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Application of machine learning to optimize process parameters in fused deposition modeling of PEEK material

MAT21-102

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Keywords: Additive manufacturing, Fused deposition modeling (FDM), Machine Learning, Polyetheretherketon (PEEK), FEM

Abstract

Due to the high-performance mechanical properties and the desirable chemical- and temperature-resistance, polyetheretherketone (PEEK) is often used as a replacement for metals in both academia and industry [1]. However, high thermal gradients and different cooling distributions in the fused deposition modeling (FDM) process frequently result in residual stresses and non-negligible deformations of PEEK parts, such as warping (Fig. 1) [2-4]. Furthermore, it is a challenging task to tune the process parameters affecting the mechanical properties, accuracy, and quality of the subsequent products [5]. In this paper, we focus on a framework applying machine learning (ML) to AM (Fig. 2). The FDM process was macroscopically and transiently simulated using the commercial software ABAQUS, considering the material properties as functions of temperature and the material deposition as a function of time. Then, the finite-element simulation was validated by actual experiments using a thermal camera and an optical 3D measurement system. In order to acquire the training data, this simulation was automatically carried out many times with python scripts under various process conditions. The algorithm XGBoost was selected to train the ML model for the regression task and to provide a evaluation of feature importance. Moreover, the recurrent neural networks (RNN) with long short-term memory (LSTM) can reproduce loading history in good agreement with the simulation because of its excellent capacity in dealing with time series.

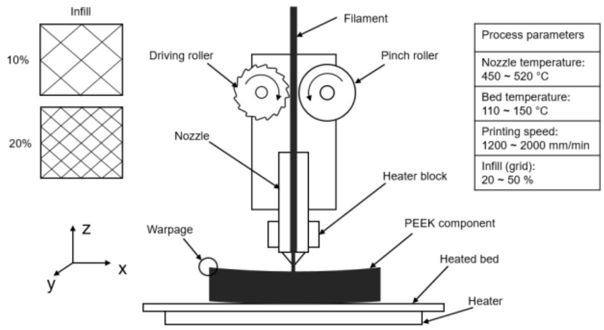

Figure 1. FDM process and 4 related process parameters in this work

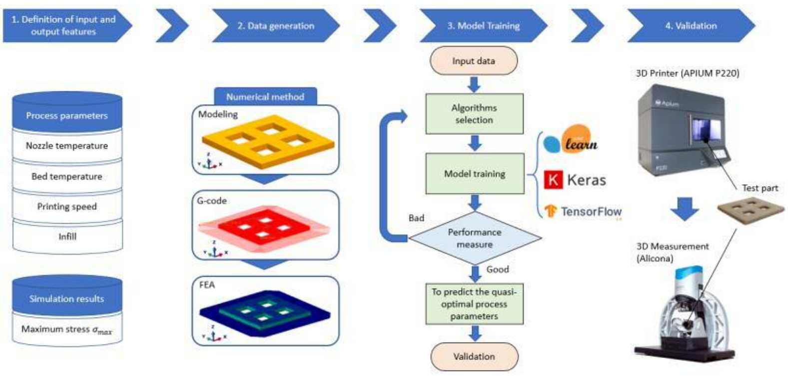

Figure 2. Overall framework of optimizing process parameters in the FDM

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Selectively weakened material for post-processing of additively manufactured components

MAT21-103

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Additive Manufacturing; LPBF Process; Post-Processing; Milling; Heat Treatment

Abstract

Machining of additively manufactured (AM) metal parts is necessary for functional surfaces, however this post-processing is done based on experiences for conventional components [1, 2]. This also applies for high performance parts in aerospace and other demanding industries [3]. With the design freedom of AM, it is possible to influence the underlying conditions for the machining process, and therefore selectively enhance cutting conditions. Especially the laser powder bed fusion (LPBF) process offers various control possibilities for this purpose [4, 5].

In this study a method for adjustment of the LPBF process parameters on the subtractive post-processing, a novel weakened structure, is used to selectively reduce the strength of the material and improve the cutting conditions [6]. In particular, the hatch distance of the additive process has been refined with the goal to adapt the properties of the material that is to be removed. This reduces the structural integrity and therefore the encountered process forces, significantly improving post-processing. For this purpose, AM specimen made of maraging steel with and without an increased hatch distance have been produced and machined to analyse chip formation, surface finish, cutting forces, acoustic emission, and vibrations during milling. In addition, the influence of heat treatment strategies on the presented method are considered, using hardening and solution annealing processes. The encountered process forces during milling could be reduced by up to 45 %. This effect could also be shown with hardened and solution annealed specimen, with a process force reduction of up to 50 %, and 45 % respectively (see Fig.1).

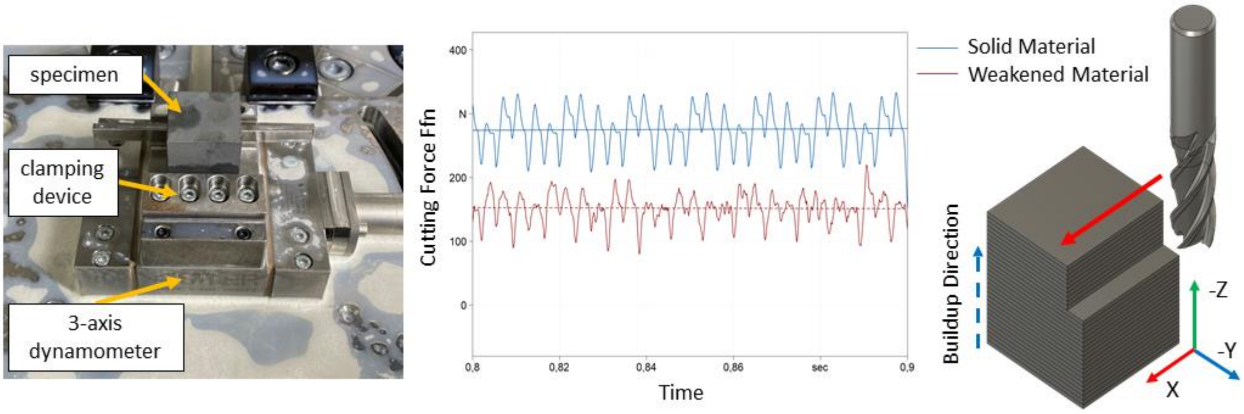

Figure 1. Machining setup (left), force measurements (center) and machining schematic (right)

On the basis of these findings, the decisive advantage of the weakened structure to reduce machining forces can be revealed. This helps with parts that cannot withstand high machining forces, giving more freedom for the design and post-processing of lightweight components. It is particularly beneficial for sophisticated machining of cutting edge AM components.

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Electrical discharge machining of dental implants in ultrasonic stimulated dielectric

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MAT21-104

CrCoMo, ultrasonic-assisted EDM, Hybrid manufacturing

Abstract

In dental industry electrical discharge machining (EDM) is used for the production of high-precision dental prostheses made of hard non-precious alloys (CrCoMo) and titanium alloys. When using conventional EDM, deposits are formed on the machining surface of the dental prostheses, which can cause health damage. Ultrasonic-assisted EDM allows cleaning processes during the EDM process. This leads to higher electrical conductivity at the electrode surfaces and reduces the formation of deposits.

This paper presents the strategy and technology of EDM with ultrasonic stimulated dielectric of cavities for swivel latches in CrCoMo dental implants. A EDM machining basin stimulated with plate oscillators is used to analyze the influence of cavitation effects on the machining process. Therefore the correlation between the cavitation effects and the corresponding particle sizes and the deposition intensities are investigated as a function of the medium used. In order to increase the efficiency of the ultrasonic-assisted EDM process, the fundamental relationships between selected process parameters are investigated experimentally. Using the design of experiments, the correlation between the tool electrode wear ϑ, arith. average roughness Ra and cavitation bubble size is investigated.

MAT21-105

Observation of local heat dissipation in NiCr microcircuit

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Thermally excited terahertz waves, s-SNOM, Local heat dissipation, Thermal imaging

Abstract

Local heat dissipation could cause large thermal gradients on tiny length scales in microelectronics devices, resulting in serious performance problems. Nanoscale thermal mapping is a powerful method to directly observe and manage local heat dissipation. Local heat dissipation origins from thermally excited terahertz evanescent waves (wavelength: 8- 25 μm) on material near-field surface, caused by thermal fluctuation due mainly to electron movements and lattice vibrations(refer to Figure 1 (a)).

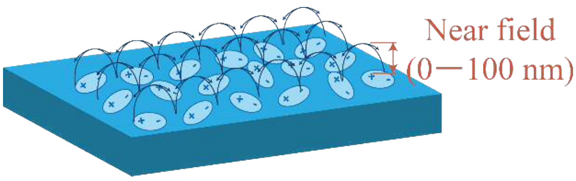

Figure 1. Thermal evanescent waves in near-field region

A home-made passive scattering-type Scanning Near-field Optical Microscope (s-SNOM), equipped with the terahertz detector named CSIP [1], was developed to map nanoscale heat distribution without utilizing external illumination [2]. Composition of the passive s-SNOM is shown in Fig. 2 (a), which consists of a confocal optical microscope, collecting near-field signal and transporting to the CSIP, and a AFM probe control unit, where the probe-sample distance is precisely controlled within 100 nm (near field) in Shear Force feedback mode which is generally used in AFMs [3].

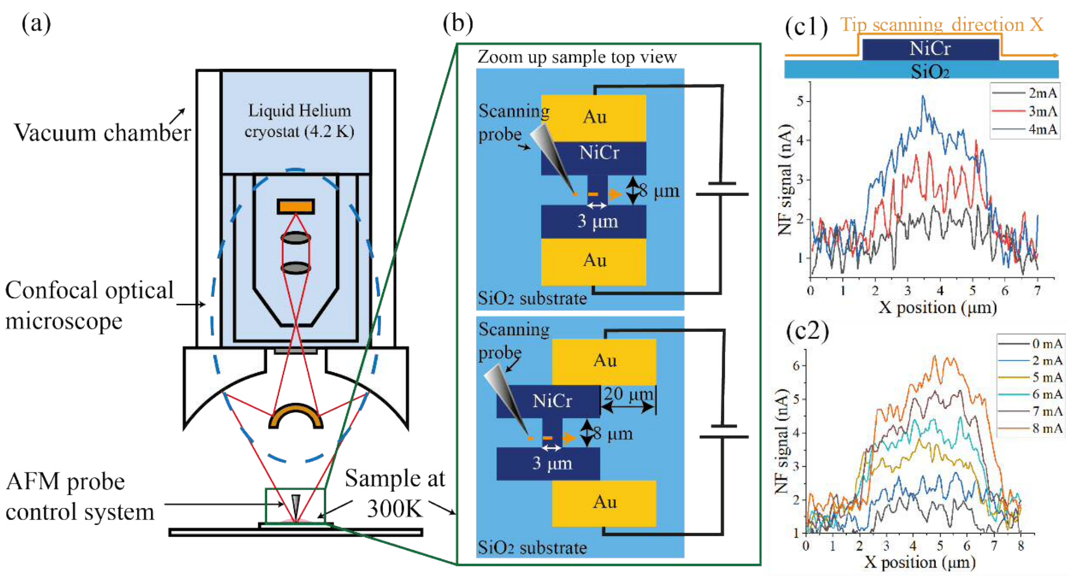

Figure 2. (a) Schematic diagram of the passive s-SNOM (Zoom-up diagram: probe scattering evanescent waves into far field) **(b)** Current carrying NiCr microcircuit with and without Au electrode offset **(c)** 1D near-field mapping along orange dotted line in **(b)** under different current bias

This research dedicates to visualizing the nanoscale heat dissipation on current-carrying NiCr wires with the passive s-SNOM. Near-field signal mapping experiments have carried out on microcircuits with central scale of 8 times 3 μm (refer to Figure 2 (b)). Experiment result and Finite Element Method Joule heating simulation suggest that localized hot-spot appears to develop along narrow wires. The larger current bias is attached, the more intense local heat dissipation occurs (refer to Figure 2. (c1)), in which process inhomogeneous heat dissipation distribution gradually shows up in the sample with 20 μm electrode offset (refer to Figure 2.(c2)). This research directly observes nanoscale local heat distribution and shows that abnormal current density distribution induced by electrode offset could lead to inhomogeneous heat dissipation.

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Multi-step electrochemical polishing of additively manufactured 316L stainless steel components

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MAT21-106

Key words: Laser powder bed fusion, multi-step processing, electrochemical polishing

Abstract

Powder bed fusion (PBF) additive manufacturing has been recognised as an enabling technology for the upcoming industrial revolution, however, it still suffers poor surface finish due to the partially melted powders attached to the outer surface[1,2]. Electrochemical polishing (EP) treatment on laser PBF (L-PBF) additive manufactured components has attracted significant attention in recent years with the drive towards quality improvement for functional use[3,4]. However, single electrolyte and polishing conditions (temperature, agitation, and potential) have limited polishing capability, meaning that it is difficult to obtain a fine surface (roughness Sa < 1 µm) from a rough one (roughness Sa > 10 µm) using a one-step EP process[4,5]. In this work, an investigation was undertaken into the possibility of sequentially using commercial electrolyte A2 (Struers) and NaCl-based electrolyte to polish L-PBF 316L stainless steel. The polarisation curve of the polishing system with different electrolytes was measured using an Autolab potentiostat, and the areal roughness (Sa), surface morphology, height distribution of as-built and polished surfaces were characterised using an Olympus LEXT microscope. The results indicate that the commercial electrolyte, polishing at ambient temperature and 40 V potential, can reduce the surface roughness from 13.454 µm to 1.411 µm with high efficiency. The NaCl-based electrolyte can continue reducing the Sa to 0.824 µm after 20 mins polishing at 6 V, but can cause pitting corrosions on the sample surface. Figure 1 show the surface morphology and physical surface before and after two-steps EP proceses, where a smooth and mirror-like surface is given.The proof-of-assumption process can guide the subsequent adjustment of the electrolyte composition and concentration, having the potential to improve the surface quality of L-PBF components in a low-cost, easy-to-handle and damage-free process.

