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Kai Cheng

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Prof. Wasim Ahmed Khan
Faculty of Computer Science
Institute of Business Administration
City Campus, Garden Road
74400 Karachi
Pakistan
e-mail: Wasim_khans@hotmail.com

Prof. Kai Cheng
School of Engineering and Design
Brunel University
UB8 3PH Uxbridge, Middlesex
UK
e-mail: kai.cheng@brunel.ac.uk

Prof. Dr. Abdul Raouf
University of Management and Technology
Johar Town C-2
54600 Lahore
Pakistan
e-mail: abdulraouf@umt.edu.pk

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Wasim A. Khan

Sadaf, Arqam, Sarah and Muhammad

Abdul Raouf

Dr. Razia Raouf

Kai Cheng

Lucy Lu

Preface

According to MSN Encarta the term ‘virtual reality’ is commonly used to express Simulated Reality, Computer Simulation, Simulation, Cyberspace, Computer Modeling or Computer Graphics. In today’s scientific scenario, virtual reality is classified on a continuum from Real environment to its variations to virtual environment. These variations of virtual reality are from real environment to augmented reality to augmented virtuality to the virtual environment. All the intermediate representations are known as mixed reality.

Azuma et al. describes the Augmented Reality (AR) in their survey paper published in IEEE Computer Graphics and Applications [November/December 2001] as having the following properties:

1 AR combines real and virtual objects in a real environment;
2 AR runs interactively and in real time, and;
3 AR registers (aligns) real and virtual objects with each other.

The world of virtual reality still requires a specific definition of virtual reality considering the domains it is addressing. In such cases the particular research group provides a relevant definition. In this book, the augmented reality as defined by Azuma et al. is considered applicable.

A discrete manufacturing operation involves tangible activities such as machinery and its operation, use of tools and measurement gadgets, use of pick and place technology and use of storage and transportation equipment etc. On the other hand, the intangible part includes services such as process planning, scheduling, inventory, management information system and business accounting etc.

Establishment of discrete manufacturing facility for specified range of discrete products includes the factory and offices layout, machinery layout, operation of design office, operation of new and old machinery, production planning and control, scheduling, assembly, quality assurance, inventory, transportation, budgeting and accounting and financial activities. Monitoring of all these and other functions is required once the facility has been setup and is functional.

Modern virtual reality techniques using programming languages such as VRML (Virtual Reality Modeling Language), Open GL and object oriented tools C#, Java and Small Talk have allowed extension of concepts of real time simulation to real time simulation with user control in feed back environment. The simulation can be implemented to the extent that from an elaborate statement of corporate strategy to the smallest movement of part of the machine can be modeled and controlled. The supporting database allows maintenance of properties of metal in interaction with a moving tool, storage of different type of simulated machinery and other models and parameters. These models are based on mathematical or procedural methods facilitating functional characteristics of processes such as scheduling and process planning respectively.

The scope of this text is to describe development of virtual factory simulation software for discrete manufacturing based on Object Oriented Design (OOD) using Unified Modeling Language (UML). This book builds up from description of a micro level virtual reality construction of machine component to the virtual reality construction of discrete manufacturing organization. The executable version of virtual factory software for discrete manufacturing is available at the publisher's website (www.springer.com/). There is a scarcity in the market for a title, which has been written to introduce the students and professionals with virtual reality for Discrete Manufacturing as that of subject that can be practiced best through the study of relevant subject areas and that also addresses the relevant components of the technology. This book describes the concepts and technology associated with manufacturing equipment and their control at process and system level for product realization in modular form. It uses examples elaborating procedure to virtually describe processes and systems used in discrete and continuous manufacturing while experiencing flow of material, flow of information and flow of energy. The major emphasis is given to develop Augmented Reality (AR) for the following control gadgetry:

1. CNC based processes,
2. PLC based processes,
3. Industrial Manipulators,
4. Embedded systems based processes,
5. Mechatronics based processes and
6. SCADA based processes.

These micro level virtual realities are later amalgamated into virtual discrete manufacturing systems composed of procedural and mathematical models for intangible production functions.

The book has been divided into twelve chapters. The book can be consulted on the basis of individual chapters depending on the level of the reader. Chapter 1 sets the theme for the establishment of Augmented Reality based various levels of human computer interactions as the necessary requirement of the factory of the future. Chapter 2 explores the discrete and continuous manufacturing processes and examines the current technological trends. Chapter 3 surveys the current use of automation and control in manufacturing and comments on future directions it may take. Chapter 4 examines the possibility of using sensors, transducers and actuators in a feed back virtual environment. Chapter 5 provides methodology for converting EIA 274 D based Computer Numerical Controlled (CNC) machinery into corresponding AR based machinery. Chapter 6 provides methodology for converting JIS SLIM (Standard Language for Industrial Manipulator) based manipulators into AR based robot controller. AR for gantry and conveyor is also discussed in this chapter. Chapter 7 details AR based process control using IEC 61131-3 based PLC programming languages. Chapter 8 examines conversion of embedded system based control to AR based processes. Chapter 9 details AR for SCADA based processes. Virtual reality for Mechatronics based applications are explained in Chap. 10. Methodology to simulate the intangible production functions is described in Chap. 11. Step by step construction of AR based discrete manufacturing facility based on either single or multiple CNC based processes, PLC based processes, embedded system based processed, SCADA based processes and/or Mechatronics based processes is described in Chap. 11. Chapter 12 provides the rationale for adopting AR strategy. The description of virtual discrete manufacturing organization uses both UML diagrams and software listing in part. Appendices at the end of the book provide basic information regarding software development process, Comprehensive bibliography is also provided at the end of each chapter to guide reader to the wealth of information available on the subject. This book is intended for manufacturing professionals with a background in mechanical engineering, industrial engineering, computer engineering and computer Science.

