

發展高動態阻抗反應之協作型機器人及其應用

人機協作

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本技術提出具備高動態阻抗反應能力的新型協作型機器人，旨在解決現有協作型機器人與人類手臂間力覺反應性能上的顯著差距。透過研發高動態阻抗控制技術與扭矩控制關節模組，提升機器人的動態反應與柔順性，同時保持機械手臂的高剛性、高重複精度、優異的負載對總重量比及成本效益。本研究整合了變勁度機構設計與機器學習技術，建立精確的關節模組動態模型，以實現快速且柔性的運動控制，並能即時精準調節對環境的輸出力量。所開發之機器人已透過協作研磨、插件自動組裝及工具機上下料等實際應用場域進行測試與驗證，展現了本技術在高性能人機協作領域的廣泛應用潛力。

計畫亮點

- 扭矩控制關節模組技術開發與精確的數學動態模型建立，以提升機器人整體控制效能。
- 變勁度機構設計之動態阻抗反應系統，實現具高柔順性且可即時調節的阻抗控制性能。
- 協作型研磨機器人的系統整合與現場應用測試，驗證其高效率與實務操作性。
- 應用機器學習技術建構關節模組動態特性預測模型，提升控制精度與穩定性。
- 多自由度關節模組之自動化插件系統設計與示範，顯著提高生產效率及應用彈性。

產業應用

- 自動化機器人插件組裝，實現高效且靈活的零件裝配。
- 自動化機器人研磨與拋光，提高表面品質，有效降低人力成本與提升產品競爭力。
- 工具機自動上下料作業，優化生產流程與提高生產效率，降低作業人員的勞務負擔。
- 人機協作環境之高動態安全性與互動性應用，廣泛適用於智慧製造、精密裝配等多元產業領域。

AUG.21

Development of Collaborative Robots With High Dynamic Impedance Response for Industrial Applications

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Dr. Chao-Chieh Lan

Human-robot
Collaboration



This technology introduces a novel collaborative robot featuring high dynamic impedance response capabilities, addressing the significant gap in force-sensing performance between existing collaborative robots and human arms. By developing advanced high-dynamic impedance control techniques and torque-controlled joint modules, the robot achieves improved dynamic responsiveness and compliance without sacrificing arm rigidity, repeatability, payload-to-weight ratio, and cost efficiency. Integrating variable stiffness mechanism designs and machine learning models, the precise joint module dynamics facilitate rapid and compliant motion control, allowing for accurate real-time adjustment of interaction forces with the environment. The developed robot has been validated through practical applications, including collaborative grinding, automatic plug-in assembly, and machine tool loading and unloading tasks, demonstrating significant potential in various high-performance human-robot collaboration fields.

Project Highlights

- Development of torque-controlled joint modules and establishment of accurate mathematical dynamic models to enhance overall robot control performance.
- Dynamic impedance response systems based on variable stiffness mechanism designs, achieving highly compliant and real-time adjustable impedance control.
- System integration and practical field tests of collaborative grinding robots, demonstrating high efficiency and operational practicality.
- Application of machine learning techniques to construct predictive dynamic models for joint modules, improving control accuracy and stability.
- Design and demonstration of automated peg-in-hole systems for multi-degree-of-freedom joint modules, significantly enhancing production efficiency and application flexibility.

Industrial Applications

- Automated robotic peg-in-hole assembly for efficient and flexible component assembly, meeting diverse industrial requirements.
- Automated robotic grinding and polishing processes that enhance surface quality, effectively reducing labor costs and improving product competitiveness.
- Automated loading and unloading tasks in machine tools, optimizing production workflows, enhancing efficiency, and reducing operator workload.
- High-dynamic safety and interactive applications in human-robot collaboration environments, widely applicable in smart manufacturing, precision assembly, and other diverse industrial sectors.

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基於多模態感知及 AI路徑生成的多人多機協作避碰動作規劃

人機協作

國立臺灣科技大學機械工程系
林柏廷 教授團隊

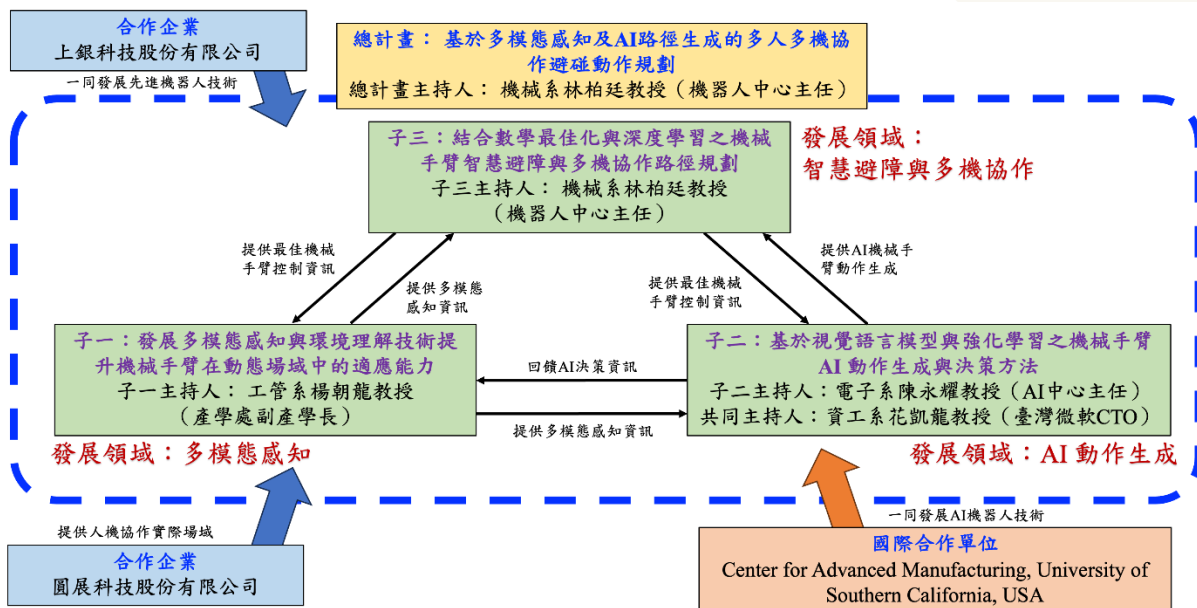


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陳永耀 教授

當前製造業正朝向智慧化、自動化、人機協作的方向發展，然而傳統機械手臂仍存在感知能力有限、無法自主適應環境變化、避障策略不夠靈活等挑戰，使得人機協作的安全性與效率難以進一步提升。本計畫提出結合多模態感知、AI動作生成與智慧避障的研究架構，發展具備環境理解、決策適應與自主避障能力的智慧機械手臂。子一的多模態感知技術整合視覺、語音與人體動作資訊，提升機械手臂對環境與人類行為的即時理解能力；子二專注於AI動作生成技術，利用視覺語言模型與強化學習，使機械手臂能夠根據不同場景自主調整動作策略；子三負責發展智慧避障與多機協作技術，使機械手臂能夠在多人多機環境中即時避障並規劃最佳路徑，以確保人機協作的安全與效率。

計畫亮點

- 多模態感知資料同步與融合
- 即時AI語意驅動動作生成
- 多人多機智慧避碰動作規劃
- 視覺語言模型（VLM）與強化學習整合
- 邊緣運算平台與即時資料處理



產業應用

- 機械手臂人機協作組裝產線
- 多款式機械手臂協作避碰系統
- 智慧製造現場作業效率優化
- 工業視覺及聲音異常事件偵測
- 智慧備料與加工任務執行系統

專利資訊：周邊物體快速探知方法及其系統

專利證書號 I811816

專利權期限 2021.10.21-2041.10.20

本發明提出一種以機器學習快速探測機械裝置周邊物體位置與距離之方法與系統，能即時判斷碰撞風險並自動修正路徑。

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

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Dr. Po-Ting Lin

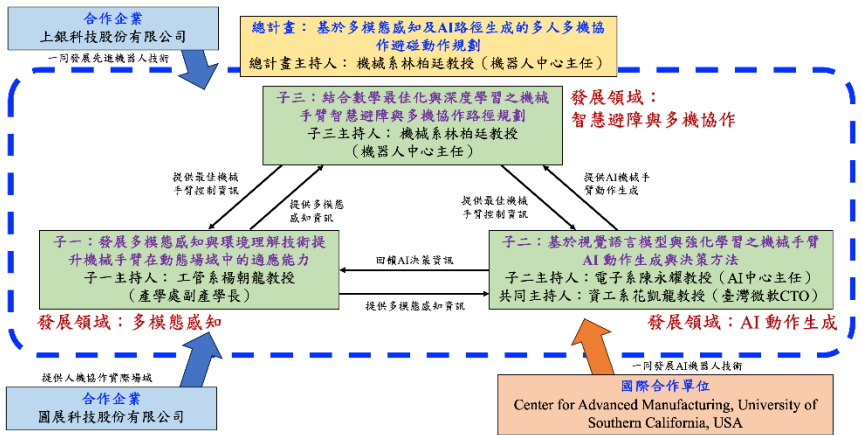


Department of Electronic and Computer Engineering, National Taiwan University of Science and Technology
Dr. Yung-Yao Chen

Modern manufacturing is shifting towards smart automation and human-robot collaboration, yet traditional robotic arms still face limitations in perception, adaptability, and obstacle avoidance. This project aims to address these challenges by integrating multi-modal perception, AI-driven motion generation, and intelligent obstacle avoidance. Multi-modal perception techniques allow robots to integrate visual, speech, and human motion data. AI-driven motion generation leverages Vision-Language Models and reinforcement learning to enable robotic arms to autonomously adjust their movements according to various scenarios. Intelligent obstacle avoidance and multi-robot collaboration strategies ensure real-time robot path planning and safe operation in dynamic environments.

Project Highlights

- Multi-modal perception data synchronization and fusion
- Real-time AI semantic-driven action generation
- Intelligent collision avoidance action planning for multi-person and multi-robot systems
- Integration of visual-language models (VLM) with reinforcement learning
- Edge computing platform and real-time data processing



Industrial applications

- Human-robot collaborative assembly lines
- Collaborative collision avoidance system for multiple robot arms
- Operational efficiency optimization for smart manufacturing sites
- Industrial visual and auditory anomaly detection
- Intelligent material preparation and machining task execution system

Patent: METHOD AND SYSTEM FOR QUICKLY DETECTING SURROUNDING OBJECTS

Patent Number I811816	Patent Term ~2041.10.20
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This invention presents a method and system utilizing machine learning to rapidly detect positions and distances of surrounding objects relative to a mechanical apparatus, enabling instant collision risk assessment and automatic path correction.