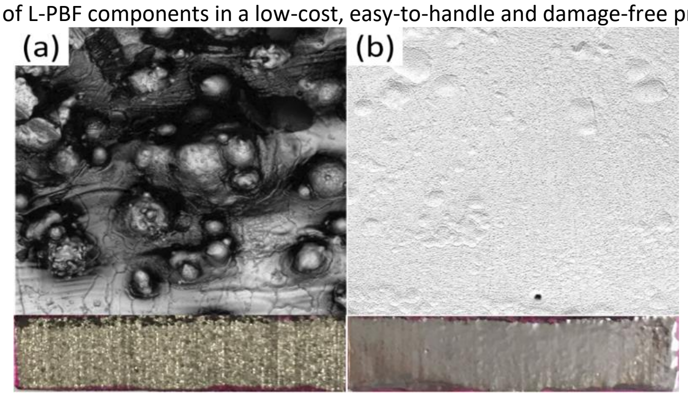

Figure 1. Surface morphology and physical map of 316L stainless steel (a) before and (b) after two-steps electrochemical polishing, the morphology size is 257 × 257 µm and the polishing area is 20 × 5 mm

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Effect of Fixturing on surface quality of Ti-6Al-4V in Vibratory Manufacturing Process

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MAT21-107

Keywords: Surface finishing; Vibro polishing; Mechanical Surface treatment

Abstract

Advanced compressor design with superior aerodynamic and fatigue life performance demands superior surface quality, typically Ra ≤ 0.25 µm. Media finishing technologies are commonly employed to mass finish aerospace engine components such as blisks [1]. Vibropeening is a media finishing technology where the work piece or coupon is rigidly attached to the trough or tub filled with granular media[1, 2]. In this study, as shown in Figure 1, the effect of fixturing the coupon to the trough (In-trough) and detached from the trough (Out of trough) is explored. Frequency of vibration, location and orientation of coupon, media size, lubrication and process time are known to impact the performance of Vibratory Manufacturing Process (ViMap)[3-5]. Effect of In-trough and Out of trough fixturing is studied with Rosler™ RKH4 plastic media and Rosler™ FC120 with water as lubricant at various depth of immersion of Ti-6Al-4V alloy coupons, representative of a blisk blade. The Ti-6Al-4V alloy coupons were milled and shot peened to surface roughness (Ra) of 0.5-0.7 µm prior processing in ViMap. Confocal Microscope images showed greater traverse motion of the media over the coupons for Out of trough fixturing. Furthermore, contact profilometer indicated up to 50% higher Ra reduction for Out of trough fixturing. In addition, at various depth of immersion for In-trough and Out of trough fixturing Tri-axial forces are measured, surface quality , mass of material removed and bulk media motion simulations are investigated and discussed.

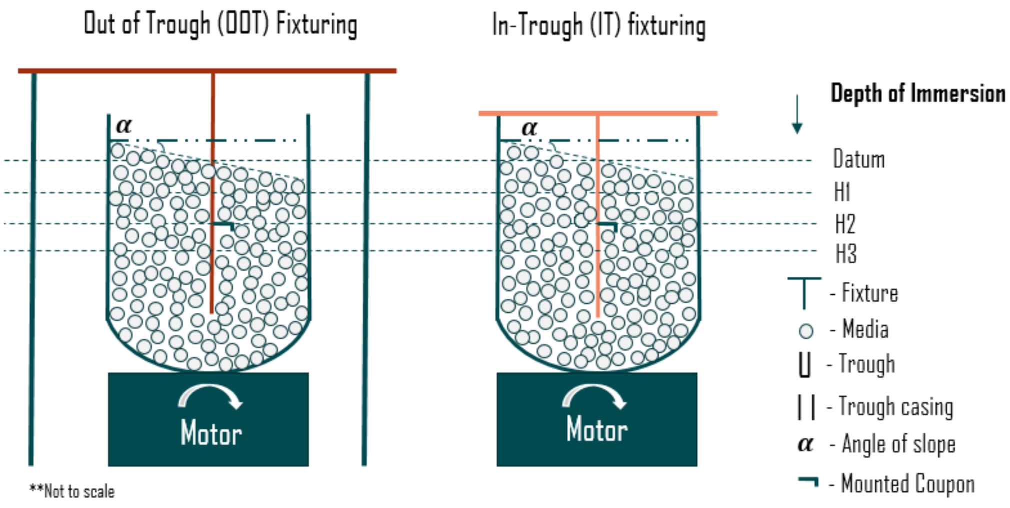

Figure 1. In-Trough and Out of Trough fixturing of Coupon in ViMap

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Digital twins for CNC machining – A Review

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MAT21-108

Digital Twins, Application, Challenges, Literature review

Abstract

Digital twinning, as one of important industry 4.0 technologies has seen great interest in academia and industries for the possible advances for CNC machining, such as predictive maintenance, error prediction, automated controls, and automatic optimisation. Due to this, different methods of creating digital twins have been theorised, research, and tested by many researchers. This paper is a literature review on digital twins that will cover what they are, current research, methods to develop them, case studies, challenges faced, and future work needed. The goal of this paper is to provide a solid foundation for the reader of the current state of digital twins and what is needed in the future.

Digital twins were first thought of in 2003 and their application has changed over the years to include more industries, this has coursed the original definition to become outdated. In this paper other definitions are reviewed and the most suitable for CNC machining is recommended.

As digital twins are still lacking in standards a comparison of how others have developed digital twins will be reviewed to identify the similarities in approach. Examples of how digital twins are used in different industries are given to show how universal this technology is. Case studies of how digital twins are being used in CNC are reviewed to high light affective methods and possible improvements

The challenges identified in this paper are the coupling of digital twins, sensor reliability, back words compatibility, operational safety, network security, reliability and transparency, clear user interface, IT infrastructure, prediction accuracy, digital twin standards, ease of updating system and simulation accuracies. The results are also shown in Figure 1 with the frequency of each issue being addressed. Among them IT infrastructure, digital twin standards and decision-making reliability are regarded as the most common challenges discussed for the general application of digital twins for CNC machining.

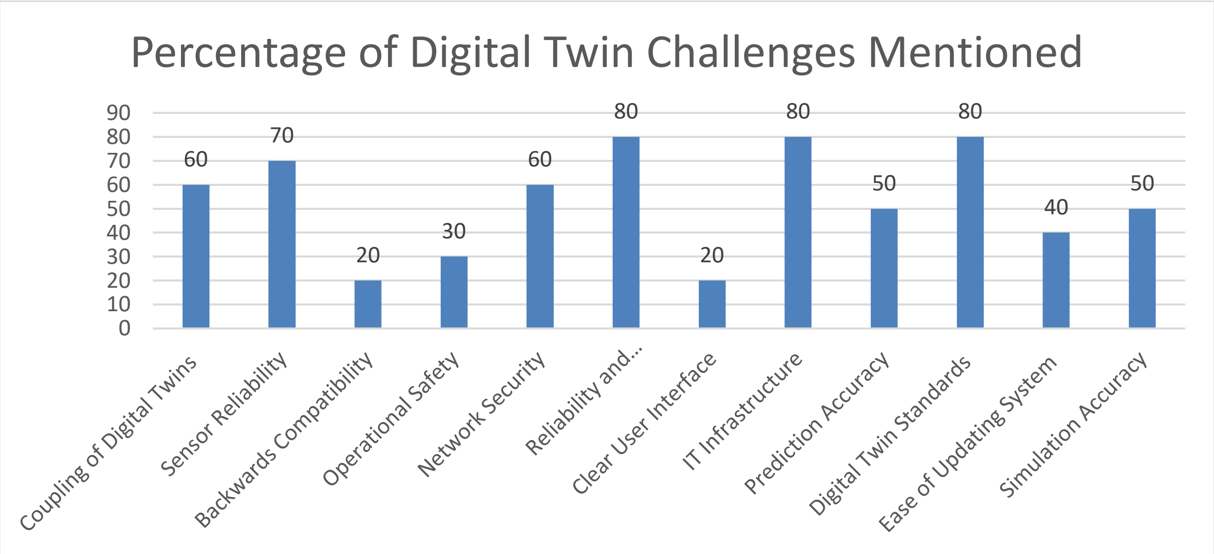

Figure 1. Digital twin challenges mentioned.

The simplest way to advance digital twins quickly would be to develop a standardised structure, specification and development methods that have a widespread appeal within the research and industrial communities.

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Low carbon emission laser cleaning processes

MAT21-109

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Keywords: laser cleaning, carbon emissions, low carbon manufacturing, net zero.

Abstract

A clean and homogenous surface is key requirement for high performance in many joining manufacturing processes such as welding, adhesive bonding and application of coatings. In addition, some modern manufacturing processes in microelectronics demand cleanliness from particles that can adhere to the surface [1]. Components are often contaminated, oxidised or covered in layers not required for some manufacturing processes. The laser provides an innovative, selective and non-contact tool to de-contaminate, clean or strip surfaces. The ojective is to use the laser to ablates the layers with a fast-processing speed without the need for subsequent polishing or cleaning agents. These features make laser cleaning the preferred choice [2] [3] and a candidate to be optimised for green and sustainable manufacturing.

While welding, drilling or cutting with lasers have been known for years, laser surface cleaning is still considered a niche technology. It is only recently that industrial cleaning has utilised lasers, although the process can remove most organic material effectively [3] [4] [5]. Presently, there is a wide range of pulsed and continuous beam lasers in operation for a variety of applications including de-coating paint from delicate surfaces, striping insulation from conductors, engraving surfaces by ablation or cleaning moulds [4]. It is also becoming of increasing importance for industries to pursue a net zero emission strategy. However, previous studies have not detailed Scope 1 and 2 emissions for laser processes [6-9] which is important for the net zero transition.

The present work is a collaboration between the UK and China and is focused on developing a low carbon manufacturing framework and the manufacturing capability of laser cleaning. Different laser parameters in the range of nanosecond and picosecond pulses have been used, investigating the laser cleaning quality and the energy consumption in removing hard coatings from tooling to enable re-use. The work contributes towards a deeper understanding of energy requirements and carbon emissions in laser material processing to inform the net zero transition.

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New online position correction approach of an industrial robot by using a new photogrammetric measurement system

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MAT21-110

Keywords: Online correction, Photogrammetry, 3DoF Measurement, Tool Center Point (TCP), Accuracy, Robotics, Online-Calibration

Abstract

This article discusses the online Tool Center Point (TCP) correction of a robot system by using a new photogrammetric approach, called Multi-Aperture-Positioning-System (MAPS). As described by T. Luhmann [1], for online measurement of a TCP, previously multi-camera solutions were needed. MAPS offers the advantages of a single camera system described by T. Luhmann [2] and the features and accuracy of a multi-camera system at the same time.

This paper reports the online correction of an ABB IRB 120 Robot with the aforementioned measurement device MAPS. A special correction algorithm was engineered based on the measurement values to correct the robot TCP to the setpoint position. For this purpose, two experiments were planned in which the robot drives along a path. In the first experiment, only the TCP of the robot was tracked online via MAPS, while in the second experiment also a 3DoF correction of the TCP took place. To simply present the deviation between a corrected and uncorrected robot system, a straight-line drive of 50 mm in the robot's x-direction at a speed of 0.1 mm/s was executed by the robot.

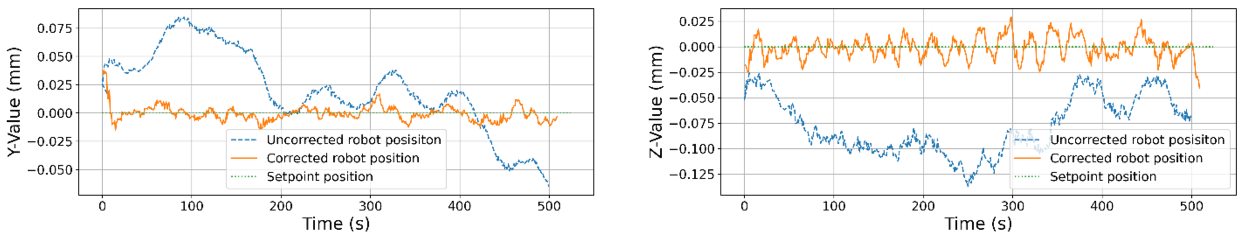

Figure 1. Comparison of robot accuracy with and without online position correction. In the experiment, a straight line of 50 mm in robot x-direction at a speed of 0.1 mm/s was executed. Left: Y-accuracy. Right: Z-accuracy.

Correcting X-, Y- and Z-position results in a significant increase in the robot's path accuracy, as shown in Figure 1. While driving parallel to the robot's x-axis, the TCP should not vary in y- and z-direction. However, there is a measurable deviation of max. -0.137 mm in the z-direction and 0.084 mm in the y-direction, due to the tolerances of the robot arm's kinematic system. These deviations are within the tolerance range specified by the manufacturer [3].

The calculated mean absolute error (MAE) points out, the significant increase in accuracy by the online correction of factor 1.3 in the x-direction, 7 in the y-direction, and 9 in the z-direction. These results can be classified into those of comparable solutions like the offline modeling approach done by A. Nubiola et al. [4] which resulted in a position accuracy by a factor of 2.65. Another online correction approach by T. Kubela et al. [5] leads to an increased accuracy by 10 – 15 %.

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New photogrammetric approach for measuring the position of a Tool-Center-Point

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MAT21-111

Keywords: Photogrammetry, 3DoF measurement, online measurement, TCP, accuracy, robotics, online calibration

Abstract

Automated handling systems are well integrated into today's production processes. However, processes like 3D printing, monitoring moving objects, glueing processes or welding processes need high repeatability and high precision handling systems. Thus a calibration of the handling system is necessary to achieve the needed accuracies. This needs a precise measurement of the actual position of the tool-center-point (TCP)[1].

This article discusses a new photogrammetric approach using an aperture array and a single camera to measure the TCP of a machine under test. As described by T. Luhmann [2], for online measurement of a TCP, multi-camera solutions are needed. These offer accuracies in the range of 0.2 – 0.5 mm over a range of 2 m. The Multi-Aperture-Positioning-System (MAPS) described in this paper offers an online measurement of the TCP using a single camera. The advantages of a single camera solution are described by T. Luhmann [3] as the following, a low setup cost, no need for synchronisation between the cameras and comparatively low spatial conditions. Thus, MAPS offers the advantages of a single camera system and the features and accuracy of a multi-camera system at the same time.

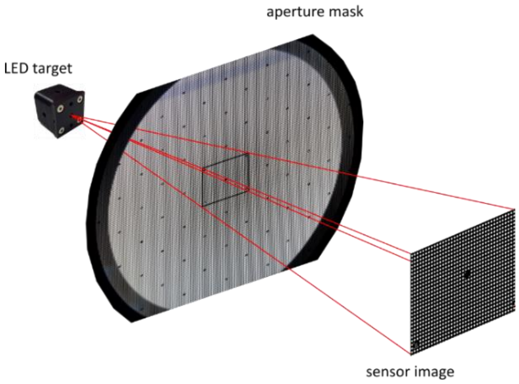

Figure 1. The measurement principle of MAPS. The light emitted by the LED target passes the aperture mask, containing holes arranged on a grid and is measured by a camera sensor behind the aperture mask.

The MAPS measurement system is based on a single camera and a light-emitting target. Only an aperture mask is used as the imaging optics. In **Figure 1,** the measurement principle of MAPS is displayed. It contains an LED target, the aperture mask and the sensor image produced by the used camera sensor. The light emitted by the LED target travels through the holes in the aperture mask and create spots in the image plane. These spots are measured by the camera sensor and can be detected by an algorithm. Matching the position of the spots measured at the sensor with the corresponding holes in the aperture mask generates two positional values that can be connected via lines. Calculating the intersection point of these lines determines the origin of the light emitted by the LED target. In the following paper, the mathematics used algorithms and the positional repeatability of the MAPS system are described.

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Model based view planning for the robot-guided automation of optical 3D digitization based on a variable mesh resolution processing approach

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MAT21-112

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View planning, optical 3D-scanning, automated geometry digitization, machine vision

Abstract

The digital 3D representation of manufactured parts plays a crucial role in the quality assurance and automated handling during the production of small, individualized lot sizes. Machine vision systems, such as optical 3D-scanners, guided by an industrial robotic arm, allow for a contactless full digital reconstruction of surface geometries in production environments. In order to digitize the whole geometry, it is necessary to acquire 3D-scans of several different viewpoints with respect to the part, which in combination cover the entire surface. With efficiency in mind, this results in an optimization problem between a high surface area coverage and low measurement effort, referred to as the view planning problem.

