「溫」故知新：
台灣研究團隊打造 AIoT 智能溫控新時代

文／科技部提供

近年來數位科技領域之蓬勃發展，先進國家均投入大量資源開發各種數位科技前瞻關鍵技術，配合行政院科技會報辦公室「數位國家．創新經濟發展方案」(DIGI+) 方案，科技部推動大數據、人工智慧、物聯網等關鍵技術開發，促使學術界團隊與產業界共同研究合作，協助企業開發數位相關系統或產品，落實產業之需求，以提升國內技術競爭力。

工業製造流程中經常出現高精度之溫控生產步驟，而溫度敏感性生產牽涉參數間複雜的互動，因此常仰賴老師傅的經驗，透過頻繁量測與停機校正來確保生產品質。在科技部「數位經濟技術創新研發與應用」專案計畫的支持下，國立陽明交通大學資訊工程學系團隊研發「工業物聯網溫控生產預測技術」，透過物聯網 (IoT) 蒐集工業大數據 (Big Data)，並成功運用人工智慧 (AI) 技術建立溫控生產之即時品質監控與預測系統，不但大幅縮減煩瑣的人工測溫與校正流程，還能“溫”故知新，根據過往的製造經驗，預測從未生產過產品的製程參數，協助工廠快速進入新產品量產階段。本計畫開發之工具與流程已在百條產線落地，實證研發成果帶來溫控生產品質與效率的顯著提升。

溫控生產主要的挑戰在於生產品質和生產標的物承受的溫度和時間有關。而製造過程中，我們僅能控制生產設備的加溫曲線，這與生產標的物實際接受到的常有不同。無法精準掌握即時環境、設備，甚至於生產標的物的變動，便造成了生產品質的下降。雖然透過頻繁和定期的量測和調校，或由經驗豐富的工程師持續觀察與修正，可以確保生產品質，但無形中也增加了設備與人力的負擔。更重要的是，大量新產品的推出帶給製造端很大的困擾，新產品的導入需透過嘗試錯誤 (trial and error) 才能讓生產穩定，而製程參數設計與優化往往耗費相當多的時間、人力與物力。為此陽明交大資工研發團隊投入溫控生產研究多年，透過安裝少量但關鍵的物聯網感測裝置，捕捉溫控生產環境與過程之動態特性，累積工業生產大數據，並運用人工智慧技術建立溫控生產之即時生產品質監控與預測系統，除了免除人工測溫與校正流程，精準掌握每一個產品的生產品質外，還能根據過往的製造經驗，預測從未生產過產品的製程參數，快速進入新產品量產階段。

▲ 合影左起為研華科技楊瑞祥技術長、國立交通大學資訊工程學系曹孝櫟教授、科技部工程司徐碩鴻司長、「數位經濟技術創新研發與應用」計畫辦公室楊得年領域召集人。

研發團隊以印刷電路板（Printed Circuit Board Assembly, PCBA）生產為例，說明本研發成果帶來產能和品質突破性的提升。近來年電子產品面對嚴苛的生產要求，無論是少量多樣造成換線 / 調機頻繁，品質規格隨著產品特性如車規、醫規逐年提高，產品大小如穿戴式、主機等差異巨大，這些特性讓生產難度提高，製程配方設計困難。其中關鍵步驟『表面黏著技術（Surface Mount Technology, SMT）』被廣泛應用於印刷電路板的生產中，簡單來說，SMT 製程便是將電子零件黏著在塗滿錫膏的印刷電路板上，透過回焊爐（Reflow Oven）高溫加熱進行回流焊接（Reflow Soldering），將電子零件緊緊固定在板卡上。而回焊爐的溫度控制是最為關鍵的項目，過高的溫度可能導製電子零件的損壞，而不適當的溫度或加熱速度則可能造成焊接缺陷。為了確保產品的良率，SMT 工程師需要為每種產品個別設計專屬的製程參數，並在回焊爐產線上反覆測試，佔用許多寶貴時間。

為了協助產業界升級電子產品製程，將「工業物聯網溫控生產預測技術」應用於 SMT 產線，主要技術亮點在於下列三項。

人工智慧溫度預測模型達到 100% 的生產履歷追蹤

研發的溫控生產預測技術在回焊爐加裝溫度感測器，結合熱力學模型與機器學習模型，以人工智慧建立個別印刷電路板之溫度預測模型，即時精準推論每一片板卡的生產溫度曲線。有別於傳統需要在每次生產前花費時間測溫，並只能紀錄單一樣品的溫度曲線，本系統透過即時感測，便可自動化達到 100% 的生產履歷追蹤。

工業製程大數據分析協助新產品快速導入

過去對於全新板卡產品的生產，需要透過反覆的試生產和調整，導入時間與花費都相當可觀，本溫控生產預測系統累積足夠多生產與製程參數資訊後，可以進一步透過機器學習分析印刷電路板設計、回焊爐製程與實際產品溫度變化的關係，推薦新產品的製程參數，協助工廠收斂製程參數，將新產品導入快速推進到量產階段。

與產業密切合作將技術落地

透過與研華科技的密切合作，一開始便深入工廠了解產線運作流程，取得第一手資料進行分析。研發團隊選定實際用於量產印刷電路板的 SMT 產線進行技術導入，在不影響到產線生產的情況下安裝感測器與部署系統，以即時的生產資料驗證技術與完善系統，排除實務上遇到的各種問題。因此，當系統的準確性與效能被驗證完成之後，便可以快速地複製到各地工廠的多條產線上，讓技術真正落地，帶來立即、顯著的效益。

