International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-12, Issue-2; Mar-Apr, 2026
Journal Home Page: https://ijaems.com/
DOI: https://dx.doi.org/10.22161/ijaems.122.7

Application of Industrial Internet of Things in Fastener Forming Process Quality

Chih-Wei Hsu

Guangzhou Institute of Science and Technology, Guangzhou, China
e120247013@gmail.com

Received: 03 Feb 2026; Received in revised form: 05 Mar 2026; Accepted:10 Mar 2026; Available online: 13 Mar 2026

Abstract— *In the manufacturing industry, the current common practice for quality traceability and anomaly detection is to purchase a large number of inspection devices and implement full inspection of semi-finished and finished products to fulfill quality assurance commitments to customers. However, this approach consumes significant production time, labor, and related resources. Therefore, to save costs, many factories currently adopt "manual sampling inspection" for quality monitoring, but this method fails to achieve comprehensive quality management. To prevent the escalation of losses caused by defective products and to improve yield rates, full inspection of all finished products at a high cost becomes necessary.The Industrial Internet of Things (IIoT)-embedded fastener forming process system, through sensor deployment and machine networking to collect big data, can avoid decision-making models that previously relied solely on experienced operators and the substantial losses caused by delayed responses. This system eliminates the need to maintain inventory and tie up capital to handle large quantities of scrapped products. The approach described in this paper can halt machine operation before anomalies occur, preventing the escalation of losses. More importantly, through the recording of historical data, it enables traceability of factors related to personnel, machines, materials, methods, measurement, and environments—namely, 5M1E. Big data analysis of processing conditions helps identify the root causes of anomalies and implement effective countermeasures to achieve optimal condition settings, while also extending the manufacturing lifecycle.*

Keywords— ***Manual sampling inspection, Industrial Internet of Things (IIoT), Fastener forming process, Sensor deployment, Machine networking, Big data.***

I. INTRODUCTION

Screws and nuts are collectively referred to as fasteners, which are commodities widely used in applications ranging from basic civilian needs to high-tech fields and industries. Although the fastener industry is classified as a traditional industry, the consumption volume of fasteners is regarded as an indicator of a country's industrial development. According to data from Zion Market Research [1], the global industrial fastener market size was USD 92.56 billion. It is projected to reach USD 141.88 billion by 2032, exhibiting a Compound Annual Growth Rate (CAGR) of 4.86% during the forecast period from 2024 to 2032. The report provides a comprehensive analysis of the market, highlighting factors influencing market growth, potential challenges, and possible opportunities in the industrial fastener market over the next decade.

The prospects for the fastener industry are promising. However, a characteristic of traditional industries is the pursuit of mass production scale; greater production capacity naturally leads to greater production benefits, but when anomalies occur, the resulting losses are also substantial. Traditionally, the fastener forming process could only rely on numerous patrolling inspectors and the experiential judgment of senior on-site technicians, as the machinery did not transmit key information, making it impossible to know the machine's status during production. Consequently, besides being labor-intensive, this approach also led to issues such as the mixing of defective products, and the inability to immediately resolve machine or other anomalies when they occurred. This resulted in an inability to improve fastener processing quality, excessive scrap, and reduced equipment uptime due to damage, compounded by delayed customer deliveries, leading to significant losses.

This study employs an Industrial Internet of Things (IIoT) approach, involving sensor deployment and machine networking to collect big data, embedded within the fastener forming process for real-time monitoring of fastener production. This effectively reduces the current heavy reliance on manual inspection and addresses machine production problems. The implementation process of using IIoT in the fastener forming process enables timely detection of quality anomalies and ensures maximum machine uptime. Simultaneously, it allows for advance scheduling of production downtime, online quality control, preventing defective products from mixing with good ones, and reducing customer complaint compensation.

II. LITERATURE REVIEW

The research and writings of previous scholars on topics such as "sensor data collection in metal forming processes" and "industrial internet of things applications" were collected, using the research findings of many predecessors as the theoretical foundation for this study.

2.1 Sensor Data Collection in Metal Forming Processes

The Industry 4.0 revolution stems from advancements in digitalization, enabling the acquisition of information on workpiece surface roughness and forming tool wear to improve productivity, reduce costs, or maintain constant tool life, making factories smarter and more efficient. Giampiccolo et al. [2] suggested that Small and Mid-size Enterprises (SMEs) implement data-driven methods, manage data processes, and review the impact of data quality to address key data challenges within companies (such as data volume and data accuracy). Their research developed a general model for the evolution of result accuracy from sheet metal forming data functions, subsequently generating data content and missing data, and proposed the concept of economic data volume for data infrastructure scaling.

