

**Module 1**

**Chapter 1 : Computer Graphics 1-1 to 1-74**

**1.1 Introduction** : Scope of CAD/CAM in product life cycle, CAD/CAM hardware and software, 2D and 3D computer graphics representation, Mapping of Geometric Models.

**1.2 Parametric representation of curves and surfaces**  
Synthetic Curves - Bezier curves, Hermite Curves, B-spline curves. Surface representation.

**1.3 Solid Modeling** : Constructive solid geometry (CSG), Boundary Representation (BRep), Wire Frame Modeling, Solid Modeling, Surface Modeling, Parametric Modeling, Feature based modeling, Constraint Based Modeling.

**1.1 Scope of CAD/CAM..... 1-2**

**1.2 Conventional Product Cycle..... 1-2**

**1.3 CAD/CAM in Product Cycle..... 1-3**

**1.4 Advantages, Limitations and Applications of CAD/CAM..... 1-3**

1.4.1 Advantages of CAD/CAM..... 1-3

1.4.2 Limitations of CAD/CAM ..... 1-4

1.4.3 Applications of CAD..... 1-4

1.4.4 Applications of CAM..... 1-4

**1.5 Hardware in Cad ..... 1-5**

**1.6 Graphics Display Devices..... 1-5**

1.6.1 Cathode Ray Tube (CRT) ..... 1-5

**1.7 Types of Graphics Display Devices..... 1-6**

1.7.1 Random-Scan (Stroke-Writing or Vector Scan) Type Display ..... 1-6

1.7.2 Raster-Scan Display ..... 1-7

1.7.3 Liquid Crystal Display (LCD) ..... 1-9

1.7.4 Light Emitting Diode (LED) Display ..... 1-10

1.7.5 Comparison of Graphics Display Devices ..... 1-11

1.7.6 Comparison of Random Scan (Vector Scan) and Raster Scan Displays ..... 1-11

**1.8 Input Devices..... 1-12**

1.8.1 Alphanumeric Keyboards .....1-12

1.8.2 Cursor Control Devices .....1-12

1.8.3 Digitizers .....1-14

1.8.4 Scanners .....1-15

1.8.5 Other Input Devices .....1-15

**1.9 Output Devices ..... 1-15**

1.9.1 Printers .....1-15

1.9.2 Pen Plotters .....1-16

1.9.3 Hard-Copy Units (Dry Silver Copiers) .....1-17

1.9.4 Electrostatic Plotters .....1-17

1.9.5 Computer-Output-to-Microfilm (COM) Units .....1-18

**1.10 Central Processing Unit (CPU)..... 1-18**

**1.11 Storage Devices (Memory Units).....1-18**

1.11.1 Primary Storage Devices (Main Memory) .....1-18

1.11.2 Secondary Storage Devices (Auxiliary Memory) .1-19

**1.12 CAD/CAM Software .....1-19**

**1.13 Functions of Graphics Software ..... 1-20**

**1.14 Generation of Graphic Element Line ..... 1-21**

**1.15 Mapping of Geometric Models.....1-22**

**1.16 Representation of Curves.....1-22**

1.16.1 Representation of Curves .....1-22

1.16.2 Comparison between Non-Parametric and Parametric Curves .....1-23

**1.17 Types of Curves ..... 1-23**

1.17.1 Comparison between Analytic and Synthetic Curves .....1-23

**1.18 Synthetic Curves ..... 1-23**

1.18.1 Continuity Conditions .....1-24

1.18.2 Approaches of Generation of Synthetic Curves .....1-25

**1.19 Types of Synthetic Curves ..... 1-26**

**1.20 Hermite Cubic Splines ..... 1-26**

**1.21 Bezier Curves ..... 1-34**

**1.22 B-Spline Curves ..... 1-43**

**1.23 Comparison between Hermite Cubic Spline Curve, Bezier Curve and B-Spline Curve..... 1-44**

**1.24 Surface Representation ..... 1-45**

**1.25 Types of Surface Entities..... 1-46**

1.25.1 Analytic Surfaces ..... 1-46

1.25.2 Synthetic Surfaces..... 1-48

