of production and degree of automation
Categories of Material Handling Equipment

1. Transport equipment - to move materials inside a factory, warehouse, or other facility
2. Positioning equipment – to handle parts at one location
3. Unit load formation equipment - refers to (1) containers to hold materials and (2) equipment used to load and package the containers
4. Storage equipment - to store materials and provide access to those materials when required
5. Identification and control equipment - to identify and keep track of the materials being moved and stored
## Plant Layout

- Material handling equipment considerations must be included in the plant layout design problem.
- Correlation between layout type and material handling equipment:

<table>
<thead>
<tr>
<th>Plant layout type</th>
<th>Material handling equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-position</td>
<td>Cranes, hoists, industrial trucks</td>
</tr>
<tr>
<td>Process</td>
<td>Hand trucks, forklift trucks, AGVs</td>
</tr>
<tr>
<td>Product</td>
<td>Conveyors for product flow</td>
</tr>
<tr>
<td></td>
<td>Trucks to deliver parts to stations</td>
</tr>
</tbody>
</table>
Material Transport Equipment

Five categories:
1. Industrial trucks
2. Automated guided vehicles
3. Rail-guided vehicles (e.g., monorails)
4. Conveyors
5. Cranes and hoists
Automated Guided Vehicles

An Automated Guided Vehicle System (AGVS) is a material handling system that uses independently operated, self-propelled vehicles guided along defined pathways.

- **Types of AGV:**
  - Towing vehicles for driverless trains – used to move heavy loads over long distances
  - Pallet trucks – used to move palletized loads along predetermined routes
  - Unit load carriers – used to move unit loads between stations in a facility
Automated Guided Vehicles

(a) Driverless train, (b) AGV pallet truck, and (c) unit load carrier
AGV
AGVs
AGVs Applications in Production and Logistics

1. Driverless train operations - movement of large quantities of material over long distances

2. Storage and distribution - movement of pallet loads between shipping/receiving docks and storage racks

3. Assembly line applications - movement of car bodies and major subassemblies (motors) through the assembly stations

4. Flexible manufacturing systems - movement of workparts between machine tools
Vehicle Guidance Technology

• Method by which AGVS pathways are defined and vehicles are controlled to follow the pathways

• Technologies include:
  – Imbedded guide wires
  – Paint strips
  – Magnetic tape
  – Laser-guided vehicles
  – Inertial navigation
Typical AGV Route
Vehicle Guidance Using Guide Wire
Rail-Guided Vehicles
Self-propelled vehicles that ride on a fixed-rail system

• Vehicles operate independently and are driven by electric motors that pick up power from an electrified rail

• Fixed rail system
  – Overhead monorail - suspended overhead from the ceiling
  – On-floor - parallel fixed rails, tracks generally protrude up from the floor

• Routing variations are possible: switches, turntables, and other special track sections
Conveyor Systems
Large family of material transport equipment designed to move materials over fixed paths, usually in large quantities or volumes

1. Non-powered
   - Materials moved by human workers or by gravity

2. Powered
   - Power mechanism for transporting materials is contained in the fixed path, using chains, belts, rollers or other mechanical devices
Conveyor Types

(a) roller
(b) skate wheel
(c) belt
(d) in-floor towline
(e) overhead trolley
Integrated Material Handling Systems
Cranes and Hoists

Handling devices for lifting, lowering and transporting materials, often as heavy loads

- **Cranes**
  - For horizontal movement of materials

- **Hoists**
  - For vertical lifting of materials

- **Cranes usually include hoists so that the crane-and-hoist combination provides**
  - Horizontal transport
  - Vertical lifting and lowering
Hoist

Hoist with mechanical advantage of four:
(a) sketch of the hoist
(b) diagram to illustrate mechanical advantage
Cranes

(a) Bridge crane, (b) half-gantry crane, and (c) jib crane
Chapter 11: Storage Systems

Sections:
1. Introduction to Storage Systems
2. Conventional Storage Methods and Equipment
3. Automated Storage Systems
4. Analysis of Storage Systems
Automated Storage and Retrieval Systems (AS/RS)

• AS/RS is a combination of equipment and controls that handles, stores, and retrieves materials with precision, accuracy, and speed under a defined degree of automation.