Casbas-Gimenez et al. [3] utilized the versatility of piezoelectric sensors in measurement technology and enabled the sequential development of wireless and networked solutions by embedding sensors directly into machines, fixtures, and tools. In their study, piezoelectric sensors were used during ongoing operations to monitor the mechanical strength of metal structures in real-time. Through the control of mechanical components, the strength was studied using piezoelectric sensors, measuring the structural behavior and geometric changes under bending loads, and quantifying loads and micro-strains in specific time-frequency domains under operating conditions. Furthermore, modeling metal forming processes is a fundamental task in production engineering. Due to recent technological developments, a wide variety of models are available and continuously expanding, making it important to select the appropriate model.

Additional articles outline the classification and characterization of metal forming modeling and common models, and introduce the model selection process. Based on this model classification, the upcoming challenges in modeling constraints for various related metal forming processes are discussed [4,5]. Ralph et al. [6] utilized Digital Twins within a common system, using industrial software for data logging and analyzers for automated further processing, monitoring and controlling forming units with different technological maturity levels, and explored the possibility of connecting metal forming machines, simulation programs, and automation software using finite element analysis simulation procedures.

The above literature reviews relevant theories of metal forming processes and outlines how to design integration and response for fastener research.

2.2 Industrial Internet of Things Applications

Generally speaking, the overall architecture of the Industrial Internet of Things can be divided into three layers: the perception layer, the network layer, and the application layer. First, equipment collects data through the perception layer, which is then transmitted from the network layer to the application layer for the most effective use [7]. Consequently, in studying production systems focused on data driving, equipment utilizes sensors for data collecting. The collected data primarily pertains to information relevant to the product lifecycle. Subsequently, through data transmission, individual pieces of equipment communicate with each other, aggregating the various aspects of information collected. This mainly involves using machine networking communication technologies to transmit product-related data in real-time to the network layer, enabling interconnection between machines or communication between humans and machines. The network layer is primarily constructed on wireless communication networks. Its main function is to virtualize the information collected by the perception layer, allowing the collected information to be freely accessed via the cloud, and to determine the transmission of information gathered by the perception layer to the cloud, finally passing it to the application layer for processing. The network structure can be divided into intranet and internet. The intranet is the so-called local area network, where all sensors establish an internal network to exchange information and perform data storage. Next, the cloud carries out data processing, as well as advanced techniques like data mining, to analyze the data collected by multiple sensors, further understanding relevant information throughout the product lifecycle. The external network is the internet, which connects the local area network to larger networks via routers, and then transmits the collected information outward through the internet.

With the advancement of sensor technology, during complex manufacturing production processes, production and testing equipment rapidly generate vast amounts of data. An increasing amount of data within manufacturing plants can now be comprehensively collected, including production history data, equipment parameter data, factory utility data, and measurement quality parameter data. However, the manufacturing shop floor faces both visible and invisible problems. The former includes equipment malfunctions, product defects, excessive cycle times, poor Overall Equipment Effectiveness (OEE), etc. The latter includes equipment performance degradation, component wear, insufficient raw materials, etc. [8]. Typically, visible problems in the manufacturing process can be resolved through continuous improvement, whereas invisible problems like equipment performance degradation can only be detected after a malfunction occurs.

In the perception layer, physical equipment needs to support real-time information acquisition, communication devices should provide high-speed transmission of heterogeneous information, and the shop floor must ensure rapid reconfiguration and adaptability. Huisingh et al. [9] noted that due to the Internet of Things and advanced information technologies, such as Radio Frequency Identification (RFID) tags and smart sensors, these are widely used in daily production and management within manufacturing enterprises, generating a huge volume of data impacting Product Lifecycle Management (PLM) processes. Du [10] stated that with the advent of Industry 4.0, current industrial processes are transforming into intelligent processes. Particularly, many modern industrial processes are equipped with meticulously designed sensors to collect process-related data in order to discover existing or emerging faults within the process.

III. IMPLEMENTATION PROCESS OF THE IIOT-EMBEDDED FASTENER FORMING PROCESS

The screw manufacturing process primarily proceeds from wire rod to wire drawing, heading, threading, heat treatment, and plating. The subject of this study is the heading machine. A smart fastener factory first receives data at the perception layer. This data is then transmitted through the network layer and connected to the application layer. Within the network layer, big data analysis is conducted using artificial intelligence methods to obtain analytical results. Subsequently, the application layer integrates these results and delivers them to the visualization system of the control center.

