2025國科會AI機器人×智慧製造創新技術媒合交流會

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半導體先進封裝製程之線上智能化AOI關鍵檢測技術與虛實整合系統研發

虛實加工

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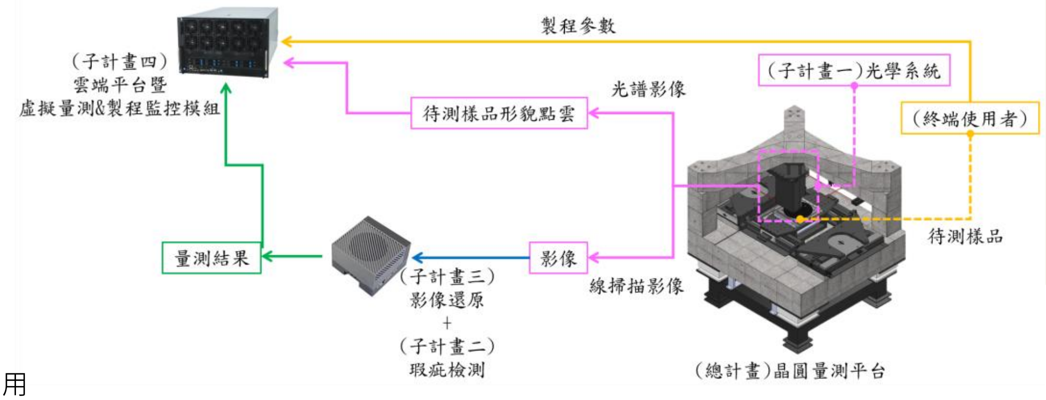
本計畫聚焦於半導體先進封裝製程所需之線上智能化微奈米級檢測與精密量測技術，結合實體量測（極高速彩色共焦光學系統）與虛擬監控（製程模型與虛擬量測技術），開發線上智能化微奈米級檢測與精密量測技術，並整合創新性的12吋晶圓三軸掃描平台，具300×300×5 mm^3量測範圍、300 mm/s等速掃描速度及50 nm內定位誤差，達5-6 WPH量測速度，接軌世界頂尖水準。計畫整合台大、交大、台科大、北科大及多家產業夥伴，共同研發多模組系統，並於第三、四年完成設備整合及實地驗證。此計畫將強化台灣半導體檢測設備自主研發能力，提升全球競爭力。

計畫亮點

- 自行發展微型化光纖式干涉位移量測模組，位移解析度達0.1 nm，並可成功解析5 nm 步進。
- 單軸多光束角度乾量測干涉儀可接西 0.275 Arcsec 之傾斜姿態。
- 自行發展六自由度線上干射儀迴授系統。
- 「高數值孔徑、高工作距離遠心色散物鏡」，該10倍物鏡具有世界上第一梯隊之數值孔徑的同時，具有半導體量測設備所需之高工作距離性質。
- 「高數值孔徑、高工作距離遠心鏡筒透鏡」，相比於市售物鏡，該物鏡具有市面上最大的數值孔徑與入瞳尺寸的同時，具備遠心特性。市面上無該類類規格之競品。
- 「高數值孔徑、大視寬遠心寬頻掃描鏡」，該掃描鏡為市場上唯一數值孔徑大於0.08之遠心掃描鏡組，並且引入優異的色散控制，進而可以搭建如光譜儀或其他高解析大範圍量測系統所使用。
- 「高速微小化大視寬線掃描光譜儀模組」具備高光學解析的同時將峰值提取掃描速度提升至每秒7,000~20,000張光譜，補足市場上之技術缺口。
- 振鏡掃描式全域彩色共焦量測探頭。
- 利用高速精密平台高速位移配合位置同步觸發技術及FPGA嵌入式影像擷取系統發展之高速線掃描之量測探頭。
- 「先驗知識影像預處理」：將來源域影像亮度與對比度調整至與目標域直方圖一致，縮小域間風格差異。
- 「多目標域合成與適應框架」：採用強化學習最佳化數位孿生結合Conditional GAN生成合成目標域資料，雙判別器協同訓練，使合成域及真實目標域IoU均提升9.7%分別提升至53.3%及61.9%。
- 「剪枝演算法最佳化策略」：貝氏優化自動搜尋剪枝參數，模型參數量減少83.6%、推論時間縮短98%、檢測效能提升近50倍。
- 「後影像處理分類模組」：對語義分割輸出進行尺度轉換、二值化、去噪及輪廓面積篩選，達成96.8%準確度、100%召回率、93.5%精確率。
- 整合不確定性量化與飄移偵測之深度線上學習架構」建構可即時更新的深度集成架構，同步估計資料與模型不確定性。
- 「即時計算預測區間」使模型具備自我信賴度評估能力，提升預測區間品質。
- 「開發Z分數飄移偵測器（ZDD）」即時監控預測區間與實際誤差間之對應關係是否偏離常態分佈。
- 「實現基於飄移偵測與模型狀態識別的自動模型更新與替換機制」搭配動態學習率調整以提升模型穩定性與反應速度。



產業應用

- 本團隊與國內半導體大廠合作，開發高速錫球檢測、彩色共焦零組件與虛擬量測整合系統，並應用於CMP與銅線咬蝕預測，提升良率。另發展影像超解析與自動化瑕疵檢測技術，成功導入金屬圓管與TFT-LCD產線，分類準確率達95%以上。

專利資訊：線形掃描彩色共焦量測系統

專利證書號 I801149	專利權期限 ~2042/02/23

本發明揭示一種線形掃描彩色共焦量測系統，透過色散物鏡產生多道具有不同聚焦深度的色散光，搭配光導引模組與二維振鏡掃描，取得待測物的光譜資訊並重建其三維形貌。

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Research and Development of In-line Intelligent AOI Key Techniques and Integrated Platform for Advanced Semiconductor Packaging Processes

Cyber Physical Systems

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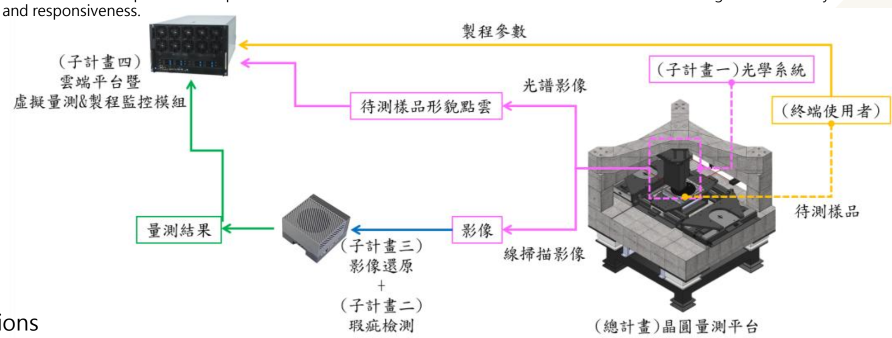
This project focuses on developing online intelligent micro/nano-scale inspection and precision metrology technologies essential for advanced semiconductor packaging processes. By integrating physical measurements (ultra-high-speed chromatic confocal optical systems) with virtual monitoring (process modeling and virtual metrology), the project aims to establish a smart, online inspection and metrology solution. A key outcome is the development of an innovative 12-inch wafer three-axis scanning platform featuring a measurement range of 300 × 300 × 5 mm³, constant scanning speed of 300 mm/s, and positioning error within 50 nm, achieving a world-class throughput of 5–6 wafers per hour (WPH). The project unites research teams from NTU, NYCU, NTUST, and NTUT, along with several industrial partners, to co-develop various functional modules. System integration and field testing will be completed in the third and fourth years. This initiative will enhance Taiwan's capabilities in semiconductor inspection equipment and boost its global competitiveness.