This work requires support from its user in order to improve the further editions. The authors welcome comments and suggestions. Authors may be contacted through authors20@yahoo.com

Contents

About the Authors

Professor Dr. Wasim Ahmed Khan

Professor Dr. Wasim A. Khan holds the first degree in Mechanical Engineering from NED University of Engineering and Technology, Karachi, Pakistan. He later obtained a PhD degree in the area of Operations Research from the Department of Mechanical Engineering, University of Sheffield, UK. He is a chartered engineer (CEng) of the Engineering Council, UK; and a Fellow of the Institution of Mechanical Engineers (FIMechE), UK. He has diverse work experience including working with manufacturing industry, software development for local and overseas clients and teaching production engineering and computer science students. Currently, Dr. Wasim holds a position of Professor at the Faculty of Computer Science, Institute of Business Administration, Karachi, Pakistan.

Professor Dr. Abdul Raouf

Professor Dr. Abdul Raouf is a distinguished scholar of international ranking, having a doctoral degree in Industrial Engineering and over 57 years experience in teaching, research and industry. He was at the University of Windsor, Ontario, Canada for more than two decades as Head of Industrial Engineering. He served King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia as Professor in Systems Engineering Department for ten years. He was Rector Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan for six years. He has been University Professor and Advisor of University of Management and Technology, Lahore since 2005. Dr. Raouf has been appointed Patron and Professor, Institute of Quality and Technology Management, University of Punjab.

Dr. Raouf has published extensively in the areas of Performance Evaluation which include Modeling and Optimization of Tasks involving Information Conservation, Information Reduction, Information Generation and Production System Optimization in the areas of Quality, Safety and Maintenance of Production

Systems. He has authored/co-authored ten books and contributed more than 150 research papers in refereed Journals and refereed conference proceedings.

Recognizing his scholarly pursuits, Dr. Abdul Raouf was bestowed upon the coveted title of ‘Sitara-e-Imtiaz’ by the Government of Pakistan. He was declared “Best Scientist” in the field of engineering by the Pakistan Academy of Sciences. The Higher Education Commission of Pakistan conferred upon him the title of Distinguished National Professor.

Besides being the Editor-in-Chief of International Journal of Quality in Maintenance Engineering Dr. Abdul Raouf is on editorial advisory boards of nine international research Journals. He is Chairman, National Quality Assurance Committee constituted by HEC. He has been appointed as a member of the Accreditation Committee, Education Department, and Government of Punjab. He is member of Governing bodies of number of public and private Universities.

Professor Dr. Kai Cheng

Professor Dr. Kai Cheng holds the chair professorship in Manufacturing Systems at Brunel University. His current research interests focus on micro manufacturing, design of precision machine tools, and global/sustainable manufacturing and systems. Professor Cheng has published over 160 papers in learned international journals and referred conferences, authored/edited five books and contributed six book chapters.

Professor Cheng is a fellow of the IET and IMechE. He is the head of the Advanced Manufacturing and Enterprise Engineering (AMEE) Department at Brunel University, which consists of ten academics and over 40 research assistants/fellows and PhD students. The department is currently working on a number of research projects funded by the EPSRC, EU 7th Framework Programs, Technology Strategy Board (TSB) high value manufacturing program, KTP Programs and the industry. The department is involved in 2008 RAE (research assessment exercise) Generation Engineering unit submission and ranked the 5th in the country. Professor Cheng is the European editor of the International Journal of Advanced manufacturing Technology and a member of the editorial board of International Journal of Machine Tools and Manufacture.

Amir Hussain

Software Engineer

Amir Hussain is a senior software engineer at the Faculty of Computer Science, Institute of Business Administration, Karachi, Pakistan. He holds a B.S degree in Computer Science and more than 10 years experience of software development.

Chapter 1
Augmented Reality for Manufacturing

1.1 Virtual Reality

The origin of the term 'Virtual Reality' can be traced back to the work of French playwright, actor and director Antonin Artaud [1938]. Artaud's drama 'Theatre and its double' was first of the sequel to be followed by several fiction and nonfiction novels, dramas, and movies generating enthusiasm in this novel area of work.

In current scenario, MSN Encarta defines the term virtual reality as commonly used to express simulated reality, computer simulation, simulation, cyberspace, computer modeling or computer graphics.

Michael Heim identifies seven different concepts of virtual reality as simulation, interaction, artificiality, immersion, telepresence, full-body immersion, and network communication.

The term virtual reality is also defined as a technology that allows a user to interact with a computer simulated environment whether that environment is a simulation of the real world or an imaginary world. The forms of virtual reality currently being practiced are visual experiences displayed on computer screen or through stereoscopic displays. Some simulations provide simple sensory information, while others make use of haptic sensors in a close loop feedback system. Some of the advance applications of the virtual reality utilize multimodal devices such as wired glove, the Polhemus boom arm, and omnidirectional treadmill.