In a modern manufacturing context, a digital 3D-representation of the manufactured product is usually available from the design phase and can be utilized for the determination of suitable viewpoints a priori to the scanning process (see figure 1). However, depending on the resolution and quality of the 3D-model, results and execution durations may vary.

In the presented work, investigating the view planning problem, two popular viewpoint candidate generation methods are implemented: Firstly, a surface-based random sampling method [1,2], which generates viewpoints within a solution space, in which visibility of a given model surface can be expected. Secondly, a view sphere viewpoint generation approach [3], which is independent of the object geometry but avoids clustering by generating evenly spaced viewpoints on a sphere around the centre of the object.

Using an adjustable remeshing procedure, a multi-stage approach is implemented (see figure 2) by generating multiple meshes with different resolutions. Through this, the benefits of working on a coarse mesh, such as fast viewpoint candidate evaluation and selection, is combined with the level of detail of a fine mesh.

It is found that it is possible to considerably reduce the mesh resolution while maintaining a reasonably high surface area coverage on a reference model. The multi-stage approach can furthermore be used to identify surface areas that are unlikely to be visible on the fine mesh and can therefore be omitted for further processing steps, such as interior areas, reducing the overall processing time. Applying the proposed procedure to the view planning for a 3D-scan using a state-of-the-art 3D fringe projection scanner with highly sophisticated scanning capabilities, it is shown that the view sphere approach is more suitable for this use-case due to the large measurement volumes of the 3D-scanner, whereas the frequently used random sampling approach requires an excessively higher computational effort to achieve similar results.

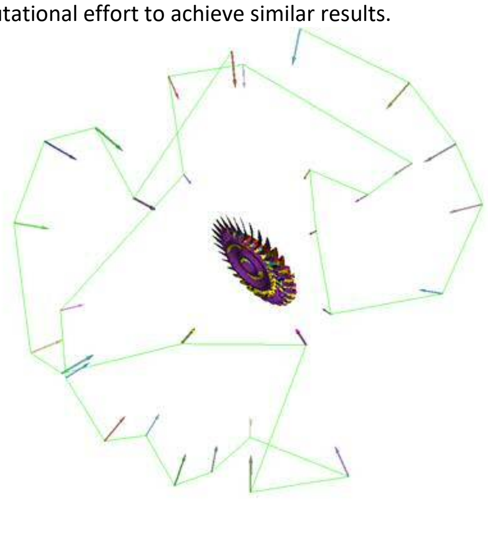

Figure 1. View planning result for a blisk. Coloured arrows represent the determined viewpoints, visible surface of the part is coloured accordingly. Green line represents the calculated robot path.

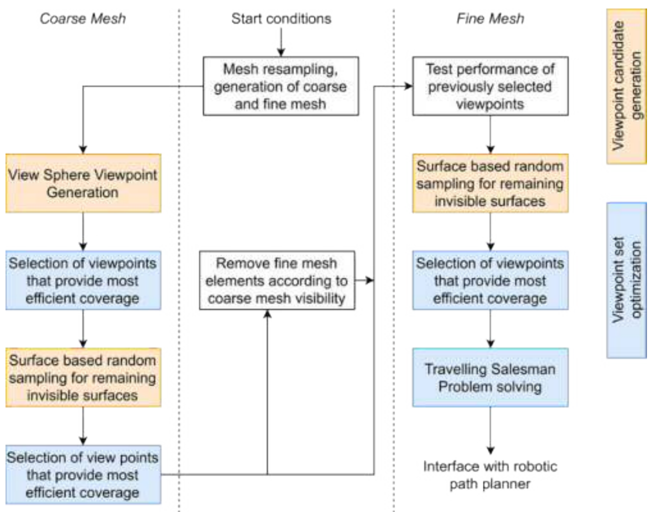

Figure 2. Flowchart of the proposed view planning process

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3D/4D Printing a bioinspired leaf biosensor

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MAT21-113

Keywords: Electrochemical, glucose, biosensors, 3D printing, advanced material, yellow rust

Abstract

A plant leaf is a highly hierarchical and complex structure essential for plants to perform photosynthesis and to develop. It is also through the leaf and in particular through their stomata, openings used by the plant for gas exchange , that pathogenic fungus after germination penetrate the leaf and infect the plant. At the University of Manchester, we are developing a multi-material and multi-functional biosensor (figure 1), mimicking the structure of a plant leaf in terms of structure and topography and able to detect the presence of specific pathogens (e.g yellow rust, brown rust). This biosensor has been designed based on the concept of biomimicry to obtain an exact replica of the leaf structure as it sensing surface. A critical aspect is the fabrication of the upper layer, with a layer thickness ranging between 50 and 80 μm, presenting stomata structures able to open and close depending on external stimuli (e.g. temperature). The sensing layer of the biosensor uses the concept of amperometric non enzymatic glucose sensor. This paper describes the combined use of additive manufacturing (3D Printing) and different material mixing to create such layers.

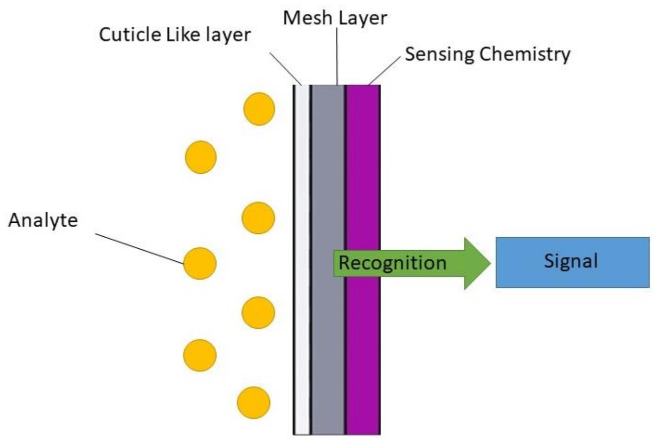

Figure 1: Diagram of the multilayer biosensor designed to detect yellow rust

Design and evaluation of a novel core-shell bio-additive extrusion system for tissue engineering

MAT21-115

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Co-axial Extrusion, Tissue Engineering, Core-shell Fibres, Multi-mateiral

Abstract

Additive manufacturing (AM) is a key technology for the fabrication of tissue engineering scaffolds, 3D structures that support cell attachment, proliferation, and differentiation. However, commercially available printing heads for tissue engineering applications present limitations concerning the fabrication of complex multi-material hierarchical structures resembling natural tissues. The use of co-axial extrusion printing heads represents a relatively new development in the field of additive manufacturing allowing to produce core-shell filaments by printing two different materials or hollow filaments by using a sacrificial core material. However, most co-axial nozzles [1-3] are assembled with two needles being able only to process low-viscosity or liquid-based materials. This paper presents a novel printing head assembled with a new designed co-axial nozzle that aims to generate core-shell filaments. Compared to commercially available co-axial extruders, which usually use needle-based nozzles and can only process liquid materials, the novel co-axial printing head is able to process both low-viscosity and high-viscosity materials. Two independent extruding systems that can be replaced by screw-based or pressure-based extruders are assembled on the co-axial nozzle allowing different type of materials to be processed. An expanding chamber is placed at the cross section of the inner and outer channel to achieve a symmetrical velocity distribution. Simulation results demonstrated that the novel co-axial nozzle allows a balanced fluid flow enabling uniform co-axial filaments.

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A method for down-selecting temperature sensor locations for machine thermal error modelling

MAT21-116

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Optimal sensor selection, Thermal error modelling

Abstract
Thermal errors contribute a significant part of the dimensional errors in machined components. Data-driven models are widely used in thermal error compensation strategies to map relevant measurements, such as temperature of key structural points, to the positional errors at the tool tip. The accuracy of these models partly depends on the selection of an appropriate set of sensors whose readings accurately reflect the thermal state of the machine tool and by extension the resultant thermal deformation of the machine tool structure being modelled. Various approaches for sensor placement have been proposed, such as recursive sensor selection, use of reduced order models and use of thermal modal analysis.

This work explores the use of an optimal sensor placement technique for signal reconstruction in selecting the set of sensors used in modelling and compensating thermal errors. The proposed approach takes advantage of temperature data captured non-invasively, during normal machine operation, as a training dataset. The correlations in the readings from different sensors are used in determining which sensors are required to infer all the other measurement readings and reconstruct the thermal state of the machine tool. Critically, this approach means the choice of sensors used can be optimised to the operating condition of the machine during normal operation, not just related to abstract test conditions. Reducing temperature inputs will reduce computational overheads and help to avoid over-fitted algorithms. The approach relies on Proper Orthogonal Decomposition (POD) and QR pivoting linear algebra algorithms which are fast and widely implemented in many programming languages. This makes the approach efficient and scalable. The results obtained from thermal error modelling using the proposed approach are compared against other sensor selection approaches that exist in literature.

Rectilinear strain sensing framework for real time compensation of structural distortions in precision machinery

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MAT21-118

CNC Machine Tool, Thermal error, Structural distortion, Strain measurement

Abstract
Precision machinery such as machine tools use heavy duty structural elements to provide high accuracy and repeatability. However, external forces and thermal effects can still cause significant errors. Machine builders put significant emphasis on good design for error avoidance and more recently, also utlise software-based error compensation methods to further improve performance. For geometric errors which result from build tolerances, and which normally only vary slowly over time, most Numerical Control systems provide functionality for pre-calibrated error compensation. For compensation of thermal errors, temperature sensors are often used to provide data for a model which calculates the effect of the temperature field on the machine structure [1]. Although this method is widely researched, there is often significant residual error due the time-variant non-linear relationship between temperature and the error between the tool and workpiece. This may be exacerbated by introducing multi-material structural elements to reduce weight. Direct measurement and combining temperature with direct measurement can enable more precise modelling [2] but can add significant cost of additional sensors.

In this research a direct measurement method is applied using a series of short-range, low-cost displacement sensors organised in a rectilinear framework to enable detection of the bending of a machine tool structure, an example of which is shown in figure 1 (left). The design provides high resolution measurement of strain over arbitrary lengths and low-cost hardware for permanently embedding on a machine. The displacement sensor, shown in figure 1 (right), is designed with a particular arrangement of a compact array of slotted photo-microsensors with specially designed shutter assembly and signal processing to significantly reduce sensitivity to ambient light, input voltage variation, circuit electronics drift, etc. The sensor principle and the characterisation results are described by Potdar [3] with the prototype having a linear measurement range of 20 µm and resolution of 21 nm. The system was applied to the ram of a high precision 3-axis machine tool and used to compensate the thermal error caused by running the integrated high-speed spindle. The machine has a high-quality spindle chiller system to reduce this error mechanically, and the compensation system was able to further compensate the residual error electronically from 10 µm to 4 µm, even reducing the magnitude of the effect of the chiller cycles.

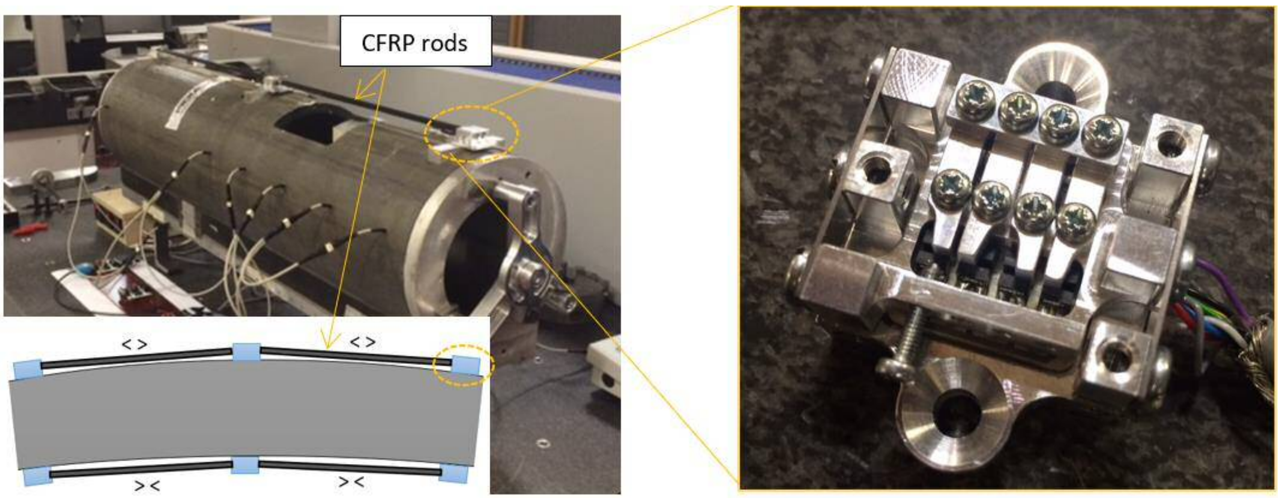

Figure 1. Sensor framework bench testing (left), and displacement sensor module (right).

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Cobot assisted "intelligent sorting" of additively manufactured parts

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MAT21-120

Intelligent, Additive manufacturing, SLS, Cobot

Abstract

The usual method for removing parts from a Selective Laser Sintering (SLS) 'cake' is by manual extraction and physical agitation to release the components. This process can often cause unsintered SLS powder particles to become airborne, increasing the risks associated with powder ingestion, which can prove harmful [1] [2]. The research presented describes the development of a prototype system used to organise components extracted from a SLS cake intelligently, safely and cleanly using a Universal Robot cobot and three Onrobot attachments, without providing prior information of the part's locations within the 3D volume of the build cake. The system has been proven to successfully extract and systematically organise a wide variety of geometric shapes and different sized components meaning that it can be implemented on a wide range of SLS 'cakes'. The method proposed intends to contribute to the automation and safety of the part extraction process, reducing human intervention. However, it has also highlighted limitations with the capability of the system, particularly in the movement of parts which it struggles to pick up, such as those with tapered geometries and H-type shapes - proposed solutions for future work are presented.

Figure 1. The intelligent and automated SLS component extracting and organising system mid-process displaying the set-up.

The process involves a search through the cake using a raster inspired path where the tip of the cobot's gripper is submerged in the cake. Once an impact of greater than 3.5N is detected, the cobot will begin probing the part to locate its centre and measure the size of the part in both the x and y direction. Following this, the gripper picks up the part, clears loose powder and places it on the bench to be scanned by the vision system. Once scanned by the vision system, the part will again be picked up and sorted onto a coloured dot depending on its size, classified as either small, medium or large. This entire process is completed with no prior knowledge of how many parts are in the cake, their orientation or any information about their geometry. The only data programmed into the cobot is the size and location of the cake, though with further work this data could be gathered by the vision system. The system can search through a cake with dimensions of 440 x 460 x 165mm in approximately 40 minutes, while part removal and sorting takes between 127 and 183 seconds per part depending on the size of the part and whether it needs to correct itself.

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On-CMM core temperature measurement using ultrasonic phase-shift method

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MAT21-121

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Core temperature, manufacturing, phase-shift, ultrasound.

