Abstract

In this paper, we propose a new method of reconstructing the hand models for individuals, which include the link structure models, the homologous skin surface models and the homologous tetrahedral mesh models in a reference posture. As for the link structure model, the local coordinate system related to each link consists of the joint rotation center and the axes of joint rotation, which can be estimated based on the trajectories of optimal markers on the relative skin surface region of the subject obtained from the motion capture system. The skin surface model is defined as a three-dimensional triangular mesh, obtained by deforming a template mesh so as to fit the landmark vertices to the relative marker positions obtained motion capture system. In this process, anatomical dimensions for the subject, manually measured by a caliper, are also used as the deformation constraints.

Key Words

Digital human modeling; Digital hand; Motion capture; Joint center estimation

Abstract

Recently, renovations of plant equipment have been more frequent because of the shortened lifespans of the products, and as-built models from large-scale laser-scanned data is expected to streamline rebuilding processes. However, the laser-scanned data of an existing plant has an enormous amount of points, captures intricate objects, and includes a high noise level, so the manual reconstruction of a 3D model is very time-consuming and costly. Among plant equipment, piping systems account for the greatest proportion. Therefore, the purpose of this research was to propose an algorithm which could automatically recognize a piping system from the terrestrial laser-scanned data of plant equipment. The straight portion of pipes, connecting parts, and connection relationship of the piping system can be recognized in this algorithm. Normal-based region growing and cylinder surface fitting can extract all possible locations of pipes, including straight pipes, elbows, and junctions. Tracing the axes of a piping system enables the recognition of the positions of these elements and their connection relationship. Using only point clouds, the recognition algorithm can be performed in a fully automatic way. The algorithm was applied to large-scale scanned data of an oil rig and a chemical plant. Recognition rates of about 86%, 88%, and 71% were achieved straight pipes, elbows, and junctions, respectively.

Key Words

Laser scanning; Object recognition; As-built model; Piping system; Point clouds

Abstract

Similar to the essential components of many mechanical systems, the geometrical properties of the teeth of spiral bevel gears greatly influence the kinematic and dynamic behaviors of mechanical systems. Logarithmic spiral bevel gears show a unique advantage in transmission due to their constant spiral angle property. However, a mathematical model suitable for accurate digital modeling, differential geometrical characteristics, and related contact analysis methods for tooth surfaces have not been deeply investigated, since such gears are not convenient in traditional cutting manufacturing in the gear industry. Accurate mathematical modeling of the tooth surface geometry for logarithmic spiral bevel gears is developed in this study, based on the basic gearing kinematics and spherical involute geometry along with the tangent planes geometry; actually, the tooth surface is a parametric surface defined on a parallelogrammic domain. Equivalence proof of the tooth surface geometry is then given in order to greatly simplify the mathematical model. As major factors affecting the lubrication, surface fatigue, contact stress, wear, and manufacturability of gear teeth, the differential geometrical characteristics of the tooth surface are summarized using classical fundamental forms. By using the geometrical properties mentioned, manufacturability (and its limitation in logarithmic spiral bevel gears) is analyzed using precision forging and multi-axis freeform milling, rather than classical cradle-type machine tool based milling or hobbing. Geometry and manufacturability analysis results show that logarithmic spiral gears have many application advantages, but many urgent issues such as contact tooth analysis for precision plastic forming and multi-axis freeform milling also need to be solved in a further study.

Key Words

Spiral bevel gear; Mathematical modeling; Parametric surface; Geometrical characteristics; Manufacturability
• Development of integrated design methodology for various types of product–service systems  
Tuan A. Tran and Joon Y. Park, pages 37-47, DOI: 10.7315/JCDE.2014.004  
Abstract  
We propose a new generic design methodology for different types of PSS. Product – Service System (PSS) has received much attention recently from academia and industry because of its benefits. PSS can provide customers values and functionalities, as well as physical products, to fulfill economic, social and environmental goals. Many methodologies have been proposed for designing PSSs. Most of the existing methodologies are domain specific and were proposed to solve specific problems in certain projects. Some methodologies are generic but they provide neither guideline to practitioners and designers nor reflect the differences in various PSS types. As a generic approach to guide practitioners and designers in designing PSS effectively, the proposed methodology also takes into account user involvement, business model and organizational structure. The proposed methodology is demonstrated through design examples of different types of PSSs.  
Key Words  
PSS; Product service system; Design methodology; Product service integration; Integrated design methodology  