In this book, it is proposed that the virtual manufacturing organization is an application of the augmented reality that apportions planning for a nonexistent manufacturing system, operation monitoring of the existent system, maintenance planning, fault diagnostic, rapid maintenance, practicing quality assurance, optimizing the local and global human–computer interfaces, optimizing the flow of information, acquiring rapid response from the system, training at the manufacturing systems, distance learning, practicing e-commerce and possibility of implementing different production philosophies.

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1.2 Reality Virtuality Continuum

The reality virtuality continuum is a terminology used to describe a concept that there is continuous scale ranging between the completely virtual (virtual reality) and the completely real (reality). The reality virtuality continuum encompasses all possible variations and compositions of real and virtual objects. The reality virtuality continuum is depicted in Fig. 1.1.

This book relies on Azuma's description of augmented reality (AR). According to Azuma, AR is a state on reality virtuality continuum that exhibits following properties:

- AR combines real and augmented objects
- AR runs interactively and in real times, and
- AR registers (aligns) real and augmented objects with each other.

1.3 Augmented Reality: An Alternate Human–Computer Interaction

With enormous use of computers in almost all the walks of life, the user interface commonly known as human–computer interaction (HCI) has became the primary focus for research. The centuries-old lessons learned from the famous man–machine interface have been enhanced to meet the challenges of human–computer interaction. Over the years, the human–computer interaction itself has evolved to an extent whereby the user interfaces of 1960s have matured, and criticism on such human–computer interaction tool is commonly available in the contemporary literature. The design parameters for human–computer interaction include both hardware- and software-related parameters. On the other hand, the design theory for the human–computer interaction has now leaped from user-centered design to user involvement in the design. These components of HCI are utilized in designing an augmented reality for the discrete product.

These human–computer interaction parameters have progressed with the merits and demerits of batch processing with nonexistent user, command mode interaction using MS DOS or UNIX operating systems and graphics user interface (GUI) with MS WINDOWS. The current-generation human–computer interfaces are now addressing virtual environment using factors such as user's movement and voice.

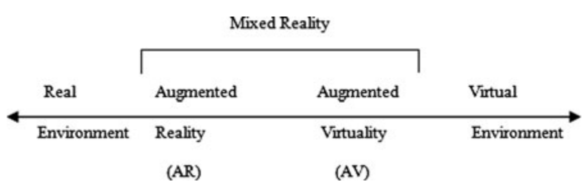


Fig. 1.1 Reality Virtuality Continuum

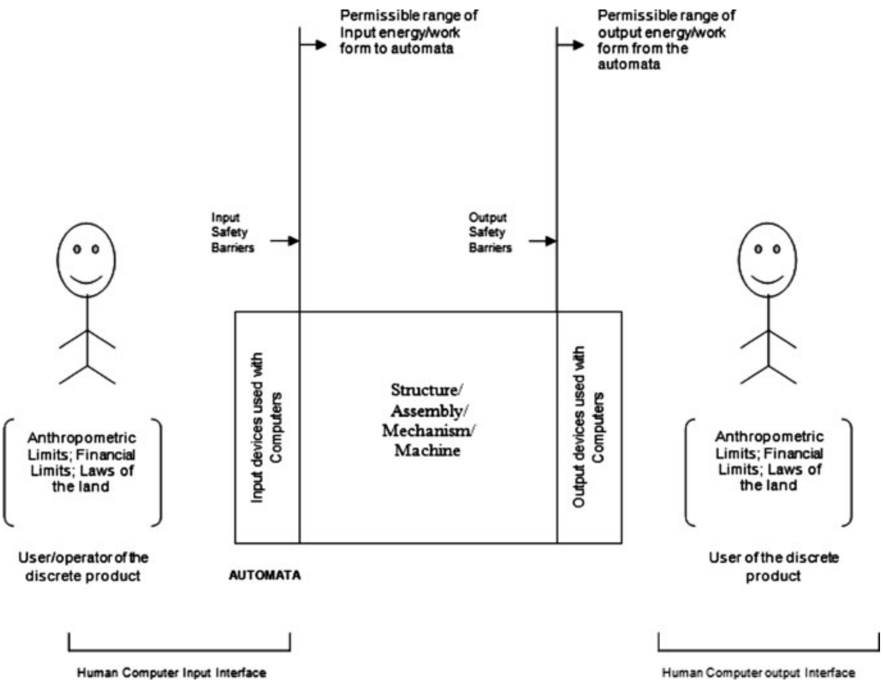


Fig. 1.2 Human–computer interface for discrete products. Extracted with permission from 'Standards for Engineering Design and Manufacturing' [28]

The use of AR to enhance human–computer interaction is demonstrated throughout this book.

The modern discrete products extensively utilize microprocessor-based control of the features. These characteristics require the design of a human–computer interface, allowing more automation in the operation of discrete products. A description of the scope of HCI in discrete products is presented in Fig. 1.2.

1.4 Virtual Manufacturing

In this book, virtual manufacturing (VM) is considered to be an augmented reality (AR) environment exercised to enhance all levels of control in a discrete or continuous manufacturing system. Virtual manufacturing objects include both tangible and intangible functions of production, including manufacturing, costing, process planning, scheduling, quality control, and management information system.