Abstract
Temperature variation in manufactured workpieces can affect that workpiece's accuracy [1]. In large workpieces, the core temperature can vary significantly from the part's surface temperature. This temperature gradient can result in an inaccurate representation of the part's temperature. Conventional sensors used in CMM temperature measurements can only measure the surface temperature of the workpiece. The temperature of a material affects the velocity of sound travelling through it, when an ultrasonic wave travels through a material, its average velocity can be known if the transit time and the length of travel are known. This average velocity can in turn be used to estimate the core temperature of the part. However, the main limitation is the required acquisition electronics for obtaining high resolution measurements required in precision manufacturing [2]. Using an ultrasonic phase-shift method, in-process experiments were carried out on the CMM for core temperature measurement. The created ultrasonic phase-shift system which makes use of a dual element piezoelectric transducer achieves higher resolution than the traditional pulse-echo method which is more expensive and more complicated to use. The results show that the estimated temperature using the ultrasonic method predicts material expansion with higher accuracy than the surface temperature probe, with the error from the surface predicted expansion being 1.1 µm while the error from the ultrasonic thermometry is 0.58 µm. The results also show a high level of repeatability. The set-up for the experiment and the result are given in figure 1 and figure 2 respectively.

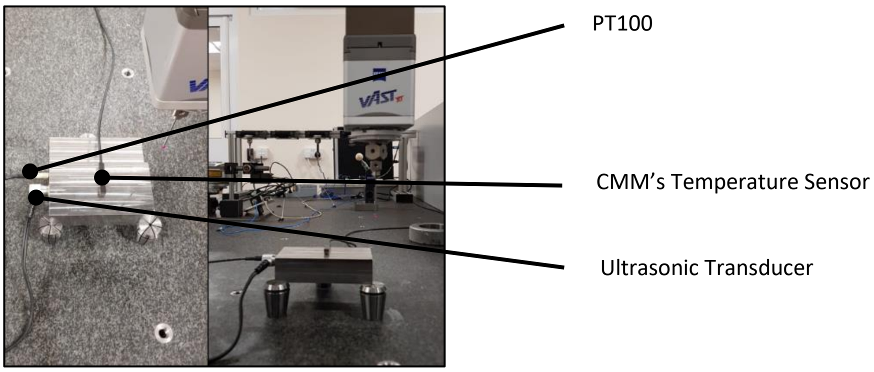

Figure 1: On-CMM ultrasonic thermometry set-up

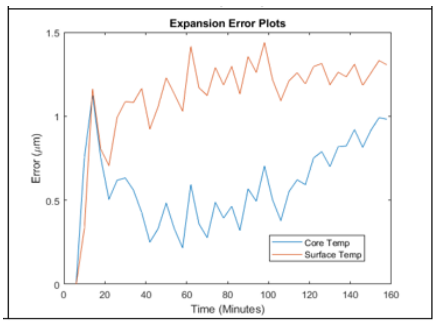

Figure 2: Core and Surface temperature expansion error plot

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Digital technologies for the prevention and management of occupational chronic obstructive pulmonary disease

MAT21-122

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COPD; Human cyber-physical systems; Industry 4.0; IoT; Occupational health and safety; Operator 4.0

Abstract

Chronic Obstructive Pulmonary Disease (COPD) has now become one of the top three causes of death globally. COPD is defined by a progressive and irreversible limitation in airflow in the lungs. Workers exposed to substances that can cause COPD are one of the susceptible groups. Occupationally related COPD has raised common attention, and it is all known that effective prevention and intervention measures are needed. Current used personal perspective equipment (PPE) and intervention methods are inadequate and require substantial improvements. The fourth industrial revolution, enabled by a more considerable available computational power and wireless networks, brings new opportunities for observing risks and worker behaviour.

Current research on how digital technologies such as IoT and artificial intelligence can support occupational-related COPD is more based on medical applications, which focus on the treatment of people diagnosed with COPD, rather than occupational health and safety (OHS) management, which focus on protection and prevention of COPD. Recent systematic reviews reported current digital health interventions (DHIs) on COPD show some usability problems, like low compliance rates and lack of personalisation [1]. Some remote monitoring is restricted to specific times during the day [1]. Measurement should be adjusted to their target population. So far, much more significant falls in forced expiratory volume in 1 second (FEV1) is required to identify an occupational COPD patient and the measurement accuracy of regular pulmonary function test (PFT) for workers is low [2]. In addition to health condition detection, other hindrances to early prevention and intervention exist in the workplace. First of all, there are various types of substances that can cause COPD. IoT monitoring systems include air concentrations monitoring and vapours, gases, dust and fumes (VGDF) monitoring [3]. Secondly, commonly prevention measures like local exhaust ventilation (LEV) system, blower fans, and wet methods lack effectiveness [4]. Smart working environment (SWE) is another popular topic of OHS 4.0. Automatic response to environmental parameter changes with primary intervention like increasing the speed of blower fans and the water flow in wet method with pre-set values can be both practical and economical. With the help of IoT, alarming messages and suggestions can also be sent to interactive terminals, e.g., APP on the mobile phone.

After the data acquisition stage, digital technologies also play a crucial role in analysis and assessment. Data fusion could combine the information from different parts of the site-wide wireless sensor network (WSN) and help determine what happened at where and when, and to whom. Artificial intelligence (AI) has been used for COPD assessment and prediction [5]. To sum up, the research gaps based on the finished literature review can be found in the following areas:

1. Personal health condition detection: Current detection methods show some usability problems. Low measurement accuracy in routine PFT could lead to delayed diagnoses. Restrictions on test time show a low compliance rate.

2. Environmental monitoring and prevention: The COPD risk factors in one workplace are usually various. WSNs or IoT systems with fixed alarm value are not effective enough. What's more, it should be noticed that some exceeding could be easily avoided by combining environmental monitoring with primary real-time intervention control.

3. COPD risk assessment: COPD risk assessment in workplaces should be more personalised and more dynamic. The lack of personalisation that using the same standard for different workers at different ages with different jobs could also cause misdiagnoses. Without motion working state recognition, health condition monitoring is meaningless. Assessment should be based on the combination of personal health condition monitoring and environmental exposure monitoring.

This project aims to establish a cyber-physical system (CPS) framework with WSN to help the optimal decision making for occupationally related COPD prevention and intervention. The outlook of future work contains three phases with regard to the research gaps. Phase one is the design of smart PPE and environmental WSN. Phase two is using data fusion on the monitoring network built in phase one. Phase three is to establish a complete CPS with data-driven and AI-assisted intervention decision making.

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MATADOR

A fog computing based framework for context-aware and real-time energy usage analysis in discrete manufacturing systems

MAT21-123

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Fog computing, Context-aware, Energy, Manufacturing systems

Abstract
A thorough energy usage analysis requires proper understanding of interactions among the miscellaneous energy-influencers in manufacturing systems. The advent of fog computing has provided the possibility of dissecting these interactions by connecting energy usage and its context. This paper presents a fog computing based framework for context-aware and real-time energy usage analysis in discrete manufacturing systems, including three functional components: (i) context sensing; (ii) load disaggregation and operating state identification; (iii) context reasoning. The presented framework is basically data-driven, cross-deployable and serves as promising catalyst for continuous improvement of industrial energy performance from the perspective of production & operation. Finally, this framework was implemented in a die-casting workshop to demonstrate its effectiveness and practicality.

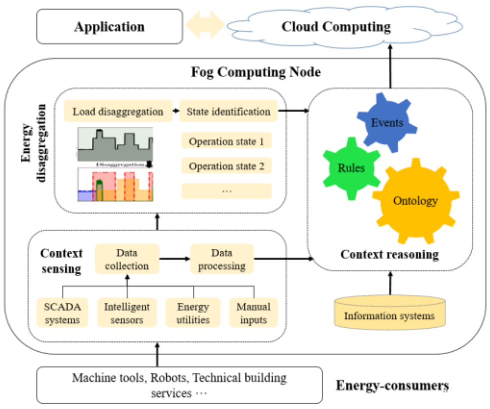

Figure 1. The reference architecture of the presented framework. .

The term context is generally defined as the set of elements having implicit and explicit effect on the energy usage [1]. Thanks to the adequate computing power with low latency of fog computing, the presented framework with three functional components can achieve context-aware and real-time industrial energy usage analysis. More precisely, context sensing aims to enrich energy usage data with multi-source heterogeneous context information, simultaneously performing data processing to guarantee data reliability. Load disaggregation and operating state identification with machining learning techiniques like support vector machine enable an understanding of the machine-specifc load profile and operating state to provide insights on value-added and non-value-added energy. Further, context reasoning is used to identify the contextual activity that causes changes in the machine's operating state using techniques such as ontological reasoning, rule-based approach, probabilistic logic, fuzzy logic and Bayesian networks.

Table 1 Context reasoning results.

Activity	Accuracy
Planned activities	98%
Production disturbances	98%

The presented framework performed high accuracy in operating state identification and context reasoning with an accuracy rate of 98% and 92%, respectively. By relating energy usage to its context, it permits to identify, quantify, analyze, and achieve energy-saving potential more thoroughly.

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Machined Surface Texture Investigation and Modelling of End Milling Process

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MAT21-124

Machined surface, surface prediction, surface texture, endmilling surface

Abstract

Machined surface texture prediction with the numeric model is one of the important alternatives to surface inspection by high-end equipment. Instead of performing the surface inspection offline and estimating surface characteristics parameters, a successful numeric model can only use spindle speed, feed and depth of cut as input to predict point clouds of machined surface texture which were normally obtained by high-end equipment. Many successful models using the profile of tool nose to determine the Z-Height value of each workpiece point, were introduced respectively for different machining processes, such as side milling and micro-end milling processes. [1] For such a method, each point of the workpiece might need to be judged twice since the tool nose will pass each point more than once. This paper proposed an optimised algorithm that modelled low-frequency waveform (Base Surface, BS) and Ideal Tool Trace (ITT), respectively. And then, the final point clouds are obtained by combining BS and ITT together.
The proposed method was verified by multiple end milling trials which applied different spindle speeds, feed and depth of cut. The texture of the surface texture, roughness and processing time were compared to evaluate the precision of the mathematical model and the efficiency of the algorithm. The results (**Figure 1** and **Figure 2**) of the validation showed that the model can accurately reconstruct the surface for face milling. By examining the surface roughness, the error of surface roughness $S_a$was simulated to be 0.7±0.05 µm. The root-mean-square height R_q of different sections of the reconstructed surface showed that the match rate of local R_q is within 70 % - 95 %. In addition, in the comparison, for each generation of 2 million sample points, CSG based method cost more than 2160 seconds and the proposed method only cost less than 0.52 seconds (**Table 1**).
In summary, three major contributions are included in this study: 1 developing analytical endmilled surface texture model based on surface generation mechanism of endmilling process; 2 Model modularisation - users can customised their tool nose model according to the application; 3 The model is designed as a dimensionless model which can potentially be applied to micro-endmilling, traditional endmilling and larger endmilling-like processes.

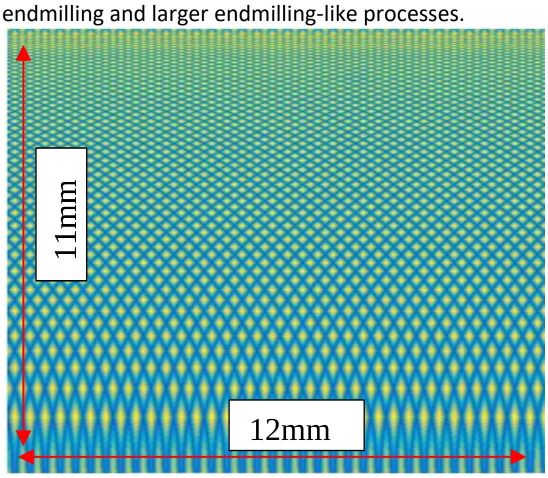

Figure 1. Simulated machined surface texture.

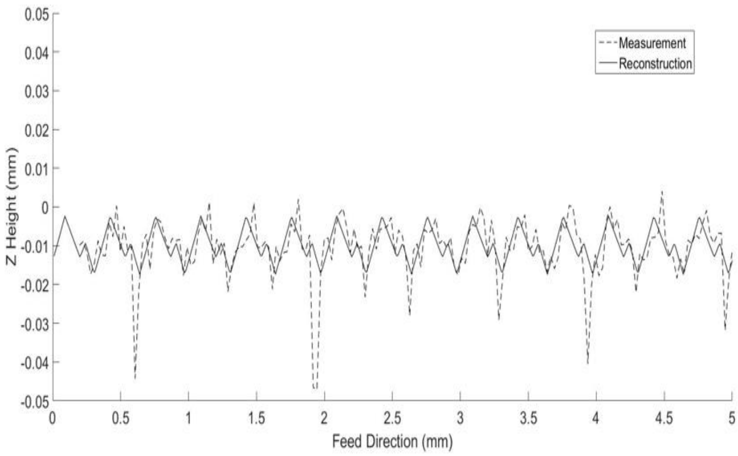

Figure 2. Comparison between simulated profile and measurement.

Table 1 Processing Time (CPU: Intel Core 2700k): CSG vs Proposed Method

Methods	Test 1	Test 2	Test 3
CSG method (s)	2160	3720	2280
New algorithm (s)	0.46	0.52	0.48

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Processing of fe-cr-co hard magnetic alloy by two stage thermomagnetic treatment technique

MAT21-125

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Keywords: hard magnetic alloy, Fe-Cr-Co, thermomagnetic heat treatment, coercive force, magnetic fields, magnetization.

Abstract
Fe-Cr-Co alloys were prepared by vacuum induction melting and further processed by thermomagnetic and aging treatments. Fe-Cr-Co is a typical spinodal decomposition type magnetic alloy. Semi-hard magnets find applications in magnetic devices like brakes, relays, tooling, chucks, flip signs, anti-theft tags, stirrers and sensors [1]. FeCrCo magnetic alloy, one of the semi-hard magnetic materials, is important because of good ductility and good magnetic properties. Being highly workable these alloys are important for thin designs and ductile applications. Magnetic properties are developed by a microstructure consisting of strongly magnetic cobalt rich α_1-phase and weakly magnetic chromium rich α_2-matrix. Kaneko et al [2] successfully developed FeCrCo magnetic alloys with high Curie temperature, good magnetic, corrosion and mechanical properties. Method for manufacturing FeCrCo alloys is through melting and casting [3]. Investigation of effect of processing parameters on magnetic characteristics of the alloy was carried out. Magnetic properties including induction, coercivity and energy product were measured. In this study composition used were Fe30Cr23Co and Fe-25Cr-12Co-2Si. Chemistry, microstructure and thermal property investigations were carried out. Enhancement of properties was observed in specimens processed by two stage thermomagnetic treatment. Energy product up to 5 MGOe was achieved.