Project Highlights

- Independently developed a miniaturized fiber-based interferometric displacement measurement module with a resolution of 0.1 nm, capable of resolving 5 nm stepping movements.
- A single-axis multi-beam angular interferometer achieves tilt detection accuracy up to 0.275 arcseconds.
- Independently developed a six-degree-of-freedom online interferometric feedback system.
- Developed a "high numerical aperture (NA), long working distance telecentric dispersive objective lens." This 10× objective achieves world-class NA while maintaining the long working distance required for semiconductor metrology equipment.
- Developed a "high-NA, long working distance telecentric tube lens" that surpasses commercially available objectives by combining the largest available NA and entrance pupil size with telecentricity. There are no comparable specifications on the market.
- Developed a "high-NA, wide field telecentric broadband scanning mirror." This is the only telecentric scanning mirror available with NA > 0.08, featuring excellent dispersion control, suitable for high-resolution and large-area measurement systems such as spectrometers.
- Developed a "high-speed, miniaturized, wide-field line-scan spectrometer module" with high optical resolution and peak extraction scan rates of 7,000–20,000 spectra per second, filling a critical gap in current market technologies.
- Developed a galvanometer-scanning full-field chromatic confocal measurement probe.
- Developed a high-speed line-scan measurement probe by combining high-speed precision platforms, position-synchronized triggering technology, and an FPGA-based embedded image acquisition system.
- "Prior Knowledge-Based Image Preprocessing": Adjusts source domain image brightness and contrast to match the histogram of the target domain, reducing cross-domain style discrepancies.
- "Multi-target Domain Synthesis and Adaptation Framework": Utilizes reinforcement learning to optimize digital twins and generate synthetic target domain data using a conditional GAN. Dual discriminators are trained collaboratively, increasing IoU by 9.7% to 53.3% and 61.9% for synthetic and real domains, respectively.
- "Pruning Algorithm Optimization Strategy": Employs Bayesian optimization for automatic pruning parameter search, reducing model parameters by 83.6%, shortening inference time by 98%, and boosting detection performance by nearly 50×.
- "Post-Image Classification Module": Performs scale conversion, binarization, denoising, and contour area filtering on semantic segmentation outputs, achieving 96.8% accuracy, 100% recall, and 93.5% precision.
- "Integrated Uncertainty Quantification and Drift Detection in Deep Online Learning Architecture": Constructs a real-time updateable deep ensemble architecture for simultaneous estimation of data and model uncertainty.
- "Real-Time Prediction Interval Computation": Enables models to assess their own confidence levels, enhancing prediction interval reliability.
- "Development of a Z-Score Drift Detector (ZDD)": Continuously monitors whether the relationship between prediction intervals and actual errors deviates from the normal distribution.
- "Implementation of an Automatic Model Update and Replacement Mechanism Based on Drift Detection and Model State Recognition": Uses dynamic learning rate adjustment to improve model stability and responsiveness.



Industrial Applications

- Our team has collaborated with leading domestic semiconductor companies to develop high-speed solder ball inspection, color confocal components, and integrated virtual metrology systems, successfully applied to CMP and copper wire erosion prediction to improve yield. We also advanced image super-resolution and automated defect inspection technologies, which have been implemented in metal tube and TFT-LCD production lines, achieving classification accuracies of over 95%.

Patent：Linear Scanning Chromatic Confocal Measuring System

Patent Number I801149	Patent Term ~2042/02/23

The present invention discloses a line-scan chromatic confocal measurement system that utilizes a dispersive objective to generate multiple chromatic beams with different focal depths. Combined with a beam-steering module and a two-dimensional scanning mirror, the system acquires spectral information from the sample and reconstructs its three-dimensional morphology.

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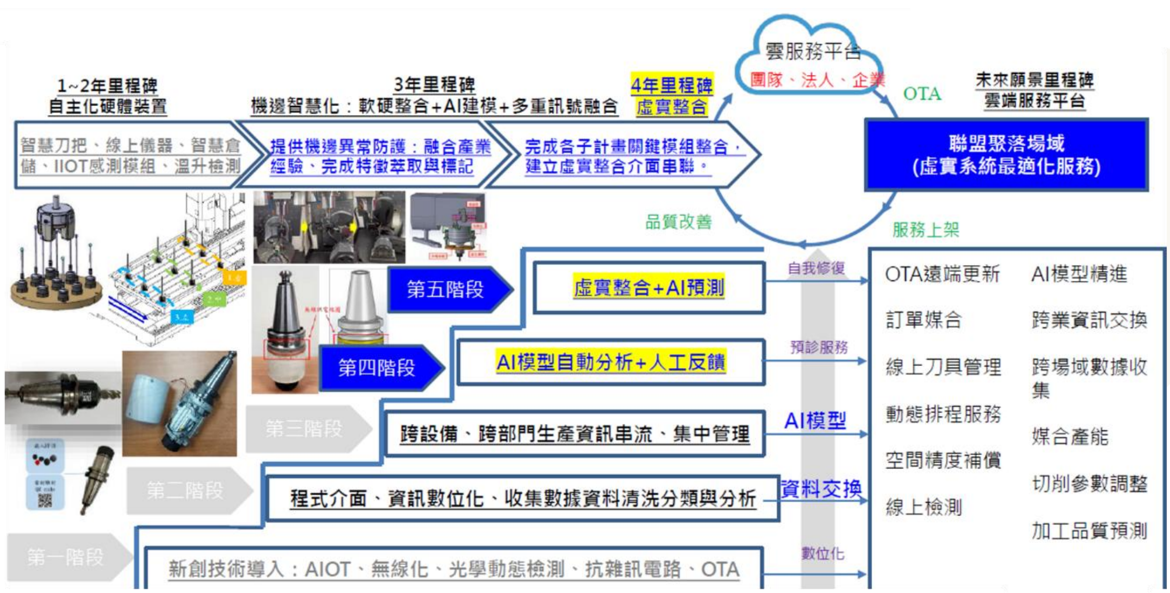
本計畫聚焦於航太與模具產業中高階精密加工製程，因其對製程穩定性要求極高，極適合導入數位分身技術。計畫目標是開發一套全製程即時監控與模擬預測系統，以協助產業提升品質穩定、縮短製程規劃時間、預測產品品質，並因應全球大廠持續的成本降低壓力。
計畫結合上中下游產業鏈與法人單位成立「航太虛實整合聚落」，整合控制器、設備商、加工業者與感測器供應商，以終端加工品質為導向，推動產業升級。
本計畫將開發：多重感測融合與光學檢測系統、即時切削力感測與預測系統、切削履歷與刀具壽命管理預測平台、智慧管理系統最終導入虛擬加工模擬平台，實現數位雙生與雲端化刀具管理、進度媒合、訂單服務，並由中華電信協助資安保障與平台營運。