結合AI之腫瘤消融機器人系統

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人機協作



本計畫開發之手術機器人系統為醫師在腫瘤消融手術中的機器人助手，在手術規劃階段，進針決策模型結合生成式AI與醫師的臨床經驗，透過AI與醫師的互動，更有效率地規劃安全且有效的下針路徑；在手術執行階段，本系統透過感測器與機器人系統提供精準定位控制，完成醫師所下達的操作指令，降低醫師手眼操作負擔；在安全監控方面，本系統結合CT影像與超音波影像融合技術，並搭配導航人機介面，提供術中即時的影像資訊，讓醫師不需要大量拍攝CT也能夠掌握進針過程的安全性與準確度。本計畫與醫師團隊緊密合作，已於台北榮總醫院進行多次手術機器人場域測試。

計畫亮點

- 結合生成式AI與醫師的臨床經驗，更有效率地規劃安全且有效的下針路徑。
- 機器人系統精準控制，降低醫師手眼操作負擔，減少病人CT掃描次數，提高手術安全性。
- CT與超音波影像融合技術，於術中提供即時資訊，避免軟組織變形造成穿刺誤差與手術風險。



產業應用

- 腫瘤消融治療：可應用於肝腫瘤、肺腫瘤等穿刺手術，提升精準度與安全性。
- 微創手術導引：結合即時影像與機器人控制，有助於各類微創手術的定位與導航。
- 術中決策輔助：為醫師提供個人化手術建議，提升決策效率。

專利資訊(1)：機器人導航系統以及機器人導航方法

專利證書號 I744037

專利權期限 ~2041/10/20

一種機器人導航系統包括手持式機器人、空間資訊量測裝置、計算模組以及顯示器介面。手持式機器人具有彼此連接的本體、工作具以及可動連接機構。可動連接機構連接於本體與工作具之間，藉以使工作具相對本體移動。空間資訊量測裝置設置以追蹤本體、工作具與目標。計算模組連接空間資訊量測裝置以獲得本體、工作具與可動連接機構相對目標之間的相對位置。計算模組根據相對位置與手持式機器人的機械參數計算導引區域。導引區域的坐標以目標為基準。顯示器的顯示介面至少包含了配置以目標的坐標為基準顯示導引區域以及手持式機器人的本體。

專利資訊(2)：協作式手術規劃系統及其操作方法

專利證書號

專利權期限

一種協作式手術規劃系統包括主機、分辨式人工智慧模組、使用者導航介面及生成式人工智慧模組。分辨式人工智慧模組電性連接主機，配置以根據複數個電腦斷層影像形成複數個器官分割影像。使用者導航介面電性連接主機，配置以顯示器官分割影像、初步下針路徑、複數個建議下針路徑與最終下針路徑。生成式人工智慧模組電性連接主機，使得主機將使用者導航介面與生成式人工智慧模組連接。生成式人工智慧模組配置以根據器官分割影像與初步下針路徑產生建議下針路徑並於使用者導航介面顯示。

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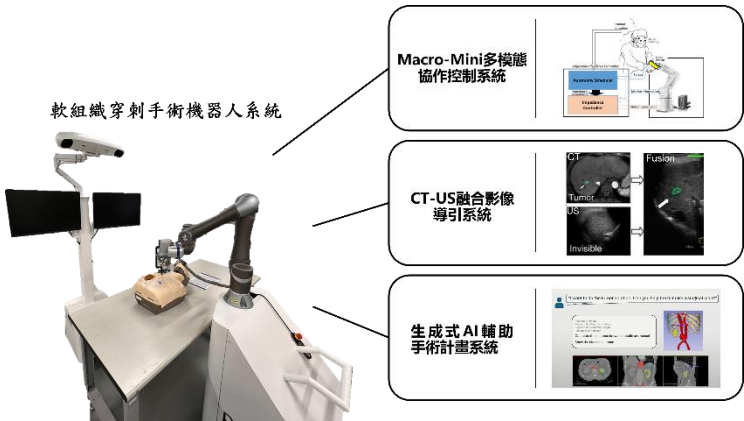
An AI-enhanced Robotic Platform for Tumor Ablation

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Human-robot
Collaboration



This project develops a surgical robotic system that serves as an assistant to physicians during tumor ablation procedures. During the planning phase, the needle insertion decision model integrates generative AI with clinical expertise to collaboratively plan safe and effective insertion paths with greater efficiency. In the execution phase, the system leverages sensors and robotic control to provide precise positioning, executing physician commands while reducing manual coordination burdens. For intraoperative safety monitoring, the system fuses CT and ultrasound imaging, combined with a navigational human-machine interface, delivering real-time visualization that enables physicians to accurately monitor the insertion process without relying on frequent CT scans. The project is conducted in close collaboration with a medical team, and multiple field tests have been successfully carried out at Taipei Veterans General Hospital.



Project Highlights

- By combining generative AI with physicians' clinical expertise, the system efficiently plans safer and more effective needle insertion paths.
- Precision control of the robotic system alleviates manual coordination demands on physicians, reduces the frequency of patient CT scans, and enhances overall surgical safety.
- The fusion of CT and ultrasound imaging provides real-time intraoperative information, mitigating puncture errors and surgical risks caused by soft tissue deformation.

Industrial Applications

- Tumor ablation therapy: Applicable to needle-based procedures for liver and lung tumors, improving precision and safety.
- Guidance for minimally invasive surgery: Integrates real-time imaging and robotic control to assist in accurate tool positioning and navigation.
- Intraoperative decision support: Provides personalized surgical recommendations to enhance clinical decision-making efficiency

Patent (1) : ROBOT GUIDING SYSTEM AND ROBOT GUIDING METHOD

Patent Number I744037

Patent Term ~2041/10/20

A robot navigation system includes a handheld robot, a spatial information measuring device, a computing module and a display. The hand-held robot has a base, a tool and a movable connection mechanism. The movable connection mechanism is connected between the base and the tool, so that the tool can move relative to the base. The spatial information measuring device is configured to track the base, the tool and a target. The computing module is connected to the spatial information measuring device to obtain a plurality of relative positions between the base, the tool and the movable connection mechanism relative to the target. The computing module calculates a guiding region according to the relative positions and mechanical parameters of the handheld robot. The display is configured to display the guiding region and the handheld robot based on the coordinates of the target.

Patent (2) : ASSISTED SURGICAL PLANNING SYSTEM AND OPERATION METHOD THEREOF

Patent Number

Patent Term

An assisted surgical planning system includes a host computer, a discriminative artificial intelligence (AI) module, a user navigation interface, and a generative AI module. The discriminative AI module is electrically connected to the host computer, and is configured to form plural organ segmentation images based on plural computed tomography (CT) images. The user navigation interface is electrically connected to the host computer, and is configured to display the organ segmentation images, an initial needle insertion path, plural suggested needle insertion paths, and a final needle insertion path. The generative AI module is electrically connected to the host computer, such that the host computer connects the user navigation interface to the generative AI module. The generative AI module is configured to generate the suggested needle insertion paths based on the organ segmentation images and the initial needle insertion path, and display the suggested needle insertion paths in the user navigation interface.

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AI智慧機器人應用於工件去毛邊加工處理

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張禎元 講座教授

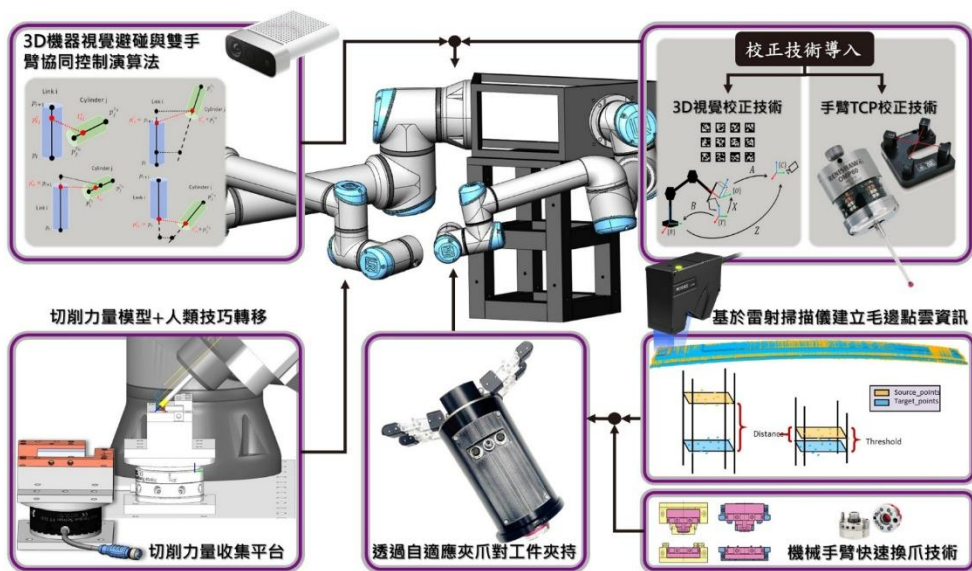
人機協作



本計畫聚焦於智慧型機器人在人機協作與智慧製造應用的技術整合。團隊開發結合語音理解、生成式AI、三維視覺與擬人機械手臂的系統，實現自主技能學習、物體夾取與力控制等功能，能執行如去毛邊加工、物品遞交與語音互動等任務。技術涵蓋雙手臂協同控制、感知融合、技能轉移與互動決策等面向，具模組化與彈性化優勢，展現於航太加工與智慧服務場域之落地潛力，符合人因導向的製造與服務新趨勢。

計畫亮點

- 結合語音辨識、生成式 AI 與智慧機械手臂控制技術，實現語意理解與動作生成的智慧互動系統。
- 發展具捏取功能之欠驅動機械夾爪，具備柔順控制與自適應包覆力，提升人機互動安全與抓握穩定性。
- 整合三維視覺、即時力感知與障礙物避讓控制，支援機器人於智慧製造與服務應用場域之落地部署。
- 開發創新力量控制演算法，結合主動式致動器，有效提升機器人於加工任務中的精度與強健性。



產業應用

- 結合語音 AI 與智慧機械手臂控制技術，推動人機協作應用場域之智慧化。
- 衍生應用包括智慧製造、教育陪伴、服務型機器人與高齡照護場域，如：自動物品夾取遞交、工廠人機協同作業與新進人員操作訓練輔助。

專利資訊：機器人與機器人手眼校正方法

專利證書號 US 12257726 B2

專利權期限 2043/06/01

本發明提供一種機器人手眼校正方法，結合機械手臂、攝影機與處理器，透過校正影像自動取得座標對應，建立相機與機器人間之對應關係，以提升感知與操控精度。

AUG.21

AI-Driven Intelligent Robots
for De-Burring Manufacturing

National Tsing Hua University, Department of Power Mechanical Engineering
Dr. Jen-Yuan Chang

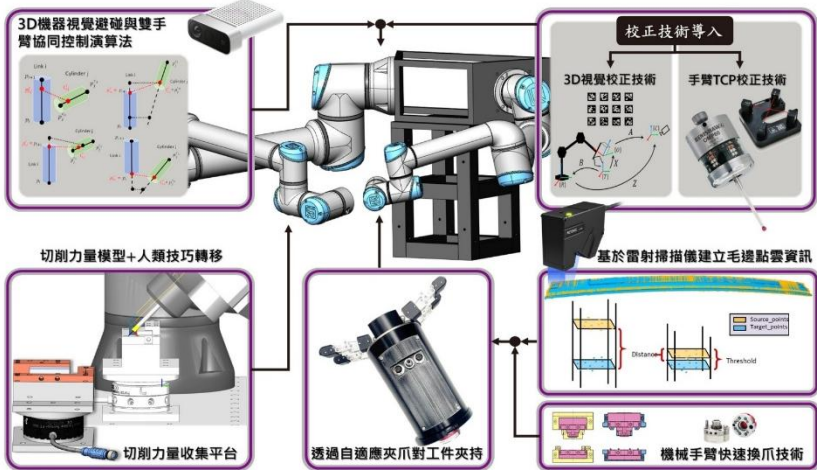
Human-robot
Collaboration



This project focuses on human-robot collaboration for intelligent manufacturing and interactive service. Our team integrates generative AI, 3D vision, force sensing, and anthropomorphic robotic grippers to enable skill learning, force-aware manipulation, and voice interaction. Applications include de-burring, object delivery, and task planning via natural language. With modular and flexible design, the system features dual-arm coordination, perception-driven control, and human-in-the-loop adaptability, supporting future deployment in aerospace, smart factories, and assistive robotics.

Project Highlights:

- Developed an intelligent interactive system that integrates voice recognition, generative AI, and robotic arm control to achieve semantic understanding and action generation.
- Designed an underactuated robotic gripper capable of dexterous grasping, featuring compliant control and adaptive enveloping force for enhanced safety and stability in human-robot interaction.
- Integrated 3D vision, real-time force sensing, and obstacle avoidance to support on-site deployment in smart manufacturing and service-oriented applications.
- Proposed a novel force control algorithm combined with active actuators to improve precision and robustness in robotic machining tasks.



Industrial Applications:

- The technology integrates voice AI and intelligent robotic arms to enable smart human-robot collaboration.
- Applications include smart manufacturing, assistive education, service robotics, and elderly care, such as object handover, collaborative factory tasks, and training support for new operators.