**1.26 Geometric Modeling ..... 1-49**

**1.27 Methods of Geometric Modeling..... 1-49**

**1.28 Wire-Frame Modeling..... 1-49**

1.28.1 Types of Wire-Frame Modeling ..... 1-50

1.28.2 Advantages of Wire-Frame Modeling ..... 1-50

1.28.3 Limitations of Wire-Frame Modeling ..... 1-50

**1.29 Surface Modeling ..... 1-51**

1.29.1 Advantages of Surface Modeling ..... 1-51

1.29.2 Limitations of Surface Modeling ..... 1-52

**1.30 Solid Modeling ..... 1-52**

1.30.1 Comparison between Wire Frame Modeling and Solid Modeling..... 1-52

1.30.2 Geometry and Topology ..... 1-53

1.30.3 Advantages of Solid Modeling ..... 1-53

1.30.4 Limitations of Solid Modeling ..... 1-54

1.30.5 Solid Entities (Primitives) ..... 1-54

1.30.6 Mathematical Representation of Solid Entities (Primitives) and their Surfaces ..... 1-55

**1.31 Methods of Solid Modeling..... 1-56**

1.31.1 Constructive Solid Geometry (CSG or C-REP) ..... 1-56

1.31.2 Boundary Representation (B-REP) ..... 1-58

1.31.3 Sweeping ..... 1-61

1.31.4 Parametric (Analytical) Solid Modeling ..... 1-62

1.31.5 Primitive Instancing ..... 1-63

1.31.6 Feature Based Modeling ..... 1-63

1.32.7 Constraint Based Modeling ..... 1-67

1.31.8 Comparison of Constructive Solid Geometry (C-Rep) Approach and Boundary Representation (B-Rep) Approach ..... 1-68

**1.32 Solid Manipulations.....1-69**

**1.33 Applications of Solid Modeling.....1-70**

**Module 2**

**Chapter 2 : Geometric Transformation 2-1 to 2-50**

2.1 Homogeneous Coordinate system, Matrix representation, Concatenations, 2D and 3D geometric transformation (Translation, Reflection, Scaling, Rotation)

**2.1 Two-Dimensional Geometric Transformations..... 2-2**

2.1.1 Translation ..... 2-3

2.1.2 Rotation ..... 2-3

2.1.3 Scaling ..... 2-4

2.1.4 Reflection ..... 2-4

2.1.5 Shear ..... 2-6

2.1.6 Concatenated (Composite) Transformations ..... 2-7

**2.2 Two-Dimensional Geometric Transformations Using Homogenous Coordinates..... 2-9**

2.2.1 Translation ..... 2-9

2.2.2 Rotation ..... 2-9

2.2.3 Scaling ..... 2-9

2.2.4 Reflection ..... 2-10

2.1.5 Shear ..... 2-10

**2.3 Two-Dimensional Inverse Transformations.....2-11**

2.3.1 Inverse Translation ..... 2-11

2.3.2 Inverse Rotation ..... 2-11

2.3.3 Inverse Scaling..... 2-11

2.3.4 Inverse Reflection ..... 2-11

**2.4 Three-Dimensional Geometric Transformations.....2-42**

2.4.1 Translation ..... 2-42

2.4.2 Rotation ..... 2-42

2.4.3 Scaling..... 2-43

2.4.4 Reflection ..... 2-43

**2.5 Coordinate Systems ..... 2-45**

**2.6 Mapping of Geometric Models ..... 2-4**

2.6.1 Comparison between Geometric Transformation and Geometric Mapping..... 2-47

**2.7 Two-Dimensional Geometric Mappings..... 2-47**

2.7.1 Geometric Mapping of Graphics Element..... 2-47

2.7.2 Translational Mapping..... 2-47

2.7.3 Rotational Mapping..... 2-48

2.7.4 General Mapping ..... 2-48

**Module 3**

**Chapter 3 : Modeling Based on Biomedical Data**  
**3-1 to 3-11**

**3.1 Introduction to medical imaging :** Computed tomography (CT), Cone beam CT (CBCT), Magnetic resonance (MR), Noncontact surface scanning, Medical scan data , Point cloud data

