Title:
An Automated Intelligent Feature-based Maintenance Plan Generation Method

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Introduction:
Maintenance is a labour-intensive industrial process that is still planed and performed manually. Currently, industries are aiming to automate as many industrial processes as possible to improve production and service, as well as industrial safety. For maintenance, the time taken to complete a preventive or corrective task depends on the operator's knowledge and experience. New maintenance operators are starting at industries with an entry-level experience every day. It takes time for them to be trained by experienced operators, which are not always available. Automating maintenance processes will help to solve these current problems. However, maintenance is one of the areas that represents a great challenge when it comes to automating the entire process. Planning and execution of maintenance tasks, for example, are still challenging to automate with the existing technology due to the complexity and level of difficulty of disassembly tasks. On the other hand, knowledge-based decisions are needed for maintenance planning to reduce downtime, which is a task currently done by experienced professionals.

There are some research areas that are contributing to improving maintenance processes [1,2,3]. Many researchers have worked to improve specific areas of maintenance processes to make it more intelligent, efficient, safe and easy to perform. Even though it will take a long time to fully automate all maintenance processes, the development of a method, which is capable of autonomously generating maintenance plans and assistance during the process, represents a big step forward. The framework integrates different methods to support the maintenance process at the product and component levels. Existing methods are discussed in section two, followed by the proposed methodology. Three different case studies are discussed and finally the conclusion and future work.

Main Idea:
The framework in Fig. 1 is designed to support maintenance operators by automatically identifying real products, generate or provide the maintenance procedure and receive a step-by-step guidance (if required) for corrective maintenance procedure at the product and component level.

First, CAD models and 3D points-cloud data are supported as an input to the system. The developed application for maintenance plan generation is linked to the knowledge-based decision algorithms. Three different modules are available and driven by the knowledge-base when required. A reverse engineering module is able to reconstruct the CAD model when the real product is 3D scanned to generate points-cloud data. Another module is an algorithm proposed in our previews work [5], which automatically extract the geometric features of the model. Then, user defined features (UDF) are searched on the CAD model extracted data to identify the product. Once identified, the product is linked to the knowledge-base where the maintenance information is stored. If the knowledge does not exist for a particular model, the last module is able to generate a new procedure from existing knowledge at a product level. The component level maintenance plan generation is another contribution of this paper, which assist operators in performing corrective maintenance path towards the defective component. A step-by-step guidance is provided to reach components with higher chances of failing for inspection and repair. The method proposed is a generic knowledge-based framework, which can allow other applications and new modules integration. The description of the proposed three modules followed by the knowledge-based algorithms and developed application are presented below.

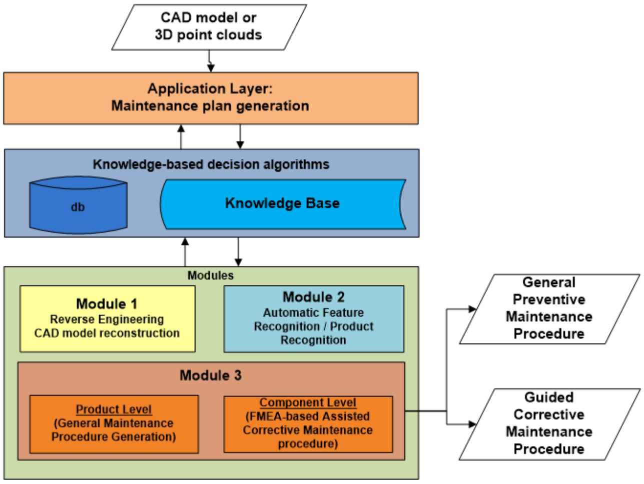

Fig. 1: Feature-based Intelligent Maintenance Plan Generation Framework.

Module 1: Reverse Engineering

Commonly, a mechanical component behaves as a property of having a limited number of primitives (regular shape). In this paper, our study is focusing on these mechanical products and a comprehensive reverse engineering method for CAD model reconstruction is used. This method enables a fast and accurate reconstruction from raw points-cloud to a CAD. The flowchart of the proposed method is presented in Fig. 2. First, 3D points-cloud is collected as an input through a laser or depth-cameras. Then, a random sample consensus (RANSAC)-based algorithm [6] is introduced to efficiently obtain parameters of primitives by surface fitting. Modelling operations are performed depending on the topological relations of primitive surfaces to construct CAD model. Finally, the CAD model is sent to the AFR module for product recognition.