Patent : ROBOT & ROBOT HAND-EYE CALIBRATING METHOD

Patent Number US 12257726 B2

Patent Term ~2043/06/01

The invention provides a hand-eye calibration method for robots that maps robot and camera coordinates via a calibration image, improving perception and manipulation accuracy.



人機協同工業機器手臂 與無人車整合於鑄造件拋光研磨應用

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蕭俊祥 教授團隊



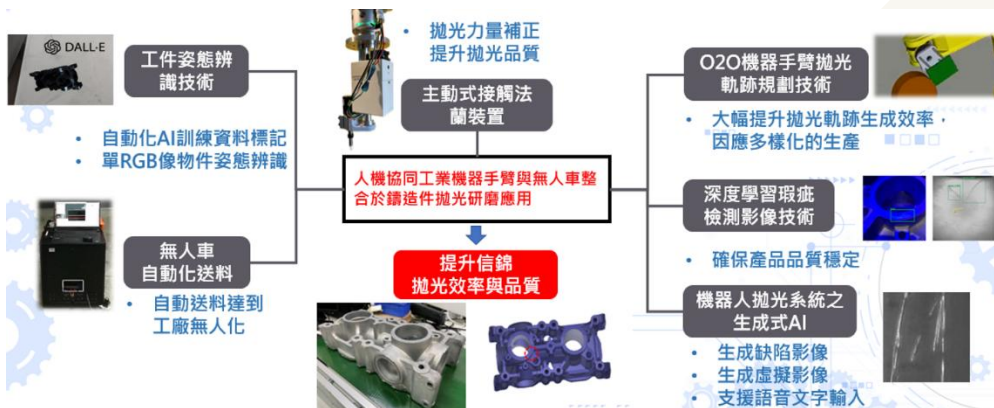
國立陽明交通大學
林顯易 教授

人機協作

本計畫針對鑄造件進行拋光自動化，開發整合人機協同工業機器手臂與AMR的應用系統，導入主動式接觸法蘭ACF、O2O軌跡教導系統、6D姿態估測、以及AOI瑕疵檢測流程。系統能精確自動完成物件定位、打磨、品檢與搬運任務，達成拋光製程之全流程自動化，預期可大幅降低人工負擔並提升拋光品質穩定性。

計畫亮點

- 開發主動式接觸法蘭 (ACF)，達成 $\pm 0.15\text{N}$ 高精度拋光力量控制
- 建立具備O2O功能之人機協同拋光軌跡教導系統，有效降低超過70%教導時間
- 整合6D姿態估測與三點校正，精確定位不規則鑄件並修正加工軌跡
- 導入AOI瑕疵檢測技術，30秒內完成表面檢測，準確率達97%，可檢出0.3mm沙孔
- AMR具備 $x, y < 2\text{cm}$ 與 $R_z < 3^\circ$ 定位精度，自主導航與遠端叫車成功率 $> 90\%$



產業應用

- 本技術可應用於鑄件、水五金與傢俱拋光產業，導入後可取代50%人工；物流倉儲使用AMR可減少30%人力；機器人塗裝透過O2O提升效率；導入AOI於鑄件與PCB檢測，準確率達90%以上。

專利資訊 (1)：基於機械手臂的三維物件輪廓數據建立系統及其方法

專利證書號 I845450

專利權期限 2024/06/11~2043/11/23

本發明提出一種基於機械手臂的三維物件輪廓數據建立系統與方法。透過物件輪廓計算裝置建立觀測物件與法蘭端部之間的物件法蘭運動矩陣，並自影像裝置取得影像參數，自控制裝置取得手臂空間座標及法蘭手臂運動矩陣。系統進一步依據上述資訊計算手臂影像運動矩陣，並將三組運動矩陣相乘以求得物件影像運動矩陣。接著，結合影像裝置內部參數，利用三角測量法計算觀測物件各三維座標點對應於二維平面的投影位置，進而生成物件的輪廓影像。此技術可有效建立高精度的三維物件輪廓數據，提升建模效率與應用便利性，適用於機器視覺、智慧製造等場域。

專利資訊 (2)：使用音圈馬達的法蘭裝置及其接觸控制方法

專利證書號 I802224

專利權期限 2024/05/11~2042/01/13

一種使用音圈馬達的法蘭裝置及其接觸控制方法，透過力量感測器、位移感測器以及慣性測量單元進行接觸數據的感測，將接觸數據透過慣姿態航向參考系統演算法進行濾波計算得到力量控制指令對法蘭裝置進行位移方向與位移距離控制，使法蘭裝置使用音圈馬達以調節拋光裝置與待拋光物件的接觸狀態，藉此可以達成提供安靜、控制精準以及響應快速的電磁式調節接觸狀態裝置的技術功效。

AUG.21

Human-Robot Collaboration and AMR
Integration for Polishing and Grinding of Casting Parts

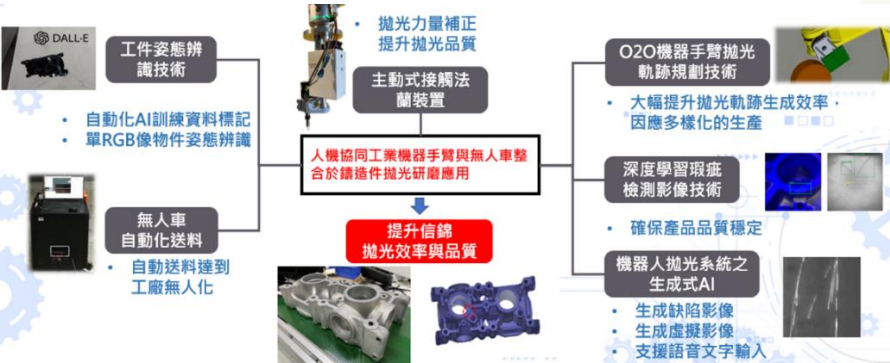
National Taipei University of Technology
Dr. Jin-Siang Shaw

Human-robot
Collaboration



National Yang Ming Chiao Tung University
Dr. Hsien-I Lin

This project develops an integrated system for automated polishing of casting parts by combining human-robot collaborative arms and Autonomous Mobile Robots (AMRs). The system features Active Contact Flange , O2O trajectory teaching, 6D pose estimation, and AOI-based defect inspection. It enables precise and automated polishing, inspection, and loading/unloading. In its fourth year, the system has been validated in real factory environments, demonstrating its capability to enhance quality, reduce labor, and support smart manufacturing applications.



Project Highlights

- Designed Active Contact Flange (ACF) with $\pm 0.15\text{N}$ precision for consistent polishing force
- Developed O2O human-robot trajectory teaching system, reducing path teaching time by over 70%
- Integrated 6D pose estimation with 3-point calibration for accurate casting part alignment
- Implemented AOI-based defect detection with 97% accuracy in 30 seconds, detecting defects $\geq 0.3\text{mm}$
- AMR achieved $< 2\text{cm}$ positional and $< 3^\circ$ angular precision, with $> 90\%$ remote call success rate

Industrial Applications

- The system applies to polishing of castings, metal hardware, and furniture, reducing 50% labor; AMR cuts logistics manpower by 30%; O2O improves robot painting; AOI enables 90%+ accuracy in casting and PCB inspection.

Patent (1) :

3D OBJECT OUTLINE DATA ESTABLISHMENT SYSTEM BASED ON ROBOTIC ARM AND METHOD THEREOF

Patent Number I845450

Patent Term 20240/6/11~2043/11/23

The present invention proposes a system and method for establishing three-dimensional object contour data based on a robotic arm. An object flange motion matrix is established between the observed object and the flange end through an object contour calculation device, and image parameters are obtained from an imaging device, and the arm space coordinates and flange arm motion matrix are obtained from a control device. The system further calculates the arm image motion matrix based on the above information, and multiplies the three sets of motion matrices to obtain the object image motion matrix. Then, combined with the internal parameters of the imaging device, the triangulation method is used to calculate the projection position of each three-dimensional coordinate point of the observed object corresponding to the two-dimensional plane, thereby generating a contour image of the object. This technology can effectively establish high-precision three-dimensional object contour data, improve modeling efficiency and application convenience, and is suitable for fields such as machine vision and smart manufacturing.

Patent (2) : FLANGE DEVICE USING VOICE COIL MOTOR AND CONTACT CONTROL METHOD THEREOF

Patent Number I802224

Patent Term 2024/05/11~ 2042/01/13

A flange device using a voice coil motor and a contact control method thereof senses contact data through a force sensor, a displacement sensor, and an inertial measurement unit. The contact data is filtered and calculated using an inertial attitude and heading reference system algorithm to generate force control instructions to control the displacement direction and distance of the flange device. The flange device uses the voice coil motor to adjust the contact state between the polishing device and the object to be polished, thereby achieving the technical effect of providing a quiet, precisely controlled, and fast-responding electromagnetic contact state adjustment device.

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耐腐蝕、高靈敏、可量產： 次世代二維材料氣體感測晶片技術

國立清華大學材料科學工程學系
闕郁倫 講座教授

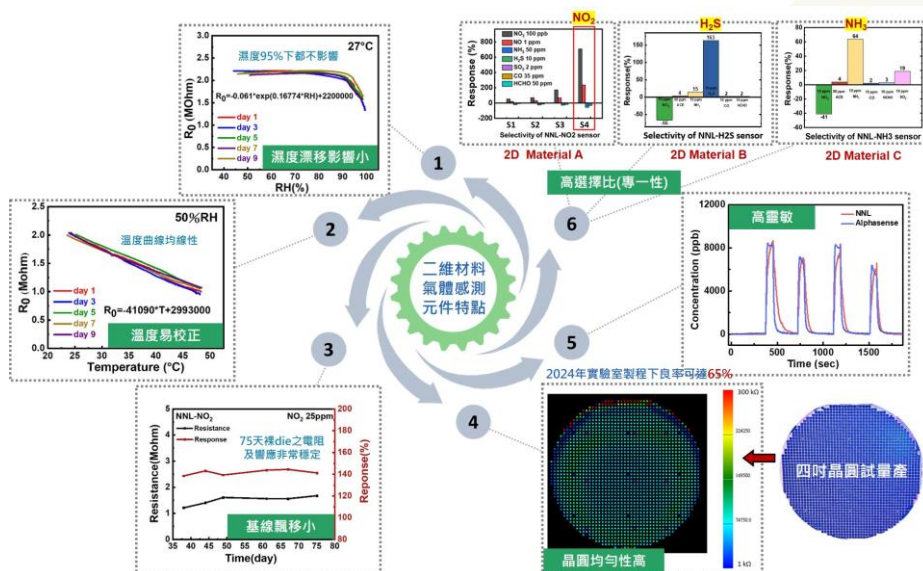
智慧微塵感測器



面對電化學感測器衰減快的挑戰，本團隊聚焦於 NH_3 、 H_2S 、 NO_2 等腐蝕性氣體，開發具高耐用性與穩定性的二維材料感測器，降低更換與校正成本。技術優勢包括：濕度與基線飄移小、溫度易校正、高靈敏與選擇比、晶圓均勻性佳。第三方驗證顯示團隊產品對 NH_3 與 H_2S 皆優於市售競品，並可即插即用，展現高穩定性與即時性。

計畫亮點

- 市場定位：團隊產品將注重提高耐用性和穩定性，減少感測器衰減的速度，從而延長替換週期並降低總擁有成本。
- 二維材料六大核心技術優勢：(1)濕度飄移影響小(2)溫度易校正(3)基線飄移小(4)晶圓均勻性高(5)高靈敏度(6)高選擇比
- 完成第三方驗證(性能驗證 α -site)：性能驗證顯示團隊元件靈敏穩定，優於市售競品。



產業應用

- 半導體產業-部署在工廠環境中的氣體感測器，用於監測工業過程中的有毒氣體排放和工作場所的空氣品質。
- 推進智慧城市，實時提供精確的環境數據，促進城市公共形象和提升居民的生活品質。