**3.2 Working with medical scan data :** Pixel data operations, Using CT data : a worked example, Point cloud data operations, Two-dimensional formats, Pseudo 3D formats, True 3D formats, File management and exchange

**3.1 Medical Modeling (Bio-Modelling) ..... 3-2**

**3.2 Introduction to Medical Imaging ..... 3-2**

3.2.1 Medical Scanning Process ..... 3-2

3.2.2 Types of Medical Scanners ..... 3-2

**3.3 Computed Tomography (CT) ..... 3-3**

3.3.1 Principle of Operation of Computed Tomography (CT)..... 3-3

3.3.2 Hounsfield Scale ..... 3-3

3.3.3 Applications of CT Scan ..... 3-4

**3.4 Cone Beam CT (CBCT) ..... 3-4**

3.4.1 Working principle of Cone Beam CT..... 3-4

3.4.2 Advantages of Cone Beam CT (CBCT) ..... 3-4

3.4.3 Limitations of Cone Beam CT (CBCT)..... 3-4

3.4.4 Applications of Cone Beam CT ..... 3-4

**3.5 Magnetic Resonance Imaging (MRI)..... 3-4**

3.5.1 Principle of Operation of MRI ..... 3-4

3.5.2 Applications of MRI ..... 3-5

3.5.3 Comparison Between MRI and CT ..... 3-5

**3.6 Non-Contact Surface Scanning..... 3-6**

**3.7 Medical Scan Data..... 3-6**

**3.8 Point Cloud Data ..... 3-6**

**3.9 Pixel Data Operations ..... 3-6**

**3.10 Procedure of Using CT Data**  
**A Worked Example ..... 3-7**

**3.11 Point Cloud Data Operations..... 3-8**

**3.12 Two-Dimensional Formats ..... 3-8**

**3.13 Pseudo 3D Formats..... 3-9**

**3.14 True 3D Formats..... 3-9**

**3.15 File Management and Exchange..... 3-9**

3.15.1 STL Format ..... 3-9

3.15.2 Object Format ..... 3-11

3.15.3 Virtual Reality Modelling Language (VRML) Format ..... 3-11

3.15.4 X3D Format ..... 3-11

**3.16 Standards for Exchange of Model Data..... 3-11**

**Module 4**

**Chapter 4 : Subtractive Manufacturing** **4-1 to 4-116**

**4.1 Introduction :** NC/CNC/DNC machines, Machining Centers, Coordinate system

**4.2 CNC machining practices and programming :** setup and operation of two- and three- axis CNC machines programming using manual part programming method, Canned Cycles.