計畫亮點

- 結合高階精密製造產業上中下游與法人單位共同建立一虛實整合聚落，透過進行AIOT、實機監控、瞬時感測、Digital Twins等技術，完成全製程的動態監控與關鍵設備數位分身建立。
- 降低未來製程規劃時間，提前預測產品品質，提升台灣國防精進與自主能力、接單能力，毛利率至少提升20%以上，落實國機國造。
- 運用台灣網通產品與ICT產業專長，協助智慧機械產業通過相關無線與電子認證如NCC、EMI、CE、FCC，推物聯網與AI產業。
- 本計畫開發智慧製造技術與產品，將從底層電路板設計、韌體撰寫、軟體編譯、演算法進行技術開發，提升關鍵自製率達80%以上。



產業應用

- 在營運方面透過智慧化設備維運管理、高良率試產與異常預防、客製化高複雜零件加工來提高設備運轉效率
- 在加工過程中使用異常預警與智慧調控、製程數據回饋閉環、跨廠區設備整合監控來即時監測、調整加工狀態

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The Development of a Dynamic Digital Twin System Using in Aerospace Virtual and Real Factory Settlements

Cyber Physical Systems

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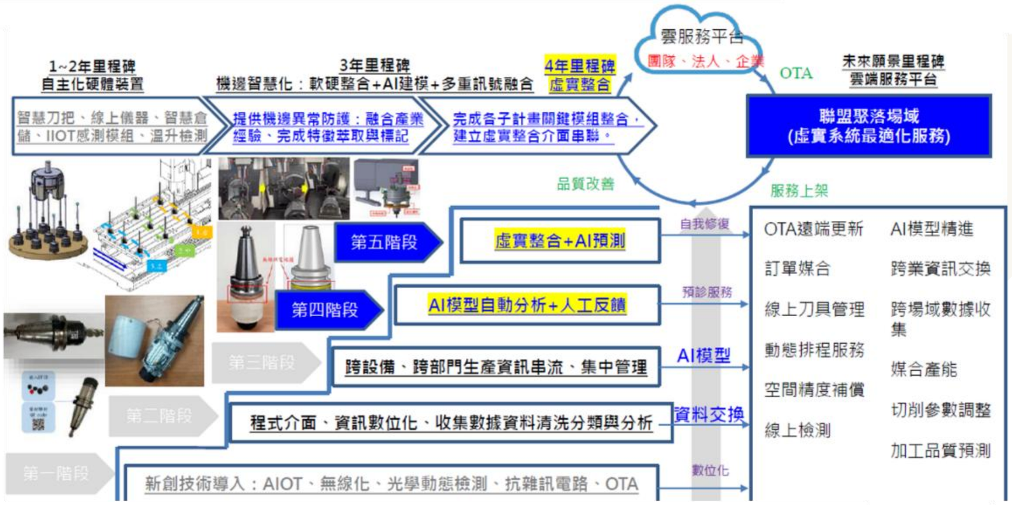
Dr. Wen-Yuh Jywe

This project targets the aerospace and mold industries, where high-precision manufacturing requires strict process control—making it ideal for digital twin implementation. The goal is to develop a real-time monitoring and predictive simulation system to enhance product quality, shorten process planning time, and meet the global demand for cost reduction.
The project will establish an Aerospace Cyber-Physical Integration Cluster, combining upstream, midstream, downstream, and sensor providers. The focus is on end-to-end product quality and industry transformation.
Key developments include: Multi-sensor fusion and optical detection system; Real-time sensing and AI prediction of cutting forces; On-machine cutting history tracking and tool life prediction using AI models; Smart management system integrated with ERP.
The final system integrates dynamic and static machining data into a virtual machining platform (via Siemens' tools), enabling digital twin-driven production, cloud-based tool management, scheduling coordination, and quoting services. Chunghwa Telecom will provide cybersecurity support and assist in operating the service platform.

Project Highlights

- Establish an integrated cyber-physical cluster by uniting upstream, midstream, and downstream players in high-end precision manufacturing along with research institutions. Leverage AIoT, real-time monitoring, instantaneous sensing, and digital twin technologies to achieve full-process dynamic monitoring and digital replicas of critical equipment.
- Reduce future process planning time, enable early prediction of product quality, enhance Taiwan’ s defense autonomy and order fulfillment capability, and increase profit margins by over 20%, contributing to the goal of indigenous national defense manufacturing.
- Utilize Taiwan’ s strengths in networking and ICT industries to assist smart machinery companies in obtaining wireless and electronics certifications such as NCC, EMI, CE, and FCC, promoting the integration of IoT and AI technologies.
- Develop smart manufacturing technologies and products, covering all layers from PCB design, firmware development, and software compilation to algorithm design. The goal is to achieve a key component localization rate of over 80%.



Industrial Applications

- In operations, enhance equipment utilization efficiency through smart maintenance management, high-yield trial production, anomaly prevention, and customized high-complexity parts machining.
- During the machining process, implement real-time monitoring and adaptive control via anomaly detection, closed-loop process data feedback, and cross-factory equipment integration.

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半導體材料超音波複合加工之智慧即時監控與遠端服務技術

虛實加工

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針對台灣具有全球優勢的半導體產業，聚焦用戶需求，進行垂直深度的技術整合，研發本土化獨特與創新性的CNC超音波加工技術，以光機電整合與軟硬整合技術，將超音波加工刀把與智慧驅動器模組、無線IOT感測的即時與遠端監控、AI預測優化、AOI光學檢測、網路技術與資安防護等技術進行深度整合，開發一個具有可信賴性的先進材料超音波加工的智慧即時監控與遠端服務的整合性技術。目標使台灣成為亞洲/全球的先進材料加工的高階裝備之研發與供應基地，產出台灣獨特的創新技術、專利與人才，本計劃成果的外溢性包括半導體、IC封裝、光電、5G、3C電子、醫療器材、精密儀器、 航太、電動車、能源等產業的先進材料CNC加工。

計畫亮點

- 本土化且高值化的半導體材料超音波複合加工之智慧即時監控與遠端服務技術
- 簡易且快速安裝的外掛式非接觸電能傳輸的超音波刀把模組技術。
- 可遠端監控的智慧超音波驅動器技術。
- 可即時監控與遠端服務的IOT智慧刀把技術。
- 智慧超音波刀具振幅的光學影像量測技術。

產業應用

- 半導體產業：半導體製程配件/晶圓/探針卡/陶瓷微鑽孔，石英/SiC/陶瓷研磨
- 生醫產業：不鏽鋼與鈦合金微鑽孔與輪廓銑削
- 航太汽車產業：鎳基合金/耐熱合金銑削
- 光電產業：顯示器面板玻璃微鑽孔與輪廓磨邊
- 模具產業：Stavax/碳化鎢/SiC模具材料的精密加工