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Low latency object detection with neural networks for mobile resources using 5G and edge computing in production environments

MAT21-126

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Object detection, 5G communications, Edge computing, Autonomous Mobile Robots, Production Systems

Abstract

Operation of autonomous mobile robots (AMR) in production environments requires powerful control mechanisms capable of sensing and understanding the robots environment to enable it to react to dynamic changes in real-time [1]. However, these algorithms, such as artificial neural networks, often demand for extensive computational resources that are generally not available on AMRs, e.g. due to energy consumption considerations [2]. To establish complex anatomies, decentralized processing of data acquired by the AMRs enables high flexibility and supplies the computational resources required for complex tasks [3] [4], but has not been possible in the past due to the latency and reliability limitations of conventional wireless communication systems such as WiFi [5]. 5G, as a new wireless technology, is designed to satisfy both low latency and high reliability communication demands and provides enough bandwidth in order to resolve the aforementioned issues.
Subject of this work is to evaluate the capability of 5G as a communication technology for edge-based robot control regarding the runtime performance of an artificial neural network-based object recognition algorithm. A data processing pipeline (*c.f. figure 1*) consisting of a camera sensor attached to an on-board computer controlling of a Robotnik Kairos mobile robot and a NVidia Jetson Xavier AGX GPU capable edge device has been set up. The runtime of a pretrained YOLO v3 object detector [6] and latencies of the system where measured and compared 1) running on the CPU of the on-board computer only, 2) using conventional WiFi and 3) 5G for transmitting image data to the edge for inference. For this purpose, the time between image acquisition, inference with Yolo v3 on the edge system and retrieving the results is assessed. The runtime measurements indicate that outsourcing computing operations to edge systems for time-critical and computationally intensive applications is beneficial as a normal CPU for computations such as inference on a neural network is not sufficient for context-aware real-time response. With the used setup, the average processing time of an image with YOLO v3 object recognition architecture on the on-board CPU of the AMR is 11386 ms, which is too large for time-critical operations. Opposed to that, inference on the edge device requires 113 ms only. In the latter case, the network's latency must be considered for the overall runtime of the pipeline. For such applications, 5G is a necessity due to a significant improvement with respect to existing wireless technologies in latency and reliability of the connection. In our setup, the overall latency of the whole system including 5G communication was 61 % lower than the overall latency of the system with Wi-Fi communication. However, there is still the possibility to optimize in the system's pipeline, eventually reducing the overall latency. Implementing an image compressor before transmitting the images and optimizing the image resolution for the object detector could relieve the network and reduce lower response times. Running the system in other modes of the 5G network (like ultra-reliable and low latency, URLLC) could also improve overall performance.

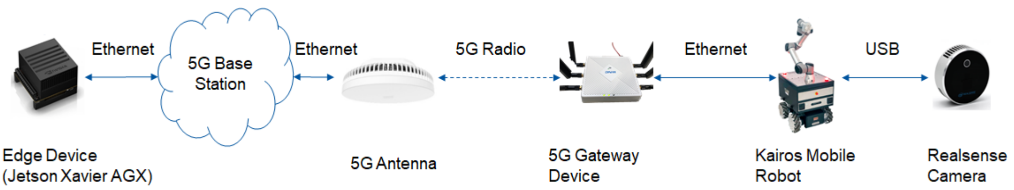

Figure 1. Setup architecture for the data processing pipeline

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Analysing Tool Strength of an SPTT with Grooved Micro-channel on Tool Rake for Enhanced Heat Transfer

MAT21-127

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Single Point Cutting Tool, microchannel, negative rake tool

Abstract
High heat generation during machining is a significant consideration for machinability of any material. Thermal damage enhances with the usage of negative raked cutting tool, compelling the use of positive raked tool having inferior strength. Application of cutting fluids reduces the thermal damage [1]. However, ineffectiveness of cutting fluid applications is well documented in various published reports. The article investigates the potential of generating microchannel on tool rake face to effectively transfer cutting fluid to the close vicinity of the cutting zone to obtain better cooling performance. The technique could effectively take part in lubrication and cooling action while maintaining reduced coolant consumption. However, meandering microchannel on tool rake may hamper the strength of the tool. This article is focussed towards analysing the effect of microchannel geometry and proximity on its strength.
A significant advantage of fluid flow inside a microchannel is surface tension driven flow that can contribute towards enhanced heat transfer depending on differentiating geometric parameters [2]. The study considers four different geometries viz. rectangular, traphezoidal, semi-circular and V-channel. A representation of grooved microchannel is represented in figure 1.

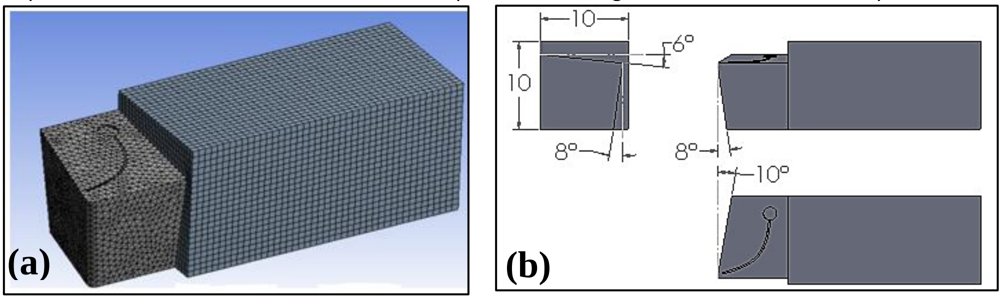

Figure 1. Negative raked cutting tool with microchannel (a) Mesh geometry (b) Tool geometry

Faliure analysis of the load subjected on the cutting tool (AISI M2 HSS) while machining mild steel is performed using maximum principal stress theory [3]. Microchannel with the aforementioned geometry were considered at five different positions from principal cutting edge. The obtained stress values are provided in figure 2. It was observed that none of the Stress Analysis resulted in the failure of any of the 20 single point turning tools. Thus it can concluded that a micro channel can be fabricated on the rake face of the tool and can be used in machining without causing the tool to fail. Also, preliminary investigation suggestes traphezoidal and semi-circular microchannel to have advantage over the other two.

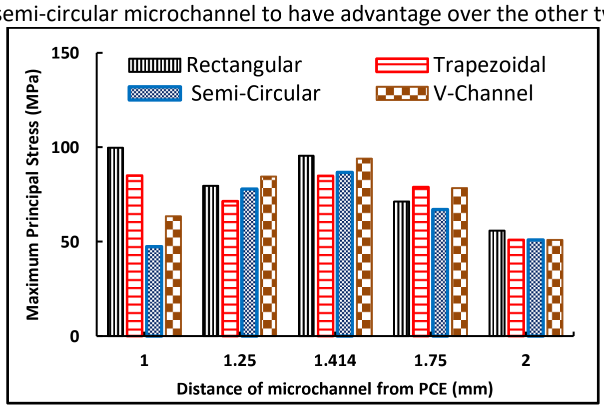

Figure 2. Maximum principal stress for different considerations

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Review of the Key Challenges, Guidelines and Cost-effective Digital Solutions for SMEs

MAT21-128

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Industry 4.0, SME, Manufacturing,Digitalisation

Abstract
The importance of small and medium-sized enterprises (SMEs) boost day by day. The report published by the World Trade Organization (WTO) in 2020 explained that all around the world 95% of companies consist of SMEs and these companies cover 60% of employment. According to the same report, SMEs were influenced by the COVID-19 pandemic seriously because of the restricted economic source [1]. To minimize the negative effect of economic fluctuation and unpredictable changes, SMEs should merge their traditional systems with digital cost-effective solutions. Digitalisation of production in SMEs will increase their competitiveness in the market while helping them to reduce wastes and achieve the goal of circular economy [2]. The key barriers in front of the SMEs can be summarized by the high price of technological equipment, lack of qualified staff, and the difficulties that arise from the multidisciplinary transformation processes [3]. This critical review paper compares the existing roadmaps, lists the challenges for SMEs, and at the same time analyses the existing implementations, e.g., in production scheduling, automation and monitoring. Hence the paper starts with an explanation of the general challenges of SMEs and then gives an overview and comparison of existing roadmaps created to adapt SMEs to digital technologies. The last part of the article summarizes the current limitations and research needs in this field. The flow of the paper is shown in Figure 1. As a preparation for future work, a new framework is proposed before conclusion.

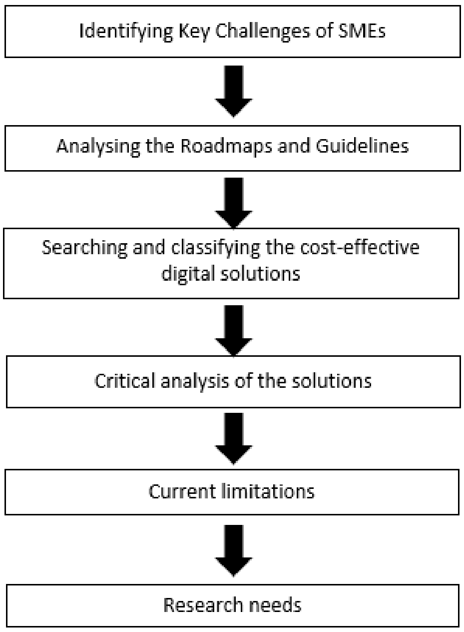

Figure 1. Research Details

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Dimensional nanometrology to support UK science and industry

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MAT21-131

Dimensional nanometrology, traceability, nanotechnology, interferometery

Abstract

The last decade has seen an increase in nanotechnology based research with the emergence of products and devices working at the nanoscale for example: positioning heads for hard disks, semiconductors, nanoparticles for targeted drug delivery, emerging quantum based sensors e.g. single electron transistors and x-ray optics. This is driving the requirement for accessible traceable nanometrology from National Metrology Institutes. The talk will give an overview of dimensional nanometrology research at NPL, the UK's National Metrology Institute, to meet current and future requirements for nanotechnology to support science and industry. The main point of entry into the nanoscale world is the atomic force microscope (AFM) [1] with applications that include imaging, manipulation, writing and metrology. NPL has established a route to traceability for AFMs via the development of bespoke metrological atomic force microscopes (see figure 1) turning the AFM from a qualitative imaging instrument into a quantitative traceable metrological tool [2,3]. More recently NPL has brought metrology to high speed atomic force microscopy with development of its metrological high-speed AFM [4]. The AFM work has also been supported by development of intelligent sampling strategies [5,6] calibration standards and more accurate nanopositioning [7]. Optical interferometry is the established traceability route for length metrology and NPL's work in developing high accuracy displacement measuring optical interferometers will be described [8]. The 2019 revision of the International System of Measurement (SI) included an updated *Mise en pratique* for the metre with a new route to traceability for dimensional nanometrology through the lattice parameter of silicon [9]. NPL realises this through x-ray interferometry [10] which can be regarded as an atomic scale ruler that can be used to investigate non-linearity errors in optical interferometers and other high accuracy displacement measuring systems (See figure 2) as well with the use of silicon based calibration artifacts for AFM calibration [11].

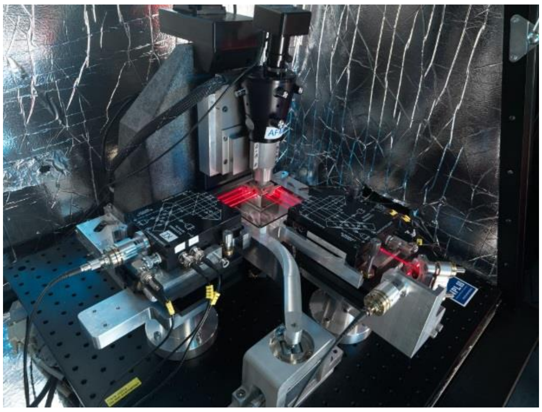

Figure 1. The NPL Metrologial atomic force microscope

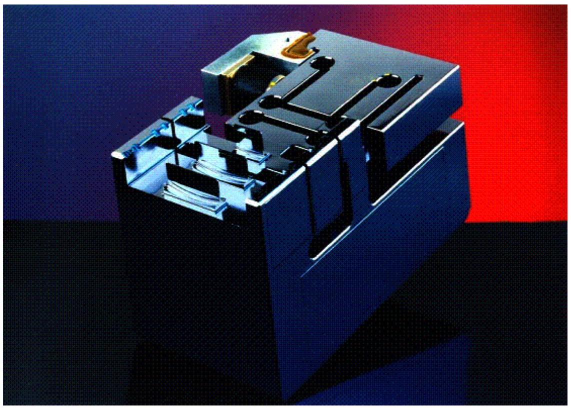

Figure 2. A monolithic scanning x-ray interferometer

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Feasibility of improving productivity through the usage of higher axial depth of cut per pass during MQL based sustainable micro-milling

MAT21-132

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Micro-milling, Productivity, Burr, Surface roughness, Tool wear

Abstract
Mechanical micro-milling process emerged as an economic, time-efficient, and easily controllable micro-fabrication process that can be applied to a wide variety of materials. During fabrication of deeper micro-features using micro-milling process, application of larger axial depth of cut can enhance productivity by reducing the number of passes. However, machining with a larger depth of cut can degrade the machinability in several ways. The influences of the axial depth of cut during minimum quantity lubrication (MQL) [1] assisted micro-milling on Ti-6Al-4V using 500 µm diameter TiAlN-coated tungsten carbide (WC/6Co) tools are studied here.

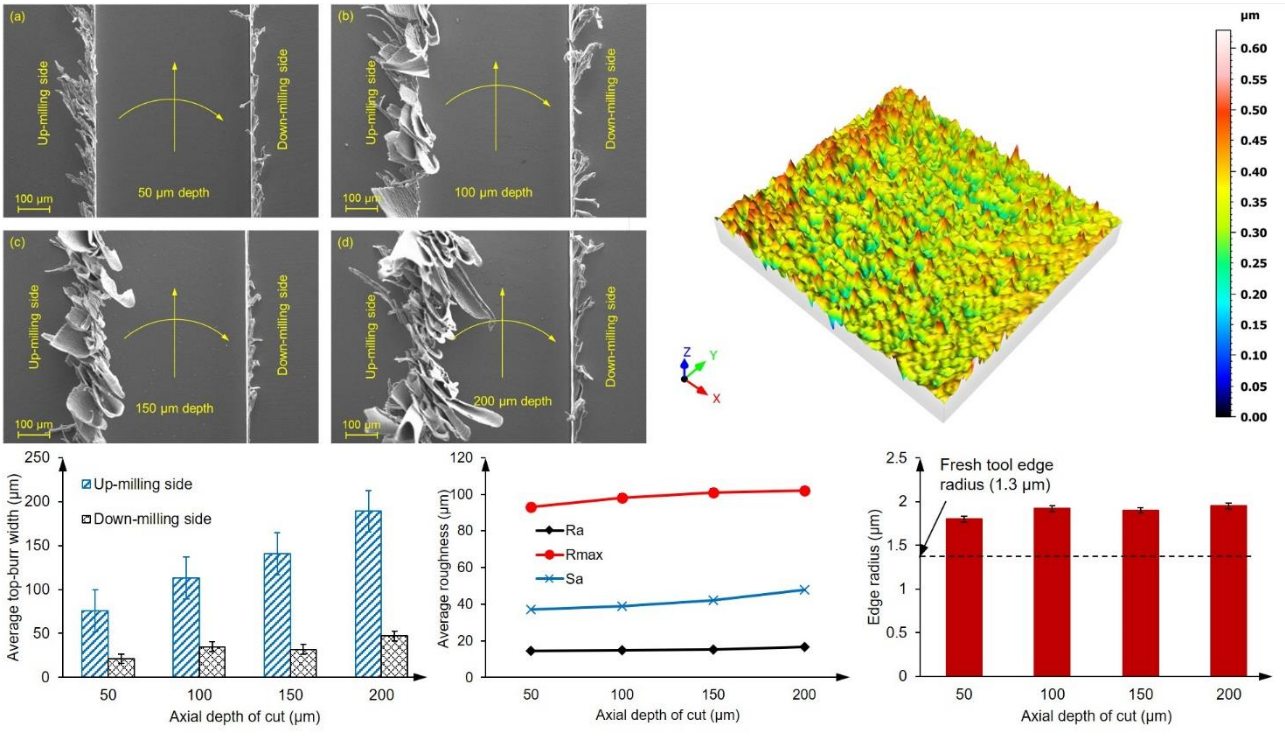

Figure 1. Effect of the axial depth of cut (50, 100, 150, and 200 µm) on top-burr size, surface roughness, and tool wear (45,000 rpm, 2.0 µm/flute)

During micro-milling with a given tool, the plastically deformed material bends in the lateral direction of the side-walls to generate top-burr. As the volume of this plastically-deformed material increases proportionally with the axial depth of cut, the top-burr size also increases (Fig. 1). An increase in the average width of the up-milling side top-burr from 76 – 189 µm is observed when axial depth is increased from 50 – 200 µm. Undesired inward flow of the burrs (bending towards the slot) is also clearly detected. Down-milling side top-burr, however, does not change perceptibly. Surface texture roughness R_a and R_{max} also change only marginally with the increase in axial depth. Significant change in the areal roughness (S_a) is also not detected. As usual, the fresh tool suffers rapid break-in wear in the initial 5.0 mm length of cut; however, the final edge radius remains more-or-less same across all the trials. Thus, it is the top-burr that predominantly limits the usage of high axial depth of cut per pass. There are several micro-scale deburring processes reported in the literature [2] that can remove burrs with negligible collateral damage. Therefore, higher axial depth can be employed during micro-milling to enhance productivity, provided that the component can be processed through a deburring technique.