• Automatic detection of the optimal ejecting direction based on a discrete Gauss map  
Masatomo Inui, Hidekazu Kamei and Nobuyuki Umezu, pages 48-54. DOI: 10.7315/JCDE.2014.005  
Abstract  
In this paper, the authors propose a system for assisting mold designers of plastic parts. With a CAD model of a part, the system automatically determines the optimal ejecting direction of the part with minimum undercuts. Since plastic parts are generally very thin, many rib features are placed on the inner side of the part to give sufficient structural strength. Our system extracts the rib features from the CAD model of the part, and determines the possible ejecting directions based on the geometric properties of the features. The system then selects the optimal direction with minimum undercuts. Possible ejecting directions are represented as discrete points on a Gauss map. Our new point distribution method for the Gauss map is based on the concept of the architectural geodesic dome. A hierarchical structure is also introduced in the point distribution, with a higher level  
Key Words  
Ejecting direction; Undercut detection; Injection molding; Feature recognition; Concurrent engineering; CAD  

• Novel computational approaches characterizing knee physiotherapy  
Wangdo Kim, António P. Veloso, Duarte Araújo and Sean S. Kohles, pages 55-66. DOI: 10.7315/JCDE.2014.006  
Abstract  
A knee joint’s longevity depends on the proper integration of structural components in an axial alignment. If just one of the components is abnormally off-axis, the biomechanical system fails, resulting in arthritis. The complexity of various failures in the knee joint has led orthopedic surgeons to select total knee replacement as a primary treatment. In many cases, this means sacrificing much of an otherwise normal joint. Here, we review novel computational approaches to describe knee physiotherapy by introducing a new dimension of foot loading to the knee axis alignment producing an improved functional status of the patient. New physiotherapeutic applications are then possible by aligning foot loading with the functional axis of the knee joint during the treatment of patients with osteoarthritis.  
Key Words  
Instantaneous axes of the knee (IAK); Cylindroidal coordinates; Perception-action coupling manifold; Gibson  

• Development of educational software for beam loading analysis using pen-based user interfaces  
Yong S. Suh, pages 67-77. DOI: 10.7315/JCDE.2014.007  
Abstract  
Most engineering software tools use typical menu-based user interfaces, and they may not be suitable for learning tools because the solution processes are hidden and students can only see the results. An educational tool for simple beam analyses is developed using a pen- based user interface with a computer so students can write and sketch by hand. The geometry of beam sections is sketched, and a shape matching technique is used to recognize the sketch. Various beam loads are added by sketching gestures or writing singularity functions. Students sketch the distributions of the loadings by sketching the graphs, and they are automatically checked and the system provides aids in grading the graphs. Students receive interactive graphical feedback for better learning experiences while they are working on solving the problems.  
Key Words  
Beam loading analysis; Pen-based interface; Education software; Shape matching
Volume 1, No. 2

- **Voronoi diagrams, quasi-triangulations, and beta-complexes for disks in R2: the theory and implementation in BetaConcept**, Jae-Kwan Kim, Youngsong Cho, Donguk Kim and Deok-Soo Kim, pages 79-87. DOI: 10.7315/JCDE.2014.008

**Abstract**

Voronoi diagrams are powerful for solving spatial problems among particles and have been used in many disciplines of science and engineering. In particular, the Voronoi diagram of three-dimensional spheres, also called the additively-weighted Voronoi diagram, has proven its powerful capabilities for solving the spatial reasoning problems for the arrangement of atoms in both molecular biology and material sciences. In order to solve application problems, the dual structure, called the quasi-triangulation, and its derivative structure, called the beta-complex, are frequently used with the Voronoi diagram itself. However, the Voronoi diagram, the quasi-triangulation, and the beta-complexes are sometimes regarded as somewhat difficult for ordinary users to understand. This paper presents the twodimensional counterparts of their definitions and introduces the BetaConcept program which implements the theory so that users can easily learn the powerful concept and capabilities of these constructs in a plane. The BetaConcept program was implemented in the standard C++ language with MFC and OpenGL and freely available at Voronoi Diagram Research Center (http://voronoi.hanyang.ac.kr).