專利資訊：高頻振動主軸系統	
專利證書號 TWI671159B	專利權期限 2037/09/15
一種高頻振動主軸系統，刀把結合於主軸前端，電能傳輸裝置設置於主軸的前端或後端，透過非接觸電磁感應方式來傳輸電能，使設置於刀把中的振盪器接收到電能，而致使刀具產生振動。	

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AUG.21

Motion Planning with Collision Avoidance for Multi-Human-Multi-Robot Collaboration Based on Multi-Modal Sensing and AI Path Generation

Cyber Physical Systems

Department of Mechanical Engineering, National Chung Hsing University
Dr. Jenq-Shyong Chen

Focusing on Taiwan's globally competitive semiconductor industry, this project addresses user-driven needs by developing localized and innovative CNC ultrasonic machining through deep vertical integration. It leverages mechatronic and hardware-software integration technologies to combine ultrasonic tool holders, smart driver modules, wireless IoT sensing for real-time and remote monitoring, AI-based prediction and optimization, AOI optical inspection, network communication, and cybersecurity. The aim is to create a reliable, intelligent system for advanced material machining and position Taiwan as a leading R&D and supply hub, with spillover benefits to semiconductors, IC packaging, optoelectronics, 5G, 3C electronics, medical devices, aerospace, EVs, and energy industries.

Project Highlights

- Localized and high-value smart real-time monitoring and remote service technology for ultrasonic composite machining of semiconductor materials.
- Easy-to-install, plug-in, non-contact power transmission ultrasonic tool holder module technology.
- Ultrasonic spindle integral with electric power transmitting function
- Remote-monitorable intelligent ultrasonic driver technology.
- IoT-enabled smart tool holder technology for real-time monitoring and remote service.
- Optical imaging measurement technology for the amplitude of intelligent ultrasonic tools.

Industrial Applications

- Semiconductor Industry: Shower head/Wafer / probe card / ceramic micro-drilling, quartz / SiC / ceramic grinding
- Biomedical Industry: Stainless steel /Titanium micro-drilling and milling
- Aerospace Industry: Titanium/Nickel-based alloy / heat-resistant alloy drilling and milling
- Optics and display panel : glass micro-drilling and edge grinding, drilling and grinding of optics.
- Mold Industry: Tungsten carbide / titanium alloy milling

Patent: A High Frequency Vibration Spindle System

Patent Number TWI671159B	Patent Term ~2037/09/15

A high frequency vibration spindle system. The tool holder is combined with the front end of the spindle. The power transmission device is set at the front or rear end of the spindle. The power is transmitted through non-contact electromagnetic induction, so that the oscillator set in the tool holder receives the power. Causes the tool to vibrate.
A high frequency vibration spindle system, with the tool holder integrated at the front end of the spindle, and a power transmission device positioned at either the front or rear end of the spindle. The power is transmitted via non-contact electromagnetic induction to the oscillator located within the tool holder, inducing vibration in the tool.

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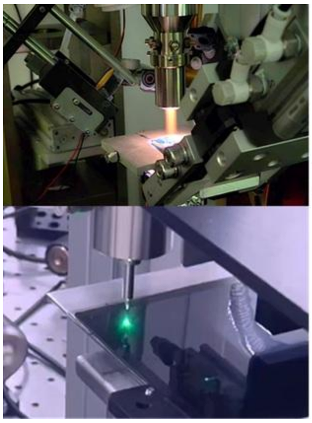
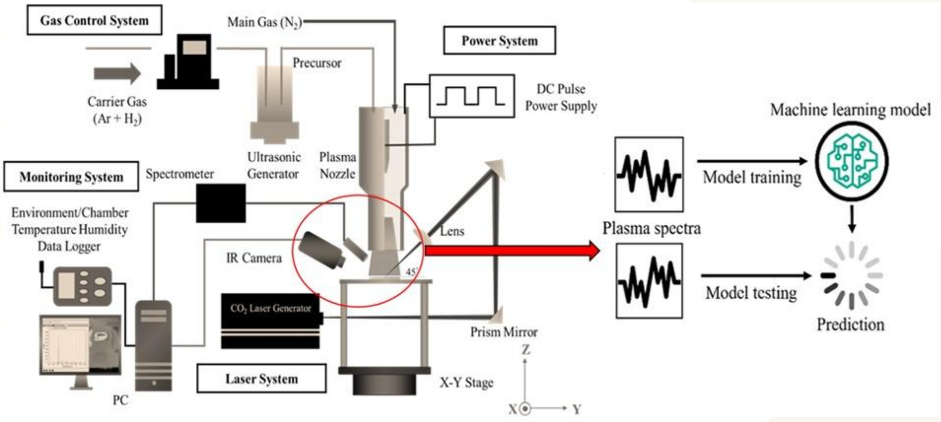
本計畫研究團隊成功開發「雷射低碳製造技術」，可大幅縮短製程工序時間及材料成本，同時具備靈活的製程與設備整合彈性。團隊所開發的雷射鍍膜及圖樣化技術可在常壓常溫下進行，並將原本多道工序縮減為一次工序即可完成圖樣化，大幅降低製程所造成的能源消耗及碳排放。反應溶液採用對生物環境較為友善的溶劑與還原劑，進一步增強綠色製程的優勢。此技術可應用於三維電子半導體元件、軟性光電半導體元件及矽光子元件等極具未來市場價值的產品製造。團隊結合運用工程物理模擬分析與人工智慧，開發雷射製程模擬與分析技術，並藉由揉合應用多重物理耦合模擬、人工智慧及光學即時監測分析等技術，提升製程的效率和穩定性。

計畫亮點
- 常溫常壓環境雷射直析製程。
- 常溫常壓環境雷射電漿製程。
- AI賦能光機資電系統整合及製程參數動態優化技術。





產業應用
- 雷射三維鍍膜圖樣化製程技術具備高精度、高選擇性與高彈性的特點，兼顧製程碳排減量與製程效率。揉合工程力學與人工智慧，解決「數據資料稀缺」關鍵問題，顯著提升製程參數預測的準確性及製程系統監控的穩定性。

專利資訊(1)：電子電路的製造方法以及金屬離子溶液

專利證書號 I842105	專利權期限 ~2042/9/25

專利鍍膜原料配方與製程所製作的金屬微細導線電阻率等同甚或優於其他相似製程，透明金屬氧化物導電膜的光電性質也已達到商用水準。反應溶液採用對生物環境較為友善的溶劑與還原劑，具綠色製程的優勢。

專利資訊(2)：透明導電圖樣的形成方法

專利證書號 I834267	專利權期限 ~2042/8/29

專利資訊(3)：用於製造導電結構的反應墨水以及製造導電結構的方法

專利證書號 I529223	專利權期限 ~2034/11/19

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AI-Enabled Laser Green Manufacturing Technology