With enormous advancement in computer software and hardware design and development, augmented reality (AR) has taken a frontal role in the description, planning, and real-time operation monitoring, fault diagnostic and recovery, and training related to industrial products and processes. Ease in production planning, process monitoring, fault diagnostics and recovery through fast response maintenance are identified as the major benefits of the use of augmented reality in state-of-the-art production methods.

The basic configuration of discrete and continuous manufacturing systems by Chryssolouris is considered. This comprises the following:

- Job shop
- Project shop
- Cellular system
- Flow line
- Flexible manufacturing system, and
- Continuous manufacturing.

These ideal layouts for discrete manufacturing system along with assembly methods constitute the core of the augmented reality template required for defining any virtual reality application in manufacturing. The processes required to build a manufacturing system are mainly adopted from Kalpakjian's description of current manufacturing processes comprising all or some of the following general areas:

- Metal forming processes
- Bulk deformation processes
- Sheet metal working processes
- Metal cutting processes
- Metal joining processes
- Thermal properties modification processes
- Surface properties modification processes
- Fabrication of micromechanical and microelectronics devices
- Nonconventional processes
- Continuous manufacturing processes.

The discrete manufacturing systems are composed of physical structure for the processes and the system, control characteristics of the processes and the system, and dynamics involved in the operation of the processes and the system. Augmented reality for discrete manufacturing systems involves defining steps required to build an augmented reality (AR) for a manufacturing process such as metal cutting process from component to mechanism to machine level and subsequently integrating the augmented reality (AR) of the process into the augmented reality (AR) of the manufacturing system such as job shop, project shop, cellular system, flow line, and continuous manufacturing system along with the dynamics of energy, material and information flow of a particular manufacturing system.

In a true augmented reality of discrete or continuous manufacturing system, the manufacturing processes should be defined with high level of virtuality encompassing all their functionality and should be capable of being configured on a chosen manufacturing system layout (e.g. on one of Chryssolouris' models of manufacturing system) along with comprehensive energy, information, and material flow capability.

The simulated processes have the capability to mimic real manufacturing processes and are configured on a simulated factory layout. It is possible to configure each of the tangible operations in variable quantity and size depicting a real factory. It is also possible to integrate tangible and intangible production functions in a virtual manufacturing system.

The manufacturing system and the manufacturing processes chosen in the virtual domain are reconfigurable, thus allowing infinite possibilities for the development of augmented manufacturing organization depending on the processing capability of the host computer. The processes are operated using variants of EIA 274D [8–10] and JIS SLIM (Standard Language for Industrial Manipulator), techniques used in programmable logic controllers (PLC) such as defined by IEC 61131-3, embedded system and Supervisory Control and Data Acquisition (SCADA) and other pertinent standards. The simulation interactively use inter departmental transportation methods using gantries and conveyors.

To provide an entirety to virtual discrete manufacturing system, the intangible functions of production are modeled mathematically. These models refer to the following activities:

- Costing
- Accounting and finance
- Sales
- Inventory management
- Procurement
- Process planning
- Quality assurance
- Scheduling
- Management information system.

Intangible functions are incorporated using mathematical models interfaced with factory simulation to maintain the record of presence of various physical objects and decision parameters, e.g. machine selection, machining parameters, and tools/fixtures are defined by the process-planning competency. All the simulations and mathematical models, virtual product in Direct X format, and other parameters are stored in databases.

Layout, machines, product, and their types are all parameters that have a presence. The augmented system detailed here is capable of modeling a discrete manufacturing facility and providing an insight into a nonexistent system. Alternatives may be generated by changing the layout of the manufacturing system and by increasing or decreasing the number and types of machines. The diversity of the product and its quantity can be changed to provide the feasibility of manufacturing system during the proposed period so that the system achieves the break even and profit margins may be implemented in a competitive e-market. For an existent system, the augmented factory contributes in operational planning and maintenance planning. The augmented manufacturing system may also be used for advance training and research in the operation of competencies, production philosophies, and the quality assurance procedures. The system shall prove an excellent training resource and may also be used in distance learning. One novel software application of the virtual manufacturing organization is its use of e-business through semantic web employing web-enabled agents. The human–computer interface (HCI) at various levels of the organization can also be explored. The augmented discrete manufacturing facility is applicable to all type of discrete manufacturing facilities. This scheme models product, processes, and system in real time.

Communication in virtual manufacturing system is carried out through Internet, extranet and intranet. Due to the inherent flexibility of the augmented organization, the flow of information in an augmented organization can be reorganized conveniently. The development of software for augmented reality and procedural/ mathematical models employ objected-oriented technique. Unified modeling language (UML) is used to model the software. Object-oriented high-level language C# is used to develop simulation and models with the support of dot Net framework. Graphic Modeler 3D Studio Max and rendering engine True Vision are used for graphic support. Other software tools that may be used to develop such AR system are listed in "Appendix 1".

1.4.1 Virtual Manufacturing Systems

Virtual manufacturing systems are synthetic environment designed to exhibit manufacturing systems operation on a reality virtuality continuum. The reality–virtuality state exhibited by the manufacturing system falls into the following categories.

