<table>
<thead>
<tr>
<th>Title</th>
<th>Emerging Trends In Reverse Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Bidanda, Bopaya; Geng, Zhaohui</td>
</tr>
<tr>
<td>Date</td>
<td>2016</td>
</tr>
<tr>
<td>URL</td>
<td><a href="http://hdl.handle.net/10220/41854">http://hdl.handle.net/10220/41854</a></td>
</tr>
<tr>
<td>Rights</td>
<td>© 2016 by Pro-AM 2016 Organizers. Published by Research Publishing, Singapore</td>
</tr>
</tbody>
</table>
ABSTRACT: This paper presents an overview of reverse engineering - an often ignored but critical part of additive manufacturing. The quality of a 3D printed part is limited by the quality of computer model that details the part, which in turn, is governed by the quality of the acquired data in the computer. Data is typically acquired by reverse engineering. While the discipline has progressed significantly over the past decade, there is still much to be done. This paper describes new trends in the field that include increased speed and accuracy and even explores exciting possibilities in the future.

KEYWORDS: Reverse Engineering, 3D Printing, Virtual Prototyping

HISTORICAL BACKGROUND

Reverse Engineering (RE) is the process of duplicating existing objects by measuring, analyzing, and testing to gain information about a product. This idea, which is counter-intuitive to the more common forward engineering process, is actually widely accepted and used in our daily life. Many modern machines were inspired or partially influenced from our natural surroundings. The designs of airplanes and submarines are two good examples of bio-mimicry (a form of reverse engineering) and evolutionary designs. These two designs were developed by reverse engineering and reengineering, based on observing and simulating a variety of birds and fishes – today’s shapes and designs still have some similarities to these biological creatures. From this, we can see how RE provides a path to reconstruction, reproduction, reengineering, and even to shorten the throughput time from reverse engineering to design to production.

Depending on the scope of the definition utilized, RE can be found in most major engineering applications. For examples, RE is practiced by major military powers, from replication and analysis for defense to reengineering. One of the widely cited examples may be the U.S. B-29 Superfortress bombers and Soviet Tupolev Tu-4(Bull) bombers (Raja & Fernandes (2007)). Further, in the automotive industry, RE is also widely practiced, either as part of the process of kaizen or continuous improvement or for analyzing a competitor’s products, to better compete in the global marketplace. On one hand, RE helps automotive companies get information on existing products without their computer-aided design (CAD) models – extremely useful information to improve their design to help product enhancement and innovation. On the other hand, it must be noted that RE allows you to ‘keep up’ with the competitors, not necessarily to allow you to ‘get ahead’ in today’s global market place.

RE applications abound in the software industry, from software maintenance to security auditing. Defined as “the process of analyzing a subject system to create representations of the system at a higher level of abstraction”, the software reverse engineering considered the “first leg” of software reengineering (Wang (2010)) or ‘reconstruction’, and is a powerful tool in replicating existing software from a functional perspective. However, this idea can sometimes be associated with piracy or with intent to plagiarize and capitalize on the work of others, with major implications in terms of copyright infringement. Over the past years, software anti-tamper and anti-reverse engineering technologies have emerged to protect the intellectual property. Some software is deliberated ‘infected’ with redundant code to prevent reverse engineering.

Further, over the past two decades, new applications areas with a significantly more positive outlook have emerged. These include implantable and non-implantable medical and rehabilitation products (Creehan & Bidanda (2006)). Other exciting areas include the replication of printed circuit boards (PCB) in consumer electronics, et al., that has attracted great attention during recent years.
This paper concentrates on reverse engineering undertaken for the purpose of obtaining a geometric computer aided design (CAD) model of a mechanical component. CAD typically the first step of manufacturing; however, designers often build physical models and iterate a series of these models into a final design. In order to scale up the production effort from a prototype into small batch manufacturing, an accurate and well-structured 3D model of the part in CAD software is needed. Sometimes, after a series of physical performance tests, detailed design information of the approved prototype is needed for further redesign or manufacturing. In the past, these physical models were painstakingly replicated by taking multiple physical measurements and inputting into a CAD model. Based on these multiple needs, a more modern and semi-automated mode of RE is provided as a strong and high-tech tool that sharply shortens the product design and manufacturing life cycle (Bidanda & Honi (1994)). Also, the RE provides a closed loop between physical and digital worlds between design, engineering and manufacturing, and thus forms the foundation for robust design. With the improvement of software and hardware, RE has become more attractive by identifying increased application areas and by increased accuracy.

CURRENT STATE

Reverse engineering can be considered as a systematic process to extract design information of an existing object with a general process steps as shown in the flowchart Figure 1. This shows RE process can be divided into three major phases: geometric data acquisition, data processing and CAD model generation for further CAE or CAM use.

Geometric Data Acquisition
To get the object design information, accurate geometric acquisition is considered as the starting point of every RE project. This phase can be broadly divided into two types of methods: contact (Dasai & Bidanda (2006)) and non-contact methods (Crehan & Bidanda (2006)). The taxonomy of RE technologies in Figure 3 shows RE family is pretty large which makes the selecting of “appropriate” strategy is a critical issue for different type of designs.