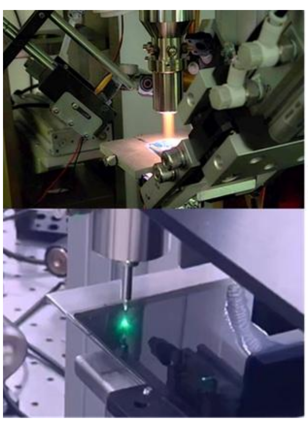
Cyber Physical Systems

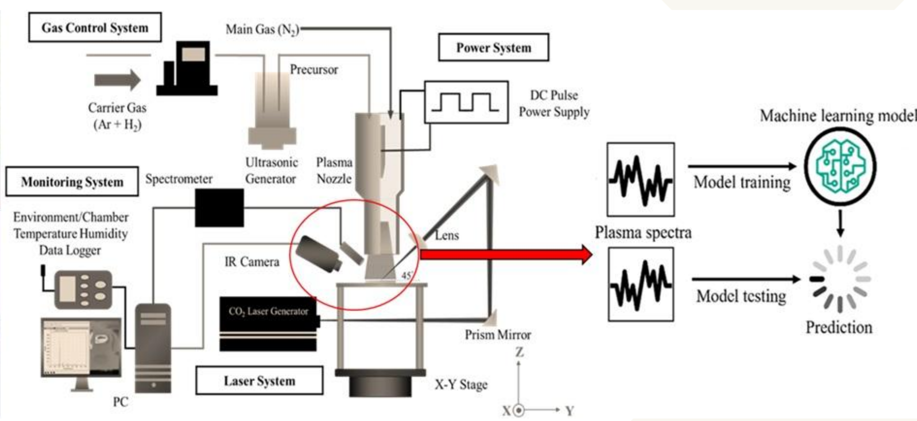
Department of Power Mechanical Engineering, National Tsing Hua University
Dr. Ming-Tsang Lee

We successfully developed an innovative green laser deposition and patterning technology that operates at ambient temperature and pressure, significantly reducing processing time and complexity. It effectively lowers material costs and energy consumption while offering high flexibility in process design and system integration. Furthermore, the reactive solutions used employ environmentally friendly solvents and reducing agents. We also integrated multiphysics modeling, generative artificial intelligence, and real-time optical diagnostics to build a Digital Twin smart manufacturing platform. This technology is highly suitable for producing emerging, high-value electronic and photonic products, including 3D semiconductor components, flexible optoelectronic devices, and silicon photonics.

Project Highlights

- Laser Direct Synthesis and Patterning
- Laser-Atmospheric Pressure Plasma Jet Thin Film Deposition and Patterning
- AI-opto-mechatronic integration for intelligent laser manufacturing system.





Industrial Applications

- The innovative 3D laser manufacturing processes and systems integrating artificial intelligence enable sustainable, high-precision, selective, and flexible fabrication of optoelectronics.

Patent (1)：METHOD OF FABRICATING ELECTRONIC CIRCUIT AND METAL ION SOLUTION	
Patent Number I842105	Patent Term ~2042/9/25
The patented precursor and the laser deposition process yield electrical and optical properties comparable to, or surpassing, those produced by similar techniques, while offering the advantages of a green manufacturing process.	

Patent (2)：METHOD FOR FORMING TRANSPARENT CONDUCTIVE PATTERN	
Patent Number I834267	Patent Term ~2042/8/29

Patent (3)：REACTIVE INK FOR FORMING CONDUCTIVE STRUCTURE AND METHOD OF MAKING CONDUCTIVE STRUCTURE	
Patent Number I529223	Patent Term ~2034/11/19

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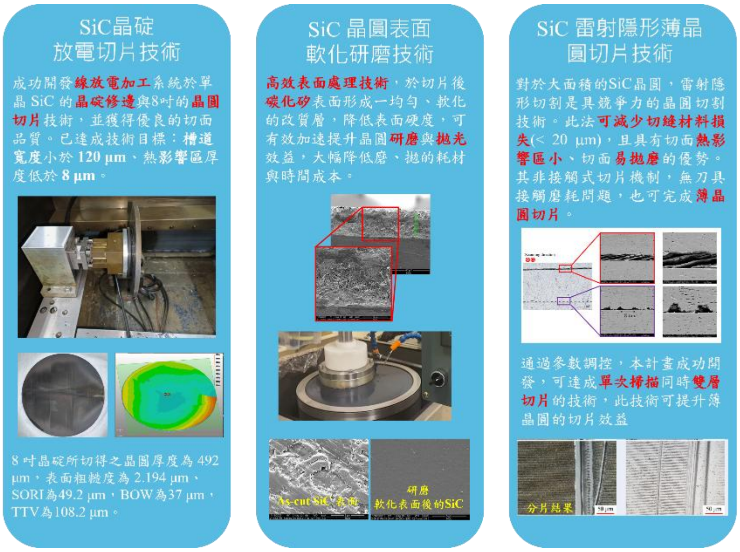
具人工智能安全與檢測感知能力之高功能基板精密複合加工系統研發

虛實整合

國立中央大學機械工程學系
何正榮 教授

碳化矽（SiC）為第三代半導體材料，適用於高功率與高頻元件；玻璃則具穩定性與低介電損特性，是μ-LED、高頻模組與中介層(3D封裝)的優良基板。本計畫以8吋SiC晶圓與多層玻璃電路板為對象，開發智慧複合加工製程。針對SiC切片與研磨效率低、耗材成本高等瓶頸，導入線放電切片、雷射改質輔助研磨，以及雷射隱形晶粒切割等創新技術；在玻璃基板加工方面，發展低毛邊與低沉積物的通孔與微槽道製程，並實現雷射輔助無電鍍金屬化與穿透式玻璃接合。全製程整合人工智慧、機器學習、邊緣運算與虛實整合技術，實現智能化加工系統。成果顯示：SiC切片寬度可達 <120 μm（放電）、<20 μm（雷射），研磨與切割效率顯著提升；玻璃通孔孔徑 <20 μm、深寬比 >10，線寬/線距達5/10 μm。所開發技術具備高度應用潛力，可推動SiC加工與高頻玻璃電路板製程設備之國產化。



計畫亮點

- 碳化矽晶圓智慧製程突破：導入線放電切片、雷射改質輔助研磨與隱形切割，提升切片效率、降低耗材與切口損傷。
- 高密度玻璃電路板創新技術：開發雷射改質/蝕刻通孔、無電鍍金屬化、雷射玻璃接合等先進製程，滿足高頻與Micro-LED應用需求。
- 飛秒雷射精密加工：應用高速振鏡系統提升玻璃加工速度至1000 mm/s，實現微結構高效率製作與接合。
- 智慧製造技術整合：導入AI、機器學習、邊緣計算、虛實整合、資安與分散式雲端，打造完整智能化製程架構。
- 高階技術指標達成： SiC晶圓切口寬從180 μm降至120 μm，研磨與切割效率提升1倍以上；玻璃通孔<20 μm、線寬/間距達5/10 μm。
- 國產設備研發與落地：開發碳化矽切片機、複合研磨機與玻璃電路板設備，協助台灣產業智慧升級與自主化。
- 學術價值與人才培育：研究脆硬材料加工與金屬化機理，培育智慧機械系統整合人才，推動中小企業智慧轉型。

產業應用

- 本計畫技術可導入碳化矽晶圓與高密度玻璃電路板之智慧量產製程，協助國內廠商開發國產化設備，強化高頻、高功率與Micro-LED關鍵元件製造能力，提升台灣半導體與PCB產業競爭力。