**Key Words**

Voronoi diagram of disks; Additively-weighted Voronoi diagram; Quasi-triangulations; Beta-complexes; Beta-shapes; Spherical atoms; GUI program

- **Quadrilateral mesh fitting that preserves sharp features based on multi-normals for Laplacian energy**, Yusuke Imai, Hiroyuki Hiraoka and Hiroshi Kawaharada, pages 88-95. DOI: 10.7315/JCDE.2014.009

**Abstract**

Because of the cost of performance testing using actual products is expensive, manufacturers use lower-cost computer-aided design simulations for this function. In this paper, we propose using hexahedral meshes, which are more accurate than tetrahedral meshes, for finite element analysis. We propose automatic hexahedral mesh generation with sharp features to precisely represent the corresponding features of a target shape. Our hexahedral mesh is generated using a voxel-based algorithm. In our previous works, we fit the surface of the voxels to the target surface using Laplacian energy minimization. We used normal vectors in the fitting to preserve sharp features. However, this method could not represent concave sharp features precisely. In this proposal, we improve our previous Laplacian energy minimization by adding a term that depends on multi-normal vectors instead of using normal vectors. Furthermore, we accentuate a convex/concave surface subset to represent concave sharp features.

**Key Words**

CAD model; Hexahedral mesh; Sharp feature; Fitting algorithm; Multi-normalvectors

- **Direct construction of a four-dimensional mesh model from a three-dimensional object with continuous rigid body movement**, Ikuru Otomo, Masahiko Onosato and Fumiki Tanaka, pages 96-102. DOI: 10.7315/JCDE.2014.010

**Abstract**

In the field of design and manufacturing, there are many problems with managing dynamic states of three-dimensional (3D) objects. In order to solve these problems, the four-dimensional (4D) mesh model and its modeling system have been proposed. The 4D mesh model is defined as a 4D object model that is bounded by tetrahedral cells, and can represent spatio-temporal changes of a 3D object continuously. The 4D mesh model helps to solve dynamic problems of 3D models as geometric problems. However, the construction of the 4D mesh model is limited on the time-series 3D voxel data based method. This method is memory-hogging and requires much computing time. In this research, we propose a new method of constructing the 4D mesh model that derives from the 3D mesh model with continuous rigid body movement. This method is realized by making a swept shape of a 3D mesh model in the fourth dimension and its tetrahedralization. Here, the rigid body movement is a screwed movement, which is a combination of translational and rotational movement.

**Key Words**

Four-dimensional mesh model; Three-dimensional mesh model; Fourth dimension; Rigid body movement

- **A multi-user selective undo/redo approach for collaborative CAD systems**, Yuan Cheng, Fazhi He, Bin Xu, Soo-hung Han, Xiantao Cai and Yilin Chen, pages 103-115. DOI: 10.7315/JCDE.2014.011

**Abstract**

The engineering design process is a creative process, and the designers must repeatedly apply Undo/Redo operations to modify CAD models to explore new solutions. Undo/Redo has become one of most important
functions in interactive graphics and CAD systems. Undo/Redo in a collaborative CAD system is also very helpful for collaborative awareness among a group of cooperative designers to eliminate misunderstanding and to recover from design error. However, Undo/Redo in a collaborative CAD system is much more complicated. This is because a single erroneous operation is propagated to other remote sites, and operations are interleaved at different sites. This paper presents a multi-user selective Undo/Redo approach in full distributed collaborative CAD systems. We use site ID and State Vectors to locate the Undo/Redo target at each site. By analyzing the composition of the complex CAD model, a tree-like structure called Feature Combination Hierarchy is presented to describe the decomposition of a CAD model. Based on this structure, the dependency relationship among features is clarified. B-Rep re-evaluation is simplified with the assistance of the Feature Combination Hierarchy. It can be proven that the proposed Undo/Redo approach satisfies the intention preservation and consistency maintenance correctness criteria for collaborative systems.

**Key Words**
Undo/Redo; Collaborative CAD; Intention preservation; Configuration management

**Orthogonal projection of points in CAD/CAM applications: an overview,**
Kwanghee Ko and Takis Sakkalis, pages 116-127. DOI: 10.7315/JCDE.2014.012

**Abstract**
This paper aims to review methods for computing orthogonal projection of points onto curves and surfaces, which are given in implicit or parametric form or as point clouds. Special emphasis is placed on orthogonal projection onto conics along with reviews on orthogonal projection of points onto curves and surfaces in implicit and parametric form. Except for conics, computation methods are classified into two groups based on the core approaches: iterative and subdivision based. An extension of orthogonal projection of points to orthogonal projection of curves onto surfaces is briefly explored. Next, the discussion continues toward orthogonal projection of points onto point clouds, which spawns a different branch of algorithms in the context of orthogonal projection. The paper concludes with comments on guidance for an appropriate choice of methods for various applications.