陽明交大團隊與研華科技等四家廠商共同合作，透過工廠產線的實際導入，在大量場域數據的驅動下，成功建立了回焊爐製程即時生產品質監控與預測系統，目前已經部署到全球各地超過 7 個工廠，100 條以上產線，總體效益已超過每年 5,000 萬。創新工業人工智慧 (Industrial AI) 應用的擴散，尚需考慮到異質設備與不同場域的物聯網和數據整合，快速 AI 模型的建立與部屬，AI 模型的持續修正與維護，這些皆仰賴平台技術的加速，本計畫積極與研華科技工業雲端平台（WISE-PaaS）合作，將本研究成果「工業物聯網溫控生產預測技術」以 WISE-Marketplace APP 的形式上架並對外推廣，期待帶動溫控生產工藝的升級，創造更高的產業效益。

Gain New Insights Through Reviewing the Past:

Enhance Temperature–Sensitive Manufacturing Productivity and Quality through Industrial Big Data and Artificial Intelligence

High-precision temperature control process is commonly applied to industrial manufacturing. To guarantee the quality of temperature-sensitive manufacturing, it often leverages veteran engineers' experiences by frequently adjusting configuration which also implies suspending running machines. Thanks to the support of Digital Economy Project from Ministry of Science and Technology (MOST) of Taiwan, the research team at Department of Computer Science, National Yang Ming Chiao Tung University (NYCU) developed "Industrial IoT Temperature Control Mechanism for Production Prediction" to collect Industrial Big Data and establish a real-time production monitoring & prediction system based on artificial intelligence (AI). With the system, the complicated manual process of thermal profiling and calibration could be significantly reduced. Moreover, the parameters of manufacturing process for new products could be estimated based on historical manufacturing records, and therefore the process from new production introduction (NPI) to stable and mass manufacturing would be accelerated.

The challenge of high-precision temperature control production is that production quality is greatly related to the precise regulated temperature and time on target product. However, only the temperature of heating device can be well controlled. The heating temperatures are often different from what the target products suffer. The rough temperature control of facilities and environment could result in the production degradation. To achieve stable production, veteran engineers must frequently observe the production behaviors and adjust the process parameters. It increases the load of both facilities and labors. Moreover, the mass NPI keep engineers occupied to optimize the process parameters for each new production because the procedure of NPI depends on trial and error before an available recipe obtained. To solve the issues, the research team of NYCU CS have been investing several years in temperature-sensitive production. With some critical IoT sensors, the dynamic properties of process and environment in temperature-sensitive production can be captured. Thus, the real-time production monitoring & prediction system is created based on Industrial Big Data and AI. With the system, many complicated processes of manual profiling and calibration can be omitted while the quality of each product is monitored precisely. Furthermore, the process parameters of new product, which is never manufactured, can be easily estimated based on the past manufacturing records, and the mass manufacturing stage can be quickly achieved.

Take Printed Circuit Board Assembly (PCBA) for example, the diversity of electronic product brings strict production restrictions while the quality requirements are continuously increasing. It is difficult to design suitable recipe of manufacturing process quickly to achieve good production quality with complicated and various product properties. Surface Mount Technology (SMT) is a critical procedure for PCBA production and has been widely used. In SMT procedure, electronic components are placed on a Printed Circuit Board (PCB) that solder paste has been spread on. Then the board will pass through the reflow oven under high temperature for soldering to attach the electronic components to the board solidly, and the temperature control is the most critical point. Overheating could damage the electronic components and insufficient heating behaviors could result in solder defects. To guarantee the product quality, SMT engineers must design specific process parameters for each product and verify it on production line; therefore, the efficiency of SMT production is decreased.

In this project, "Industrial IoT Temperature Control Mechanism for Production Prediction" is applied on SMT production line to assist industry in enhancing process of electronic products, and three highlights should be pointed out.

First, Intelligent Sensing with Hybrid Models. Thermal sensors are installed in reflow oven to capture real-time temperature curves. Combing thermodynamic and machine learning models, temperature prediction model of particular PCBA could be created, and real-time temperature curves for each product would be estimated. Different from the conventional approach, where only one sample board are recorded with frequently manual profiling, the proposed system could achieve 100% production history tracking based on real-time sensing and monitoring.

Second, Industrial Big Data Analysis. Repeated production trials and adjustments are required for introducing entire new PCBA and cost considerable time and money. With the proposed system, the massive data from IoT devices and industrial process of manufacturing can be efficiently collect for further analysis via machine learning. The PCBA designs and reflow soldering process are studied; therefore, the process parameters of new PCBA product could be easily recommended and enter to mass manufacturing stage quickly.

Third, Real Field Application Driven. In this project, the research team closely collaborates with Advantech Co., Ltd. to study real manufacturing processes in depth and obtain firsthand data. The SMT production lines for PCBA mass manufacturing are selected for applying the proposed technology. The system and the sensors are deployed without affecting the regular production, and the system is continuously enhanced and verified with real-time production data. The real issues are immediately solved in this process; therefore, the system can be quickly duplicated to all production lines while the accuracy and efficiency has been verified. It brings instant and significant benefit.

Under the collaboration with four companies in this project, the real-time reflow production monitoring & prediction system has been created successfully based on the massive field data. The system has been introduced into more than 100 production lines, 7 factories around the world, and the overall benefit could exceed NTD 50M. For spreading novel industrial AI applications, several topics should be well studied, i.e., integration of heterogeneous facilities and fields, rapid creation and deployment of AI models, continuous enhancement and maintenance of AI models. The research team aggressively collaborate with Advantech Co., Ltd. to leverage its WISE-PaaS, which is a cloud platform for accelerating industrial AI applications. The proposed "Industrial IoT Temperature Control Mechanism for Production Prediction" would go on the market as WISE-Marketplace APP for promotion. We are looking forward to promoting the upgrade of temperature-sensitive manufacturing and raising industry benefit.