專利資訊：材料複合加工方法與系統	
專利證書號 I797797	專利權期限 2023/04/01-2041/10/25
本發明關於一種材料複合加工方法，其包含：使用雷射對工件之欲改質區域發射雷射光，而對該欲改質區域進行改質以改變該欲改質區域之性質；應用光學影像定位輔助設備對該工件之已改質區域或該工件上之定位標記進行精密定位，以將刀具對準該已改質區域；以及驅動該刀具對該已改質區域進行加工作業。	

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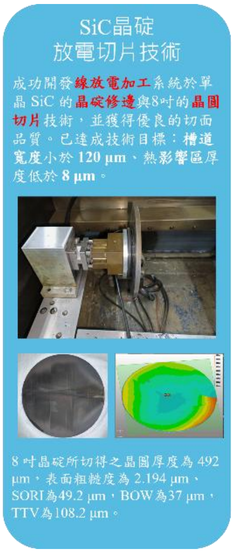
Development of an Information-security, Artificial-intelligence and Detection-perception Smart Fabrication System for Precision Hybrid Machining of High-performance Substrates

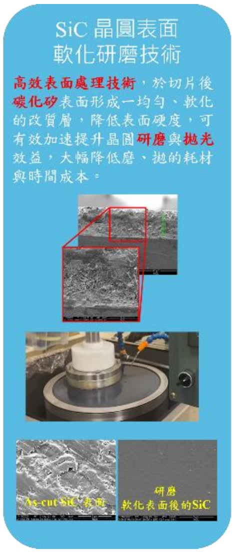
AUG.21

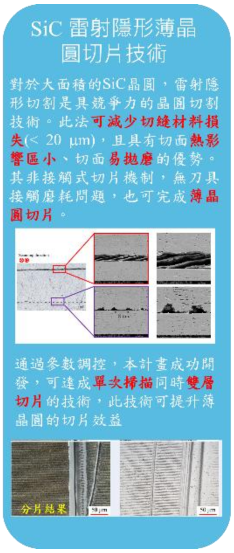
Cyber Physical Systems

Department of Mechanical Engineering,
National Central University
Dr. Jeng-Rong Ho

Silicon carbide (SiC) is a third-generation semiconductor material, well-suited for high-power and high-frequency devices. Glass, on the other hand, offers excellent thermal and chemical stability along with low dielectric loss, making it an ideal substrate for μ-LEDs, high-frequency modules, and interposers in 3D packaging. This project focuses on developing intelligent hybrid processing technologies for 8-inch SiC wafers and multilayer glass circuit boards.
To overcome bottlenecks such as low efficiency in SiC slicing and grinding and the high cost of consumables, the project introduces innovative techniques including wire electrical discharge slicing, laser-induced modification-assisted grinding, and stealth laser dicing. For glass substrate processing, advanced fabrication methods are developed to produce through-holes and microchannels with minimal burrs and residue, alongside laser-assisted electroless metallization and laser-based through-glass bonding.
The entire process is integrated with artificial intelligence, machine learning, edge computing, and cyber-physical fusion technologies to realize a fully intelligent manufacturing system. Project outcomes demonstrate that SiC slicing kerf widths can be reduced to less than 120 μm (via electrical discharge) and even under 20 μm (via laser), with significantly enhanced grinding and cutting efficiency. For glass substrates, through-hole diameters of less than 20 μm, aspect ratios greater than 10, and line/space resolutions of 5 μm/10 μm have been achieved.
The developed technologies hold strong application potential and are expected to drive the localization of SiC processing and high-frequency glass circuit board manufacturing equipment.







Project Highlights

- Breakthrough in SiC Wafer Processing: Adopted wire EDM, laser-assisted grinding, and stealth dicing to improve slicing efficiency and reduce kerf damage.
- Innovative Glass PCB Technology: Developed laser-based via/microchannel formation, electroless metallization, and through-glass bonding for high-frequency/Micro-LED use.
- High-Speed Femtosecond Laser Processing: Utilized galvanometer scanners for precision structuring and bonding at speeds up to 1000 mm/s.
- Integration of Smart Manufacturing: Incorporated AI, machine learning, edge computing, cyber-physical systems, cybersecurity, and distributed cloud into production.
- Advanced Technical Milestones: Reduced SiC kerf width (180 → 120 μm), doubled grinding/singulation rates; achieved <20 μm vias, 5/10 μm L/S in glass PCBs.
- Localized Equipment Development: Built domestic SiC dicing/trimming systems, hybrid wafer grinders, and glass PCB machines to empower Taiwan's industry.
- Academic and Talent Impact: Provided deep insights into brittle material processing and system integration, fostering high-level talent for smart manufacturing.

Industrial Applications

- The proposed technologies enable intelligent mass production processes for SiC wafers and high-density glass circuit boards. By supporting the development of localized equipment such as SiC dicing machines, hybrid grinders, and laser-based glass PCB systems, the project empowers Taiwanese manufacturers to meet the growing demands of high-frequency, high-power, and Micro-LED components. These advancements enhance the global competitiveness of Taiwan's semiconductor and PCB industries, while also accelerating the adoption of smart manufacturing in local enterprises.

Patent：Hybrid Method and System for Material Processing

Patent Number I797797	Patent Term 2023/04/01-2041/10/25

The present invention relates to a hybrid processing method for materials, comprising: emitting a laser beam toward a target area intended to be modified by a laser; performing property modification in the target area; implementing an optical image equipment to assist precise positioning to the target area of the work piece or to the positioning marker on the work piece, so as to align a machining tool to the target area; and, driving the machining tool to perform processing of the target area.