**Key Words**
Orthogonal projection; Point projection; Curve projection; Registration; Minimum distance; Directed projection

**Characterization of machining quality attributes based on spindle probe, coordinate measuring machine, and surface roughness data,**
Tzu-Liang Bill Tseng and Yongjiin James Kwon, pages 128-139. DOI: 10.7315/JCDE.2014.013

**Abstract**
This study investigates the effects of machining parameters as they relate to the quality characteristics of machined features. Two most important quality characteristics are set as the dimensional accuracy and the surface roughness. Before any newly acquired machine tool is put to use for production, it is important to test the machine in a systematic way to find out how different parameter settings affect machining quality. The empirical verification was made by conducting a Design of Experiment (DOE) with 3 levels and 3 factors on a state-of-the-art Cincinnati Hawk Arrow 750 Vertical Machining Center (VMC). Data analysis revealed that the significant factor was the Hardness of the material and the significant interaction effect was the Hardness + Feed for dimensional accuracy, while the significant factor was Speed for surface roughness. Since the equally important thing is the capability of the instruments from which the quality characteristics are being measured, a comparison was made between the VMC touch probe readings and the measurements from a Mitutoyo coordinate measuring machine (CMM) on bore diameters. A machine mounted touch probe has gained a wide acceptance in recent years, as it is more suitable for the modern manufacturing environment. The data vindicated that the VMC touch probe has the capability that is suitable for the production environment. The test results can be incorporated in the process plan to help maintain the machining quality in the subsequent runs.

**Key Words**
Machining quality; Coordinate measuring machine (CMM); Design of experiment (DOE); Vertical machining center (VMC); Dimensional accuracy; Surface roughness

**Intelligent 3D packing using a grouping algorithm for automotive container engineering,**
Youn-Kyong Joung and Sang Do Noh, pages 140-151. DOI: 10.7315/JCDE.2014.014

**Abstract**
Storing, and the loading and unloading of materials at production sites in the manufacturing sector for mass production is a critical problem that affects various aspects: the layout of the factory, line-side space, logistics, workers' work paths and ease of work, automatic procurement of components, and transfer and supply. Traditionally, the nesting problem has been an issue to improve the efficiency of raw materials; further, research into mainly 2D optimization has progressed. Also, recently, research into the expanded usage of 3D models to implement packing optimization has been actively carried out. Nevertheless, packing algorithms using 3D models are not widely used in practice, due to the large decrease in efficiency, owing to the complexity and excessive computational time. In this paper, the problem of efficiently loading and unloading freeform 3D objects into a given container has been solved, by considering the 3D form, ease of loading and unloading, and packing density. For this reason, a Group Packing Approach for workers has been developed, by using analyzed truck packing work patterns and Group Technology, which is to enhance the efficiency of
storage in the manufacturing sector. Also, an algorithm for 3D packing has been developed, and implemented in a commercial 3D CAD modeling system. The 3D packing method consists of a grouping algorithm, a sequencing algorithm, an orientating algorithm, and a loading algorithm. These algorithms concern the respective aspects: the packing order, orientation decisions of parts, collision checking among parts and processing, position decisions of parts, efficiency verification, and loading and unloading simulation. Storage optimization and examination of the ease of loading and unloading are possible, and various kinds of engineering analysis, such as work performance analysis, are facilitated through the intelligent 3D packing method developed in this paper, by using the results of the 3D model.

Key Words
Packing, 3D CAD model, Grouping algorithm, Container engineering
Volume 1, No. 3

• An alternative method for smartphone input using AR markers,
Yuna Kang and Soonhung Han, pages 153-160, DOI: 10.12989/cde.2014.1.3.015

Abstract
As smartphones came into wide use recently, it has become increasingly popular not only among young
people, but among middle-aged people as well. Most smartphones adopt capacitive full touch screen, so touch
commands are made by fingers unlike the PDAs in the past that use touch pens. In this case, a significant
portion of the smartphone's screen is blocked by the finger so it is impossible to see the screens around the
finger touching the screen; this causes difficulties in making precise inputs. To solve this problem, this
research proposes a method of using simple AR markers to improve the interface of smartphones. A marker is
placed in front of the smartphone camera. Then, the camera image of the marker is analyzed to determine the
position of the marker as the position of the mouse cursor. This method can enable click, double-click, drag-
and-drop used in PCs as well as touch, slide, long-touch-input in smartphones. Through this research,
smartphone inputs can be made more precise and simple, and show the possibility of the application of a new
concept of smartphone interface.