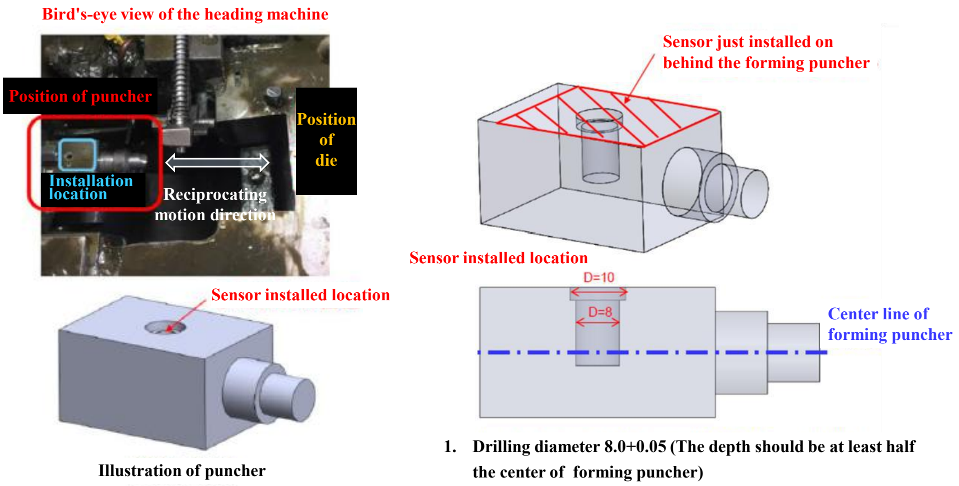
3.1 Installation of Sensing Components

After an initial requirements investigation, on-site inspection, and assessment of the machine's automation capabilities, it was found that the heading machine lacked any sensor data. Therefore, the evaluation, setup, and installation of sensors for the foundational IoT layer were confirmed. The components included the use of a Dynamic Force Sensor (DFS). This is a patented design by the Industrial Technology Research Institute (ITRI), Taiwan. It is a force sensing device featuring a double-end suspended buckle-ring structure. This design enhances the uniformity of force applied to the piezoelectric element, reducing damage caused by uneven force, and improves the convenience of disassembly and assembly. Its positioning structure design also enhances assembly precision. Furthermore, through the reading circuit, sensor module, and interface testing environment, it enables real-time monitoring and display of the impacted output force's time curve, sensitivity, and variability. The piezoelectric dynamic force sensor is shown in Figure 1 (Source: ITRI).

Fig 1: Piezoelectric Dynamic Force Sensor

The dynamic force sensor uses highly sensitive piezoelectric ceramic materials. Its structural design incorporates a mix slot to enhance the uniformity of force distribution under high impact loads and improve component reliability. The circuit design employs a quasi-static charge retention technique to read the sensing signals, reducing signal distortion and increasing the usable signal bandwidth. Simultaneously, the module system integrates the sensor readout circuit, PLC communication circuit, and sensing signal acquisition and computation unit. Online analysis software has been developed to judge the good or bad status based on the pressure curve during the process, achieving the effect of full inspection.

Many current studies integrate sensors directly into machinery, fixtures, and tools. However, before the deployment and installation of sensors in the fastener forming process can become operational, a comprehensive understanding of the heading machine's operation and maintenance procedures is required. The component molds are fixed, and processing one product requires two strokes of reciprocating mechanical action. During the continuous operation and control of mechanical parts, sensors are used to monitor the mechanical strength of the metal structure in real-time [3]. Therefore, the appropriate placement of sensors on the heading machine is critically important.



1. Drilling diameter 8.0+0.05 (The depth should be at least half the center of forming puncher)
2. Drilling diameter 10.0+0.05 (Depth 8.5+0.10 mm)

Fig 2： Installation Position at the Punch End

3.2 Evaluation of Sensor Installation Options

Correctly selecting the appropriate location for sensors to obtain representative data requires detailed evaluation, strictly considering the "actual on-site processing operations" and "machine structural characteristics." The following three options, A, B, and C, were evaluated:

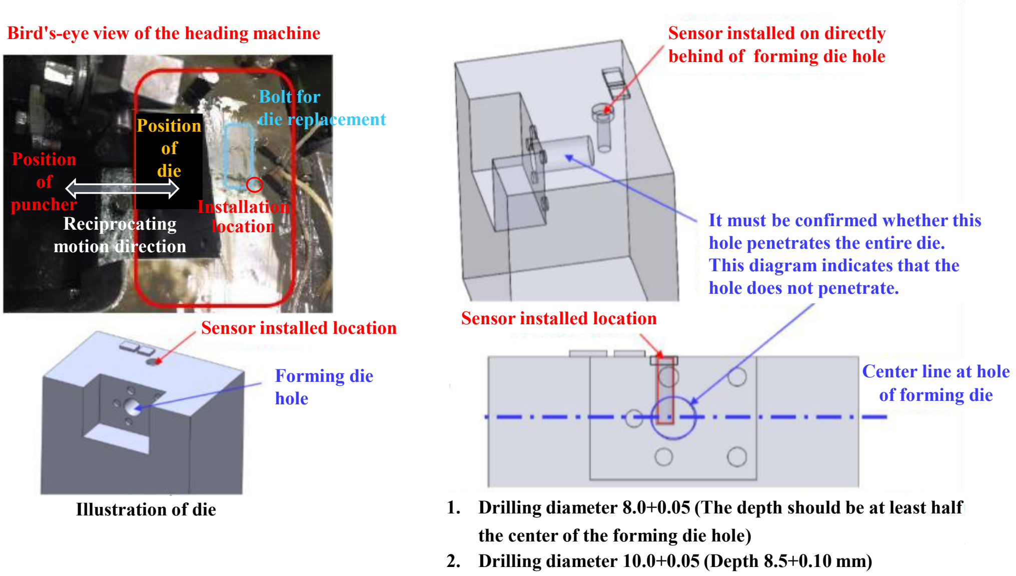
Option A: Sensor installed at the punch end (as shown in Figure 2)

