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Development of Inspection System for Hole Saw Caps

Liang-Yu Lu,[1] Wei-Lun Huang,[2] Chun-Liang Tung,[3]
Chien-Yu Lu,[2] Te-Jen Su,[4] and Lian-Wang Lee[1*]

[1]Department of Mechanical Engineering, National Chung Hsing University,
No. 145, Xingda Rd., Taichung City 40227, Taiwan (R. O. C.)
[2]Department of Industrial Education and Technology, National Changhua University of Education,
No. 2, Shida Rd., Changhua City 50028, Taiwan (R.O.C.)
[3]Department of Information Management, National Chin-Yi University of Technology,
Taichung City 411030, Taiwan (R. O. C.)
[4]Department of Electronic Engineering, National Kaohsiung University of Science and Technology,
Kaohsiung City, Taiwan (R. O. C)

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In this study, the measured data of the outer diameter, inner diameter, and pin hole diameter of the hole saw caps and the environmental inspection data of the manufacturing process were combined to develop a database collection system. As the operator inputs the measured outer diameter of hole saw caps, inner circle diameter, and pin–hole diameter, the production history can be traced. We used Microsoft Visual C# to design the graphical user interface to connect to the equipment site through the Modbus/TCP gateway in the same network domain. When the system operation process is completed, we can fill in the measured outer diameter, inner diameter, and pin hole diameter of the hole saw caps on the corresponding work order form. The operation process is planned in accordance with the production lines in the factory area, and the equipment operation information is transmitted through Zigbee wireless communication. In temperature and humidity sensing and power monitoring during the transport of hole saw caps, the industry standard RS-485 wired transmission is used to capture the sensing information and is connected to the Modbus/TCP gateway via a Wi-Fi network or Ethernet to send data to the computer and record the operation data on the specified data sheet at any time. It is easy to compare the measured data of hole saw caps and analyze the influence of various factors on the processing of hole saw caps.

1. Introduction

Industry 4.0 has become a global trend, and its goal is to integrate relevant industrial technologies, sales channels, and product experience to build a human-factors-engineered smart manufacturing factory with environmental adaptability and improved resource efficiency to facilitate precise production and dispatch existing resources , reduce excess cost and waste, and optimize the service of the production supply side.(1) In the current manufacturing industry, in a

*Corresponding author: e-mail: leelw@dragon.nchu.edu.tw
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factory, the measured data are conventionally recorded using pen and paper during inspection. The large number of paper documents makes it cumbersome to integrate data and difficult to trace data of past processes. Therefore, we propose to improve the hole saw cap production process to increase the inspection speed, convert data to electronic data to enable follow-up tracking as a priority, and combine the production history to improve the processing quality and promote the innovation of the process flow. In the move towards automated production, the use of a combination of Industrial Internet of Things (IIoT) and supervisory control and data acquisition (SCADA) is the current trend. In the manufacturing industry, SCADA can achieve smart maintenance through system monitoring, reduce unexpected downtime of existing resources and management systems, and improve productivity. According to the literature,(2) compared with planned maintenance, an intelligent maintenance system can reduce the overall maintenance cost by 30% and prevent 70% of the failures, which can effectively improve economic efficiency. Moreover, the process control can be optimized through IoT, and the database can be used to properly record various detected values to achieve intelligent production and change the traditional working environment and production processes.(3) The manufacturing process of hole saw caps can be divided into three parts: raw material cutting, hole saw cap grinding, and inspection. Our goal is to transform the manual delivery of hole saw caps in the traditional process into automated delivery and to convert the paper inspection records into electronic data files. At the same time, the environmental parameters should also be recorded to facilitate subsequent tracing of the conditions during the manufacturing process of hole saw caps. To accomplish the above goals, we adopt the method of human–computer interaction (HCI) in the design of the operation, under the four principles of simple, natural, friendly, and consistent. Therefore, we use the C# programming language introduced by Microsoft to create a graphical user interface (GUI) to connect with the system and issue instructions to the machine. Then the machine can report the system execution status to the user through this interface.(4) As an advanced object-oriented programming language, C# has the advantage of direct manipulation of visual objects on the screen and alternation of the system state. At the same time, GUI uses the .NET framework and can be based on the common language runtime (CLR), which supports the development and combination of multiple languages (C#, F#, VB.NET, C++, Python, etc.).(5)

In order to effectively record the processing procedure of hole saw caps, we divide the manufacturing process of hole saw caps into the raw material cutting station, hole saw cap grinding station, and inspection station. Each station is equipped with a DC brushless motor and indicator light to indicate the status of the motor. To detect parameters such as power consumption, humidity, and temperature change during conveyance, the high-reliability sensors and various network communication modules shown in Table 1 are used.