• Materials to be stored and retrieved include: 1) raw materials, 2) unsold finished products, 3) production parts, 4) purchased parts and subassemblies used in the assembly of products, 5) rework and scrap that result from production operations, 6) spare parts for repair of production machines and facilities, and 7) general office supplies including tools and instruments.
Objectives and Reasons for Automating Storage Operations

• To increase storage capacity
• To increase storage density
• To recover factory floor space currently used for WIP
• To improve security and reduce pilferage
• To reduce labor cost and/or increase productivity
• To improve safety
• To improve inventory control
• To improve stock rotation
• To improve customer service
• To increase throughput
Types of Automated Storage Systems

1. Fixed-Aisle Automated Storage/Retrieval System (AS/RS)
   - Rack system with mechanized or automated S/R machine to store and retrieve loads
   - Linear motions of S/R machine

2. Carousel Storage System
   - Oval conveyor system with storage baskets to contain individual items
   - Revolution of conveyor trolleys around oval track to deliver baskets to load/unload station
Fixed-Aisle AS/RS
AS/RS

Unit load AS/RS with one aisle
Carousel Storage System

Top and side views of horizontal storage carousel
Carousel Storage System

Manually operated horizontal carousel storage system
AS/RS Applications

1. Unit load storage and retrieval
   - Warehousing and distribution operations
   - AS/RS types: unit load, deep lane (food industry)

2. Order picking
   - AS/RS types: miniload, man-on-board, item retrieval

3. Work-in-process storage
   - Helps to manage WIP in factory operations
   - Buffer storage between operations with different production rates
   - Supports JIT manufacturing strategy
Automated Machine Tools and Tooling

• Includes different machines and tooling systems:
  – Machine tools
  – Auxiliary equipment (MHS, robots etc)
  – Tools
  – Tooling
Conventional and CNC Lathes
CNC Milling Machines
Drilling Machines
Sawing Machines
Surface Grinder
Fold and Shear Coiline
Automated Punching Machine
Hydraulic CNC Folder
Plastic injection molding machine
Extrusion Machine
Gas Furnace
Column Press and Straight Side Press
Forging Machine
PalletShuttle
Chapter 16: Automated Production Lines

Sections:

1. Fundamentals of Automated Production Lines
2. Applications of Automated Production Lines
3. Analysis of Transfer Lines
Automated Production Lines

• High production of parts requiring multiple processing operations
• Fixed automation
• Applications:
  – Transfer lines used for machining
  – Robotic spot welding lines in automotive final assembly
  – Sheet metal stamping
  – Electroplating of metals
Where to Use Automated Production Lines

- High product demand
  - Requires large production quantities
- Stable product design
  - Difficult to change the sequence and content of processing operations once the line is built
- Long product life
  - At least several years
- Multiple operations required on product
  - The different operations are assigned to different workstations in the line
Benefits of Automated Production Lines

- Low direct labor content
- Low product cost
- High production rates
- Production lead time and work-in-process are minimized
- Factory floor space is minimized
Automated Production Line - Defined

Fixed-routing manufacturing system that consists of multiple workstations linked together by a material handling system to transfer parts from one station to the next

- Slowest workstation sets the pace of the line
- Workpart transfer:
  - Palletized transfer line
    - Uses pallet fixtures to hold and move workparts between stations
  - Free transfer line
    - Part geometry allows transfer without pallet fixtures
Automated Production Line

General configuration of an automated production line consisting of $n$ automated workstations that perform processing operations.
System Configurations

- In-line - straight line arrangement of workstations
- Segmented in-line – two or more straight line segments, usually perpendicular to each other
- Rotary indexing machine (e.g., dial indexing machine)
Segmented In-Line Configurations

L-shaped layout

U-shaped layout

Rectangular configuration
Two Machining Transfer Lines

On the left is a segmented in-line palletized transfer line using pallet fixtures to locate work parts. The return loop brings the pallets back to the front of the line. On the right is an in-line free transfer line. Parts are represented by ovals, pallet fixtures by rectangles.
Rotary Indexing Machine
Belt-Driven Linear Transfer System

Side view of chain or steel belt-driven conveyor (over and under type) for linear transfer using work carriers
Walking Beam Transfer System

1. Fixed station beam
   - Work parts
   - Nest to locate work parts in stations
   - Transfer beam

2. Motion of transfer beam
   - Transfer beam
   - Fixed station beam

3. Motion of transfer beam
   - Transfer beam
   - Fixed station beam

4. Motion of transfer beam
   - Transfer beam
   - Fixed station beam
Geneva Mechanism with Six Slots

- Driver
- Driven member attached to workable shaft
- Motion of driven member during each rotation of driver
- Pin attached to driver enters slot to index driven member
Storage Buffers in Production Lines

A location in the sequence of workstations where parts can be collected and temporarily stored before proceeding to subsequent downstream stations.