- *Reality*: Real manufacturing operation
- *Augmented reality*: Manufacturing system control is augmented by the use of electronic hardware and computer software in order to facilitate managers with more micro- and macro-level parameters for accurate decision making leading to higher profitability.
- *Augmented virtuality*: Consist of higher level of virtuality than augmented reality. In augmented virtuality, a higher proportion of elements are synthetic in nature.
- *Virtuality*: Encompasses immersion in a completely synthetic environment.

1.4.2 Organization of Virtual Manufacturing Systems

Virtual manufacturing system is organized from component of machines to collection of machines in a cell to multiple cells on a shop floor and extending to all other processes on a factory floor.

In a real manufacturing system organization, the machines or processes are rarely moved from one place to another. On the other hand, the virtual manufacturing system has the inherited characteristics of relocation during planning in order to explore optimal output under long-term schedule. For short-term schedules, while the machine remains at the designated position, the optimal part routing can be explored. This part routing maybe within factory premises or beyond, refer to Sects. 1.10 and 12.1.

The flow of energy in a manufacturing system is carried through electric cables, gas pipelines, and fossil fuel on conveyors. The raw material in a manufacturing system is carried through automatic feeding mechanisms, fork lift, gantry, and manually. On the other hand, the flow of information can be routed to any node supervised by a manager as per the administration access rights available to the manager.

1.4.3 Components of Virtual Manufacturing Systems

The virtual manufacturing systems components comprise both real and virtual objects. These objects have the property of aligning themselves in real time.

Discrete[1] manufacturing processes are developed as mechanical artifacts to perform production. These machines produce a variety of components, structures, assemblies, mechanisms, and machines. Each manufacturing process implementation into mechanical artifacts has three distinct features:

I. The input to the equipment, e.g. material type, form and feeding mechanism, final dimension of the product, energy source and other auxiliaries.
II. The process implementation allowing transformation of raw material into required size, shape, and surface finish using tools (e.g. tools as used in metal cutting, high-energy beams or various types of jets), measuring devices and manufacturing instructions. In process, supplies such as lubricating oil and coolants may also be used.
III. The output from the equipment comprising a component (the building block of structure, mechanisms or machines) and scrap. There may be several features present at the production machinery to make the task of manufacturing simpler, easy to control, and resulting in high production rate. The design of manufacturing equipment relies on system approach to design and considers few or all of the following special design requirements:

- Structural consideration for machine frame and assemblies
- Thermal effects on the equipment
- Noise emission from the equipment
- Vibration in the machinery
- Environmental effects on the equipment

[1] Extracted with permission from 'Standards for Engineering Design and Manufacturing' [27].

- Geometric and kinematics behavior of the manufacturing equipment
- Static and dynamic behavior of the equipment
- Availability of computer numerical control (CNC) or process control using programmable logic controllers (PLC)
- Electronic circuitry for implementing control features
- Foundation and installation requirement.

Like any other discrete product, the manufacturing equipment commonly utilizes standard mechanical components, machines elements, control elements, electrical and electronic components, and software components.

Special assemblies and other accessories utilized at the construction of manufacturing equipment may also include the following:

- Tool (referring to mechanical tool, light beams, water jets, etc.)
- Tool holding devices
- Work holding devices
- Lubricating oil pump assembly
- Coolant circulation pump assembly
- Material handling equipment, and
- Scrap handling equipment.

1.4.4 Control of Virtual Manufacturing Systems

A control system at the production equipment may be defined as one or more interconnected devices that work together to automatically maintain or alter the condition of machine tool, robot, or other manufacturing processes in a prescribed manner. Such system may be mechanical, electrical, electronic, hydraulic, or pneumatic. In practice, many control systems are a combination of these and termed hybrid system. If the output quantity has no effect on input quantity, the system is called an open loop system. In real life, control systems sensors and transducers provide the feedback that is used to adjust the input depending on the current state of the output.

Technologies used in discrete and continuous manufacturing for control and automation are:

- Programmable logic controller (PLC)
- Computer numerical control (CNC)
- Industrial manipulator
- Supervisory Control & Data Acquisition (SCADA)
- Embedded systems
- Mechatronics-based system

A programmable logic controller is an electronic apparatus that uses a programmable memory for the internal storage of instructions for implementing specific function such as logic, sequencing, timing, counting, and arithmetic to

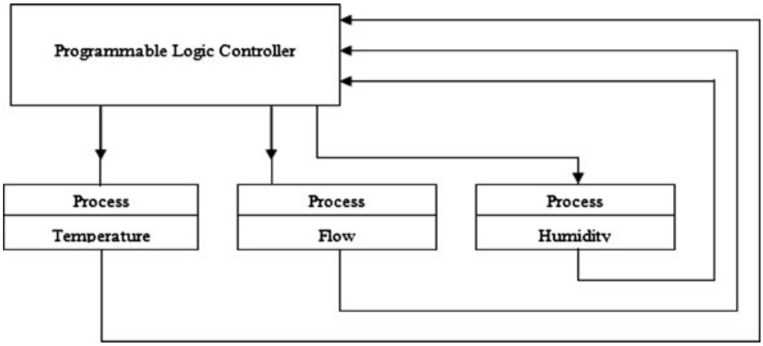


Fig. 1.3 Process parameter control using programmable logic controller (PLC). Extracted with permission from 'Standards for Engineering Design and Manufacturing' [27]