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Investigating the in vitro degradation properties of polyethylene terephthalate glycol

MAT21-133

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biomaterial, degradation, poly(ε-caprolactone), polyethylene terephthalate glycol, tissue engineering

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Abstract

Represented by porous three-dimensional (3D) scaffolds, artificial implants have been widely investigated for bone tissue engineering applications. The properties of these biocompatible and biodegradable scaffolds highly depend on the materials, processing conditions, and structure. Biodegradability is one of the most important properties of the scaffolds, which affect both biological and mechanical performance after implantation. Poly(ε-caprolactone) (PCL) is a mature material that has been widely used for scaffolds fabrication and polyethylene terephthalate glycol (PETG) is a newly proposed biomaterial for bone tissue engineering. This paper investigates the degradation profile of both PCL and PETG scaffolds. The effect of degradation on morphology and mechanical behaviours are also evaluated. Results showed that PCL scaffolds have a faster degradation rate but lower mechanical properties comparing with PETG scaffolds and the mechanical properties decreased with time.

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A Voronoi diagram based framework for fast and accurate inspection of closed 2D free-form profiles

MAT21-134

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Key-words: Free-form profiles, Voronoi diagram, discretized profile, registration, profile error estimation

Abstract

Free-form profiles or free-form curves have vast engineering applications. Due to better functionality and aesthetic reasons, many components used for biomedical, aerospace and automobile applications are composed of free-form shapes. These components are modelled using various parametric formulations and physically realized through multiple manufacturing processes[1]. The manufactured components are measured using various contact and non-contact devices. This measured data(represented as discrete point sets) is registered with the reference profile and later inspected for the profile error. Registration is accomplished in two phases, i.e. coarse registration and fine registration, and in both phases, the reference profile must be discretized appropriately for accurate inspection[2]. In this work, a Voronoi diagram based method is proposed for both profile discretization and coarse and fine registration. Fig. 1 shows the schematic of the proposed method. In both the registration phases, the structure of the Voronoi diagram is utilized for the nearest neighbour computation. Moreover, a new interpolation technique based on the same structure is also proposed for fine registration and accurate profile error estimation. Since the nearest neighbour search in the 2D Voronoi diagram executes in logarithmic time[3], the coarse registration method executes in overall O(m log n) time, whereas the fine registration method executes at the same time for each iteration. Numerical implementations are executed using a simulated NURBS profile, and the estimated profile errors are validated using the point-inversion method. The results of these implementations illustrate that the proposed methodology can be used for fast and efficient inspection of free form profiles.

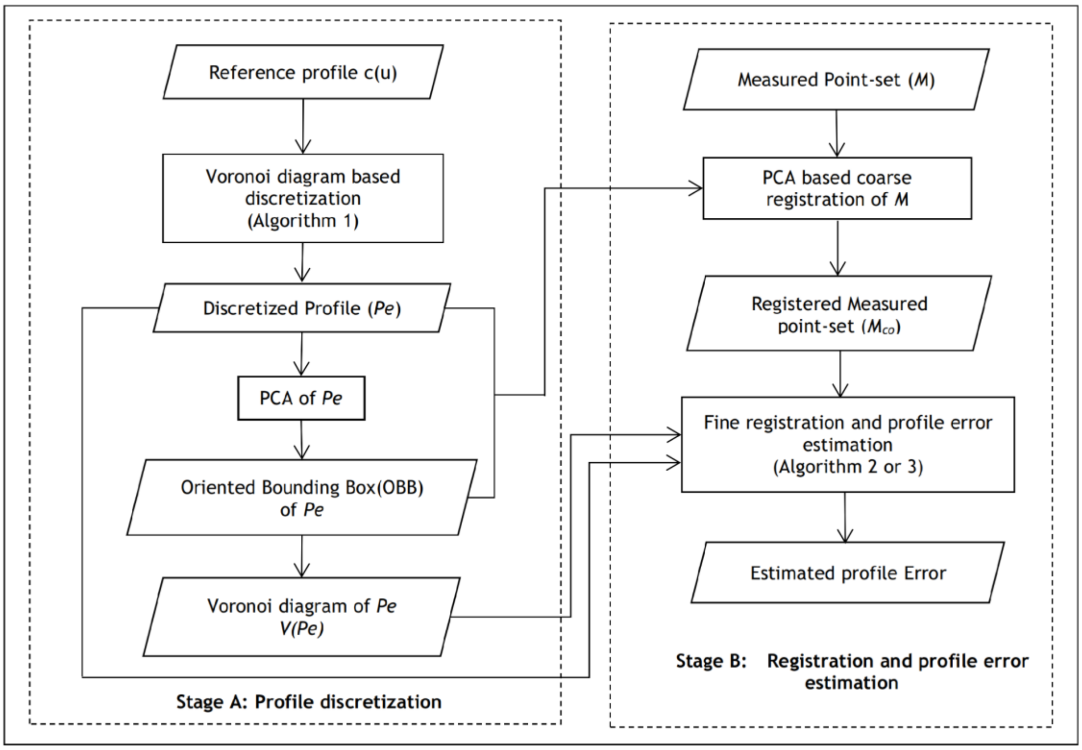

Figure 1: The overall schema

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Mobile Measuring Machine for Large Round Parts

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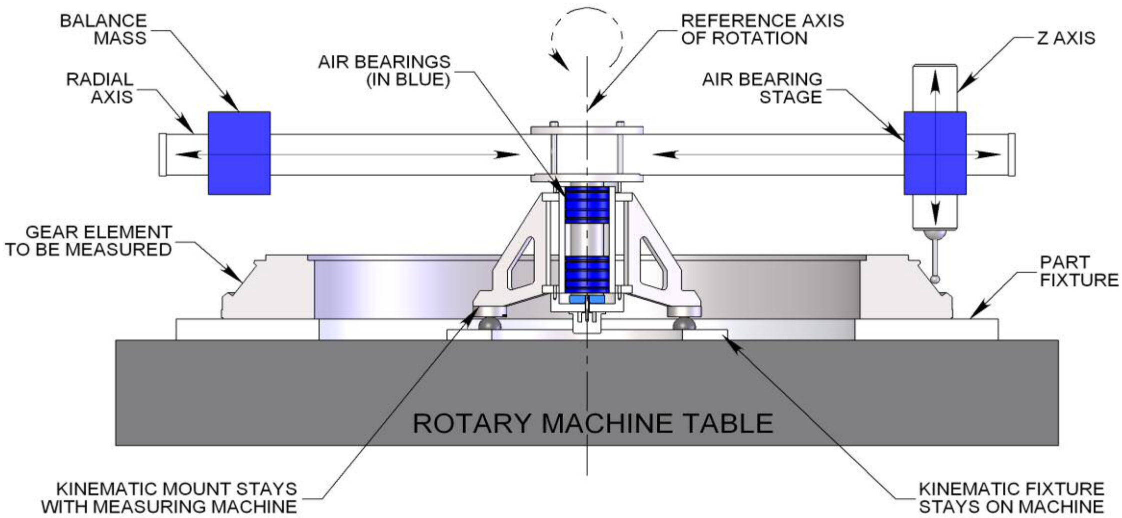
MAT21-135

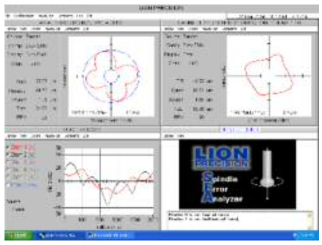
Round CMM, Mobile Measuring Machine, On Machine Measurements, Axis of Rotation Metrology

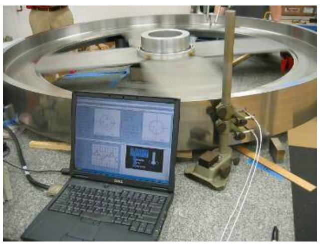
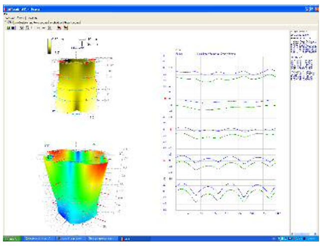
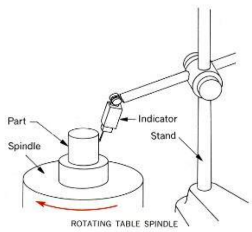


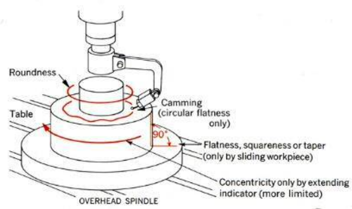
In the effort to improve the speed of manufacture and the quality of the inspection data of large bearing and gear components used in wind turbines, a fundamental change in measuring techniques is in order. Currently large round components are typically measured on a cartesian coordinate measuring machine, this is a lot like measuring a round hole with a square plug. The part must be removed from the machine and transported to a quality lab that is often a different thermal environment, then set on fixturing that is not like the machine tool or the actual mounting surfaces the component will see in use. CMMs large enough to accommodate these large parts often have very high bridges creating large structural loops and huge Abby errors that are compounded by structural errors induced by the very heavy components being measured that are not on the machine when it is calibrated.

Alternatively, a very precise axis of rotation can be used to create mobile roundness measuring machines that could be quickly brought to and kinematically mounted on center of the machine table, measuring the part as chucked, then unchucked on the table to quickly reveal fixturing, size, profile, roundness and circular flatness errors without moving the part. Such a measuring machine would have a very tight structural loop, no influence from the weight of the part, a much lower capital cost, much lower floor space requirements and much faster, convenient and precise measurements. The design would use conventional CMM or Capsitance probes and Rank Talyor Hobbson or IBS like roundness software. It could easily scale to the largest of parts.





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Milling stability prediction using non-iterative multi-frequency solution

MAT21-136

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Chatter, milling, multi-frequency solution, non-uniform tool geometry.

Abstract

Tools with non-uniform geometry, such as variable pitch or variable helix end mills, are very effective in optimising the productivity by improving the depth of cut and spindle speeds [1]. The chatter stability-based design of such tools usually has to rely on simpler models because of the high computational load of the complex time-domain models. One of these simple methods is the zero order approximation method which takes the average of the time-varying directional factors [2]. The effect of the, e.g., flip bifurcation regions can be further captured by multi-frequency solutions, but they may take too much time due to iterations. We propose a non-iterative, semi-analytical method to obtain the stability lobe diagrams for tools with non-uniform geometry. Firstly, the dynamics equation of motion are obtained in frequency domain by considering multiple frequency harmonics. Then, the stability is checked by Nyquist criterion at every spindle speed and depth of cut tuple. As shown in Fig. 1, the method has been validated for a variable pitch endmill against simulation data from Ref. [1]. Concurrently, it takes just as much time using the proposed non-iterative multi-frequency solution with 3 harmonic as using the state-of-the-art semi-discretization method. The achieved computation efficiency is significant for getting more attention to multi-frequency chatter stability simulations of tools with non-uniform geometry.

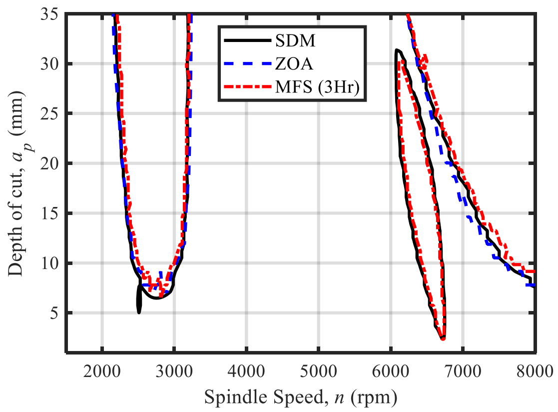

Figure 1. Verification of stability lobes for three-fluted variable pitch end mill with (120-100-140) deg tooth spacing. Cutting condition: 5.25% down milling. See Fig.10(a) by Sims et al. [1] for the original stability lobes diagram. Following methods were compared: SDM (Semi-discretization method), ZOA (Zero-order approximation) and proposed non-iterative MFS (multi-frequency solution) with 3 harmonics.

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Personalized Design and Fabrication: Intelligent Solution for Fashion Industry

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Digital manufacturing, Computaional design, Artificial intelligence, Industry 4.0

Abstract

The entire fashion industry, especially for customized clothing, is transforming and upgrading towards an intelligent and personalized design and manufacturing approach. Conventional manual measurement and manufacturing methods are time-consuming, resulting in poor user-experience and increased costs. Trial and fitting in offline retail store is time-consuming while online e-commerce faces the problem of high return rate due to improper size chosen by customers. Traditional manufacturing process includes estimation of demand, pre-production of various sizes of products for stocking up, resulting in inventory backlog and other issues. On the other aspect, there is no universal size standard in the world. Sizes could vary from manufacturer to manufacturer; thus cannot perfectly match everyone's body shape.

We provide advanced and intelligent *customer-to-manufacturer* (C2M) solutions for the manufacturers of wearable product to upgrade their business to industrial 4.0, which is based on our original *shape driven technology* equipped with AI and big data. All the aforementioned problems can be solved by our new retail model such that the manufacturing process is initiated by customer. Customer makes order to manufacturer directly. Manufacturer can then fabricate unique pattern for each customer precisely using our C2M manufacturing solution and data.

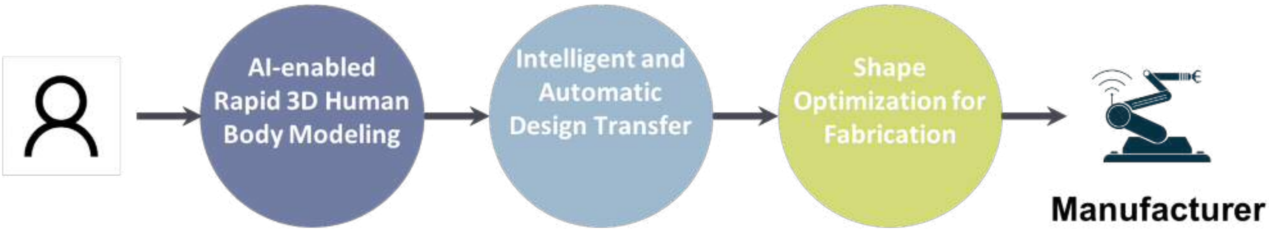
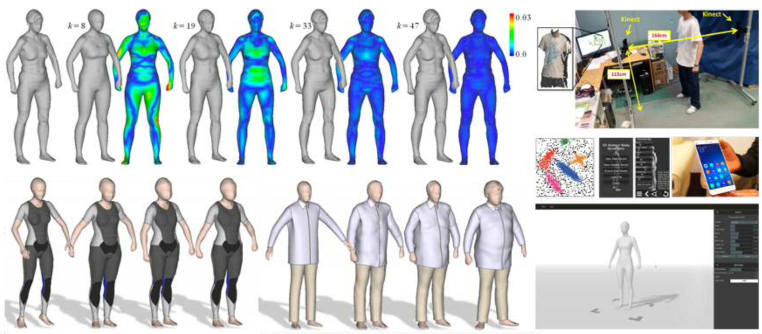


Figure 1. Our shape driven intelligent solution consists of three major techniques, including AI-enabled rapid 3D human body modelling [1-3], intelligent design transfer [4, 5] and optimization for enabling fabrication [6-8].