The signals of the conveyor motor and the indicator light are transmitted wirelessly through the Zigbee ZT-2550 communication module and converted to those for industrial standard RS485 wired transmission. The temperature, humidity, and power monitoring data of the production environment can be directly communicated using RS485. Then the transmission data are collected and converted to the Transmission Control Protocol / Internet Protocol (TCP/IP) mode through the tGW-724 gateway and transmitted via Ethernet to computer equipment. To

Table 1
Hardware used.

Module name	Model
Wi-Fi bridge	WF-2571
Modbus/TCP gateway	tGW-724
Zigbee communication module	ZT-2550
Zigbee I/O module	ZT-2043
Zigbee I/O module	ZT-2060
Digital power sensor	PM-3112
Digital humidity sensor	DL-100TM485

ensure that data can be received anywhere in the factory, we connect the Ethernet network of the tGW-724 gateway to the Wi-Fi bridge to convert the Ethernet signal into a Wi-Fi signal, so that the operating computer can be connected to the production set via Wi-Fi wireless communication within the effective range. The graphic control interface designed in C# language realizes remote control, and at the same time, it can store the production data of hole saw caps from each station in the database, so that the program itself can be multi-functional, reducing the complexity of operation. Therefore, the paging mode is adopted in the design of the graphical control interface while taking into account the control of the production line. It is also possible to retrieve various types of data in the database, resulting in traceability, because the system database is designed with multiple storage forms. Then, since each item is classified into a category, when there is a problem with the hole saw caps, the production can be traced in the time data to find the relevant information, and the production status of the work site can be checked.

A hole saw, as shown in Fig. 1, is a ring-shaped saw blade that can create a hole in a workpiece. It usually has a pilot drill in the center to prevent the saw teeth from wandering, which would cause the cutting surface to be skewed. The cutting depth of a hole saw is limited by the depth of its cup and is typically designed for relatively thin workpieces.(6) The surface of the hole saw looks simple, but there are many specifications that must be measured in the process of product inspection.

A hole saw cap is shown in Fig. 2. There are as many as 19 inspection items required to complete the manufacturing of hole saw caps, including outer diameter, inner diameter, pin–hole diameter, and height of the outer circle. These must be measured manually with a jig or projector. Accuracy is of mm order, and the measurement task is time consuming.

The hole saw manufacturing industry is still at the traditional manufacturing level. The measured data are recorded manually during inspection. The large number of paper documents makes it cumbersome to integrate measured data and difficult to trace data of past processes. To increase the market share and obtain increasingly high-standard orders, changes must be made to the overall production line. The manufacturer's first consideration is to solve the problem of time-consuming inspection and to use the production history to confirm the production status and the required time after the inspection. How to build the system for full digitalization of the factory has become a very important topic. Full digitalization of the factory should be implemented, such that a large amount of production data can be integrated. This will facilitate

Fig. 1. (Color online) Hole saws.

Fig. 2. (Color online) Hole saw cap.

subsequent data analysis, thereby improving the utilization rate of equipment, reducing the time cost of maintenance, and enabling the adoption of a management method of lean production. The production status of the production line is displayed through a graphical interface, the current production line status can be known from the remote end, and the production progress can be tracked at any time.(7) Currently, hole saw caps are still inspected manually, and no related digital production tracking management has been established. Therefore, the purpose of this study is to design a database system for hole saw caps and to trace and manage the data, such as voltage, current, humidity, and vibration data, throughout the production line.

2. Materials and Methods

SCADA is a centralized system that can monitor and control all devices, most of which are controlled via a remote terminal unit (RTU) of a control system or programmable logic controller (PLC). For example, the flow of cooling water in the production process is controlled by the PLC, while the SCADA system allows the operator to change the target value of the flow, set the display, and record the warning conditions (such as the flow rate is too low, the temperature is too high). PLC or RTU uses feedback control to control the flow or temperature, and SCADA is used to monitor the overall performance.(8) Nowadays, the SCADA technology has become very mature, and its application has gone beyond basic data monitoring, reaching the scope of level production line control.(9) In terms of function, the main role of the manufacturing execution system (MES) is still management. In the data flow of the automation platform, SCADA acts as the data provider, while MES is the data receiver. SCADA uploads the data captured by PLC or RTU to MES, and MES collects it with other information to analyze the meaning of the data and provides the result to managers.(10) In the future, SCADA can also be used with the scalability and computing power of IoT to produce analytical results with reference values, such as for equipment usage efficiency, production data, and energy consumption reports. The application and analysis of IoT data can break through the limitations of time and space, and the objects of data sharing and communication can span various platforms and environments. SCADA is mostly limited to the factory area. The combination of SCADA and IoT can endow the production line with intelligent effects, and the integration of SCADA and IoT into the cloud platform can greatly benefit economic efficiency. Nico Steyn, CEO of IoT.nxt, bluntly stated in an interview that these regulatory technologies are actually the staged division of labor of IoT. If they can be integrated and synergistic, industrial innovation and upgrading can be accelerated. Both are the key to automation, and their fundamental purpose is to improve operational efficiency and reduce costs, but the methods and focus are different.(11)