(1) Actual On-Site Processing Operations: Although a sensor could be installed on the punch, the punch frequently needs to be replaced due to production line changeovers for different screw products or wear of the tooling. This would involve repeatedly detaching and attaching the sensor, causing cumbersome recalibration and affecting accuracy. Therefore, this location is unsuitable for sensor installation.

(2) Machine Structural Characteristics: No impact.

(3) Summary of Feasibility Assessment Results: This option is not adopted.

Option B: Sensor installed directly behind the forming hole in the mold end (as shown in Figure 3)



1. Drilling diameter 8.0+0.05 (The depth should be at least half the center of the forming die hole)
2. Drilling diameter 10.0+0.05 (Depth 8.5+0.10 mm)

Fig 3: Installation Position Directly Behind the Forming Hole at the Mold End

(1) Actual On-Site Processing Operations: During mold changes or production line changeovers, bolts on the rear end of the machine need to be replaced. Installing a sensor at this location would interfere with the bolt replacement work.

(2) Machine Structural Characteristics: The impact point of the punch is shallow. The sensor must be installed flush against the recess. However, being too close to the recess poses a potential risk of structural failure.

(3) Summary of Feasibility Assessment Results: This option is not adopted.

Option C: Sensor installed on both sides of the forming hole at the mold end

(1) Actual On-Site Processing Operations: No impact.

(2) Machine Structural Characteristics: No impact.

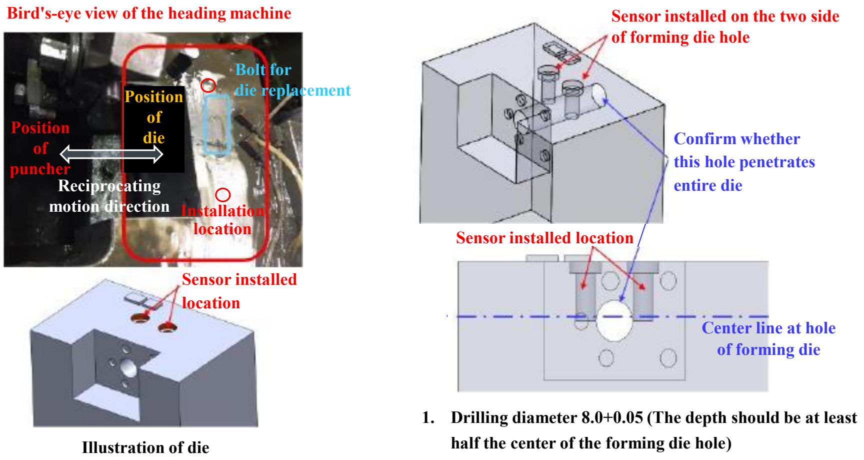
(3) Feasibility Assessment Result: This option is adopted.

Therefore, the selected dynamic force sensor was installed on the top of the mold, aligned with the reciprocating movement direction of the punching tool. Figure 4 shows the position of the installed sensor assembly within the heading machine.

3.3 Method of Sensor Installation

Hot melt adhesive is used inside the hole at the installation location, and then protected on the surface with metal AB adhesive. The external part of the wiring is protected, and a protective sleeve is added. Regarding the wiring layout, the cables are routed along the same paths as existing wiring to ensure they are not interfered with. The trigger switch primarily relies on the action of the punch rod to initiate the start and end points of vibration signal collection, as well as the counting function. A protective sleeve is added to the external part of the wiring at the installation location, leading to integration with the hardware (as shown in Figure 5). All of these tasks require close communication with experienced on-site technicians. The details are as follows:

During high-speed machine operation, lubricating oil is added to protect and cushion mechanical friction parts. The reciprocating action generates high temperatures, leading to oil mist and fumes. To prevent the lubricating oil mist from penetrating the piezoelectric sensor and interfering with detection, hot melt adhesive is used at the drilled installation site, and a layer of metal-specific AB adhesive is applied on the surface for enhanced isolation. Simultaneously, a protective sleeve is added around the outer edge of the wiring to shield the exposed cables. Furthermore, the routing of the sensor cables is positioned identically to the wiring of other components in the original mechanism (located at the side to ensure no interference during machine operation), as shown in Figure 6.