Key Words
Smartphone; Augmented reality (AR); Marker; Interface; Human-computer interaction (HCI)

• A comparison of three design tree based search algorithms for the detection of engineering parts
constructed with CATIA V5 in large databases,
Robin Roj, pages 161-172. DOI: 10.7315/JCDE.2014.016

Abstract
This paper presents three different search engines for the detection of CAD-parts in large databases. The
analysis of the contained information is performed by the export of the data that is stored in the structure trees
of the CAD-models. A preparation program generates one XML-file for every model, which in addition to
including the data of the structure tree, also owns certain physical properties of each part. The first search
gine is specialized in the discovery of standard parts, like screws or washers. The second program uses
certain user input as search parameters, and therefore has the ability to perform personalized queries. The
third one compares one given reference part with all parts in the database, and locates files that are identical,
or similar to, the reference part. All approaches run automatically, and have the analysis of the structure tree
in common. Files constructed with CATIA V5, and search engines written with Python have been used for
the implementation. The paper also includes a short comparison of the advantages and disadvantages of each
program, as well as a performance test.

Key Words
CAD; CATIA V5; Classification; Database; Dat mining; Design tree; Feature recognition; Knowledge
Discovery; Python; Search engine

• Development of a simulation method for the subsea production system,
Jong Hun Woo, Jong Ho Nam and Kwang Hee Ko, pages 173-186. DOI: 10.7315/JCDE.2014.017

Abstract
The failure of a subsea production plant could induce fatal hazards and enormous loss to human lives,
environments, and properties. Thus, for securing integrated design safety, core source technologies include
subsea system integration that has high safety and reliability and a technique for the subsea flow assurance of
subsea production plant and subsea pipeline network fluids. The evaluation of subsea flow assurance needs to
be performed considering the performance of a subsea production plant, reservoir production characteristics,
and the flow characteristics of multiphase fluids. A subsea production plant is installed in the deep sea, and
thus is exposed to a highpressure/low-temperature environment. Accordingly, hydrates could be formed
inside a subsea production plant or within a subsea pipeline network. These hydrates could induce serious
damages by blocking the flow of subsea fluids. In this study, a simulation technology, which can visualize the
system configuration of subsea production processes and can simulate stable flow of fluids, was introduced.
Most existing subsea simulations have performed the analysis of dynamic behaviors for the installation of
subsea facilities or the flow analysis of multiphase flow within pipes. The above studies occupy extensive
research areas of the subsea field. In this study, with the goal of simulating the configuration of an entire deep
sea production system compared to existing studies, a DES-based simulation technology, which can logically
simulate oil production processes in the deep sea, was analyzed, and an implementation example of a
simplified case was introduced.

Key Words
Subsea production; Discrete event simulation; 3D visualization; Fluid flow simulation

• Multicriteria shape design of a sheet contour in stamping,
Fatima-Zahra Oujebbour, Abderrahmane Habbal, Rachid Ellaiia and Ziheng Zhao, pages 187-193. DOI:
10.7315/JCDE.2014.018

Abstract
One of the hottest challenges in automotive industry is related to weight reduction in sheet metal forming
processes, in order to produce a high quality metal part with minimal material cost. Stamping is the most
expected benefits of virtual commissioning are the reduction of debugging and correction efforts during the design, manufacturing, and testing processes. While the real commissioning of a manufacturing system involves a real plant system and time-consuming debugging efforts, virtual commissioning allows for efficient and cost-effective testing and debugging in a simulated environment. This practice is particularly useful in the current shipbuilding industry, where it is of vital importance for shipyards to have the ship components' accuracy evaluated efficiently during most of the manufacturing steps. Evaluating components' accuracy by comparing each component against CAD data scanned by laser scanners and the ship's design data formatted in CAD cannot be processed efficiently when (1) extract components from point cloud data include irregular obstacles endogenously, or when (2) registration of the two data sets have no clear direction setting. This paper presents reformative point cloud data processing methods to solve these problems. K-d tree construction of the point cloud data fastens a neighbor searching of each point. Region growing method performed on the neighbor points of the seed point extracts the continuous part of the component, while curved surface fitting and B-spline curved line fitting at the edge of the continuous part recognize the neighbor domains of the same component divided by obstacles' shadows. The ICP (Iterative Closest Point) algorithm conducts a registration of the two sets of data after the proper registration's direction is decided by principal component analysis. By experiments conducted at the shipyard, 200 curved shell plates are extracted from the scanned point cloud data, and registrations are conducted between them and the designed CAD data using the proposed methods for an accuracy evaluation. Results show that the methods proposed in this paper support the accuracy evaluation targeted point cloud data processing efficiently in practice.

