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The development of an integrated haptic VR machining environment for the automatic generation of process plans

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ABSTRACT

In modern manufacturing it is crucial to be able to produce a product right first time, as efficiently as possible. Virtual prototyping can play a key part in fulfilling this requirement, allowing the simulation of production in advance without the need for unnecessary downtime, material waste or increased lead times. This makes virtual reality (VR) potentially an ideal planning tool since, with each simulation, a better understanding of requirements can be reached and a more effective solution found.

This application of haptic virtual reality is particularly relevant in the field of machining where both material and resource costs are high. Planning for the machining of a product requires an intricate knowledge of materials, processes and machining methods. Intuitive virtual reality interfaces can provide new, engineer-friendly means of generating such manufacturing sequences.

Current research in haptic virtual reality focuses on specific individual aspects of machining such as path planning or simulation for training; however, in order to simulate multi-operation machining with a view to generating practical and usable process plans, in which there are several processes involved in bringing a product to fruition; an approach is required which allows this type of functionality.

This paper presents such a haptic virtual process planning system that allows an operator to load and set up a billet for machining, set up, sequence and tear down any combination of milling, drilling or turning operations then produce a time-estimated process plan. All of the human expertise captured during this process is logged and parsed to generate the final instructions including operation times, tool lists, operation lists and route sheets in easy-to-read format.

Via three planning examples, the generation of process plans is demonstrated; with these subsequently validated through their use by a shop floor machinist who utilised them to produce the parts, and a comparison to previously existing plans for the same parts.
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1. Introduction

This paper presents a new approach to multi-operation process planning based on haptic virtual reality called Haptic Aided Process Planning (HAPP). This system seeks to take advantage of the considerable intuitive and interactive nature of virtual reality systems to provide a process planning tool with a user friendly interface which supports planning sequence generation, expert knowledge acquisition, formalisation and review.

Process planning is the phase in the product development process which takes place between design and actual product manufacture. It is the point at which all decisions are made regarding how a product will be produced, decisions made are critical and can have a significant impact on the final cost and quality of a product. The process to create a plan can be broken down into several sub-phases as defined by [1,2] and discussions with expert process planners:

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1. Drawing interpretation and material evaluation.
2. Process selection and sequencing.
3. Machine and operations sequencing.
4. Tooling selection.
5. Setting process parameters and calculating the machining times.
6. Determination of work holding requirements including set up time calculations.
7. Selection of quality assurance methods.
8. Documentation of the process plan.
9. Costing the plan.

These sub-phases are not necessarily sequential and can be iterated through in various stages depending on the quantity and complexity of the product and its associated data, before manufacturing sequence finalisation. Traditionally, process planning was carried out by an experienced process planner with an intimate knowledge of the machinery and processes available for product manufacture. However, acquiring and formalising this expertise is highly clerical, time consuming and the results are often inconsistent since they depend on each planner's specific ability. To help address some of these issues Computer Aided Process Planning (CAPP) [3] systems have been developed with the approaches used within this field generally tending to comprise either Generative or Variant systems [10]. Variant systems use index-based approaches such as a classification codes to develop new plans from existing plans of a similar type for 'standard' product variants. The advantage being that proven prior knowledge is drawn into the new design: the disadvantage being that these rely on a traditional process planning approach to acquire the manufacturing database on which they depend. Alternatively, generative systems aim to remove human intervention and develop unique plans directly from the design model files or product data every time they are created or generated. The key challenges faced by these systems include feature extraction and the ability to acquire and process human expertise [4]. In practice it appears that large manufacturers implement a mix of CAPP systems with expert engineer intervention [5] where necessary whereas small to medium size enterprises (SMEs) rely on traditional process planning methods [6]. This illustrates that commercial applications have yet to find an ideal solution for process planning. CAPP systems that are embedded into commercial tools such as CATIA, Creo or EdgeCAM are limited in functionality, focusing on the generation of machining instructions for specific CNC machinery and not including all the required functionality for a true process planning system as listed previously. It has also been hinted in [4] that these unstructured and unsystematic CAPP implementations may have hindered the growth of CAPP as a whole.

Whether CAPP systems are traditional, variant or generative they all require the input and initial formalisation of human expertise and all of these methods struggle to achieve this in an intuitive manner. What is required are new methods for capturing the initial knowledge which can be used to feed into current computer-based approaches and it is the authors' contention that virtual reality (VR) could provide such an opportunity as well as other advantages.

VR has a long history of being used to simulate tasks and promoting the increase and capturing of human expertise in many areas. With current developments in this technology it is now possible to simulate some manufacturing tasks normally carried out in the physical world in a virtual world. This has led to a paradigm shift in the field of manufacturing where prototyping tasks usually carried out in the factory can now be simulated in a virtual environment. A virtual environment (VE) can be loosely defined as the recreation of the real world within a software environment [7]. In the real world the engineer may be confined by cost, location or physical limitations; whereas in a virtual world these are removed and they can train, experience or experiment with manufacturing processes, product assembly and testing with limited financial risk. In addition to this, the human expertise generated in this process can be logged, retrieved and processed from these simulations in a manner simply not possible in the real world, and expert knowledge generated automatically after being implied from the captured virtual activities [8].

The advantages realised by this technology have resulted in several areas of research being developed with regard to manufacturing [9] which primarily include: virtual assembly, virtual manufacturing, virtual prototyping and virtual machining.

Virtual Assembly as outlined in the seminal reference paper by Seth et al. [10] investigates the use of VR to assemble the component parts of a mechanical object, capturing relevant information and using this to develop assembly instructions.

Virtual manufacturing allows the simulation of a manufacturing systems environment. A system is developed in [11] and demonstrates how the development and planning of complex production processes can be supported by VR. Whilst [12] illustrates with an industrial test case how VR can be applied to improve a manufacturing process with a VR-based continuous improvement process application.

Virtual prototyping provides the opportunity to iteratively practise the processes necessary to realise a product in advance, allowing an optimal solution to naturally evolve. A survey of virtual prototyping with regard to mechanical product development is undertaken in [13], providing a critical analysis of the state-of-the-art with a view to enabling SMEs to make decisions on its applicability.

Virtual machining focuses on simulating the actions of specific machine types with a view to either training operators or gathering machine specific information. For example a virtual machining application may simulate material removal, calculate process parameters, simulate tool breakages, etc. [9].

The review in [9] highlights an important gap in the research concluding: "...all systems regardless of focuses and approaches are capable of simulating more than one function; however, no system is capable of a complete suite of simulations." A VR system for process planning requires a suite of simulations and is therefore a key gap that this research addresses.

A later development in virtual environments was the inclusion of haptic devices [14]. These allow a sense of feel to be included in the simulation, stimulating another human intuitive sense and enabling a higher degree of interaction with the associated operations leading to a more convincing virtual environment [15]. Haptic devices come in many different forms [16] but generally consist of a series of motors and position sensors that convey interactive forces in the virtual world back to the operator by a mechanical device [17]. Haptic rendering algorithms [18,19] generate forces which are passed to the haptic device allowing the operator to feel vibration or collisions between complex objects. It is reported that the addition of haptic devices:

1. Enhance task performance in 3D environments where quick and accurate movement is required [20].
2. Alleviate visual load [21].
3. Reduce perceived workload [22].
4. Will enable the operator to manipulate objects within the virtual environment in a more intuitive manner [23] than would be possible with a mouse and keyboard.

Currently the adoption of haptics into virtual manufacturing, particularly machining, has been slow. This according to [24] is due to expense, complexity and limited workspace, and functionality. However, in spite of this, research has shown the advantages haptics and VR can bring to this field as explained.

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