1. Drilling diameter 8.0+0.05 (The depth should be at least half the center of the forming die hole)
2. Drilling diameter 10.0+0.05 (Depth 8.5+0.10 mm)

Fig 4 : Installation Position on Both Sides of the Forming Hole at the Mold End

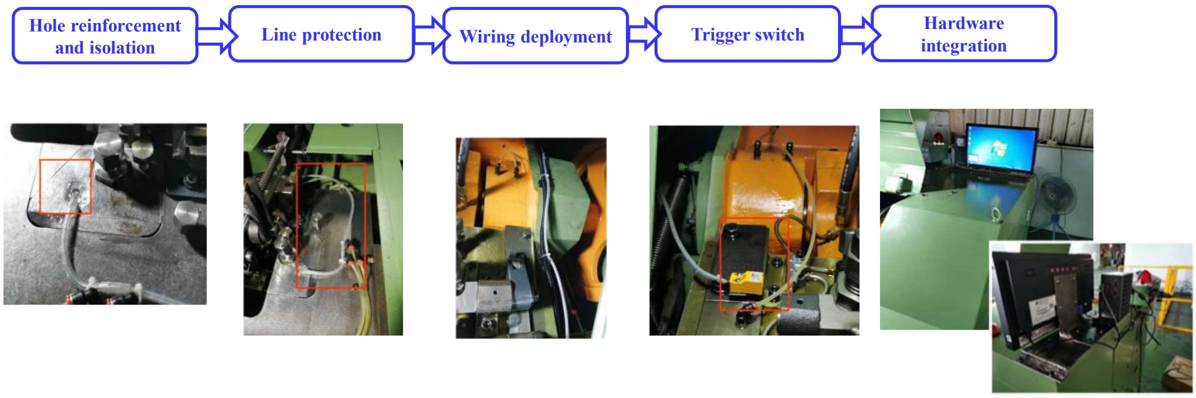


Fig 5: Method of Sensor Installation

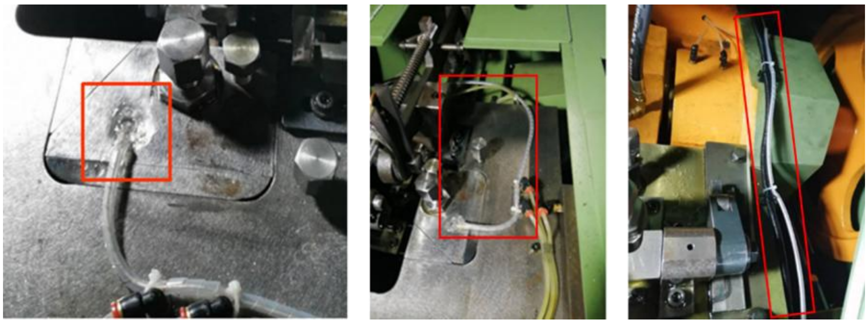


Fig 6: Reinforcement and Isolation at the Drilled Installation Site, Outer Wiring Protective Sleeve, and Cable Routing

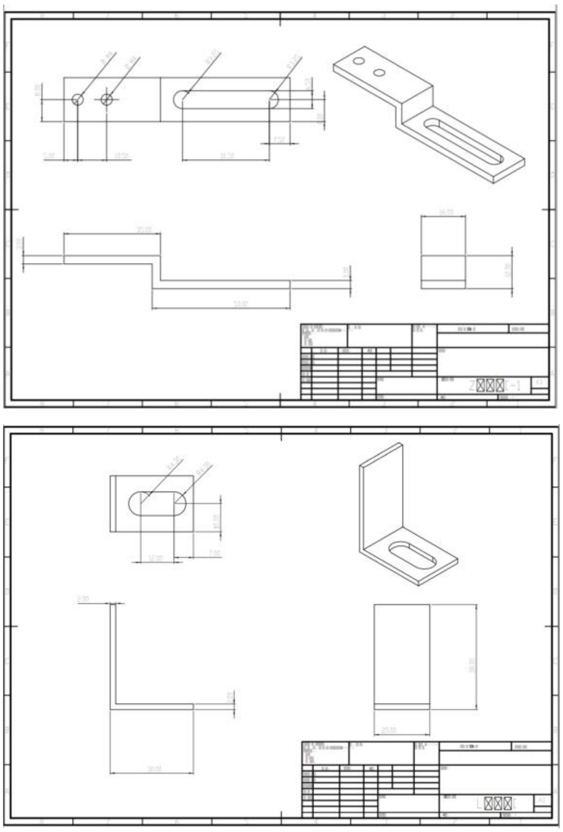


Fig 7: Engineering Design of Z-shaped Bracket & L-shaped Bracket

The trigger switch calculates the heading count and captures the signal start and end time periods to facilitate the formation of representative waveforms. The installation design principle avoids drilling holes in the machine to prevent damaging its original functional structure. Instead, it utilizes the machine's existing screw holes for fixation. A Z-shaped bracket and an L-shaped bracket fixture are fabricated and added onto the original positions. Screw holes are drilled into these fixtures, and the trigger switch is mounted and secured onto them. The engineering design drawing for the trigger switch is shown in Figure 7.