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隱形牙套的自動化生產程序、檢測與品質控制

虛實加工

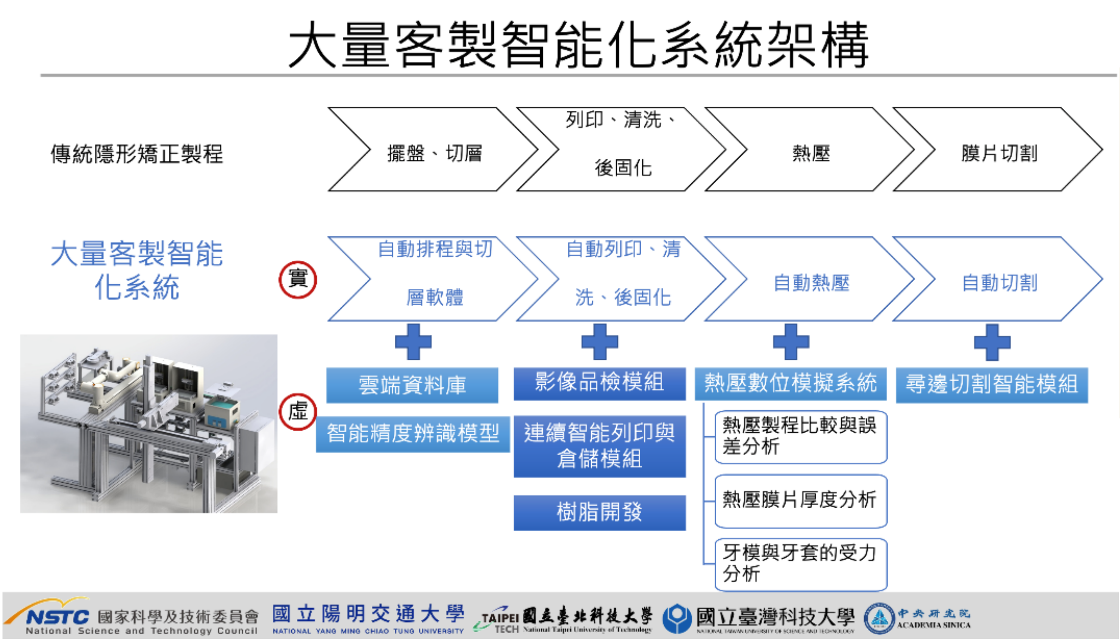
國立陽明交通大學
李士元 特聘教授團隊

國立臺北科技大學機械系
江卓培 特聘教授

本計畫開發全自動化專家系統製作隱形牙套，其技術包含列印牙模的數位排版、三維列印、牙模後處理、逆向掃描與精度比對輸出、熱壓成型牙套與牙套的牙齦線切割等工作，搭配自動倉儲成型平台模組使其能自動完成隱形牙套的製作，並能量化在列印、熱壓與切割後的誤差，並透過人工智慧的補償，使列印的牙模能獲度高精度的隱形牙套。本計畫驗證未經過補償的三維列印牙模誤差高達100微米以上，且在熱壓過程中造成的收縮可高達12%，因此所獲得的隱形牙套的精度堪慮，可能是造成矯正效率不佳的原因之一。在獲得誤差與人工智慧的補償後，且再經過模型熱壓的過程後，隱形牙套的誤差低於30微米。除此之外，本計畫透過數位孿生的方法證明隱形牙套在熱壓成型時，牙齒的高度會影響牙模片的厚度變化，牙齒越高則熱壓成型後的厚度越薄而造成矯正力不足，過薄的厚度也可能是造成矯正效果不如預期的原因。因此，本計畫所開發的數位孿生技術可以分析患者的齒列與齒高後決定合適的模片厚度以提供適合的矯正力。

計畫亮點

- 學術界團隊/國內業者共同開發隱形牙套製作全自動化專家系統。
- 應用人工智慧補償列印與熱壓所產生的誤差後，所獲得的隱形牙套誤差低於30微米。
- 應用數位孿生的分析可依據患者的齒列與齒高決定合適的模片厚度以提供適合的矯正力。



產業應用

- 牙齒矯正的隱形牙套。
- 預防睡眠呼吸中止的客製化牙套
- 運動員的客製化牙套
- 手術導板與其它樹脂類的牙齒贗復元件

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AUG.21

Cyber Physical Systems

Automated Production Process, Inspection, and Quality Control of Invisible Aligners

National Yang Ming Chiao Tung University
Dr. Shyh-Yuan Lee

National Taipei University of Technology
Distinguished Prof. Cho-Pei Jiang

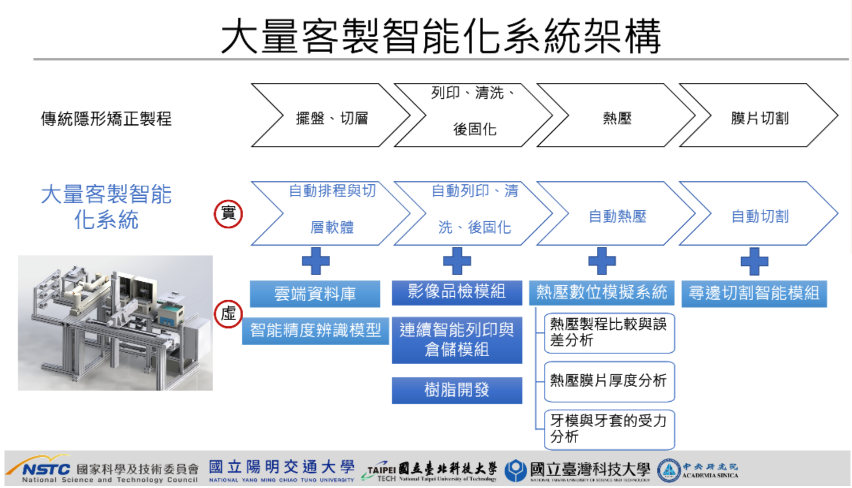
This project aims to develop a fully automated expert system for the production of invisible aligners. The system integrates key technologies including digital layout for dental model printing, 3D printing, post-processing of printed models, reverse scanning with dimensional accuracy verification, thermoforming of aligners, and automated trimming along the gingival margin. The entire workflow is supported by an automated storage and forming platform, enabling end-to-end automated fabrication of invisible aligners and quantitative evaluation of dimensional deviations during printing, thermoforming, and trimming processes. By incorporating AI-driven compensation algorithms, the system ensures high-precision alignment of printed models and final aligner products.

Validation experiments show that without compensation, the dimensional error of 3D-printed dental models can exceed 100 μm, and shrinkage during thermoforming may reach up to 12%, significantly compromising aligner accuracy—potentially one of the reasons for suboptimal orthodontic outcomes. After applying error analysis and AI-based compensation, the final aligner deviation after thermoforming was reduced to less than 30 μm.

Additionally, the project employs digital twin simulation to demonstrate that tooth height significantly influences aligner thickness during thermoforming. Specifically, taller teeth result in thinner formed regions, leading to insufficient orthodontic force. This unintended thinning may further contribute to reduced orthodontic effectiveness. Therefore, this project provides a digital twin-based analytical framework to determine optimal aligner sheet thickness based on individual dental arch geometry and tooth height, ensuring the delivery of appropriate orthodontic forces.

Project Highlights

- A fully automated expert system for invisible aligner fabrication was co-developed by our team and domestic industry partner.
- By applying AI-based compensation for errors arising from 3D printing and thermoforming processes, the final aligner deviation was reduced to below 30 μm.
- Digital twin analysis enables the determination of optimal aligner sheet thickness based on the patient’s dental arch and tooth height to ensure the delivery of appropriate orthodontic force.



Industrial Applications

- Invisible aligners for orthodontic treatment
- Customized oral appliances for sleep apnea prevention
- Customized mouthguards for athletes
- Surgical guides and other resin-based dental prosthetic components

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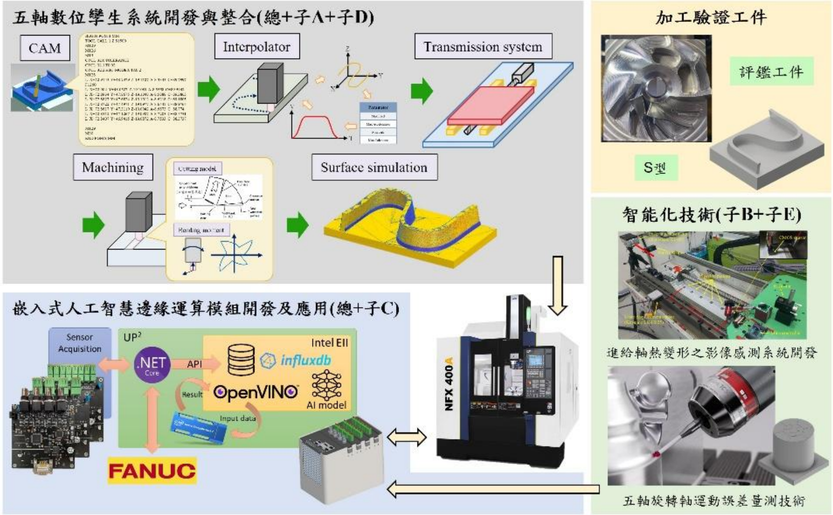
數位孿生之五軸工具機智能化技術研發