**4.1 NC Machine Tools ..... 4-2**

4.1.1 Elements of NC Machine Tool System ..... 4-2

**4.2 Classification of NC (Numerical Control) Machine Tool Systems ..... 4-3**

4.2.1 According to Control Loop Feedback Systems ..... 4-4

4.2.2	According to Type of Tool Motion Control .....	4-4	4.13.2	Types of Adaptive Control (AC) Systems .....	4-25
4.2.3	According to Programming Methods .....	4-6	<b>4.14</b>	<b>Machining Centers .....</b>	<b>4-26</b>
<b>4.3</b>	<b>Advantages of NC Machine Tools .....</b>	<b>4-8</b>	<b>4.15</b>	<b>Introduction to Part Programming .....</b>	<b>4-27</b>
<b>4.4</b>	<b>Limitations of NC Machine Tools .....</b>	<b>4-9</b>	4.15.1	Steps in Part Programming .....	4-27
<b>4.5</b>	<b>Applications of NC Machine Tools .....</b>	<b>4-9</b>	<b>4.16</b>	<b>Coordinate Systems Used in Manual Part Programming .....</b>	<b>4-28</b>
<b>4.6</b>	<b>CNC Machine Tools .....</b>	<b>4-9</b>	<b>4.17</b>	<b>Format of Manual Part Programming .....</b>	<b>4-28</b>
4.6.1	Elements of CNC Machine Tool System .....	4-10	4.17.1	Types of Formats of Block in Manual Part Programming .....	4-29
<b>4.7</b>	<b>Classification of CNC (Computer Numerical Control) Machine Tool Systems.....</b>	<b>4-10</b>	<b>4.18</b>	<b>Manual Part Programming for Turning Applications Turning Center.....</b>	<b>4-30</b>
4.7.1	According to Control Loop Feedback Systems ....	4-11	4.18.1	Coordinate System (Axes Designation Conventions) Used in Turning Center .....	4-30
4.7.2	According to Type of Tool Motion Control .....	4-12	4.18.2	Zero Points and Reference Points .....	4-31
4.7.3	According to Programming Methods .....	4-14	4.18.3	Cutting Process Parameter Selection for Turning Applications .....	4-32
4.7.4	According to Type of Controllers .....	4-15	4.18.4	G-Codes (Preparatory Functions) Used in Turning Center .....	4-33
4.7.5	According to Axis and Type of Operations .....	4-16	4.18.5	M Codes (Miscellaneous Functions) Used in Turning Center .....	4-40
<b>4.8</b>	<b>Advantages (Features) of CNC Machine Tools .....</b>	<b>4-16</b>	4.18.6	Programming Types used in Turning Applications .....	4-41
<b>4.9</b>	<b>Limitations of CNC Machine Tools.....</b>	<b>4-17</b>	4.18.7	Subprogram (Subroutines) .....	4-42
<b>4.10</b>	<b>Applications of CNC Machine Tools.....</b>	<b>4-17</b>	4.18.8	Macros .....	4-42
<b>4.11</b>	<b>Systems of NC/CNC Machine Tools.....</b>	<b>4-18</b>	4.18.9	Canned Cycles .....	4-42
4.11.1	Structure .....	4-18	4.18.10	General Structure of Turning Part Program .....	4-44
4.11.2	Spindle and Feed Drives .....	4-19	<b>4.19</b>	<b>Manual Part Programming for Milling Applications Machining Center.....</b>	<b>4-69</b>
4.11.3	Actuator Support Bearings .....	4-19	4.19.1	Coordinate System (Axis Designation Conventions used) in CNC Machining Center .....	4-70
4.11.4	Feedback Systems .....	4-20	4.19.2	Zero Points and Reference Points .....	4-70
4.11.5	Automatic Tool Changers .....	4-20	4.19.3	Cutting Process Parameter Selection for Milling Applications .....	4-71
4.11.6	Tooling .....	4-21	4.19.4	G-Codes (Preparatory Functions) used in Machining Center .....	4-73
4.11.7	Material Handling Systems .....	4-21	4.19.5	M-Codes (Common Miscellaneous Functions) used in Machining Center .....	4-83
4.11.8	Pallet Changer Systems .....	4-22	4.19.6	General Structure of Milling Part Program .....	4-85
4.11.9	Lubrication System .....	4-23	<b>4.20</b>	<b>Computer Assisted Part Programming For Milling Applications .....</b>	<b>4-114</b>
4.11.10	Coolant System .....	4-23			
<b>4.12</b>	<b>DNC Machine Tools .....</b>	<b>4-23</b>			
4.12.1	Basic Elements of DNC Machine Tool System .....	4-24			
4.12.2	Functions of DNC Machine Tool System .....	4-24			
4.12.3	Advantages of DNC Machine Tools .....	4-24			
4.12.4	Limitations of DNC Machine Tools .....	4-25			

4.20.1 Types of Computer Assisted Programming Languages .....4-115

4.20.2 Elements of Computer Assisted Programming System .....4-116

**Module 5**

**Chapter 5 : Additive Manufacturing 5-1 to 5-29**

**5.1 Rapid Prototyping** : Introduction, Classification of RP Processes, Advantages and disadvantages. RP Applications; in Design, Concept Models, Form and fit checking, Functional testing, CAD data verification, Rapid Tooling, and bio fabrication.