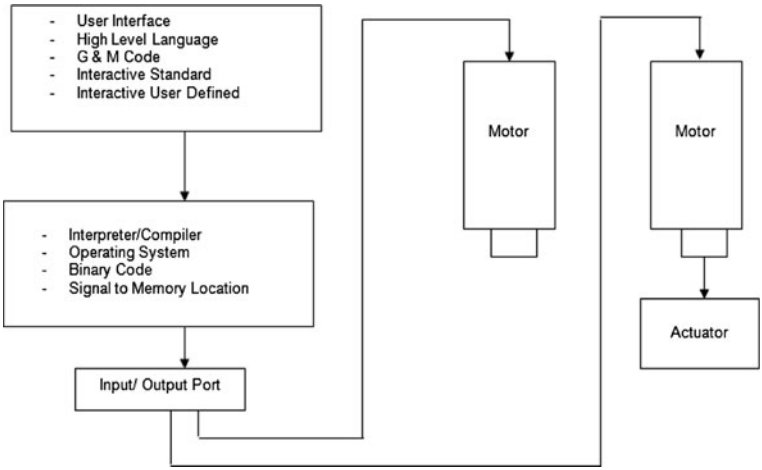


Fig. 1.4 Open loop control of CNC machines. Extracted with permission from 'Standards for Engineering Design and Manufacturing' [28]

control, through digital or analog input/output modules, various types of machines or processes. Programmable logic controller is widely used to automate discrete or continuous manufacturing processes as shown in Fig. 1.3.

Computer numerical control is the technique of giving instructions to a machine tool in the form of code (known as part program) according to a standard such as EIA 274 D that consists of numbers, letters of the alphabet, punctuation marks, and certain other symbols. The machine responds to this coded information in a precise and ordered manner to carry out various machining functions. Computer numerical control is widely implemented at the metal cutting processes. Block diagrams of open and close loop models of CNC controller are exhibited in Figs. 1.4 and 1.5.

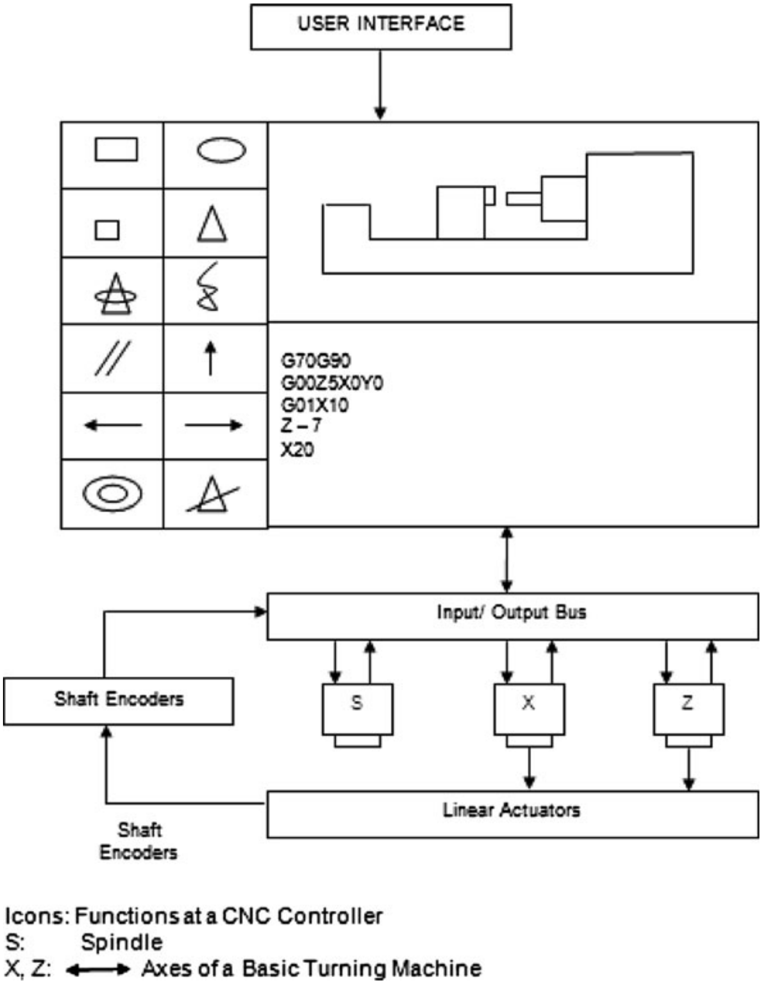


Fig. 1.5 Close loop control of CNC turning machines. Extracted with permission from 'Standards for Engineering Design and Manufacturing' [28]

Industrial manipulators are used to automate a wide range of equipment such as domestic gadgets to pick and place technology. The level of automation offered varies significantly at a manipulator used to automate a product to that in a robot used to help manufacture the product. Japanese Industrial Standard SLIM (Standard Language for Industrial Manipulator) is one of the leading standards used to control the robots. Figures 1.6 and 1.7 provide a schematic of SCADA and embedded systems, respectively. SCADA is normally used in continuous manufacturing where distances between input devices, output devices, and feedback gadgets are larger. Embedded systems are used at equipment requiring high speed of execution. Number of defined control methodologies also fall in the category of