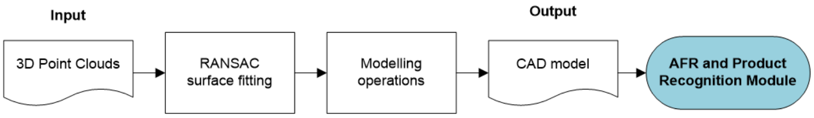

Fig. 2: Flowchart of the proposed reverse engineering method.

Module 2: Automatic Feature Recognition and Product Identification

The product level method of this module was presented in the previous work [5]. The Automatic feature recognition is designed to extract all the geometric features from the CAD model (STEP file or Solidworks part file) to a database. After which, the fast searching engine of database allows the system to look for UDFs, which defines the product. A key number is generated based on the features found from the product, which ultimately constructs the link to the knowledge-base. Depending on the case, the system is capable of providing existing maintenance procedure for the identified product and able to create a new procedure in the next module using existing knowledge.

Module 3: Product Maintenance plan Generation

This module integrates a product level submodule and a component level submodule. The product level generates a maintenance procedure from existing knowledge. The system automatically finds a similar procedure that can be modified by the user and adapted for the new product. The case is saved and ready to be used in future. Geometric similarities of the product are the main criteria used to provide existing maintenance procedure.

The component level submodule integrated is designed to provide guidance to operators specifically when performing corrective maintenance procedures. The system consists of a step-by-step guidance to disassemble the product with real-time user interaction. A precedence graph for disassembly and the failure mode and effect analysis (FMEA) are used to generate an assisted disassembly sequence for maintenance. The risk priority number (RPN) from FMEA information is an indicator of the risk associated to the failure mode or component. The higher the RPN number, the more critical the component will be. In a given product, each component RPN value is ranked from highest to lowest. This rank number is used as a criteria to follow when making disassembly sequence decisions within a given precedence graph for the disassembly of the product using knowledge-base. The user contribution relies on the physical disassembly and inspection of each component. Depending on the user observation and action taken in every step, the method will guide the user until at least the most critical components (1^{st} and 2^{nd} most critical) had been inspected and a faulty component had been repaired or replaced including the most critical one. The reason for using RPN value is that there is a higher chance to find faults in those components ranked first. If the FMEA information and disassembly precedence graph are not available in the knowledge-base, the system will provide information from the similar products. The user can then make the necessary modifications and ultimately save the case for the future usage. For the disassembly sequence precedence graph, the user is required to review and modify the suggested graph to match the information of the new product. This is done in a table where all components are listed along with the precedence relation to other components for disassembly. For FMEA data, each verified component name will be assigned to its corresponding RPN value and ultimately rank from the highest to the lowest.

Knowledge-based decision algorithm

The knowledge-base is designed to drive all the modules and make the decisions needed depending on each possible case. It automatically provides maintenance procedure and also assistance to the operator for product identification. However, and more importantly, it is also capable of saving new generated knowledge automatically when a new case base is identified. The application layer allows a two-way interaction between the user and the knowledge-base. A security check is integrated to the system in order to avoid unauthorized personnel to compromise knowledge integrity. Only authorized personnel are able to make modifications. For these reasons, the proposed knowledge-based system gets better every time as used. The database in this layer is used to store all the extracted information and is available to the system every time, if needed.

Developed Application for Maintenance

The user interaction with the system is done through the developed application, which is directly connected to the knowledge-base. Pneumatic valves are used in this paper as the product to prove the proposed method. For the case where the product is unknown and the CAD model is available, the AFR and product recognition module is called. In the event of using the reverse engineering module to construct the CAD file, the user is required to verify and make product measurement corrections as the standard points-cloud data doesn't count with product information as an original CAD file.

General product maintenance procedure is available to the user once the product is recognized. For maintenance procedure at a component level, the application shows the components and sequence to disassemble the product towards the most critical component (ranked 1st). Every disassembly direction is provided after the user inspects each disassembled component. Once the procedure is completed, repair time, failure mode, failure time and failed component are extracted and saved in the knowledge-base.