Key Words
Point cloud; Region growing method; B-spline curve; ICP; K-d tree

• Automated quality characterization of 3D printed bone scaffolds,
Tzu-Liang Bill Tseng, Aditya Chilukuri, Sang C. Park and Yongjin James Kwon, pages 194-201. DOI: 10.7315/JCDE.2014.019

Abstract
Optimization of design is an important step in obtaining tissue engineering scaffolds with appropriate shapes and inner microstructures. Different shapes and sizes of scaffolds are modeled using UGS NX 6.0 software with variable pore sizes. The quality issue we are concerned is the scaffold porosity, which is mainly caused by the fabrication inaccuracies. Bone scaffolds are usually characterized using a scanning electron microscope, but this study presents a new automated inspection and classification technique. Due to many numbers and size variations for the pores, the manual inspection of the fabricated scaffolds tends to be error-prone and costly. Manual inspection also raises the chance of contamination. Thus, non-contact, precise inspection is preferred. In this study, the critical dimensions are automatically measured by the vision camera. The measured data are analyzed to classify the quality characteristics. The automated inspection and classification techniques developed in this study are expected to improve the quality of the fabricated scaffolds and reduce the overall cost of manufacturing.

Key Words
Bone scaffolds; Automated inspection; 3D print; Classification; Regression model; Neural networks

• Efficient point cloud data processing in shipbuilding: Reformative component extraction method and registration method,
Jingyu Sun, Kazuo Hiekata, Hiroyuki Yamato, Norito Nakagaki and Akiyoshi Sugawara, pages 202-212, DOI: 10.7315/JCDE.2014.020

Abstract
To survive in the current shipbuilding industry, it is of vital importance for shipyards to have the ship components' accuracy evaluated efficiently during most of the manufacturing steps. Evaluating components' accuracy by comparing each component against CAD point cloud data scanned by laser scanners and the ship's design data formatted in CAD cannot be processed efficiently when (1) extract components from point cloud data include irregular obstacles endogenously, or when (2) registration of the two data sets have no clear direction setting. This paper presents reformative point cloud data processing methods to solve these problems. K-d tree construction of the point cloud data fastens a neighbor searching of each point. Region growing method performed on the neighbor points of the seed point extracts the continuous part of the component, while curved surface fitting and B-spline curved line fitting at the edge of the continuous part recognize the neighbor domains of the same component divided by obstacles' shadows. The ICP (Iterative Closest Point) algorithm conducts a registration of the two sets of data after the proper registration's direction is decided by principal component analysis. By experiments conducted at the shipyard, 200 curved shell plates are extracted from the scanned point cloud data, and registrations are conducted between them and the designed CAD data using the proposed methods for an accuracy evaluation. Results show that the methods proposed in this paper support the accuracy evaluation targeted point cloud data processing efficiently in practice.

Key Words
Point cloud; Region growing method; B-spline curve; ICP; K-d tree

• Survey on the virtual commissioning of manufacturing systems,
Chi G. Lee and Sang C. Park, pages 213-222. DOI: 10.7315/JCDE.2014.021

Abstract
This paper reviews and identifies issues in the application of virtual commissioning technology for automated manufacturing systems. While the real commissioning of a manufacturing system involves a real plant system and a real controller, the virtual commissioning deals with a virtual plant model and a real controller. The expected benefits of virtual commissioning are the reduction of debugging and correction efforts during the
subsequent real commissioning stage. However, it requires a virtual plant model and hence still requires significant amount time and efforts. Two main issues are identified, the physical model construction of a virtual device, and the logical model construction of a virtual device. This paper reviews the current literature related to the two issues and proposes future research directions to achieve the full utilization of virtual commissioning technology.

**Key Words**
Virtual commissioning; Virtual plant model; Virtual device model; DEVS; PLC simulation