專利資訊：過渡金屬硫族化物二維薄膜的製備方法

專利證書號 US9,460,919 B1

專利權期限 ~2036/03/04

一種製造二維過渡金屬硫族化物薄膜的方法，使用基板、過渡金屬反應膜、硫族元素來源與電漿誘發反應，以形成薄膜。

Anti-Corrosion, High-Sensitivity, and Scalable:
Next Generation 2D Material Gas Sensor Chip
Technology

AUG.21

Smart Dust
Sensors

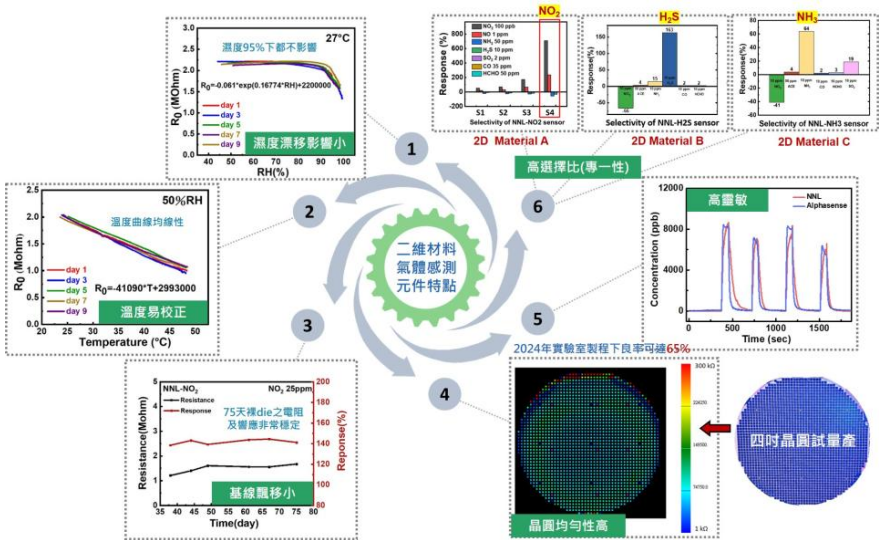
Department of Materials Science and Engineering,
National Tsing Hua University
Dr. Yu-Lun Chueh, Chair Professor



To address the rapid degradation of electrochemical sensors, our team focuses on detecting corrosive gases, offering durable and stable 2D material-based sensors to reduce replacement and calibration costs. Key advantages include minimal humidity and baseline drift, linear temperature response, high wafer uniformity, atomic-level sensitivity, and tunable selectivity. Third-party tests confirm our sensors outperform commercial ones in NH₃ and H₂S detection with better stability and plug-and-play usability.

Project Highlights

- Market Positioning: Our product focuses on enhancing durability and stability, reducing sensor degradation over time to extend replacement cycles and lower the total cost of ownership.
- Six Core Technical Advantages of 2D Materials: (a) Low humidity-induced drift (b) Easy temperature calibration (c) Minimal baseline drift (d) High wafer-level uniformity (e) High sensitivity (f) High selectivity ratio
- Third-Party Performance Verification (α-site): Independent validation confirms our sensor components are highly sensitive and stable, outperforming commercially available competitors.



Industrial Applications

- Semiconductor Industry – Gas sensors deployed in factory environments to monitor toxic gas emissions during industrial processes and to ensure workplace air quality.
- Advancing Smart Cities – Providing real-time and accurate environmental data to enhance the city's public image and improve residents' quality of life.

Patent : Manufacturing Method of Two-dimensional Transition-metal Chalcogenide Thin Film

Patent Number US9,460,919 B1 Patent Term~ 2036/03/04

A method for manufacturing 2D transition-metal chalcogenide films uses a substrate, a transition-metal reaction film, a chalcogen source, and plasma to induce a reaction, forming a thin film.

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全方位氣體感測晶片陣列之

快速智慧讀取電路設計與演算法實現

智慧微塵感測器

國立陽明交通大學電子所
洪瑞華 講座教授團隊



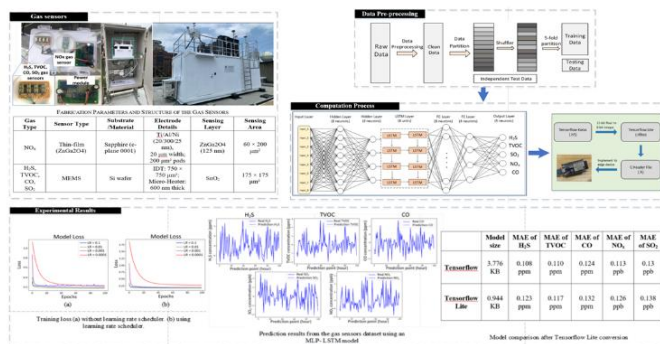
國立陽明交通大學電機學院
洪瑞華 講座教授/ 趙昌博 講座教授

本研究提出一種結合氣體感測器製程與邊緣 AI 的高穩健濃度預測架構。開發了 ZnGa_2O_4 製成的 NO_x 感測器與 SnO_2 懸浮式 MEMS 感測器，可偵測多種氣體。為應對交叉靈敏度與環境變化，採用級聯式 MLP-LSTM 模型，分別處理溫濕度特徵與時間序列趨勢。資料經插補、標準化與交叉驗證後，以 Adam 最佳化器訓練並調整學習率。模型對 H_2S 、TVOC、CO、 SO_2 、 NO_x 的 R^2 分別達 0.889、0.888、0.879、0.875、0.880，顯示優異預測力與適應性。最終部署於 ESP32-DevKitC，透過 TensorFlow Lite for Microcontrollers 實現即時低功耗推論，具高準確率與實務應用潛力。

計畫亮點

- 本研究提出創新的 MLP-LSTM 架構，有效解決氣體感測器的交叉敏感性與環境干擾問題。
- 相較於傳統靜態模型，本方法可同時捕捉空間與時間特徵，提升多氣體預測的準確性。
- 透過線性插補處理缺失資料，並採用 Z-score 標準化特徵值，提升資料一致性。

Multiple Gas Devices Sensing and At-edge Computation



- 模型部署於 ESP32 邊緣裝置，結合 TensorFlow Lite，可即時低功耗推論，實現可攜式與可擴展的環境監測。
- 實驗結果顯示對 H_2S 、TVOC、CO、 SO_2 與 NO_x 的 R^2 分別為 0.889、0.888、0.879、0.875 與 0.880，驗證模型具高度穩定性與實務應用潛力。
- 使用 UCI ML Repository 公開資料集測試，與其他氣體感測系統相比，本研究模型之 MAE 最小 (CO: 0.124 ppm、 NO_x : 113 ppb、 H_2S : 0.108 ppm、TVOC: 110 ppm、 SO_2 : 0.13 ppb)，展現優異效能與突破性。

產業應用

- 本技術具高度產業應用潛力，適用於環境監測、智慧城市、工業安全及物聯網空氣品質系統。透過將 MEMS 與 ZnGa_2O_4 感測器整合至 ESP32 等邊緣裝置，搭配輕量化 AI 模型，可即時精準偵測氣體，無需依賴雲端，特別適合資源有限場域。其低功耗、小型化與成本效益設計，便於部署於穿戴裝置、無人機與固定監測站。系統能有效早期偵測 H_2S 、 SO_2 、 NO_x 等氣體，提升安全性，並藉 AI 強化預測準確度，降低維護成本，推動智慧感測技術之商用化與普及。

專利資訊(1)：氣體感測裝置

專利證書號 I767241B

專利權期限 ~2040/05/27

一種氣體感測裝置,包括一熱絕緣單晶基板、一感測器用以感測氣體的濃度及一加熱器用以提供氣體感測所需的溫度,該感測器及該加熱器都位於該熱絕緣單晶基板的第一表面。該感測器具有微結構以提高感測的準確度。

專利資訊(2)：具懸浮式加熱器之微型氣體感測器

專利證書號 I764184B

專利權期限 ~2040/06/28

本發明提供一種具懸浮式加熱器之微型氣體感測器，其包含一包括一第一表面及一自該第一表面朝一相反於該第一表面之第二表面凹陷的隔熱穴的絕緣性基板、一懸浮式地配置在該隔熱穴上方並貼合於該第一表面之一周緣且是一具有單晶結構的金屬氧化物的圖案化氣體感測層；及一間隔地圍繞該圖案化氣體感測層以懸浮式地配置在該隔熱穴上方並貼合於該第一表面之周緣的圖案化加熱層。

AUG.21

Design and Algorithm Implementation of a High-Speed Intelligent Readout Circuit for an All-in-One Gas Sensor Chip Array

Institute of Electronics, National Yang Ming Chiao Tung University
Dr. Ray-Hua Horng

Smart Dust Sensors



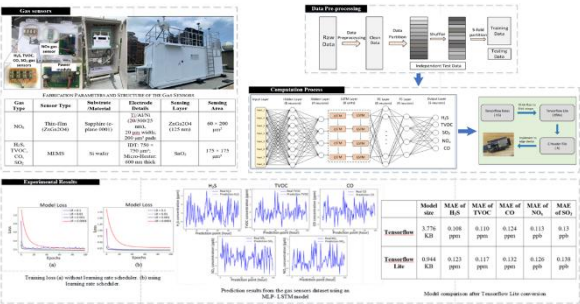
College of Electrical and Computer Engineering,
National Yang Ming Chiao Tung University
Chair Prof. Ray Hua Horng/Paul C.-P. Chao

This research proposes a robust gas concentration estimation framework by combining advanced gas sensor fabrication with edge-oriented AI modeling. Two types of sensors were developed: a ZnGa₂O₄-based NO_x sensor grown on sapphire using MOCVD, and a MEMS-based multi-gas sensor using SnO₂ films and suspended structures for detecting H₂S, TVOC, CO, and SO₂. To improve prediction accuracy under environmental interferences like cross-sensitivity and temperature/humidity variations, a hybrid MLP-LSTM deep learning model was used. Data preprocessing included missing value interpolation, normalization, and cross-validation. The model achieved R² values above 0.87 for all gases and was deployed on ESP32 with TensorFlow Lite, enabling real-time, low-power inference on edge devices.

Project Highlights

- This study proposes an innovative MLP-LSTM architecture that effectively addresses the issues of cross-sensitivity and environmental interference in gas sensors.
- Compared to traditional static models, the proposed method captures both spatial and temporal features, significantly improving the accuracy of multi-gas prediction.

Multiple Gas Devices Sensing and At-edge Computation



Industrial Applications

- The system integrates MEMS and ZnGa₂O₄ sensors with MLP-LSTM AI for accurate, low-power gas detection on edge devices, suited for smart cities, wearables, mobile, and remote monitoring.

Patent (1) : Gas Sensing Device

Patent Number I767241B

Patent Term ~2040/05/27

A gas sensing device includes a thermal insulation single crystal substrate, a sensor for sensing gas concentration and a heater for providing a temperature which is needed for sensing gas. The sensor and heater are in a first surface of the thermal insulation single crystal substrate. The sensor has a micro-structure to improve a sensing accuracy.

Patent (2) : Micro Gas Sensor With Suspended Heater

Patent Number I764184B

Patent Term ~2040/06/28

This invention provides a micro gas sensor with suspended heater, which comprises an insulated substrate including a first surface and a heat insulation cavity recessed from said first surface to a second surface opposite to said first surface, a patterned gas sensing layer suspended over said heat insulation cavity and adhered on a periphery of said first surface and been a metal oxide with single crystal structure, and a patterned heating layer surrounded apart from said patterned gas sensing layer and adhered on said periphery of said first surface such that said patterned heating layer suspends over said heat insulation cavity.