Case study

In the case study, the CAD model is not available, therefore reverse engineering module is used to reconstruct the CAD model and identify the product. The maintenance procedure and technical specifications exists in the knowledge-base. Once the user has been prompted that the product is unknown to the system and the CAD model is not available, it is required to 3D scan the product. This will generate the raw points-cloud of the product. The RANSAC-based algorithm in module 1 performs the surface fitting (Fig. 3 10b) to ultimately reconstruct the CAD model. The product in the three stages of the reverse engineering process is shown in Fig. 3 (a, b, and c). The final CAD model is then opened through the system to extract the geometric features and identify the product. The user is asked to declare that the product was 3D scanned, and then make corrections to the connection diameter of the valve. A new key number is generated and the knowledge-based decision algorithms provide the existing product information to the user. The sequence can be seen in Fig. 4 (steps 1 to 5).

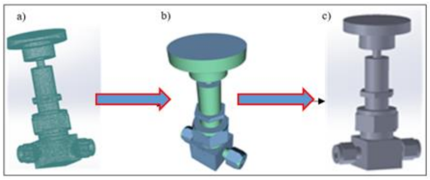

Fig. 3: Reverse engineering process: a) points-cloud data, b) surface fitting, c) reconstructed CAD model (STEP) file).

Conclusions:

The developed method proves that it can become a powerful tool for improving and automating the existing maintenance processes. In general, it integrates different technologies such as RANSAC-based reverse engineering method that in the past were not applied to support automated maintenance planning and execution. More specifically, it helps to solve maintenance execution time and knowledge needed, when non-experienced operators are recruited. The proposed method can assist them by automatically providing the proper procedure and a step-by-step guidance for corrective maintenance if needed. It works by simply recognizing a product from a CAD model. For those cases where the CAD model is not available, the system is able to process 3D points-cloud to reconstruct a CAD model and ultimately identify the product to generate a maintenance plan. This methodology is validated to support solutions in three different scenarios: unknown products to the user and system, unknown maintenance procedures and unavailable CAD files.

Future work will focus on integrating more technology and methodologies to support maintenance processes such as augmented reality, virtual reality and optimization models for fast product disassembly. In addition, further complex applications can be developed and validated through the framework to support its knowledge-base.

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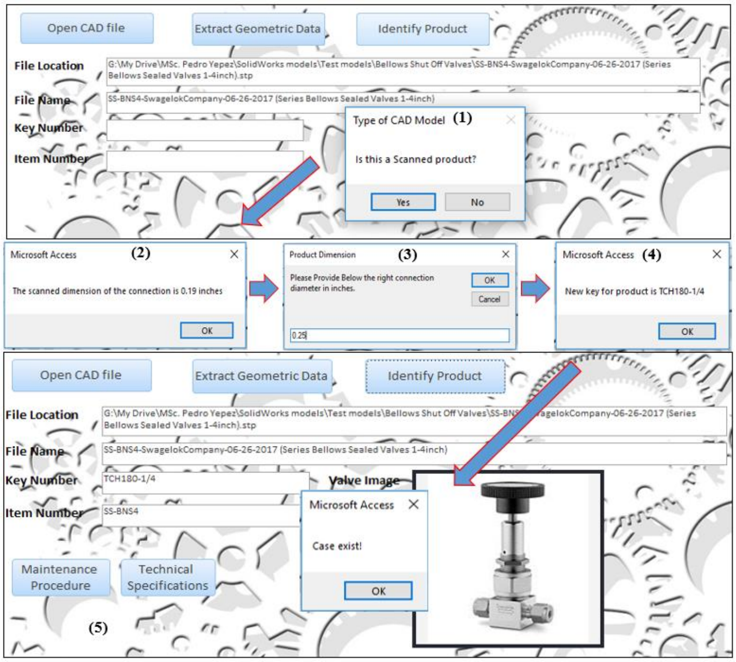

Fig. 4: Case study: (1) Type of input file (2) Scanned dimension (3) Correction of connection diameter (4) Key for identified product (5) Existing maintenance procedure provided for the identified product.

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