虛實加工

國立臺灣大學機械工程學系
蔡孟勳 特聘教授

本計畫共分三大目標：一、建立五軸工具機數位孿生系統；二、智能化邊緣運算模組與雲端安全防護以及三、開發嵌入式人工智慧系統。透過本計畫三項技術的研究開發，除了可以提升五軸工具機的加工效率和精度之外，還可以在工件加工前事先預測加工成品，使工件在首件加工即可達到所需的精度與表面品質。



計畫亮點

- 建立五軸工具機數位孿生系統，用於模擬五軸加工的運動控制、結構振動、切削力以及加工紋路，透過模擬方式進行調機與切削參數調整。本計畫加入了結構振動模擬系統，可更精確的模擬加工時的機械動態，因此與其他市售系統大為不同，為本計畫亮點。
- 於邊緣運算模組上安裝EII平台，使其能夠調用神經棒資源進行AI模型推論，具前瞻發展性。
- 應用嵌入式滑鼠感測器除了可同時執行非即時與即時(應用機器學習)熱變位監測與軸向溫補功能外，還可將其應用於軸向背隙及空間歪斜量測上。
- 使用觸發式測頭進行五軸旋轉軸量測具有量測效率高、價格便宜、使用上安裝方便並可用於不同構型的工具機，並結合OPCUA執行智能化量測補償，可實現量測結果自動回傳至電腦端並即時執行誤差計算與補償。
- 提出利用工具機自身的伺服馬達進行結構激振，搭配自製加速規振動傳遞率、模態與自然頻率等演算發開發，再經由特徵工程與機器學習，能有效進行機台長期與即時線上監測。

產業應用

- CNC控制器製造商：開發高階控制器功能，提升國內CNC控制器的加工效能與品質，進而提昇國產控制器的競爭力。
- 工具機製造商：於工具機出廠階段需經過一連串的量測，透過本技術所開發的設備可以節省機台量測時間與量測成本。
- 精密製造商：透過本技術的模擬系統，可以在加工前分析機台的運動行為與加工品質，藉由模擬方式進行加工條件與參數修改，可節省加工時間與材料損耗之成本。

專利資訊：誤差預測方法、工具機控制參數規劃方法以及系統	
專利證書號 I845262	專利權期限 2024/06/11 ~ 2043/04/18
本發明專利提出工具機轉角誤差預測方式，透過工具機插補規劃模型計算位置控制資訊，接著藉由伺服馬達模型計算位置回授資訊以及實際移動出的轉角誤差。最後使用多誤差區間機器學習模型根據位置資訊與回授資訊預測轉角輪廓誤差值。	

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AUG.21

Research and Development of Intelligent Technologies for Five-axis Machine Tools with Integrating Edge Computing and Digital Twins

Cyber Physical Systems

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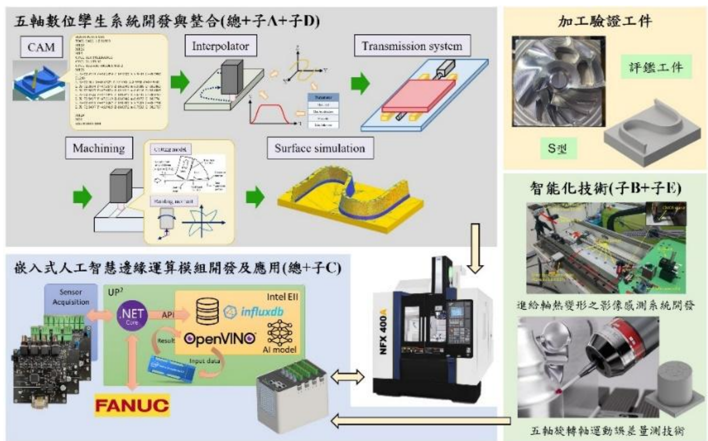
This project is divided into three main objectives: 1. Establish a digital twin system for five-axis machine tools; 2. Develop an intelligent edge computing module with cloud security protection; and 3. Develop an embedded artificial intelligence system. Through the research and development of these three technologies, not only can the processing efficiency and precision of five-axis machine tools be improved, but also the finished product can be predicted before processing, ensuring that the workpiece meets the required precision and surface quality from the first workpiece.



Project Highlights

- Establish a digital twin system for five-axis machine tools, used to simulate motion control, structural vibrations, cutting forces, and machining patterns in five-axis machining. Through simulation, this system facilitates machine tuning and adjustment of cutting parameters. This project incorporates a structural vibration simulation system, enabling more precise simulation of the mechanical dynamics during machining. Therefore, it significantly differs from other commercially available systems and is a highlight of this project.
- Install the EII platform on the edge computing module, enabling it to utilize neural stick resources for AI model inference, which offers forward-looking development potential.
- The application of an embedded mouse sensor not only allows for simultaneous non-real-time and real-time (using machine learning) thermal displacement monitoring and axial thermal compensation but can also be used for measuring axial backlash and spatial distortion.
- Using a touch-trigger probe for five-axis rotary axis measurement offers high measurement efficiency, low cost, easy installation, and compatibility with different machine tool configurations. Combined with OPC UA for intelligent measurement compensation, it enables automatic transmission of measurement results to the computer for real-time error calculation and compensation.
- Propose using the machine tool's own servo motors for structural excitation, combined with self-developed accelerometer algorithms to calculate vibration transmissibility, mode shapes, and natural frequencies. Through feature engineering and machine learning, this approach enables effective long-term and real-time online monitoring of the machine.

Industrial Applications

- This research technology can be divided into three major industrial applications:
- CNC Controller Manufacturers: Develop advanced controller functions to enhance the machining efficiency and quality of domestic CNC controllers, thereby increasing the competitiveness of domestically produced controllers.
- Machine Tool Manufacturers: During the production phase of machine tools, a series of measurements are typically required. The equipment developed through this technology can save machine measurement time and costs.
- Precision Manufacturers: With the simulation system provided by this technology, machine tool behavior and machining quality can be analyzed before processing. By simulating modifications to machining conditions and parameters, costs related to machining time and material loss can be reduced.

Patent：
ERROR PREDICTION METHOD, CONTROL PARAMETER PLANNING METHOD AND SYSTEM FOR CNC MACHINE

Patent Number I845262	Patent Term 2024/06/11 ~ 2043/04/18

This invention patent proposes a method for predicting corner errors in machine tools. It calculates position control information through a machine tool interpolation planning model, then computes position feedback information and the actual corner errors using a servo motor model. Finally, it employs a multi-error interval machine learning model to predict the corner profile error values based on the position information and feedback information.

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