- Reasons for using storage buffers:
  - To reduce effect of station breakdowns
  - To provide a bank of parts to supply the line
  - To provide a place to put the output of the line
  - To allow curing time or other required delay
  - To smooth cycle time variations
  - To store parts between stages with different production rates
Control Functions in an Automated Production Line

• Sequence control
  – To coordinate the sequence of actions of the transfer system and workstations

• Safety monitoring
  – To avoid hazardous operation for workers and equipment

• Quality control
  – To detect and possibly reject defective work units produced on the line
Standard Feed Units used with In-Line or Rotary Transfer Machines

(a) Horizontal feed drive unit, (b) angular feed drive unit, and (c) vertical column feed drive unit
Standard Milling Head

Milling head unit that attaches to one of the feed drive units in the previous slide
Chapter 22: Inspection Technologies

Sections:
1. Inspection Metrology
2. Conventional Measuring and Gaging Techniques
3. Coordinate Measuring Machines
4. Surface Measurement
5. Machine Vision
6. Other Optical Inspection Techniques
7. Noncontact Nonoptical Inspection Technologies
Inspection Metrology

Measurement - a procedure in which an unknown quantity is compared to a known standard, using an accepted and consistent system of units

- The means by which inspection by variables is accomplished

Metrology – the science of measurement

- Concerned with seven basic quantities: length, mass, electric current, temperature, luminous intensity, time, and matter

- From these basic quantities, other physical quantities are derived
Characteristics of Measuring Instruments

- **Accuracy** – how closely the measured value agrees with the true value
- **Precision** – a measure of the repeatability of the measurement process
  - Rule of 10 – the measuring instrument must be ten time more precise than the specified tolerance
- **Resolution** – the smallest variation of the variable that can be detected
- **Speed of response** – how long the instrument takes to measure the variable
- **Others**: operating range, reliability, cost
Two Basic Types of Inspection Techniques

1. Contact inspection
   - Makes contact with object being inspected

2. Noncontact inspection
   - Does not make contact with object being inspected
Contact Inspection Techniques

Uses a mechanical probe that makes contact with the object being measured or gaged

- Principal techniques:
  - Conventional measuring and gaging instruments, manual and automated
  - Coordinate measuring machines
  - Stylus type surface texture measuring machines
Noncontact Inspection Techniques

Uses a sensor or probe located a certain distance away from the object being measured or gaged

• Two categories:
  – Optical – uses light to accomplish the inspection
  – Nonoptical - uses energy form other than light

• Advantages of noncontact inspection:
  – Avoids possible damage to surface of object
  – Inherently faster than contact inspection
  – Can often be accomplished in production without additional part handling
  – Increased opportunity for 100% inspection
Coordinate Metrology

- Concerned with the measurement of the actual shape and dimensions of an object and comparing these with the desired shape and dimensions specified on a part drawing.

- Coordinate measuring machine (CMM) – an electromechanical system designed to perform coordinate metrology.

- A CMM consists of a contact probe that can be positioned in 3-D space relative to workpart features, and the x-y-z coordinates can be displayed and recorded to obtain dimensional data about geometry.
Coordinate Measuring Machine
CMM Components

• Probe head and probe to contact workpart surfaces
• Mechanical structure that provides motion of the probe in x-y-z axes, and displacement transducers to measure the coordinate values of each axis
• Optional components (on many CMMs):
  – Drive system and control unit to move each axis
  – Digital computer system with application software
Contact Probe Configurations

(a) Single tip and (b) multiple tip probes
CMM Mechanical Structure

• Six common types of CMM mechanical structures:
  1. Cantilever
  2. Moving bridge
  3. Fixed bridge
  4. Horizontal arm
  5. Gantry
  6. Column
(a) Cantilever and (b) moving bridge structure
(c) Fixed bridge and (d) horizontal arm (moving ram type)
CMM Structures

(e) Gantry and (f) Column
CMM Controls

• Four categories:

1. Manual drive CMM – human operator physically moves the probe and records x-y-z-data

2. Manual drive and computer-assisted data processing – can perform calculations to assess part features

3. Motor-driven CMM with computer-assisted data processing – uses joystick to actuate electric motors to drive probe

4. Direct computer control (DCC) – operates like a CNC machine tool and requires part program
DCC Programming

• Manual leadthrough
  – Operator leads the CMM probe through the various motions in the inspection sequence, indicating points and surfaces to be measured and recording these into control memory