After completing the setup of the trigger switch device (as shown in Figure 8), a protective sleeve is added to the external part of the wiring at the trigger switch installation location to protect the exposed cables. The cable routing is kept the same as the routing position of other existing wiring to ensure no interference. The same principle applies to the protective sleeve and routing for the sensor wiring.

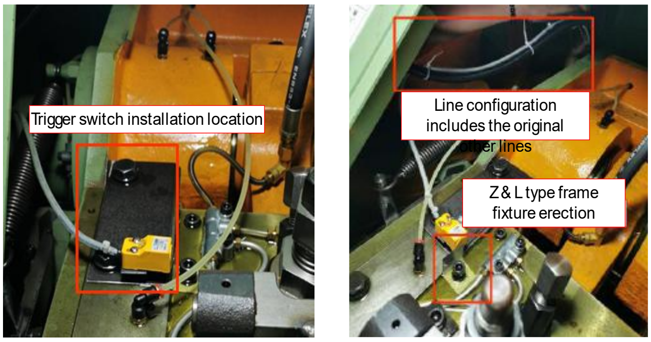


Fig 8: Trigger Switch Device Setup

Regarding hardware integration, engineering designs for components such as the computer base, monitor stand, and host unit chassis are illustrated in the related engineering drawings shown in Figure 9, facilitating the completion of sensor data collection.

The computer host and monitor are installed at the rear end of the machine operation panel, in a clearly visible location. The monitor position (front), the fixing points for the computer host and monitor (back), and the cable fixing points on the back are shown. A socket for the computer will be added later, followed by cable management, as illustrated in Figure 10.

When installing the computer and precision computing hardware, attention must be paid to on-site environmental factors such as machine vibration, high temperatures, and oil stains. During the implementation of this study, machine vibration once interfered with the sensor information received by the computer (resulting in garbled data). This issue was resolved by relocating the setup to a different position.

3.4 Data Visualization

First, an analog-to-digital converter is used to convert the detected analog signals into data waveform curves. Figure 11 shows the data browser, which serves as a basis for verifying the correctness of the waveform data. Chen, et al. [11] indicate that special sensors are used for data collection in production areas, and the data collection interface should be adjustable and scalable, as well as compatible with the visualization system for the data collection process. Furthermore, the monitoring system can effectively collect data from devices installed on the equipment and rapidly transmit the data to cloud servers in the network layer for further processing and visualization [12].

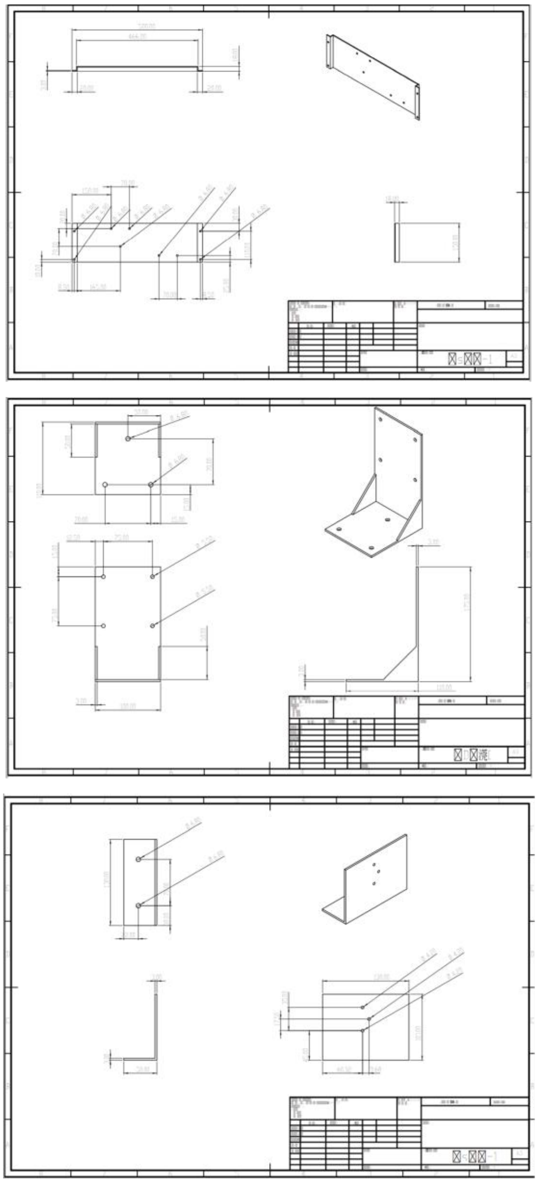


Fig 9: Engineering Design of Base & Monitor Stand & Host Unit Chassis

Fig10: Monitor Position (Front) & Computer Host and Monitor Mounting Bracket (Back) & Rear Cabling