The intelligent C2M solution [9] can also be applied to some other applications, such as customized orthodontic braces, patient specific instruments, beauty masks, VR/AR glasses etc. Shape-driven technology will lead to the next generation of customization, which is driven by shape but not size – i.e., different from made-by-measure. The design-by-code concept promoted in this solution can release the brain of designer from tedious operations by enabling the function of re-generating design automatically by software. Moreover, we are seeking the help of digital knitting to further advance the shape driven technology from 3D to 4D garments [10]. In summary, AI-enabled design and manufacturing based on shape driven technology will help open the door of Industry 4.0 in fashion industry.

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Real-time machining and adaptative closed-loop control with 5G

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MAT21-138

Type the keywords here
5G, Closed-loop Machining, in process validation

Abstract

5G communication is changing the manufacturing canvas due to its low latency, high bandwidth, and higher capacity compared with current networks. Monitoring and controlling of machining processes pose a challenge to this 5G vision as a result of the complexity of the cutting process that requires multi-sensorial approaches at high sampling rates and real-time communication to close the control loop [1]. In the scope of applications that could be improved by 5G real-time closed-loop machining are thermal offset compensation [2], tool condition monitoring [3], and detection and avoidance of chatter vibrations [4]. The latter can benefit from it since higher amplitude and frequency vibrations may lead to poor surface finishing, tool breakage, or even damages to the spindle of the machine [5]. In this study, we applied a multisensory chatter detection approach for the milling of thin-walled features. We utilised an array of sensors that includes an accelerometer, a microphone and a dynamometer to monitor and control milling chatter instabilities by relying on the smaller latency of 5G networks. The system design is described in figure 1 which emphasises the need for early and quick data analysis that allows chatter recognition. There is a limited choice available for 5G customer premise equipment at present. Interconnecting general-purpose modems, digital-to-analogue converters, amplifiers and sensors in a long chain is the most common technique used to complete the data pipeline. However, daisy-chaining the devices inevitably adds undesirable latency to the detection process. This motivated the authors to develop their own in-house all-in-one integrated solution. Our proof-of-concept test for this system included the milling of an aluminium 7075 workpiece to mimic the materials used in the aerospace industry. In every stage, our 5G control strategy guarantees that significant distortions are not added to the part with chatter conditions being monitored during every machining phase in which the 5G control loop adjusts the spindle speeds and depths of cut. [Future work will include the addition of more industrial sensors to the closed-loop.

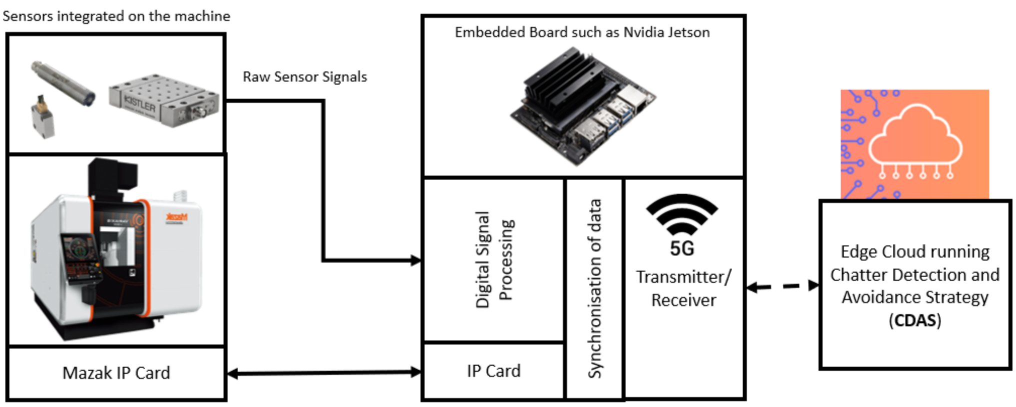

Figure 1. Experimental set-up used in the adaptative closed-loop control

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Multi-Axis Additive Manufacturing with Controlled Anisotropic Strength

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MAT21-139

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Additive Manufacturing, Multi-axis Motion, Tool-Path Generation, Anisotropic Strength

Abstract

Additive manufacturing technology is a process of join materials to fabricate objects directly from 3D digital models. In the current practice of 3D printing, the materials are normally accumulated layer upon layer along a fixed printing direction. Due to the week adhesion between layers, the anisotropic property occurred and brings the weakness in strength along the layer bounding direction [1]. For models with complex shape and stress distribution, planar-layer based printing process may fabricate models that are easy to delaminate under loading. To reinforce filament-based additive manufacturing, we introduce the multi-axis motion that enables filament alignment in 3D space. Advanced algorithms are developed to generate the toolpath that enables material locally follow the principal stress direction [2]. Using our method, the anisotropic strength through the model is controlled, which avoids the filament align with the critical stress direction, which is detected by Finite Element Analysis (FEA).

The algorithm developed in our work includes curved layer slicing and toolpath generation based on a field-based pipeline. After generating the toolpath, we consider the collision issue of the machine's multi-axis motion, and the supporting structure is generated. These processes guarantee the success in fabricating process. We verify our toolpath in two multi-axis setups: 1) the Catision-based 5-DoFs machine [3] and 2) a robot-arm assisted 3D printing system [4]. The model fabricated with our method has a significant enhancement in the breaking force compare with the planar-based toolpath with optimized printing orientation (e.g., 203% increasment for the TopOpt model as shows in Fig. 1).

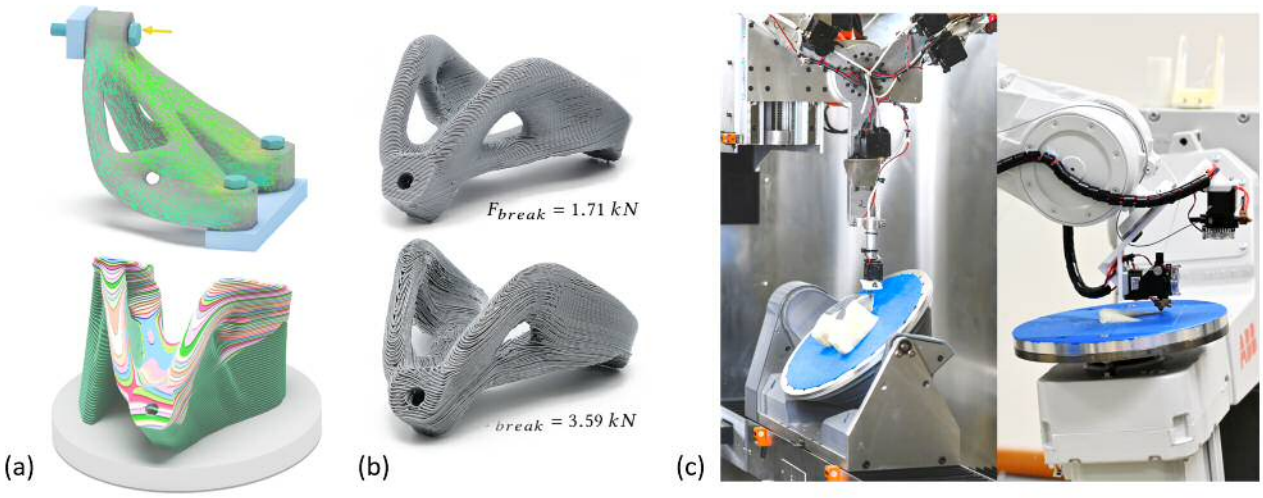

Figure 1. Our method reinforcement the 3D printing by control filament alignment direction in 3D space enabled by multi-axis motion. (a) Our pipeline slices the model with curved layers (bottom) and generates toolpaths based on the stress distribution (top) of the model under given loading. (b) The model printed with our toolpath (bottom) presents a 203% increase in the breaking force compare with planar-based printing (top). (c) We successfully test our toolpath in two types of multi-axis 3D printing machines. Left: Catision-based machine; Right: robot-arm assisted printing system.

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High-speed abrasive machining of Al-SiC composite using uni-layer brazed diamond tool with patterned grit distribution

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MAT21-140

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Patterned brazed diamond wheel, Al-SiC composite, High-speed machining

Abstract

Single-layer brazed grinding wheels are advantageous in many ways than the conventional vitrified and electroplated wheels. Stronger metal bonds and larger grit protrusion resulting in higher inter-grit chip storage space make the brazed wheels superior which can be the ultimate solution to avoid wheel loading problems in deep grinding applications. The current research work investigates the dry abrasive machining of Al-SiC composite with the help of an in-house developed uni-layer brazed diamond grinding tool (Fig. 1) with uniformly arranged abrasive grits throughout its periphery. The experiments, similar to high-speed vertical grinding (Fig. 2) were carried out in a vertical machining center at a cutting velocity of 70 m/s, table feed of 0.5 m/min in dry condition with varying depth of cut from 20 µm to 100 µm.

Figure 1. Uni-layer brazed tool with patterned grit distribution

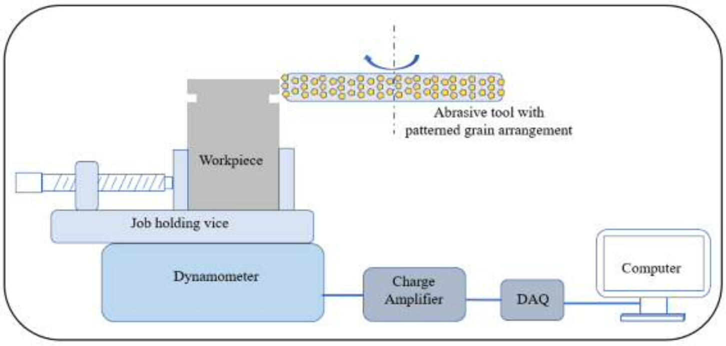

Figure 2. Schematic representation of the experimental set-up

Cutting forces, machined surface topography and grinding chips collected at different cutting depths were analyzed. The steady increase in both the tangential and normal forces with the increase in cutting depth (Fig.3) depicts the absence of wheel loading in dry machining conditions. The microscopic images of the abrasive tool described no wear or grit fracture even after dry grinding with maximum depth condition. Although the sufficient amount of grit protrusion did not allow the loading to occur, a small amount of material adhesion was noticed on the alloy layer of the brazed wheel after grinding with 100 µm depth of cut. The study assures the effective grinding of Al-alloys and composites which are regarded as difficult-to-grind materials due to their inherent stickiness property.

Experimental condition	Specification
Workpiece material	Al-SiC composite
Machining condition	Dry
Cutting Speed (V_s)	70 m/s
Table feed (V_w)	0.5 m/min
Depth of cut (d)	20 - 100 µm

Table 1 Specifications of the experimental condition

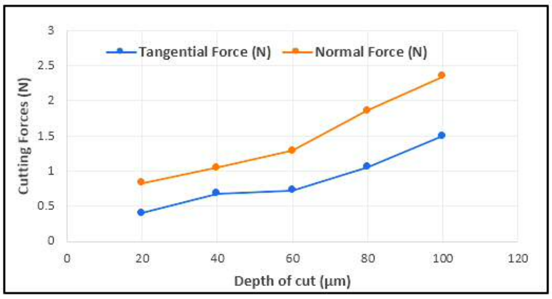

Figure 3 Variation of Cutting forces with depth of cut

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Ultrashort Pulsed Laser induced micro/nano scale surface structures on Inconel 718

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MAT21-141

Key Words: femtosecond, pulsed laser, micro nano surface structures, Inconel 718

Abstract

Among the energetic beams, the laser beams have gained great interest in the scientific and fundamental studies for surface modifications of materials, including metals and alloys. The laser based material processing is as old as lasers but the recently available short and ultrashort (ps, fs) pulsed laser found to be of extremely interesting in controlling the dramatic thermal effects and high precision processing of materials in micro nano scales [1]. Both picosecond and femtosecond pulsed lasers are advantageous in achieving micro nano features/induced surface structures. Picosecond and femtosecond pulsed lasers are of interest in recent decades for processing metals and alloys [2]. The surface texturing of nickel based super alloys are equally important, this special class of materials attribute to unique properties such as mechanical strength, high temperature, corrosion resistance, excellent thermal conductivity and resistance to aggressive atmosphere [3]. Hence finds various industrial applications including chemical, electronic, food industry and aerospace engineering etc. It has also been reported to be highly useful in nuclear complexes, in fission as well as fusion reactor technology [4]. Inconel 718 material interactions investigations with fs pulses at high repetition rates are limited Though there are many works on laser processing of super alloys, Inconel 718 material interactions investigations with fs pulses at high repetition rates are limited .

In this research, the interaction of ultrashort pulse lasers at high repetition rates of 100 KHz to 500 KHz with nickel super alloy Inconel 718 is reported. The laser system used has a wavelength of 1030 nm and pulse duration of 300 fs. Micro nano scale laser induced surface structures are observed in the pulse energy range of 16 μJ to 40 μJ. A series of various types of surface structures are observed in the studies which are in micro nano scale.The study of surface roughness (Ra) is considered to establish the process for large area surface modifications. The spot size of the laser beam is about 133 μm hence the hatching (dot and line) pitch range is considered from 10 μm to 55 μm. Energy Dispersive Spectroscopy (EDSx) analysis is also carried out at specific lasing conditions to understand changes in elemental composition due to laser irradiation. The surface structures can be observed for the change in pulse energy from 16 μJ and 40 μJ with respect to spot to spot pitch (dot hatching)/ laser beam overlap ratio. The sizes of the laser induced periodic surface structures were reduced with increase in pulse energy, structures observed from the two levels of pulse energy 16 μJ and 40 μJ can be observed in Figure 1 (a) & (b). It is also observed that the geometry of the structures are found to be varying with pulse energy and hatch pitch. In addition the observations of surface roughness can be seen in Figure 1 (c), which shows a uniform trend of Ra from hatch pitch 30 μm. Also, similar results were observed for line hatching (scan speed based) for the entire pitch. The surface roughness at pitch 30 μm is found to be uniform for the energy levels. The ablation was found to have distinguishable structures across the pitch upto 50 μm.