• Off-line programming
  – Program includes motion commands, measurement commands, and report formatting commands and is prepared off-line
CMM Software
The set of programs and procedures used to operate the CMM and its associated equipment

• Example: part programming software for DCC machines

• Other software divide into following categories:
  1. Core software other than DCC programming
  2. Post-inspection software
  3. Reverse engineering and application-specific software
Advantages of using CMMs over Manual Inspection

• Reduced inspection cycle time – translates to higher throughput rate
  – Especially with DCC, approximately 90% reduction in certain tasks
• Flexibility – CMMs are general-purpose machines
• Reduced operator errors in measurement and setup
• Greater inherent accuracy and precision
• Avoidance of multiple setups – in general all measurements of a given part can be made in one setup
Inspection Probes on Machine Tools

• Mounted on toolholders
• Stored in the tool drum
• Handled by the automatic tool-changer the same way cutting tools are handled
• Inserted into the machine tool spindle by the automatic tool-changer
  – When mounted in the spindle the machine tool is controlled very much like a CMM
  – Sensors in the probe determine when contact is made with part surface so that required data processing is performed to interpret the sensor signal
Portable CMMs

• In the conventional application of a CMM, parts must be removed from the production machine and taken to the inspection department where the CMM is located

• New coordinate measuring devices allow the inspection procedures to be performed at the site where the parts are made
  – Example: Faro gage, a.k.a. Personal CMM, is a six-jointed articulated arm
    • At the end of the arm is a touch probe to perform coordinate measurements, similar to a CMM
Advantages of In-Site Inspection

• Necessity to move parts from the machine tool to the CMM and back is eliminated
  – Material handling is reduced
• Inspection results are immediately known
• The machinist who makes the part performs the inspection
• Because part is still attached to machine tool during inspection, any datum reference locations established during machining are not lost
  – Any further machining uses the same references without the need to refixture the part
Surface Measurement

• Most surface measuring devices use a contacting stylus
  – Therefore, classified as contact inspection

• Cone-shaped diamond stylus with point radius $= 0.005$ mm (0.0002 in) and 90 degree tip angle
  – As stylus is traversed across surface, tip also moves vertically to follow the surface topography
  – Movement is converted to electronic signal that can be displayed as either
    1. Profile of the surface
    2. Average roughness value of the surface
Stylus-Type Surface Measurement
Surface measurement can be displayed as the profile of the surface as indicated by the stylus trace or the average of the surface deviations during the trace.
Machine Vision

Acquisition of image data, followed by the processing and interpretation of these data by computer for some useful application

• Also called “computer vision”

• 2-D vs. 3-D vision systems:
  – 2-D – two-dimensional image – adequate for many applications (e.g., inspecting flat surfaces, presence or absence of components)
  – 3-D – three-dimensional image – requires structured light or two cameras
Operation of a Machine Vision System
Machine Vision Applications

1. Inspection:
   - Dimensional measurement
   - Dimensional gaging
   - Verify presence or absence of components in an assembly (e.g., PCB)
   - Verify hole locations or number of holes
   - Detection of flaws in printed labels

2. Identification – for parts sorting or counting

3. Visual guidance and control – for bin picking, seam tracking in continuous arc welding, part positioning
Other Optical Inspection Methods

- Conventional optical instruments
  - Optical comparator
  - Conventional microscope
- Scanning laser systems
- Linear array devices
- Optical triangulation techniques
Scanning Laser Device

- Rotating mirror
- Collimating lens
- Collecting lens
- Laser
- Part to be measured
- Photodetector
- Signal processing-microprocessor
- Output (part size)
Linear Array Measuring Device

- Planar light sheet
- Linear photodiode array
- Light source
- Object to be measured
Optical Triangulation Sensing

- Range $R$ is desired to be measured
- Length $L$ and angle $A$ are fixed and known
- $R$ can be determined from trigonometric relationships as follows:

$$R = L \cot A$$
Noncontact Nonoptical Inspection Techniques

- Electrical field techniques
  - Reluctance, capacitance, inductance
- Radiation techniques
  - X-ray radiation
- Ultrasonic inspection methods
  - Reflected sound pattern from test part can be compared with standard
  - Parts must always be presented in the same position and orientation relative to the probe
Bringing it all Together