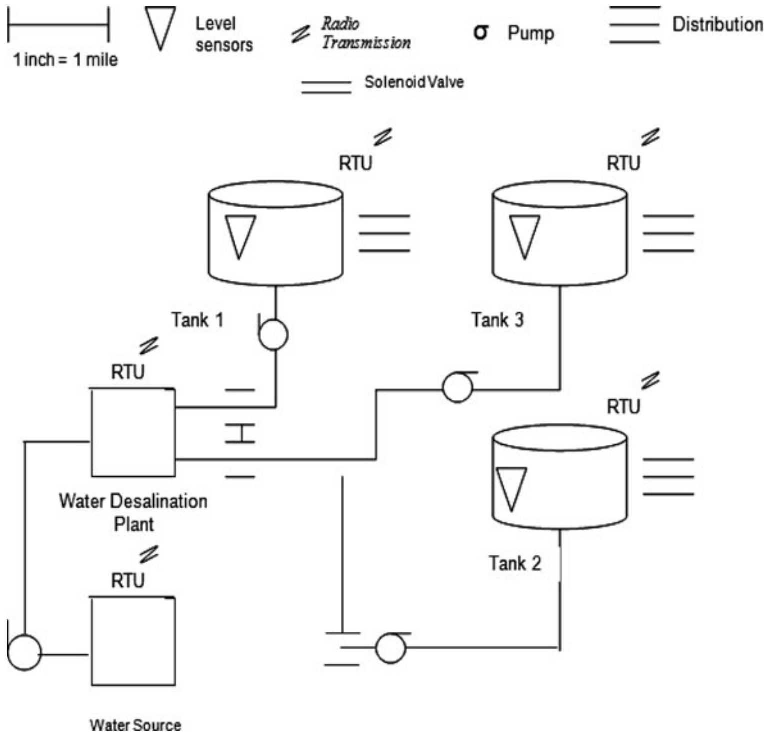
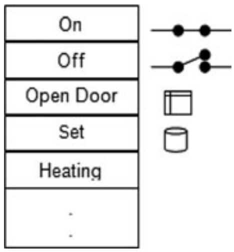


Fig. 1.6 Large-capacity water storage tanks controlled using SCADA

Fig. 1.7 A schematic of an embedded system



mechatronics-based system. These control systems are used for well-defined areas of products, while the mechatronics has a much wider scope with one exception that it must include control of mechanical parts.

An integrated manufacturing system is constituted when there are defined channels available for flow of information, flow of material, and flow of energy to operate the manufacturing system in an integrated manner. These channels may be based on established standard or may rely on company practices for the production of specified objects. There is a formation of levels of control in such systems that

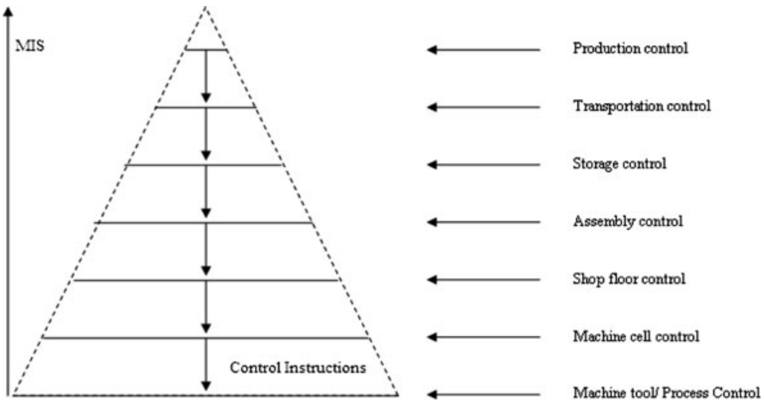


Fig. 1.8 Levels of controls in a single domain of integrated manufacturing system

are operated using a man–machine interface in the case of conventional machinery-based system or human–computer interaction in the case of automated machinery. These levels of control amalgamate in upward direction to provide control of manufacturing system, refer to Fig. 1.8

1.5 Development of Virtual Manufacturing System Using Augmented Reality

The development of virtual manufacturing system (VMS) using augmented reality is an exercise in object-oriented analysis and design from computer science perspective. The VMS requires definition of databases related to all the entities encapsulated in discrete manufacturing systems.

These entities, either at the factory floor or in the store, are an inventory item in real form as well as a graphical model or a data item in the virtual form in the database. Following database containing elements of discrete manufacturing is of importance for virtual manufacturing.

1.5.1 Machine Tool Database

The machine tool database comprises specification of all type of machine tools present in the real manufacturing system. The structure for this database considering both real and virtual objects is provided in Figs. 1.9 and 1.10. Some of the parameters for such a database may be center-to-center distance for turning operation or spindle speed ranges at a milling machine.