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創新預警的首選- MEMS氣體感測

國立高雄科技大學車輛工程系
蕭育仁 教授

智慧微塵感測器



全球氣體感測元件需求趨勢愈來愈大，本團隊開發全球微機電製備之低功耗&快速響應氣體感測元件，核心技術包含(1).低耗能加熱設計(2).3D感測元件結構製造(3).特殊感測薄膜製程(4).老化穩定測試。氣體感測器之相關產品，絕大多數為國外廠商製造，國內自主設計落地生產刻不容緩。因此本計畫產品將成為客戶採購國產感測器元件之唯一選項，達到進口替代之效果，成為系統模組客戶端提升其產品品質之最大助力。

計畫亮點

- 學術界團隊/國內業者共同開發MEMS氣體感測器，應用於VOC環境偵測。
- 進行模組與雲端物聯網監控系統的實測驗證。
- 研究成果微機電感測器元件開發，衍生新創公司促成新創公司技術移轉計畫。

產業應用

- 感測器關鍵技術(包含：模擬設計、感測薄膜製程、測試、模組及系統等)至產業落地試量產。
- VOC 氣體感測器市場：適用於半導體設備、化工設備產業、智慧化設備產業、家電設備。

開發智慧城市應用之 微型硫化氫氣體感測模組

國立高雄科技大學電子工程系
薛丁仁 教授

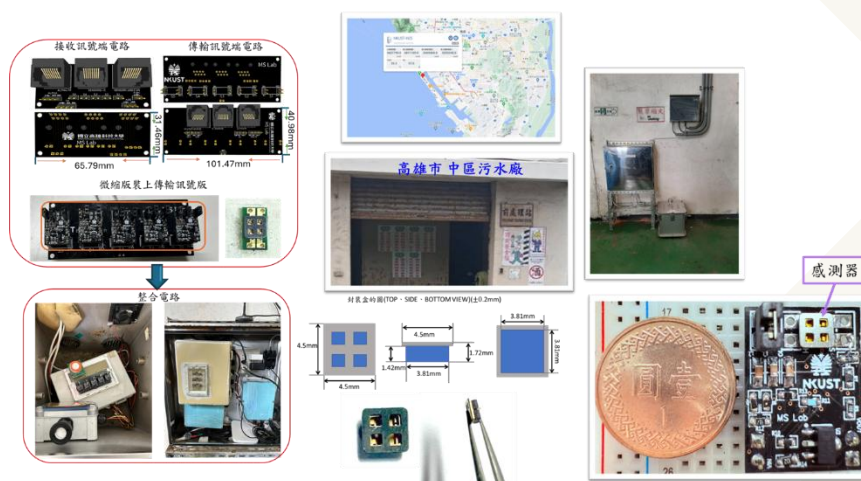
智慧微塵感測器



本團隊感測器晶片以TSRI南區分中心的6"~8"MEMS技術服務平台製作，晶片完成後在高雄科技大學半導體封測類產中心所建置的氣體感測晶片封裝技術進行小批量試產封裝感測晶片，達到低耗能、低成本，快速響應、高靈敏度、高穩定性及高選擇性之微型硫化氫氣體感測晶片，並將電路模組系統精簡化、標準化及封裝化，協助學界完成感測元件模組國產化，建立自主感測器技術能量。並於高雄旗津中區污水廠進行場域聯網架設與實測，包含實測場域設置測試訊號、聯網及供電等功能，與環境溫度及濕度計與國際標準之氣體感測器進行量測數據比對，並將數據回傳至科技雲端平台，形成區域監控網絡，提升國內產業界於氣體感測產品與智慧聯網監控產業競爭力。

計畫亮點

- 在TSRI南區分中心開發MEMS氣體感測晶片，高靈敏度H₂S晶片型氣體感測器，晶片微小，尺寸0.7mm * 0.7mm * 0.4mm
- 在旗津中區污水廠進行場域聯網架設與實測
- 國際標準氣體感測器進行量測數據比對
- 市售感測器進行量測數據比對
- 目前本計畫所開發之感測器已完成產品封裝及整合入訊號電路板



產業應用

- 在TSRI南區分中心開發MEMS氣體感測晶片，高靈敏度H₂S晶片型氣體感測器，晶片微小，尺寸0.7mm * 0.7mm * 0.4mm
- 本產品為新開發，佈點可循跡漸進先從1.恆溫恆濕之環境使用(如半導體製造工廠，儲藏室、材料分析實驗室)，2.環境溫度變化不大使用(如汙水廠、下水道、廠務.....)推廣。

專利資訊：氣體感測器之結構

專利證書號 I706571

專利權期限

本發明為一種微型氣體感測器結構，包含中空結構、絕緣層、低應力介電層、加熱元件和電極，感測薄膜設於加熱元件上，中空結構底端有氧化物層。此設計提升了支撐效能和穩定性，能感測超過500°C的高溫，增加產品競爭力和實用性。

AUG.21

Development of a Micro Hydrogen Sulfide (H₂S) Gas Sensing Module for Smart City Applications

Department of Electronic Engineering,
National Kaohsiung University of Science and Technology
Dr. Ting-Jen Hsueh

Smart Dust
Sensors

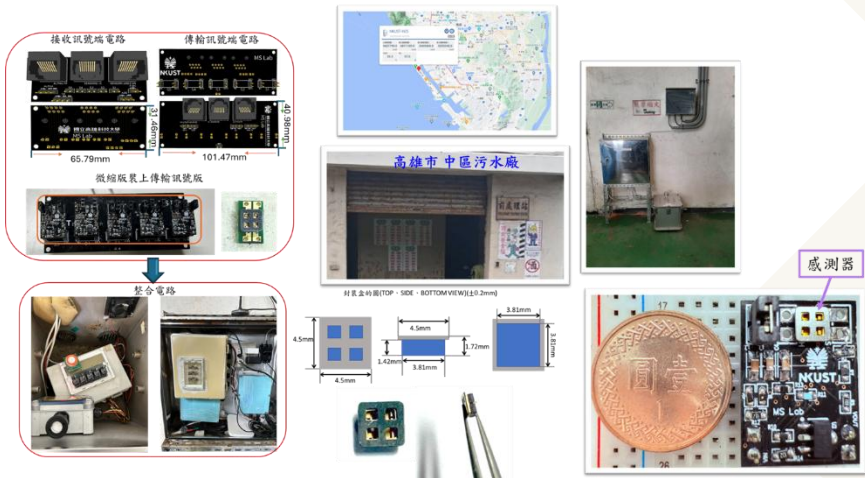


The sensor chips developed by our team were fabricated using the 6"-8" MEMS technology service platform at the TSRI Southern Regional Center. After fabrication, the chips underwent small-scale pilot packaging production at the gas sensor chip packaging facility established within the Semiconductor Packaging and Testing Center of National Kaohsiung University of Science and Technology. The resulting micro hydrogen sulfide gas sensor chips feature low power consumption, low cost, fast response, high sensitivity, high stability, and high selectivity. Furthermore, the circuit module system was streamlined, standardized, and packaged, assisting academia in achieving localization of sensor component modules and establishing independent sensor technology capabilities.

Field deployment and testing were carried out at the Qijin Central District Wastewater Treatment Plant in Kaohsiung, including setup and testing of signal transmission, networking, and power supply functions. Measurement data were compared with environmental temperature and humidity meters as well as internationally benchmarked gas sensors. The collected data were transmitted back to a cloud technology platform to form a regional monitoring network, thereby enhancing the competitiveness of domestic industries in gas sensing products and smart networked monitoring systems.

Project Highlights

- Developed MEMS gas sensing chips at the TSRI Southern Regional Center, creating a highly sensitive H₂S chip-type gas sensor with a compact size of 0.7 mm × 0.7 mm × 0.4 mm.
- Conducted field networking setup and on-site testing at the Qijin Central District Wastewater Treatment Plant.
- Performed measurement data comparisons with internationally benchmarked gas sensors.
- Performed measurement data comparisons with commercially available sensors.
- The gas sensor developed under this project has completed product packaging and has been integrated into the signal circuit board.



Industrial Applications

- Developed MEMS gas sensing chips at the TSRI Southern Regional Center, creating a highly sensitive H₂S chip-type gas sensor with a compact size of 0.7 mm × 0.7 mm × 0.4 mm.
- This product is newly developed, and deployment can be progressively expanded:

First in environments with constant temperature and humidity (such as semiconductor manufacturing plants, storage rooms, or materials analysis laboratories), Then in environments with relatively small temperature variations (such as wastewater treatment plants, sewers, or facility management sites) for broader promotion.

Patent : Structure of a Gas Sensor

Patent Number I706571

Patent Term

This invention relates to a micro gas sensor structure comprising a hollow structure, an insulating layer, a low stress dielectric layer, a heating element, and electrodes, with a sensing film disposed on the heating element. An oxide layer is formed at the bottom of the hollow structure. This design enhances support performance and stability, enables sensing at high temperatures exceeding 500 °C, and improves both product competitiveness and practicality.

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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

國立臺灣大學 機械工程學系
陳亮嘉 終身特聘教授團隊

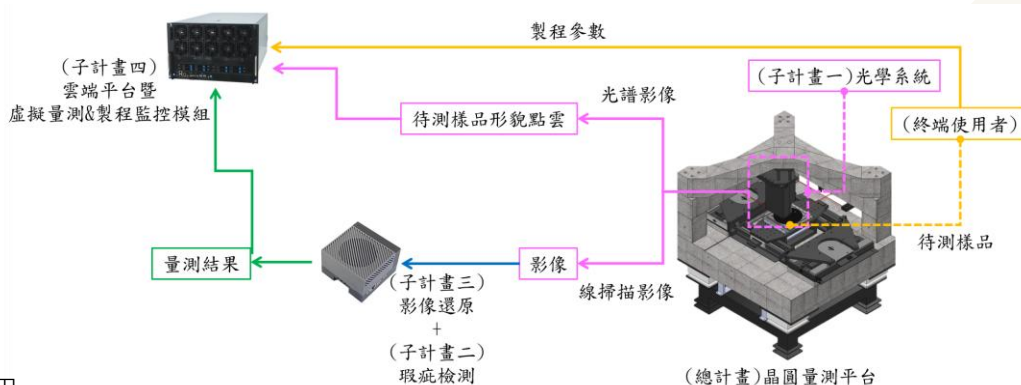


國立臺灣大學 工業工程學研究所
藍俊宏 副教授

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 $300 \times 300 \times 5 \text{ mm}^3$ 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涉儀迴授系統。
- 「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學生結合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」：對話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，提高預測區間品質。
- 「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。

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

AUG.21

Cyber Physical Systems

Department of Mechanical Engineering,
National Taiwan University
Dr. Liang-Chia Chen

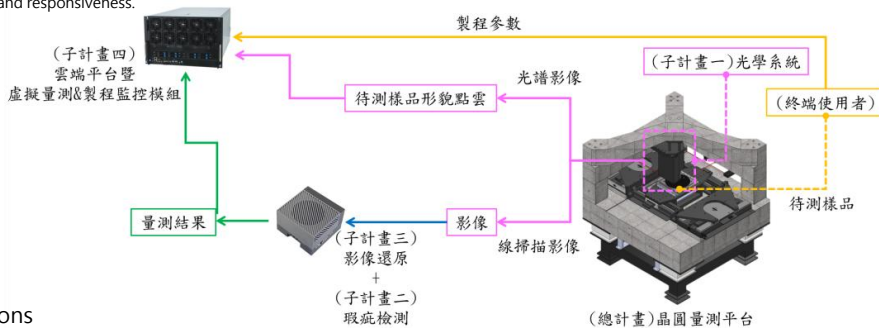


Institute of Industrial Engineering,
National Taiwan University
Dr. Jakey Blue

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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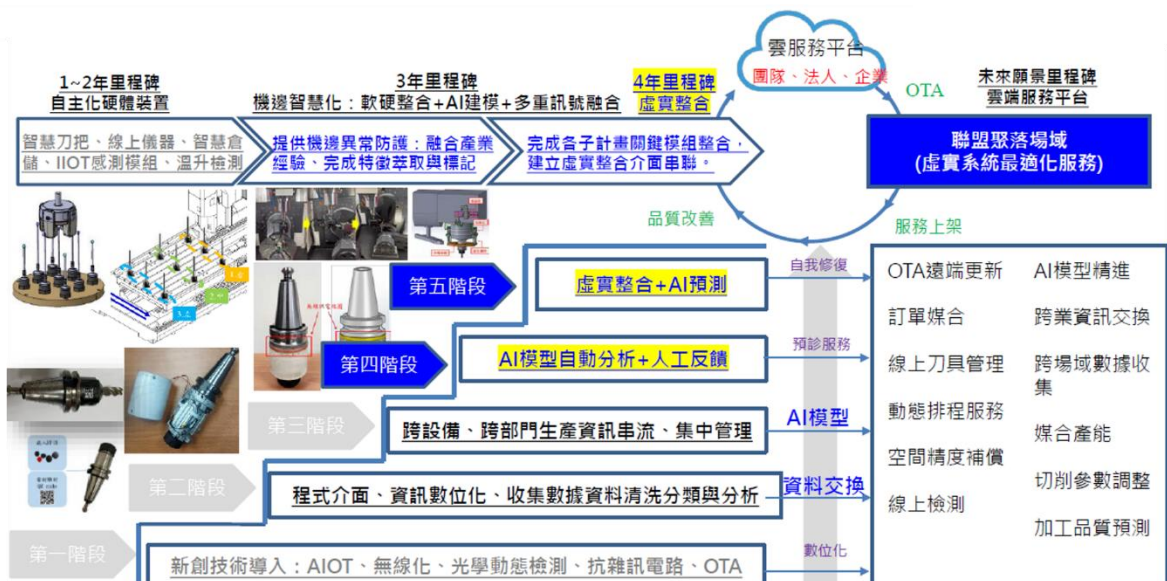
本計畫聚焦於航太與模具產業中高階精密加工製程，因其對製程穩定性要求極高，極適合導入數位分身技術。計畫目標是開發一套全製程即時監控與模擬預測系統，以協助產業提升品質穩定、縮短製程規劃時間、預測產品品質，並因應全球大廠持續的成本降低壓力。