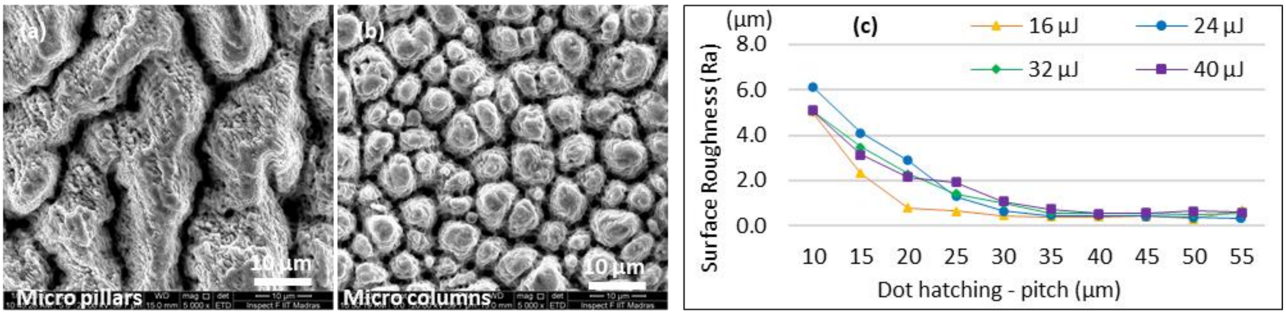

Figure 1. (a) Micro pillars with 40 μJ, (b) Micro columns with 16 μJ, (c) Change in surface roughness (Ra) with increase in dot hatch pitch for 250 pulses per spot at repetition rate 500 kHz

Formation of surface structures – micro pillars, ripples, columns etc are predominant in the hatch pitch from 10 μm to 30 μm range and with the pulse energy difference, the detailed investigations will be included in extended manuscript. Microscale structures are in the range of 4 μm to 10 μm. Nanoscale ripples in the range of incident laser beams are observed over the microstructures. Surface roughness studies will be beneficial for large scale surface polishing applications.

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Innovative and new development in broaching machining process: Mechanistic force modelling

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MAT21-144

Broaching, mechanistic modelling, force

Abstract

Tool design optimisation forms an integral part of the machining process. This stage forms the basis of the creation of complex shapes and geometries for internal and external parts such as non-circular internal holes, keyways, turbine disc fir-tree slots[1], [2]. Process parameters and design geometries are all embedded into the tooling design, hence much focus and attention are needed to produce superior geometries eliminating scrappage during the machining process [3], [4].

The development of a new concept for high-speed indexable carbide tool broaching for slot machining applications will enable the use of higher cutting speeds three times more than the traditional high-speed steel (HSS) broaching.

The developed mechanistic model was capable of simulating broaching processes based on old traditional broach tools and newly developed broach tool technology used for on-machine broaching processes as shown in **Error! Reference source not found.**. This model also focuses on a disruptive application for broaching where the broaching technology is performed on a multi-axis machine tool platform. This is to enable multi-functional operations during the manufacturing proces; unlike of the traditional broaching, which is currently performed on special and bespoke equipment specially made for the process, with the cutting tools typically very long with metres in length. The new broach tool are not typically long and flexible to use as oppose the currently used broaching tool in the manufacturing industry.

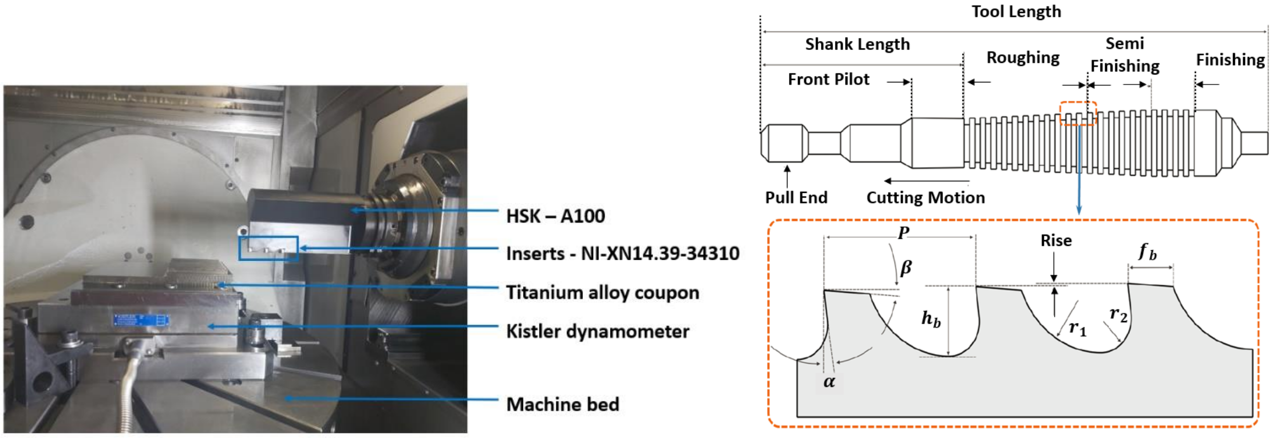

Figure 1: (a) Experimental setup showing newly developed on-machine tool for broaching, and (b) traditional broach tool

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New approach for the extension of virtual commissioning models by considering structural dynamics and drive control behaviour

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Virtual commissioning, Digital twin, Machine tool, Robots, Automation

Abstract
Virtual commissioning can be used to speed-up the development and validation of programmable logic controller (PLC) by using simulation models instead of real production and automation systems [1]. This hardware-in-the-loop simulation leads to significantly shortened commissioning times. In addition, it is possible to use virtual control systems in a model- or software-in-the-loop simulation (SiL), where the automation system can be simulated completely in a virtual environment [2]. SiL can be used for training purposes, for the reduction of down times during retrofitting and modernization, and for testing and optimization of new production cycles in parallel to the real production system.
Typically, the digital twins in the simulation environment of virtual commissioning systems only consists of kinematic models of the production systems, which describe the ideal rigid motion of the movable components of robots or machine tools. Together with the real or virtual controllers in a HiL or SiL, respectively, it is possible to detect errors in the control or CNC programs as well as collisions between machines and workpieces.
In this contribution, a possibility for the extension of the modelling approach from the existing pure rigid-body kinematics toward a complete mechatronic modelling of the production systems is presented. Therefor options for implementing the modular digital twin from Ref. [3] in a commercially available virtual commissioning system (see Fig. 1) are shown. The mechatronic model of the production system is based on experimental data and describes the behaviour of the feedback control of each machine drive as well as the structural mechanics. In the virtual commissioning system the actual position commands for each drive of the machine are available from the real or virtual controller. These signals are the input signals for the new complete mechatronic models, which are integrated as state-space models or transfer functions in the simulation environment of the virtual commissioning system. As a results, it is possible to predict the expected actual tool motion and contour errors in addition to the visualization of a virtual part, which is already possible in a classical HiL- or SiL-simulation based on the ideal tool motion.

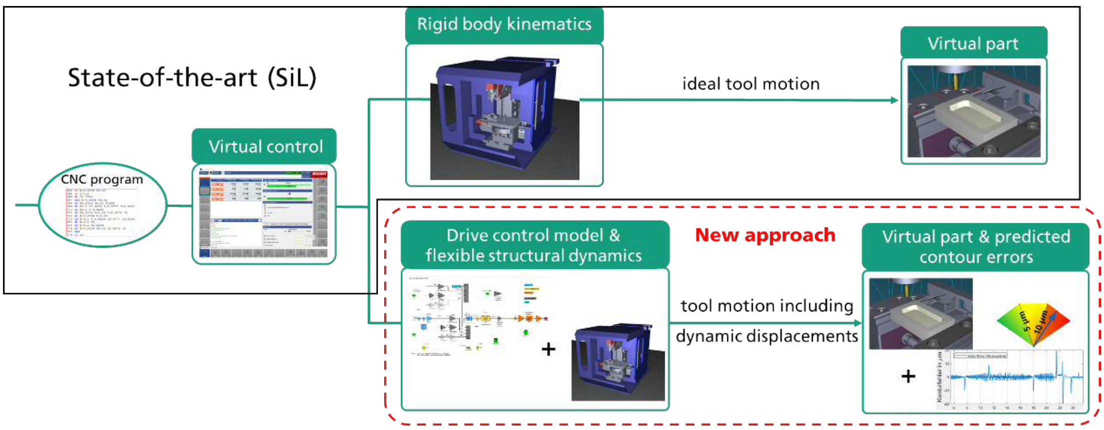

Figure 1. State-of-the-art of SiL for machining and new approach with physics-based digital twins and prediction of contour errors.

In the future, with the new approach that includes elasticity and dynamic displacements of machine tools or robots in a physics-based digital twin, virtual commissioning systems can be used over the life cycle of the production system, for example, to optimize drive control or CNC machine parameters as well as specific processes with respect to high accuracy or lower cycle times, respectively. Moreover, first concepts exist already for the integration of cutting forces or other types of process feedback and will be the content of future research.

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Interoperable Systems: Adaptive B2MML bus layer for discrete manufacturing

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ISA-95, B2MML, Machine Learning, Discrete manufacturing, ERP, MES, MOM

Abstract

Manufacturers are trending towards an increasing usage and collection of data, asking to be able to seamlessly traverse between high-level business KPI and high volumes of shop floor level information [1]. There is also a need for near real-time data visibility at different levels of business operations [2]. These demands present a variety of integration challenges such as that of ERP and MES systems. Integrating disparate enterprise systems is an additional challenge, particularly so across systems from different vendors. These systems are typically rigid and cannot easily adapt to new data sources without significant configuration, which requires resources and time. Furthermore, these customisations usually result in bespoke implementations specific to the business. International standards such as ISA-95 have gone some way to standardise ERP-MES integrations, reduce the manual data transfer, and automate business processes that operate across multiple enterprise systems. The purpose of this study is to investigate the operational benefits of a novel enterprise system integration tool that can reduce the time it takes to adopt and integrate new systems. Additionally, our tool would adaptively introduce new sources of data to existing combinations of interoperable enterprise systems. The B2MML protocol is an XML implementation of ISA-95. The proposed architecture described in figure 1 will make use of machine learning techniques to identify patterns, translate data into B2MML messages using text mining and cluster analysis to group relevant information exchanged between systems. The study will take a real-world integration challenge from a manufacturer of complex discrete mechanical assemblies as a proof-of-concept. A Manufacturing Operations Management (MOM) system will be architected using Systems Modelling Language (SysML), along with the accompanying integration of this system with the manufacturer's existing ERP solution. The integration will be facilitated through a highly adaptive B2MML bus layer that utilises machine learning to efficiently convert data from a variety of sources.

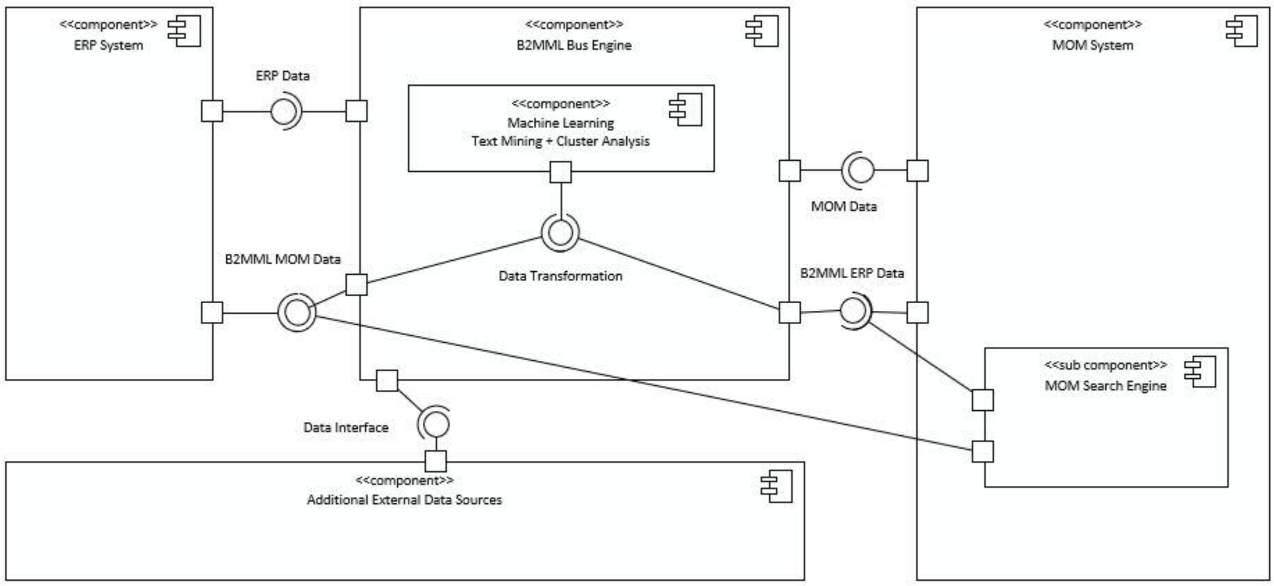

Figure 1: High level architecture representation using UML component diagram highlighting the main components of the system and the B2MML adaptative bus that interprets multiple data sources and transforms it into an ISA-95 compliant format.

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4D printing applications in the cardiovascular system

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Keywords: 4D printing, smart materials, cardiovascular diseases, medical devices, soft tissue engineering

Abstract

Cardiovascular diseases are the leading cause of death globally and include blood vessel narrowing in the heart (coronary artery disease), brain (cerebrovascular disease) and periphery (peripheral artery disease), as well as blood vessel dilatation or aneurysm formation. Intervention often involves the use of an implant through invasive or minimally invasive procedures. Medical implants are commercially developed devices like stents, grafts, stent-grafts, coils, embolic protection devices, plugs, pacemakers, and others. However, current commercial devices still suffer from many different limitations, like recovering the physiological functionality of the diseased region, which could be overcome through modern approaches.

With recent advances in additive manufacturing technologies, functional medical implants can be produced on a laboratory scale where the design space can be extended beyond complex geometries. 4D printing has emerged to bring dynamic functionality to printed products, making shape change possible within the printed product's configuration in response to external stimuli over time. In the cardiovascular setting, there may be a significant benefit to patients by harnessing this technology to develop novel devices, such as smart cardiovascular implants, tools and devices, wherein surgeons can diagnose and apply timely interventions during and after implantation. 4D printing is already making its mark on medical applications, however, further developments are imperative to extend their application to mainstream medical treatments and to address complex medical cases.

This paper focuses on the applications of 4D printing and smart materials within the cardiovascular system and the potential of 4D bioprinting to treat cardiovascular disease.

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Laser precision cutting CFRP and the relative mechanical performance analysis

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Keywords: CFRP, Laser Cutting, HAZ, Mechanical Performances, Simulation

Abstract

Carbon fiber reinforced plastic (CFRP) composite is an advanced composite material with carbon fiber as the reinforcing phase and epoxy resin as the matrix. In this report, the effects of laser parameters on the cutting quality and mechanical properties of laser cutting CFRP are discussed through experimental and numerical researches. The vaporization temperature of carbon fiber is much higher than that of resin, which leads to the faster removal rate of resin than that of carbon fiber. On the other hand, the heat conductivity of carbon fiber is higher than that of resin, which makes carbon fiber easy to be removed through heat conduction within a wider range. These above two factors make it possible to achieve “Zero heat-affected zone” laser precision machining CFRP through selecting appropriate laser parameters. In the report we also will introduce the experimental results about the influence of HAZ on the tensile, compression and flexure performances of CFRP. It is found that large HAZ reduces the mechanical properties. However, for thicker plates, the negative effect of HAZ is weakened relatively. Through simulation, it is demonstrated that the main reason for weakening the mechanical performances is that exposed carbon fiber within the HAZ cannot bear the load.