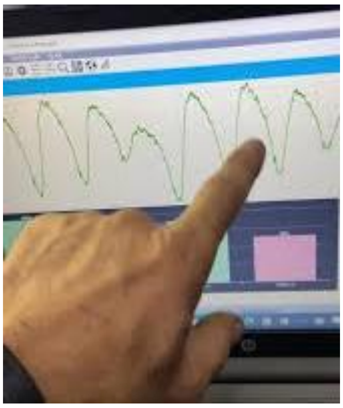


Fig11: Data Browser

During the installation process, the dynamic force changes generated during the cycle time of the heading operation are collected as relevant data through the dynamic force sensor. The collected data are then converted, and the most suitable start and end points for individual data waveform curves are extracted. In this way, each consecutive waveform pattern can be compared, analyzed, and verified between normal and abnormal forms, completing the normal waveform data and correctness verification.

3.5 Cyber-Physical Agent (CPA)

Piezoelectric sensors are installed to collect production data, detecting pressure signals and production information (such as time). The CPA universal data collection module is then used to gather data and perform simple data preprocessing (data segmentation, data cleaning). The CPA's data collection module, data preprocessing module, and even the algorithm application module are designed in a universal plug-in type format. The data collection module needs to integrate the communication method of the piezoelectric sensor, the data preprocessing module must preprocess the analog pressure signals, and the algorithm module establishes the failure mode of the heading punch.

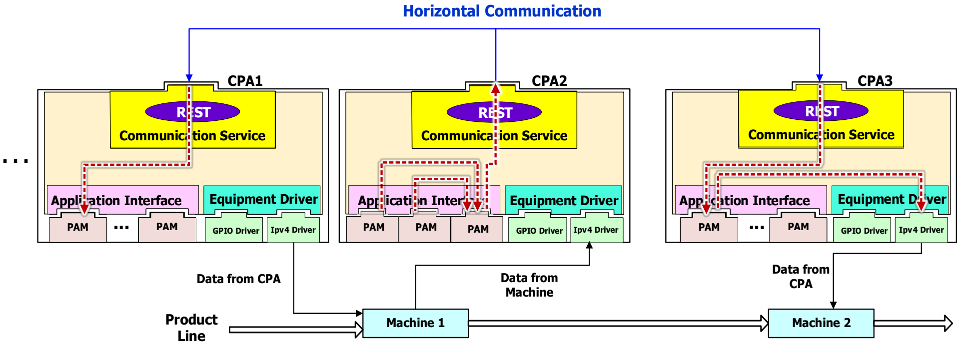


Fig.12 Design and Integration Architecture of the Cyber-Physical Agent

Regarding data collection, data preprocessing, and even the subsequent application of artificial intelligence algorithms, this study utilizes a Cyber-Physical Agent on the heading machine. The design and integration architecture of the Cyber-Physical Agent is shown in Figure 12 (Source: FS-TECH CO., LTD.). The Cyber-Physical Agent is similar to the research by Giampiccolo et al. [2] on sheet metal forming machines, which investigated the impact of data management processes and data quality on preventive maintenance and was equipped with an integrated acquisition system to record failure histories.

A universal IIoT architecture is constructed, incorporating horizontal and vertical communication designs required for future scalability. The key technological element is the CPA, which enables horizontal and vertical communication integration, providing a crucial foundation for machine intelligence and servitization, as explained below:

(1) Enabling Machine Intelligence: Enables machines to communicate and exchange data with each other. In the future, all production equipment and workpieces will be equipped with various sensors, requiring close information exchange during production or assembly to achieve precision manufacturing, assembly, and traceability. It allows for the collection of all product quality control items or yield rates for causal analysis.

(2) Enabling Machine Servitization: A critical aspect of the IoT and intelligent mechanization. It makes the CPA more accessible for use by other devices or

platforms by providing a web service to transmit machine production status data. Any authorized platform can use this web service to request machine production status data and implement necessary applications.

Furthermore, the data acquisition module of the CPA in this study needed to integrate the communication method of the dynamic force sensor. Gangoiti et al. [13] pointed out that using distributed agents with a versatile, customizable, and scalable multi-agent architecture can ensure the Quality of Service (QoS) provided by automated systems. Therefore, a universal IIoT architecture was built, and the data communication interface was connected to the dynamic force sensor data of the heading machine to verify data correctness. For further expansion, including the design for horizontal communication among multiple Cyber-Physical Agents (CPAs) and vertical communication for numerous machines, the core technology revolves around integrating machine intelligence and services, providing an important foundation.