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

AUG.21

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

Cyber Physical
Systems

Department of Mechanical Engineering, National Taiwan University
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

國立中興大學機械工程學系
陳政雄 教授



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，產出台獨獨特的創新技術、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。

AUG.21

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

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

Cyber Physical Systems



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.	



AI賦能雷射低碳製造技術

國立清華大學動力機械工程學系
李明蒼 教授

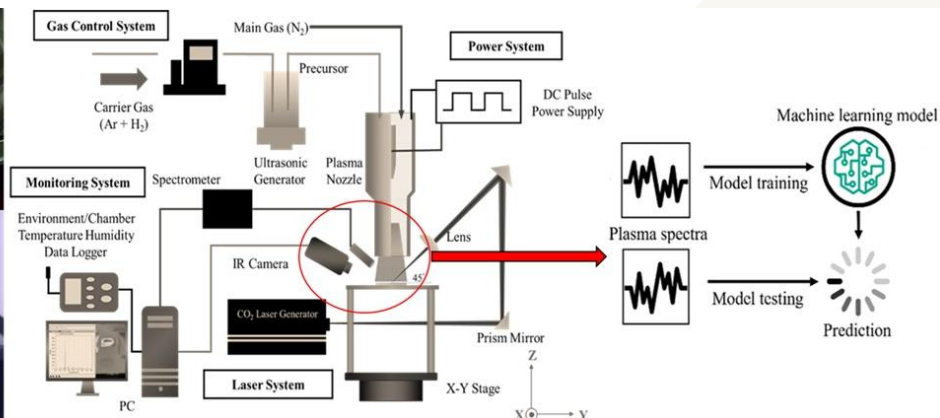
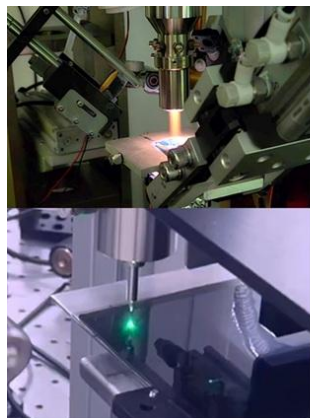
虛實加工



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

AUG.21

AI-Enabled Laser Green Manufacturing Technology

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

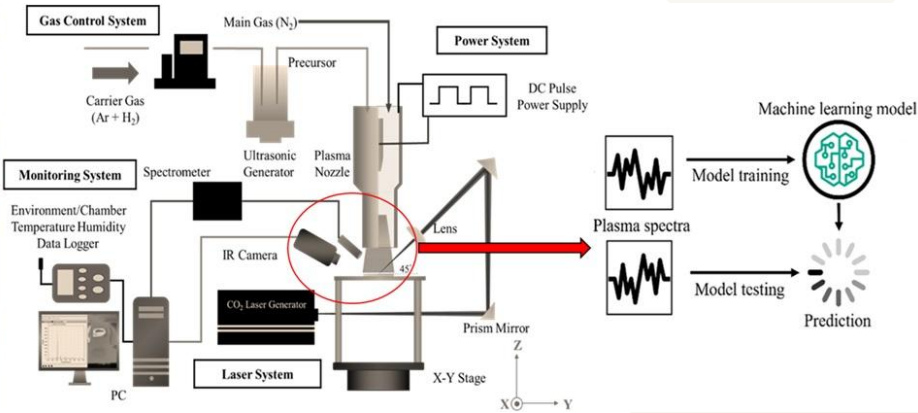
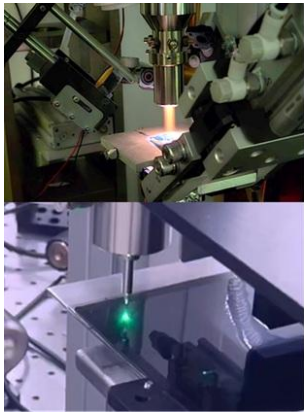
Cyber Physical
Systems



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
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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
之高性能基板精密複合加工系統研發國立中央大學機械工程學系
何正榮 教授

虛實整合



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 $<120\ \mu\text{m}$ (放電)、 $<20\ \mu\text{m}$ (雷射)，研磨與切割效率顯著提升；玻璃通孔孔徑 $<20\ \mu\text{m}$ 、深寬比 >10 ，線寬/線距達 $5/10\ \mu\text{m}$ 。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 $1000\ \text{mm/s}$ ，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 $180\ \mu\text{m}$ 降至 $120\ \mu\text{m}$ ，研磨與切割效率提升1倍以上；玻璃通孔 $<20\ \mu\text{m}$ 、線寬/間距達 $5/10\ \mu\text{m}$ 。
- 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。

SiC晶圓放電切片技術

成功開發線放電加工系統於單晶SiC的晶粒修整與8吋的晶圓切片技術，並獲得優良的切面品質。已達成技術目標：槽道寬度小於 $120\ \mu\text{m}$ 、熱影響區厚度低於 $8\ \mu\text{m}$ 。

8吋晶圓所切得之晶圓厚度為 $492\ \mu\text{m}$ ，表面粗糙度為 $2.194\ \mu\text{m}$ ，SORI為 $49.2\ \mu\text{m}$ ，BOW為 $37\ \mu\text{m}$ ，TTV為 $108.2\ \mu\text{m}$ 。

SiC晶圓表面軟化研磨技術

高效表面處理技術，於切片後碳化矽表面形成一均勻、軟化的改質層，降低表面硬度，可有效加速提升晶圓研磨與拋光效益，大幅降低磨、拋的耗材與時間成本。

研磨後之SiC表面，軟化表面後的SiC

SiC雷射隱形薄晶圓切片技術

對於大面積的SiC晶圓，雷射隱形切割是其競爭力的晶圓切割技術。此法可減少切縫材料損失($<20\ \mu\text{m}$)，且具有切面熱影響區小、切面易拋磨的優勢。其非接觸式切片機制，無刀具接觸磨耗問題，也可完成薄晶圓切片。

通過參數調控，本計畫成功開發，可達成單次掃描同時雙層切片的技術，此技術可提升薄晶圓的切片效益。

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。

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



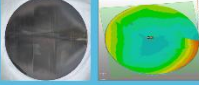
Silicon carbide (SiC) is a third-generation semiconductor material, well-suited for high-power and high-frequency devices. Glass, on the other hand, offers excellent thermal and chemical stability along with low dielectric loss, making it an ideal substrate for μ -LEDs, high-frequency modules, and interposers 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 μ m (via electrical discharge) and even under 20 μ m (via laser), with significantly enhanced grinding and cutting efficiency. For glass substrates, through-hole diameters of less than 20 μ m, aspect ratios greater than 10, and line/space resolutions of 5 μ m/10 μ m 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 $\rightarrow$ 120 μ m), doubled grinding/singulation rates; achieved <20 μ m vias, 5/10 μ m 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.

SiC晶錠放電切片技術

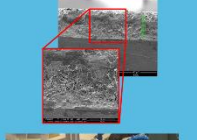
成功開發線放電加工系統於單晶SiC的晶錠修整與8吋的晶圓切片技術，並獲得優良的切面品質。已達成技術目標：槽道寬度小於120 μ m、熱影響區厚度低於8 μ m。



8吋晶錠所切得之晶圓厚度為492 μ m，表面粗糙度為2.194 μ m，SORI為49.2 μ m，BOW為37 μ m，TTV為108.2 μ m。

SiC晶圓表面軟化研磨技術

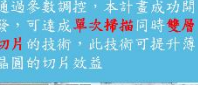
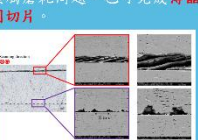
高效表面處理技術，於切片後碳化矽表面形成一均勻、軟化的改質層，降低表面硬度，可有效加速提升晶圓研磨與拋光效益，大幅降低磨、拋的耗材與時間成本。



研磨
軟化表面後的SiC

SiC雷射隱形薄片圓切片技術

對於大面積的SiC晶圓，雷射隱形切割是其競爭力的晶圓切割技術。此法可減少切縫材料損失(<20 μ m)，且具有切面熱影響區小、切面易拋磨的優勢。其非接觸式切片機制，無刀具接觸磨耗問題，也可完成薄晶圓切片。



通過參數調控，本計畫成功開發，可達成單次掃描同時雙層切片的技術，此技術可提升薄晶圓的切片效益

分片結果

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

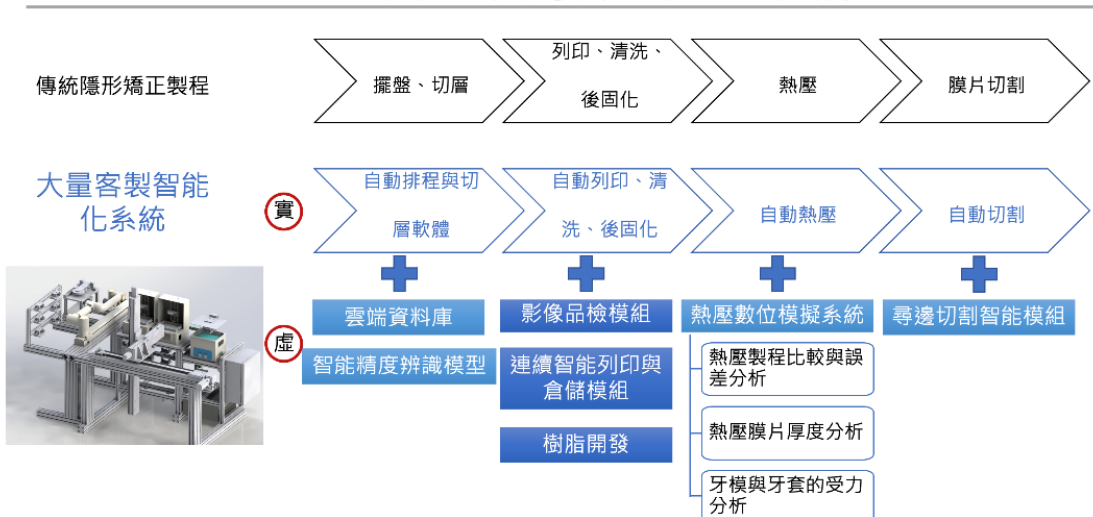
國立臺北科技大學機械系
江卓培 特聘教授

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。

大量客製智能化系統架構



NSTC 國家科學及技術委員會 National Science and Technology Council

國立陽明交通大學 NATIONAL YANG MING CHIAO TUNG UNIVERSITY

TAIPEI 國立臺北科技大學 TECH National Taipei University of Technology

國立臺灣科技大學 NATIONAL TAIWAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

中央研究院 ACADEMIA SINICA

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

聯絡窗口

國立臺北科技大學機械系
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AUG.21

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

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

Cyber Physical Systems



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.

