3D Machine Vision and Additive Manufacturing: Concurrent Product and Process Development

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Abstract. The manufacturing environment rapidly changes in turbulence fashion. Digital manufacturing (DM) plays a significant role and one of the key strategies in setting up vision and strategic planning toward the knowledge based manufacturing. An approach of combining 3D machine vision (3D-MV) and an Additive Manufacturing (AM) may finally be finding its niche in manufacturing. This paper briefly overviews the integration of the 3D machine vision and AM in concurrent product and process development, the challenges and opportunities, the implementation of the 3D-MV and AM at POLMAN Bandung in accelerating product design and process development, and discusses a direct deployment of this approach on a real case from our industrial partners that have placed this as one of the very important and strategic approach in research as well as product/prototype development. The strategic aspects and needs of this combination approach in research, design and development are main concerns of the presentation.

1. Introduction
Currently, the global trends and requirements toward product quality (aesthetics and ergonomics) become more and more complex and precise. Furthermore, global competition provides a significant impact and new challenge to the industries to continuously seek integrated manufacturing solutions in order to improve process performance as well as to accelerate product development cycle. Small and/or large product changes certainly will require changes on each component of the products. In this situation, a time requirement to conduct the changes more and more faster as well as time requirement to manufacturing processes without ignoring determined product quality [1].

To overcome with the above challenges as well as to maintain and accelerate product development cycle, two new members in advanced manufacturing technologies: 3D Machine Vision (3D-MV) and additive manufacturing (AM), have able to show their capability and offer its reliability as a solution since they are commercialized. The 3D-MV is a technology that in general enables to model a 3D surface of a product through a technique called 3D-scanning which can then be utilized to manufacture the product rapidly [2]. While AM technology, which is also known as direct digital manufacturing (DDM), has a capability to manufacture a geometrically-complex 3D part directly from 3D CAD solid model without tooing required [3,4].
Referring to the advancement of these technologies, a combination deployment of the 3D-MV and AM at Politeknik Manufaktur (POLMAN) Bandung – The Bandung Polytechnic for Manufacturing - has been accepted as an important part in supporting an advanced design and manufacturing process, especially for a geometrically complex product which difficult or impossible be manufactured through a conventional route. Engineering and design process at POLMAN Bandung which is also supported with advanced CAD/CAM/CAE technologies enable to provide solution in design concept optimization of the product prior to manufacture process and its production planning. However, in many cases, manufacturing a complex 3D physical prototype with a real 1:1 scale are still highly required and cannot be ignored because a visualization as well as an evaluation of a 3D physical part still an effective media compare to 2D or 3D scaled model.

2. **Product Development**

Recently, there are two common methods/approaches in engineering and product development: conventional and non-conventional [2]. In conventional method, product development starts with generating a 3D CAD model (wireframe/surface/solid) of the product utilizing CAD software. Through a concept modeling to realize a designed product, a format of 3D CAD model can be converted to CAE model for numeric simulation modeling and CAM model in order to generate cutting tool-path (NC-code). The conventional approach unfortunately cannot be empowered for re-engineering process, simulated and optimized the existing product design without any support data/information from CAD format. Therefore, it is required a non-conventional method that can be utilized to capture and record geometrical data of the product as well as to generate a numeric concept model that can be deployed in CAE and CAM system. This is known as a reverse engineering (RE). With the deployment of the 3D-MV in product design and development, RE is expected to grow further in the year to come.

3. **Definition and Basic Process**

3.1. **3D Machine Vision (3D-MV)**

As a concept being familiar currently, RE can be overview as an analysis process toward [5]:

1. Identification of product design information and its relation,
2. Design representation format as well as a higher level accuracy of abstraction, and
3. Realization of an assigned product design

In general, a main goal of RE is to generate a product concept model from its existing physical model. Therefore, a feature combination technique in the 3D-MV (3D scanning with a software package) has a capability to reconstruct the model is highly required [6]. In 3D-MV application, 3D scanning is deployed to capture a coordinate of 3D points (point-cloud) on the product surface. Product geometrical representation in point-cloud format is an initial step for surface parametric development. The following Figure 2 shows a deployment of RE in product design and development.
In product design and development at POLMAN Bandung, the deployment of RE to the 3D-MV implementation is derived into the following seven (7) steps procedure (Figure 2).