Contact methods
Considered as a more traditional manner of collecting geometric data, contact methods have been used for several years, still with highest accuracy and quality. The principle of contact methods is straightforward that requires contact between the surface and a measuring device, called Coordinate Measuring Machine (CMM), shown in Figure 3. With the probe or stylus at the end of the machine, these methods make it possible to scan any type of objects, also providing extremely fine details of delicate materials. More recent equipment here includes a variety of machine configurations with multiple probes.

![Figure 1. The general RE process. (Source: Bidanda & Honi (1994))](image-url)
Non-contact methods
Comparing to the probe or stylus to contact the surface, non-contact methods use light or laser beams to assess the object surface, for example, the laser scanner shown in Figure 4. Under the whole idea of this type of methods, it can be further divided into two subgroups, active and passive techniques. The idea of active technique is similar to contact methods that treat the beam as the probe to scan surface, and get the data from the reflected beam by sensors. On the other hand, the passive techniques get the design information by working with ambient light. As the improvement in the field of imaging and electronic devices, researches related to these techniques have gained more interests.
Data Processing

The output of scanning phase is point cloud data with noise and a huge number of points. With the help of filter algorithms that most appropriate for each task, the data processing phase can provide a clean, concentrate point cloud data set with convenient format for further usage.

CAD Models Generation

In order to get the goal for further computer-aided manufacturing (CAM) or computer-aided engineering (CAE), the generation of CAD models from point data is critical. And more recently, CAD software providers add modules imbedded within their product for working with the scan data, making possible for designers to use reverse engineering techniques to shorten design life cycle with complete solutions.

Over the past three decades, based on the famous Moore’s Law, the digital electronics have contributed to the drastically improvement in hardware and software engineering techniques, making the easy availability of CAD packages and have made reverse engineering as a practical and efficient tool for designers. However, with the emerging trend of other technologies, reverse engineering can provide more accurate and convenient design solutions for different uses in the future.

EMERGING TRENDS OF RE

Early reverse engineering machines consisted of crude setups with products mounted on turntable in conjunction with multiple laser beams. Today, 3D X-ray CT scanning has been implemented into the reverse engineering space and while this makes investigating the hole or inside structure without breaking it or cutting it open applicable, the setup and machines are prohibitively expensive.

Smart & ‘Integrated’ 3D printers.

The next evolution in RE will likely be related to artificial intelligence (AI) in both hardware and software. Currently, the RE includes only a cursory application of AI, along with much manual manipulation of scanner data and CAD operations. On hardware side, automating scanner operations make scanning more accurate and shorten the time of scanning. In the future, we are likely to see an eventual integration of the reverse engineering and 3D printing functions perhaps even on a single machine. As shown in Figure 5, this would then make part ‘reproduction’ a two-step process, where the original product is first placed inside a work envelope and the geometry is quickly scanned. The part is then removed and the machine begins to re-create the said part. This further enhances data exchange between scanning and 3DP functions enabling these new generation machines to reverse engineer and reproduce a part with minimal setup.

Development in the software arena could include an integrated ‘automated process planner’. This has been the holy grail in manufacturing for many decades and is moving closer to reality. The ‘integrated machine’ will also provide the maker with multiple process plans for making the same part.
Better reproduction for mass production

As shown above, RE is considered as the first step of CAM and CAE and important design part, and what’s more, RE is also treated as the other side of AM, since the inputs of AM are CAD file, STL (Surface Tessellation) file, which is just RE’s output. An interesting question of how to move a physical part to an additive manufactured part help to set up the process between RE and AM, that provide the trends of future manufacturing and service industry. However, much care is needed of the superposition error in the whole processes, that may deteriorate product usefulness. The whole process including design, manufacturing, RE and AM is shown in Figure 6. For example, a product whose size is $A$ mm was designed for some specific purpose that requires highly precision, that the required output product should be within $A \pm \sigma$ mm. After design and manufacturing, a manufacturing error is added to the initial design $A \pm \sigma_M$ mm. In order to reproduce this product without the initial CAD file, a RE process is required to gain the design information, then after scanning, data processing, CAD file generation, a RE error is added to the model, which causes the measure is $A \pm \sigma_M \pm \sigma_{RE}$ mm. The CAD file is used for AM, and after reproduction, an error of AM, $\sigma_{AM}$, is also added to the final product, whose measure is $A \pm \sigma_M \pm \sigma_{RE} \pm \sigma_{AM}$ mm. And the product’s final measure is easily out of the range of the requirements $A \pm \sigma$ mm, which makes the whole reproduction process and final product useless. Because of the highly unpredictable error in each step of the whole process, the superposition error occurs often and is not easy to solve. So, in order to get a better reproduction and a more accurate representation, a more robust system that includes tolerance stacking may be required to ensure the product is deliverable, reproducible, and feasible.

The practical integration of RE and AM is attracting more attention each year in different industries. With the idea of closed-loop design, industries such as automotive, aerospace, medical, electronics, consumer goods, et al., have take advantage of the improvement to make better design solutions for consumers’ better quality of lives. With the emergence of a new generation of smart and integrated machines, design can become much easier, as well as more creative and applicable.
REFERENCES


Creehan, K. D. & Bidanda, B. (2006). “Reverse engineering: a review & evaluation of non-contact based systems.” In Rapid Prototyping (pp. 87-106), Springer US.


Figure 6. Process flow for product reproduction with error superposition.