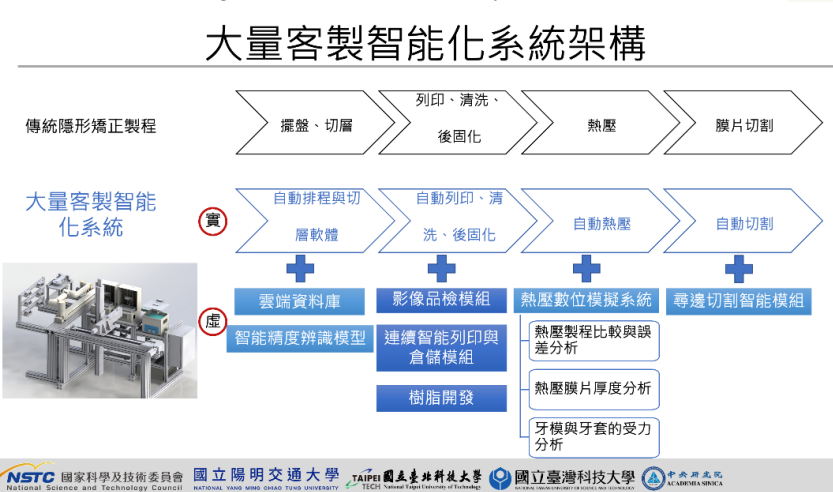
Validation experiments show that without compensation, the dimensional error of 3D-printed dental models can exceed 100 μm , and shrinkage during thermoforming may reach up to 12%, significantly compromising aligner accuracy—potentially one of the reasons for

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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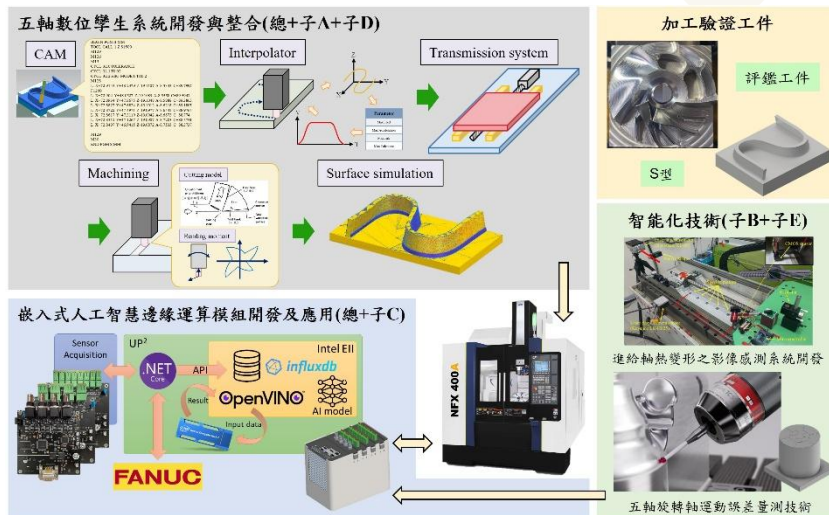
結合邊緣運算與 數位孿生之五軸工具機智能化技術研發

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。

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

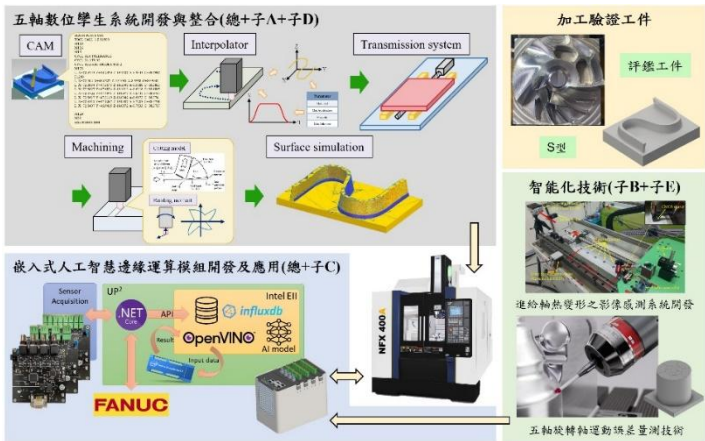
AUG.21

Cyber Physical Systems

Department of Mechanical Engineering,
National Taiwan University
Dr. Meng-Shiun Tsai



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.



整合嵌入式AI晶片與 先進CNC控制器之系統設計與研發

國立臺灣大學機械工程學系
蔡孟勳 特聘教授

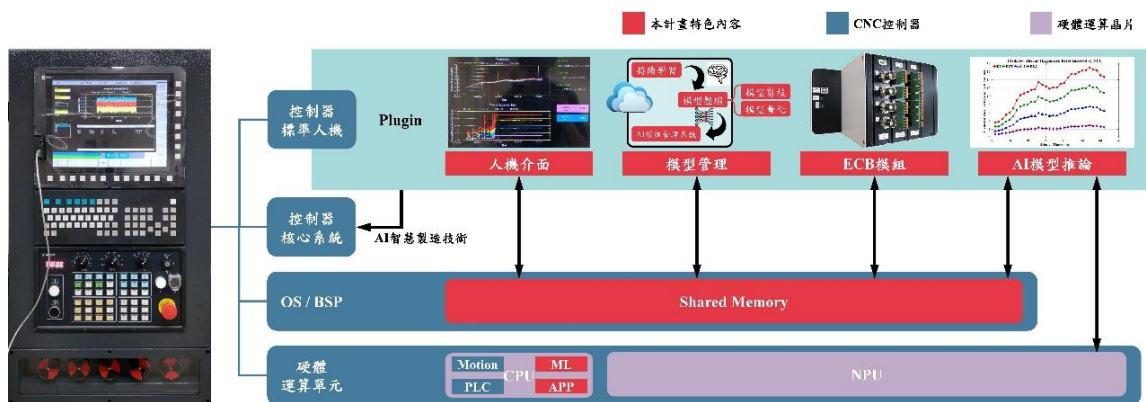
次世代智慧製造



本計畫整合機械、電機與資工背景共四位教授與業界進行跨領域合作，研發一「嵌入式AI晶片與CNC先進控制器」系統，使在商用控制器核心功能上透過AI晶片部署AI智慧製造技術。計畫目標包括：AI晶片與CNC控制器的軟硬體整合與核心參數存取、透過持續學習技術解決AI模型長期失準問題、開發CNC五軸高速高精控制器核心技術、部署AI技術進行熱變位即時補償、參數優化、刀具磨耗估測與表面紋路辨識。藉由多項的技術開發與整合，提升落地應用與產業競爭力。

計畫亮點

- 國內第一套嵌入式AI CNC控制器，透過NPU進行AI模型推論計算，以達到即時回授及補償。
- 開發X軸、Y軸與主軸之整機熱變位補償技術，維持長時間的加工精度。
- 結合感測器擷取模組，於控制器內運行AI熱變位即時補償技術。
- 透過AI模型整合插補、伺服系統、輪廓誤差與加工時間，根據使用者誤差需求，自動搜尋合適之控制器參數。
- 透過模型剪枝壓縮（包含簡化及量化）技術，使AI影像模型可以直接嵌入CNC控制器中運行。
- 建立一雲端AI模型管理系統，方便使用者於控制器端部署、更新與管理AI模型。



產業應用

- 機械產業、自動化產業、資訊產業、自駕車產業

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

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AUG.21

System Design and Development
on Integrating an Embedded AI Chip
with a 5 Axis CNC Controller

Department of Mechanical Engineering,
National Taiwan University
Dr. Meng-Shiun Tsai

Smart
Manufacturing



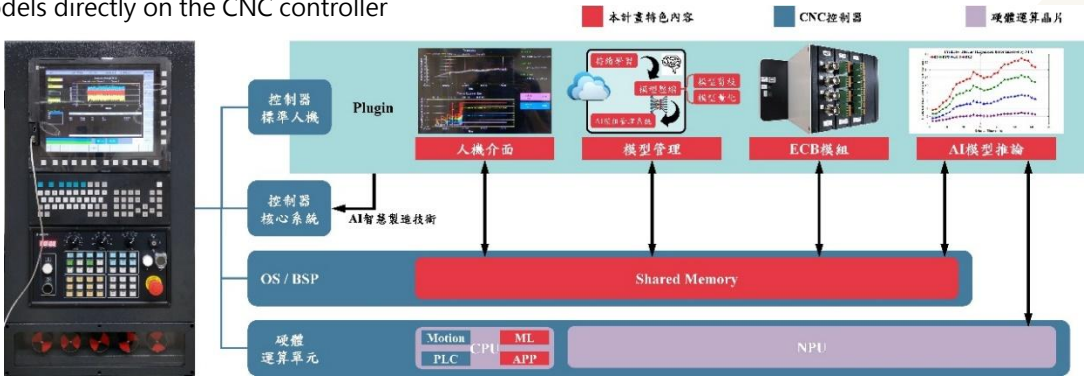
This collaborative project brings together four professors from mechanical engineering, electrical engineering, and computer science together with the CNC controller industry, to build an integrated system that combines an embedded AI chip with an advanced CNC controller. The system brings AI-driven smart manufacturing technique directly into the commercial CNC machine.

This project focuses on hardware-software integration to access core parameters, overcome long-term AI model drift via continuous learning, and develop the core of a high-speed, high-precision five-axis CNC controller. Additionally, this project develops real-time thermal displacement compensation, machining parameter optimization, tool wear recognition and identification using an on-chip neural processing unit (NPU).

By integrating these innovations, the project aims to deliver AI applications for CNC machining and boost the competitiveness of the industry.

Project Highlights

- The first embedded AI CNC controller developed locally, utilizing NPU for AI model inference, real-time feedback and compensation can be achieved.
- Development of comprehensive thermal displacement compensation for x-axis, y-axis, and spindle, maintaining accuracy over long-term processing.
- Connection of sensor acquisition module to enable real-time AI thermal displacement compensation directly within the CNC machine
- Integration of AI models with interpolation, servo systems, contour error analysis, and machining time to automatically optimize controller parameters
- Deployment of model pruning and quantizing techniques to run AI image recognition model natively inside the CNC machine
- Development of a cloud AI model management system, allowing users to deploy, update, and manage AI models directly on the CNC controller



Industrial Applications

- Mechanical industry, automation industry, information technology industry, and autonomous vehicle industry.

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.