![Figure 1. RE Deployment [1]](image)

As illustrated, the whole 7 step procedures actually are simplified and grouped into 3 main phases: Scanning Process, Processing and Modelling, and Model Verification.
Phase 1: Scanning Process
As it mentioned before, a main aim in RE is to develop a physical concept model of a product. With a current advanced technology in digitizing and data capturing, scanning is a process to capture a 3D surface data from undefined product geometry. In this scanning process, a 3D-MV is utilized to capture and record data/information of product surfaces in a numeric format in order to generate a matrix of 3D coordinate points (step 1 – 4).

A 3D-MV at POLMAN Bandung - ATOS I Optical 3D scanning system (Figure 3) is an independent facility which is deployed for an accurate 3D scanning process utilizing optical scanning technology. The heart of this 3D-MV is that its software package enables to manipulate capturing data and convert them to a format that can be utilized to generate a 3D CAD surface model (IGES, ASCII, STL) or even NC code [5].

Figure 3. 3D-MV at POLMAN Bandung: ATOS I Optical 3D Scanning System

Phase 2: Processing and Modeling
Processing and modelling captured scanning data is an important phase. Mostly, captured scanning data always require correction and modification (ie. reducing a number of points, fixing scanning results, merging different scanning results – polygonization) in order to provide a replica and a variety geometrical data of the scanned product (step 5). Thus, modified data is then imported to a reconstruction software package for converting into CAD surface concept model, which is furthermore utilized for required post-processing such as CAD/CAM/CAE and prototyping (step 6).

Phase 3: Model Verification
With the utilization of 3D CAD surface model for post-processing, a next important phase is to verify the whole processes through product quality inspection. In this case, a generated concept of the 3D CAD surface model from the 3D-MV scanning is evaluated by comparing it with a master CAD model of the product so that any deviation occur on product geometry caused by post-processing can be evaluated (step 7).

3.2. Additive Manufacturing (AM)
Additive Manufacturing (AM) has a unique capability to manufacture physically a 3D part/product with a relatively complex geometry directly from a 3D CAD solid model without tooling requirement [3,4]. Currently, the AM have become an integrated part in computer-based design process and its deployment in industry spreads widely. With an advanced development of the technology and
material, the current capability of the AM fulfils the demands of different applications. The main
general classifications of the AM application are to develop [8,9]:

1. prototype: design concept visualization, design verification & optimization, design review
2. tooling: rapid tooling (RT)
3. end/functional product: rapid manufacturing (RM)

A variety development of the AM technology is very wide and each of which deploys specific
method/technique and material to manufacture a required finished part. However, three basic
processes shown in Figure 4 below are the basic steps for all available AM technology. The first step,
utilizing CAD software, is to generate a 3D CAD solid model. The second is then to convert generated
3D CAD model to a format model that contains a stack of 2D cross-section layer on Z-axis. Thus, the
third (final) step is to develop a physical 3D model of the part/product based on a defined cross-section
layer [8].

Figure 4. DDM Basic Processes [8]

Fused Deposition Modeling (FDM) from Stratasys is the AM technology deployed at POLMAN
Bandung (Figure 5a). The technology in FDM develops a 3D solid part/product by extruding a thin
layer of thermo plastic (ie. ABS, PC) paste through thermal extrusion nozzle (Figure 5b). To build up
each layer, nozzle extrudes plastic paste which is relates to defined cross-section and then extrude next
layer on top of the previous layer.

Figure 5. Fused Deposition Modeling (FDM)
4. POLMAN Bandung Experiences

4.1. 3D Machine Vision (3D-MV) Implementation

As it mentioned previously, POLMAN Bandung equips its RE process with a 3D-MV which has a capability to transform a required real-scale model. Since 2006, the availability of the 3D-MV as well as other advanced computer-based modelling technologies has improved a quality and efficiency of product development process from design up to manufacturing process at POLMAN Bandung. With optimizing its capability, the implementation of 3D-MV at POLMAN Bandung can go beyond inspection of surface defects. The following are four main application areas of the 3D-MV implementation at POLMAN Bandung:

1. Product duplication: no drawing and manufacturing documentation available.
2. Product Re-engineering: design analysis and modification for performance and quality improvement
3. Rapid prototyping and tooling (RP&T) development
4. Quality inspection.