**5.2 Working Principle, Application, Advantages and disadvantages** : of Stereolithography Apparatus (SLA) Selective Laser Sintering (SLS), 3D Printing, Fused Deposition Modeling (FDM), and Laminated Object Manufacturing (LOM)

5.1 Introduction to Rapid Prototyping ..... 5-2

5.2 Categories of Manufacturing Processes ..... 5-2

5.3 Basic Steps in Rapid Prototyping Process ..... 5-2

5.4 Benefits (Advantages) of Rapid Prototyping .... 5-5

5.4.1 Direct Benefits of Rapid Prototyping ..... 5-5

5.4.2 Indirect Benefits of Rapid Prototyping ..... 5-6

5.5 Limitations of Rapid Prototyping ..... 5-6

5.6 Classification Of Rapid Prototyping Systems (Techniques) ..... 5-6

5.6.1 Liquid-Based Rapid Prototyping Systems ..... 5-6

5.6.2 Solid-Based Rapid Prototyping Systems ..... 5-7

5.6.3 Powder-Based Rapid Prototyping Systems ..... 5-7

5.7 Liquid Based Rapid Prototyping Systems ..... 5-7

5.7.1 Stereolithography (SLA) Process ..... 5-7

5.8 Solid Based Rapid Prototyping Systems ..... 5-9

5.8.1 Fused Deposition Modelling (FDM) ..... 5-10

5.8.2 Laminated Object Manufacturing (LOM) ..... 5-12

5.9 Powder Based Rapid Prototyping Systems..... 5-14

5.9.1 Selective Laser Sintering (SLS) ..... 5-15

5.9.2 Three Dimensional (3D) Printing ..... 5-18

5.9.3 Laser Powder Forming (LPF) ..... 5-20

5.9.4 Comparison between Stereolithography (SLA) Process, Selective Laser Sintering (SLS) Process and 3D-Printing Process .....5-20

5.10 Applications of Rapid Prototyping .....5-22

5.11 Rapid Tooling.....5-24

5.11.1 Classification of Rapid Tooling .....5-24

5.12 STL Format.....5-24

5.12.1 Advantages of STL File Format .....5-25

5.12.2 Disadvantages of STL File Format .....5-25

5.12.3 Problems of STL File Format .....5-26

5.13 4D Rapid Prototyping (4D Printing) .....5-26

5.14 Areas of Applications of Rapid Prototyping....5-28

5.14.1 Applications of Rapid Prototyping in Design .....5-28

5.14.2 Applications of Rapid Prototyping in Engineering, Analysis and Planning .....5-29

5.14.3 Applications of Prototyping in Tooling (Rapid Tooling) .....5-29

**Module 6**

**Chapter 6 : Virtual Manufacturing 6-1 to 6-4**

**6.1 Virtual Manufacturing** : Introduction, Scope, Socio-economic Aspects and Future Trends

6.1 Augmented Reality and Virtual Reality ..... 6-2

6.1.1 Augmented Reality (AR) ..... 6-2

6.1.2 Virtual Reality (VR) ..... 6-2

6.1.3 Difference between Augmented Reality and Virtual Reality ..... 6-2

6.2 Virtual Manufacturing (VM) ..... 6-2

6.3 Scope of Virtual Manufacturing ..... 6-3

6.3.1 Classification of Virtual Manufacturing (VM) Systems ..... 6-3

6.3.2 Scope and Domains of Virtual Manufacturing Systems ..... 6-3

6.4 Benefits of Virtual Manufacturing..... 6-4

6.5 Socio-Economic Aspects of Virtual Manufacturing Systems..... 6-4