IV. CONCLUSION

For a long time, to ensure process quality, production line personnel have conducted sampling inspections through manual patrols. Additionally, market trends are gradually shifting towards high-value fasteners, primarily applied in industries such as aerospace, wind and solar green energy, and medical sectors. These are characterized by high-mix, low-volume production and demand higher quality precision levels. This necessitates achieving full in-process online inspection and embedding intelligent sensing modules with machine health prediction capabilities into the IIoT to help ensure process quality, reduce equipment damage, and lower labor costs.

Traditional full inspection methods, using the cold heading machine in the fastener industry as an example, can be categorized into Off-Line Metrology (OLM), where the precision of processed parts is inspected in a laboratory, and In-Line Metrology (ILM), where the machine's own measuring tools are used to directly measure part precision. However, besides the high inspection costs, OLM suffers from measurement time delay. This delay means that when processing quality deteriorates, it cannot be known and corrected immediately, leading to mass scrap. ILM, on the other hand, incurs machine time delay, reducing the machine's available processing time and thus lowering its overall equipment effectiveness (OEE).

By connecting with the large-scale information systems that most companies already possess, vast amounts of data (e.g., sensor data) can be transmitted in real-time to the required systems and applications. Meanwhile, MES and ERP focus on production topics, output, targets, and scheduling. With each improvement monitored and predicted, the goals increasingly align with the systems, data models, and automated processes and equipment. IoT-enabled data acquisition can enhance almost any equipment or its operation. With enhanced data acquisition and the IoT, the aggregation of ERP-MES systems also takes a major step forward. These developments are suggested as designs for a powerful core to make factories intelligent and responsive.

These application examples demonstrate the advantages of real-time capability and precision, effectively assisting factories in upgrading quality from sampling inspection to a full inspection level. This not only improves production quality and increases production efficiency but also reduces overall operational costs. Furthermore, by understanding which types of machine failures cause the majority of problems, companies can formulate correct action plans.

REFERENCES

[1] Zion Market Research, 2023. Global pharmaceutical continuous manufacturing market report. New York: Market Research Store.

[2] Giampiccolo, S., Mairot, N., Masry, Z.A., Omri, N. and Zerhouni, N., 2020. Industrial data management strategy towards an SME-oriented PHM. Journal of Manufacturing Systems, 56, 23–36.

[3] Casbas-Gimenez, J., Gil-Hernandez, D., Muñoz-Navascues, O., Murillo, N., Perez-Alfaro, I. and Sanchez-Catalan J.C., 2020. Low-cost piezoelectric sensors for time domain load monitoring of metallic structures during operational and maintenance processes. Sensors, 20(5), 1471.

[4] Brosius, A., Ghiotti, A., Groche, P., Kinsey, B. L., Liewald, M., Madej, L., Min, J., Volk, W. and Yanagimoto, J., 2019. Models and modelling for

process limits in metal forming. CIRP Annals, 68(2), 775–798.

[5] Jazdi, N., Jung, T., Lindemann, B., Sahlab, N., Schloegl, W., Talkhestani, B.A. and Weyrich, M., 2019. An architecture of an intelligent digital twin in a Cyber-Physical production system. Journal of Automatisierungstechnik, 67(9), 762–782.

[6] Ralph, B.J., Schwarz, A. and Stockinger, M., 2020. An implementation approach for an academic learning factory for the metal forming industry with special focus on digital twins and finite element analysis. Procedia Manufacturing, 45, 253–258.

[7] Imran, M., Li, D., Shu, Z., Tang, S., Vasilakos, A.V., Wan, J. and Wang, S., 2016. Software-defined Industrial Internet of Things in the context of Industry 4.0. IEEE Sensors Journal, 16(20), 7373–7380.

[8] Beese, A.M., De, A., DebRoy, T., Elmer, J.W., Milewski, J.O., Mukherjee, T., Wei, H.L., Wilson-Heid, A., Zhang, W. and Zuback, J.S., 2018. Additive manufacturing of metallic components–Process, structure and properties. Progress in Materials Science, 92, 112–224.

[9] Huisingh, D., Liu, Y., Ren, S., Sakao, T. and Zhang, Y., 2017. A framework for Big Data driven product lifecycle management. Journal of Cleaner Production, 159, 229–240.

[10] Du, X., 2019. Fault detection using bispectral features and one-class classifiers. Journal of Process Control, 83, 1–10.

[11] Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M. and Yin, B., 2018. Smart factory of industry 4.0: Key technologies, application case, and challenges. IEEE Access, 6, 6505–6519.

[12] Milas, N., Mourtzis, D. and Vlachou, A., 2018. An Internet of Things-based monitoring system for shop-floor control. Journal of Computing and Information Science in Engineering, 18(2), 021005.

[13] Gangoiti, U., Iriondo, N. and Priego, R., 2017. Agent-based middleware architecture for reconfigurable manufacturing systems. The International Journal of Advanced Manufacturing Technology, 92, 1579–1590.