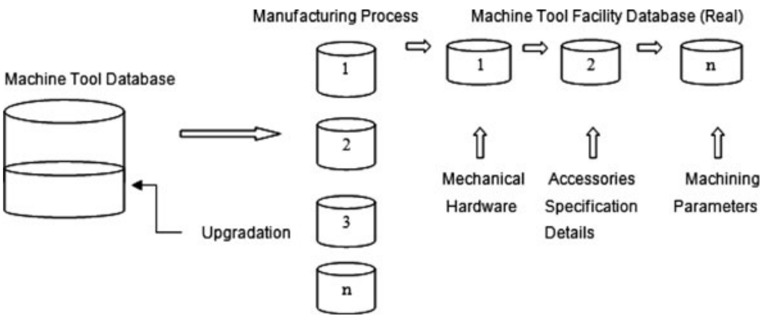


Fig. 1.9 Structure of real objects Database

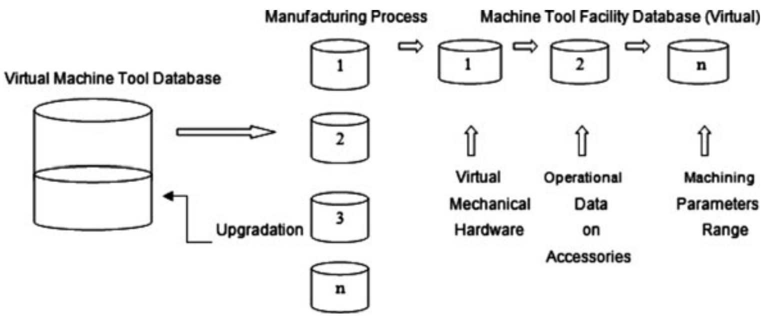
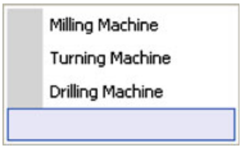


Fig. 1.10 Structure of virtual objects Database

Machines Database menu item has three subitems as shown in the following picture.



- Milling machines
  From Milling Machines Database Form, user can add new milling machine and view existing machines parameters. Refer to the form given as Fig. 1.11.
- Turning machines
  From Turning Machine Database Form, user can add new turning machine and view existing machines parameters. Refer to the form given as Fig. 1.12.
- Drilling machines
  From Drilling Machine Database Form, user can add new drilling machine and view existing machines parameters. Refer to the form given as Fig. 1.13.

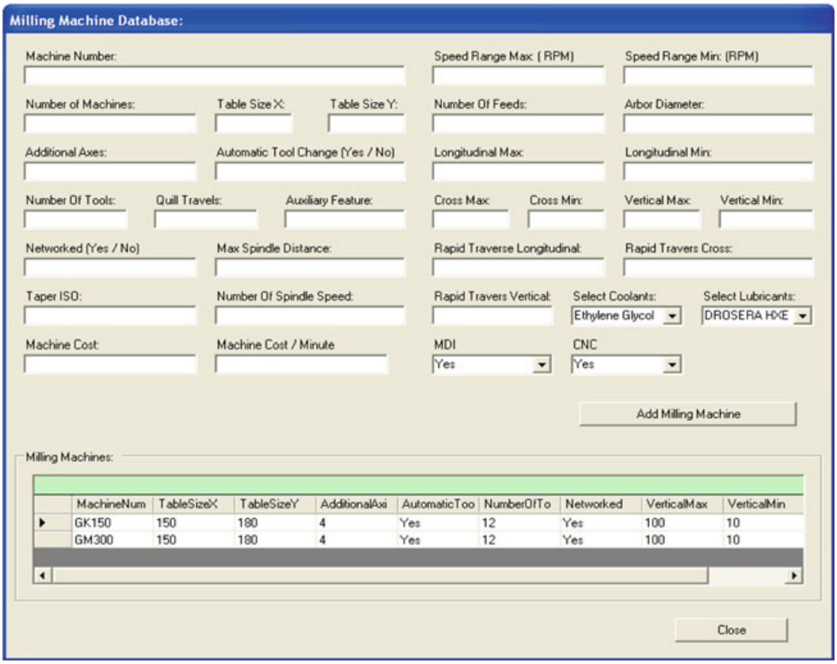


Fig. 1.11 Milling Database

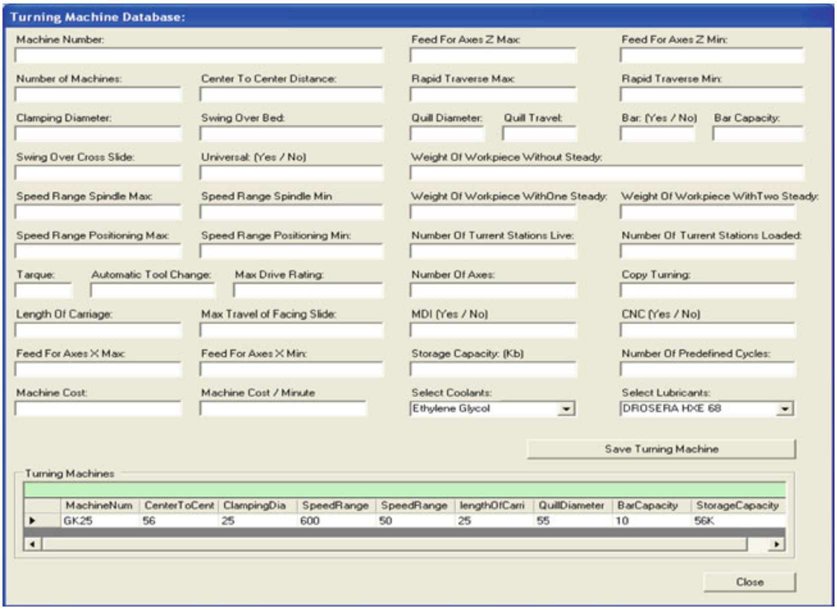


Fig. 1.12 Turning Database