To get more understanding, Figure 6 to Figure 9 show a sample of real cases which represent the implementation of the 3D-MV in related above application areas. Basically, every case in each application area has various requirements, from fixing design information up to design modification.

1. Duplication & Modification

Remark:
Modify the existing design to simplify the manufacturing the mold

![Figure 6. Ornament](image)

2. Rapid Manufacturing & Tooling (NC-Code)

Remark:
Rapid generation of NC-Code (tool path) format directly from 3D surface modeling of the available product.

![Figure 7. Oil Container](image)
3. Part Quality Inspection

Remark:
Inspect & evaluate two results of the products from two different manufacturer (measured & compared against master model).

Figure 8. Product Comparison

4. Part & Tool Quality Inspection

Remark:
Inspect & evaluate the products as a result of the designed tool.

Figure 9. Geometry Deviation

4.2. Additive Manufacturing (AM) Implementation
To be advance in product design and development, POLMAN Bandung recently deploys AM technology - Fused Deposition Modelling (FDM) - to rapid development of prototyping for design verification. Error! Reference source not found. and Error! Reference source not found. present some sample cases of main implementation of AM technology at POLMAN Bandung.
1. Prototyping 1

Remark:
Prototyping a new design of the container regarding to the exceeding spare of the lit.

Figure 10. Refreshment Container

2. Prototyping 2

Remark:
Prototyping a new design of the Francis Turbine (redesign the blade)

Figure 11. Francis Turbine

4.3. 3D-MV and AM Expansion of System

Although the 3D-MV and AM technology at POLMAN Bandung currently utilized as a means of ensuring accuracy and product quality of the product independently, initial steps have been taken to enable deviation/defect accumulated by the systems to be used for improvement of product accuracy and quality. A consideration to expand the utilization of the 3D-MV and AM in product design and development is to integrated these technologies in predicting optimum quality and measuring the defects/deviation before they actually occur. The following Figure shows a general scheme of combining 3D-MV and AM technology in designing and developing a quality part/product.

Figure 12. Combination Use of 3D-MV and AM
Of course the implementations of both 3D-MV and AM have no value if they cannot provide benefits and profits. With a proper methodology and technology structure, the implementation of the 3D-MV and AM at POLMAN Bandung has provided tangible and in-tangible benefits in term of both process and result/outcome, as follow:

1. Process: ability of providing proper technical data for design as well as manufacturing process of discontinuous products; overcome a limitation of CAD in product modification and improve its manufacturing process; improve process time through design documentation improvement.

2. Result/outcome: can be utilized to redesign a product in order to improve quality and performance.

Furthermore, the benefits of the 3D-MV and AM technology in product design and development highly depend on a starting point of the knowledge to implement the technology. If the 3D-MV and AM are deployed where technology structure of design and manufacture has not yet well established, the transition to deploy the technology will be relatively difficult and the relatively huge efforts are required. On the other hand, if the technology structures are available and well established, the deployment of the 3D-MV and AM technology in design and manufacturing is relatively easy.

Despite of the benefits, there are challenges in deploying the 3D-MV and AM technology. These technologies are not simple, fast, and an economic to be implemented. There are important issues need to be considered, such as a matriculation or introduction to the technology so that they can be integrated into the existing system, and cost justification for its implementation [10]. As the implementation of the 3D-MV and AM technology is becoming more and more intense at POLMAN Bandung, there are a trend of positive impact toward a certain technology to continuously improve the process of design and manufacturing at POLMAN Bandung.

5. Conclusions

After over viewing the basic aspects of the 3D-MV and AM technology as well as the implementation procedures at POLMAN Bandung, it is required to know and understand that the 3D-MV and AM technology can provide benefits as well as profits in design and manufacturing process of a product. More significantly, further knowledge and understanding of the 3D-MV and AM technology are highly required to improve a system integration of design process and manufacturing. In other words, implementing structured basic principles of the 3D-MV and AM technology properly becomes a key-point as well as an important step in achieving main objective for development process and product quality improvement.

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