智慧微塵感測器技術研發服務平台

國家實驗研究院國家儀器科技研究中心
陳峰志 資深研究員團隊

智慧微塵感測器



國家實驗研究院國家儀器科技研究中心
蕭文澤 研究員

本計畫建構完善的感測器製程服務平台(感測器異質整合製程平台與感測器聯網與模組化整合測試平台)，協助學界完成感測元件模組國產化，建立自主感測器技術能量。以前瞻工程實踐與整合測試技術研發為基礎，透過實際佈點與物聯網技術串接成區域監控網絡，有效提升國內產業界於氣體感測產品與智慧聯網監控產業競爭力。

計畫亮點

- 學術界團隊/國內業者共同開發半導體式、微型光譜儀/光學式氣體感測元件技術。
- 建構氣體感測器元件用公板模組，橋接學界前瞻感測器技術。
- 建構標準氣體測試驗證平台與標準化測試流程，並與國際標準感測器平行比對，藉以作為提升感測器效能之依據。
- 結合學界前瞻技術研發與法人平台加值，建構感測器國產化自主研發能量，建立產業聚落與落實產業應用。

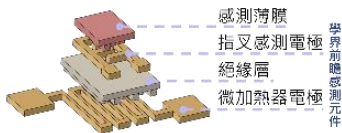
元件製程

QC品質管理

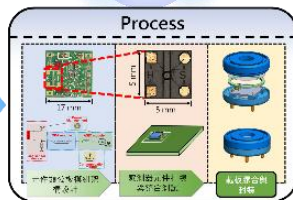
測試驗證



感測器元件垂直
堆疊式微加熱器
開發



感測器元件
公板模組



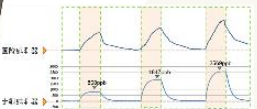
感測器晶片
與模組篩選



標準氣體量測
與驗證



導入檢測時序圖
掌握每個測試環節



可提供服務項目

- 懸浮式結構
- 微加熱電極製作
- 化學機械研磨整平
- 薄膜式感測材料

可提供服務項目

- 運算整合輸出
- 供應電壓調節
- 感測器數位訊號擷取
- 含溫濕度感測器，自校正功能

可提供服務項目

- 客製化點測探針卡
- 最大可點測6吋晶圓尺寸
- 協助學界提升感測器元件品質

可提供服務項目

- 感測器標準化測試流程
- 國際標準企業感測器測試比對
- 優化學界感測器效能

產業應用

- 介接感測器關鍵技術(如：材料、製程、電路、模組及系統等)至產業落地試量產。
- 衍生在民生、社會、工業應用題材，如：(1)環保署標準測站、(2)半導體製程場域、(3)汗水處理廠與(4)智慧城市應用

專利資訊：多點測試裝置

專利證書號 I687691

專利權期限 2020/3/11~2038/12/16

可應用於特定氣體半導體或電子元件之點測設備中之固定探針卡，進行點測作業前通入特定氣體於裝置內部，以機構設計將氣體導引流向探針針尖所在區域，複數個探針針尖同時接觸晶片的焊墊，進行晶片電性測試，確保品質。

AUG.21

Smart Dust Sensor Technology
R&D Service Platform

National Center for Instrumentation Research
Dr. Fong-Zhi Chen

Smart Dust
Sensors

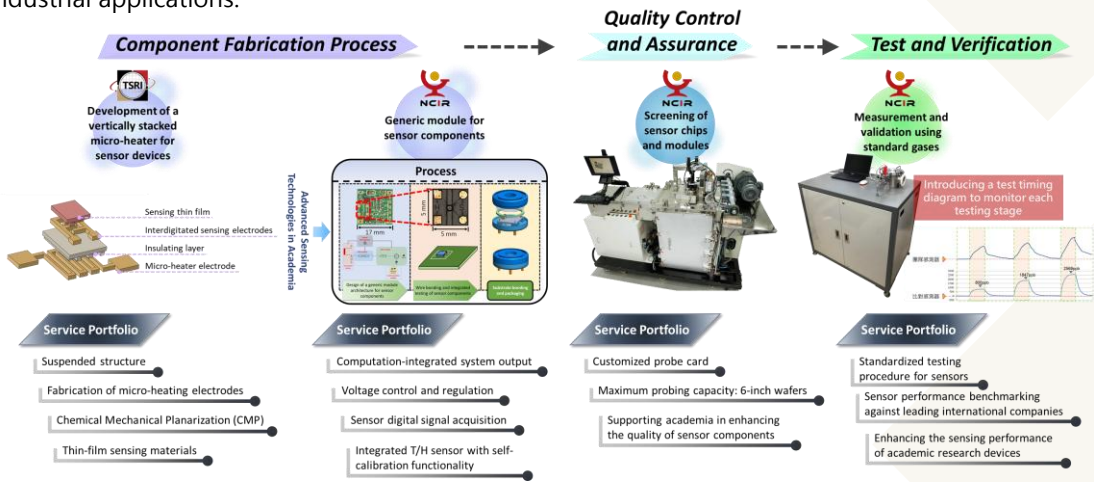


National Center for Instrumentation Research
Dr. Wen-Tse Hsiao

This project aims to establish a comprehensive sensor fabrication service platform, comprising a heterogeneous sensor integration process platform and a sensor networking and modular integration testing platform. The objective is to support academia in localizing sensor module development and fostering domestic capabilities in sensor technologies. Grounded in forward-looking engineering practices and integration testing technology development, the project will implement real-world sensor deployment and utilize IoT technologies to form a regional monitoring network. This approach is expected to significantly enhance the competitiveness of the domestic industry in gas sensing products and smart networked monitoring systems.

Project Highlights

- Collaborative development between academic teams and domestic industry on semiconductor-based, miniaturized spectrometer, and optical gas sensor technologies.
- Integration of advanced academic research with the value-added capabilities of institutional platforms to cultivate domestic self-sufficiency in sensor R&D, foster industrial clustering, and promote real-world industrial applications.



Industrial Applications

- Bridging critical sensor technologies to pilot-scale industrial implementation and localized productions - such as materials, fabrication processes, circuits, modules, and systems.
- Expanding applications to civilian, societal, and industrial domains, including:
- (1) Environmental Protection Administration (EPA) standard monitoring stations, (2) semiconductor manufacturing facilities, (3) wastewater treatment plants, and (4) smart city applications.

Patent : Multi-probing Device

Patent Number I687691

Patent Term 2020/3/11~2038/12/16

A probing device is applied to a probing and testing system for semiconductor or electronic components, especially to a probing and testing system that is used to input a specific gas inside. To fix a probe card at one end of the probing device, and then introducing a specific gas into the interior of the probing device before starting the probing operation, and guiding the specific gas to the area of the probe tips on a probe card by the mechanical design. A plurality of probe tips simultaneously contact a plurality of pads of a plurality of dies on the wafer, and an appropriate voltage or current is applied to perform an electrical test of dies on the wafer to ensure product quality.

Contact Person

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基於微型光譜儀的全場域

超微型氣體檢測及微型光譜儀應用開發

智慧微塵感測器

國立臺灣科技大學自動化暨控制研究所
柯正浩 教授

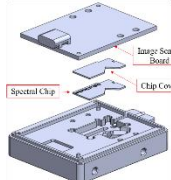


本計畫旨在開發超微型光學氣體感測器，結合光譜分析技術與物聯網介面，實現全場域即時氣體監測。核心技術包括：微型光譜儀、薄膜氣體吸附、電漿光譜感測系統。

光譜感測系統：使用自研微型光譜儀 (Spectrochip) 搭配特定波長光源，檢測氣體分子對光譜的干涉變化，並透過參數調整 (如曝光時間、訊號增益) 提升靈敏度。

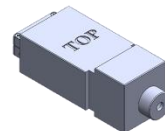
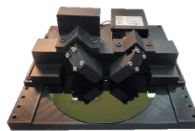
智能薄膜材料：與工研院及光洋應材合作開發多種氣敏薄膜 (如二氧化鈦、氧化鋅、三氧化鎢、量子點薄膜)，可依目標氣體 (CO、CO₂、H₂S、NO₂等) 切換，並通過溫度、濕度檢量線優化檢測精度 ($R^2 > 0.9$)。

電漿光譜感測系統：使用Spectrochip量測真空管中電漿之光譜波長，進而分析該綜合氣體中不同氣體組成。



保持相當好的分光效果
將光譜儀微縮至晶片大小
省去光學元件微調的時間
將光學元件全部一次性的生成在晶片上

訊噪比:300:1
動態範圍:500
光譜精度:0.5nm
光譜解析度:5 nm
雜散光率:<0.04%
光譜範圍:300-1000 nm
微型光譜儀則以該晶片為核心
重量:50g，較傳統光譜儀減輕300%



保持相當好的分光效果
將光譜儀微縮至晶片大小
省去光學元件微調的時間
將光學元件全部一次性的生成在晶片上

使用透鏡系統接收電漿系統分析氣體的光譜
配合演算法比對物質光譜，分析氣體組成成分

透過微針晶片採集血液或唾液樣品
比對數據庫分析出血液中數值濃度
放進機台中利用光譜儀進行光譜分析

計畫亮點

- 微型化與多氣體檢測：僅3微米薄膜厚度即可實現高靈敏度，且可更換薄膜偵測不同氣體。
- 環境適應性：在80°C至200°C、濕度20%-70%範圍內，光譜波長位移與環境參數高度線性相關，確保戶外應用可靠性。可對環境變化進行補償。
- 跨界合作：整合學界 (台科大)、研究機構 (工研院) 與產業 (光洋應材)，加速技術落地。
- 低成本光學方案：自製光譜儀取代傳統拉曼光譜等高價設備，降低部署門檻。
- 場域安全性：可通過光纖進行遠距離偵測，不需要通電，降低了場域安全風險。

產業應用

- 智慧工廠：即時監控生產線有害氣體 (如CO、H₂S)，預防風險。
- 智慧城市：部署於大眾運輸系統或公共區域，偵測空氣污染物 (PM2.5、NO₂)，優化環境品質。
- 智能家居：整合居家物聯網，偵測室內CO₂濃度或瓦斯洩漏，提升居住安全。

AUG.21

Micro-spectrometer-based Full-field
Ultra-miniature Gas Detection and
Micro-spectrometer Application Development

Smart Dust
Sensors

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This project aims to develop ultra-miniature optical gas sensors, combined with spectroscopic analysis technology, to realize real-time gas monitoring in the whole field. The core technologies include: micro-spectrometer, thin-film gas adsorption, and plasma spectral sensing system.

Spectroscopic Sensing System: This system uses a self-developed micro-spectrometer (Spectrochip) paired with a specific wavelength light source to detect spectral interference changes caused by gas molecules. Sensitivity is enhanced by adjusting parameters such as exposure time and signal gain.

Smart Thin-Film Materials: In collaboration with ITRI and Advanced Optoelectronic Technology Inc., we've developed various gas-sensitive thin films (such as titanium dioxide, zinc oxide, tungsten trioxide, and quantum dot films). These films can be swapped depending on the target gas (e.g., CO, CO₂, H₂S, NO₂) and detection accuracy (R²>0.9) is optimized using temperature and humidity calibration curves.

Plasma Spectroscopic Sensing System: This system uses the Spectrochip to measure the spectral wavelength of plasma within a vacuum tube, thereby analyzing the different gas compositions within a mixed gas environment.

SpectroChip Miniaturization

- 保持相當好的分光效果
- 將光譜儀縮至晶片大小
- 省去光學元件校準的時間
- 將光學元件全部一次性的生成在晶片上

- 訊噪比:300:1
- 動態範圍:500
- 光譜範圍:0.5nm
- 光譜解析度:5 nm
- 雜散光率:<0.04%
- 光譜範圍:300~1000 nm
- 微型光譜儀則以該晶片為核心
- 重量:50g、較傳統光譜儀減輕300%

- 保持相當好的分光效果
- 將光譜儀縮至晶片大小
- 省去光學元件校準的時間
- 將光學元件全部一次性的生成在晶片上

- 使用透鏡系統接收電磁系統分析氣體的光譜
- 配合演算法比對物質光譜、分析氣體組成分

- 透過指尖試片採集血液或唾液樣品
- 比對數據庫分析出血液中數值濃度
- 設備機台中利用光譜儀進行光譜分析

Project Highlights

- Miniaturization and multi-gas detection: High sensitivity can be achieved with a film thickness of only 3 microns, and the film can be changed to detect different gases.
- Environmental adaptability: Highly linear correlation between spectral wavelength shift and environmental parameters in the range of 80°C to 200°C and 20% to 70% humidity, ensuring reliability in outdoor applications. Compensates for environmental changes.
- Cross-border cooperation: Integration of academia (NTUST), research institutes (ITRI) and industry (OPTOTECH) to accelerate technology implementation.
- Low-cost optical solution: Self-built spectrometer replaces traditional Raman spectroscopy and other high-priced equipment, lowering the deployment threshold.
- Field security: Long-distance detection via optical fiber without power supply reduces field security risk.

Industrial Applications

- Intelligent Factory: Real-time monitoring of hazardous gases (e.g. CO, H₂S) in the production line to prevent risks.
- Smart City: Deployed in public transportation systems or public areas to detect air pollutants (PM_{2.5}, NO₂) and optimize environmental quality.
- Smart Home: Integrate the Internet of Things (IoT) in the home to detect indoor CO₂ concentration or gas leakage to enhance residential safety.

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