To construct the database, we chose the Microsoft SQL Server (MSSQL). In terms of system cooperation, MSSQL has a high degree of cooperation with .Net. In terms of companies, considering factors such as security, stability, and data processing speed, many business organizations also use MSSQL to build databases to process more data columns. An MSSQL database can be accessed and used by any programming language. In addition, because it is developed by Microsoft, it can be matched with other monitoring software, so many small and medium-sized enterprises choose MSSQL to build their own database.(12)

Modbus is the most common industry standard communication protocol for connecting industrial equipment today. It can communicate with multiple devices in the same RS-485 network, such as systems that measure temperature and humidity, and transmit the results simultaneously to a display screen and a monitoring computer. Modbus is often used to monitor computers and RTUs in the SCADA system. Generally speaking, the main device is a human–machine interface (HMI) or a monitoring and data acquisition system, and the auxiliary device is a sensor or PLC. In Modbus, the sending request and response content of the device and the network layer through which the message is sent are all defined by different levels of this protocol.(13)

Zigbee is a low-speed short-distance wireless network transmission protocol based on the IEEE 802.15.4 standard. The main features are low speed, low power consumption, low cost, support for a large number of network nodes, support for multiple network topologies, low complexity, reliability, and high security.(14) The initial development of Zigbee was aimed at automatic control, so it is suitable for intelligent control applications such as smart factories and smart homes. In the field of control applications, Zigbee can be constructed for a wide variety of devices, and in the design of the communication protocol, Zigbee uses multi-path hop communication (multi-hop) for one-to-many connection, so compared with Wi-Fi and Bluetooth, Zigbee is more flexible for device automation. Since the communication of Zigbee only focuses on sensing and control, the amount of information it transmits is very small. Because the device does not need to be turned on all the time, it is the most power-saving wireless communication technology. In addition, Zigbee supports the Advanced Encryption Standard (AES), so as long as it is set properly, it has extremely high security. It can be said that low transmission rate, low cost, power saving, high security, and dedicated communication between devices (machine to machine, M2M) are the basic characteristics of Zigbee.(14)

In accordance with the above, the inspection database system for hole saw caps is mainly composed of four parts: the control terminal, the data transmission terminal, the sensing terminal, and the action terminal.

The control terminal uses an industrial computer (Industrial PC, IPC) as the control computer in the production process. It comprises Microsoft SQL internally, operates the action components through the graphical control interface written in C#, and stores the real-time production operation data of the production process while simultaneous filling in the test data of hole saw caps. The data transmission end uses TCP/IP to connect the machines. The main process of data transmission is to convert the wired Ethernet to the industrial standard RS485 via the Modbus gateway and connect it to the sensing end (temperature and humidity sensing, power monitoring) and the Zigbee communication module, which sends the data extraction results directly to the computer through the set fixed IP. At the same time, to eliminate the length limitation of the physical cable of the traditional serial communication equipment, an Ethernet network to the Wi-Fi bridge on the Modbus gateway is installed. Connections between 802.11b/g wireless networks and standard Ethernet devices are installed, and the transparent transmission method is used for data transmission between local area network (LAN) devices, which greatly reduces the complexity of wireless system deployment. The sensing terminal is composed of a temperature and humidity sensor, a vibration sensing module, and an industrial-grade digital meter. The temperature and humidity of the factory area are often important parameters in the production process so as to prevent the mixing of water vapor during processing, which would otherwise affect the quality of the objects. The instantaneous voltage and current data provide the power consumption data for the whole process. When there is an abnormality in the control or the operation, the past records should be searched to determine when the abnormality occurred. Also when the operation is abnormal, past records are checked to find out when the abnormality occurred. The vibration sensing module is used to prevent vibration, which may cause damage to the machine parts during operation. Therefore, the sensing data is stored in the database as important data in the production history of the product. Three DC brushless motors are installed at the action end to serve as conveyor tracks for transporting the hole saw caps to the processing point. All three DC motors can operate independently or in sequence. To quickly identify the operating status of the motors, three-color indicator lights are installed on each of the three motors. A green light indicates that the motor is running, a yellow light indicates the motor is undergoing troubleshooting, and the red light indicates that the motor is shut down. Taking into account the hot air generated during operation, a fan is installed, which can be used as a heat sink for temperature and humidity adjustment during operation.

For the design of the database of hole saw caps, we refer to the utilization rate monitoring system in time-consuming maintenance, and non-real-time information is uploaded to the cloud platform.[6] Then the intuitive visual operation interface is used to effectively grasp the production process. Managers can carry hand-held devices to monitor the entire factory or even cross-factory production information. Equipment monitoring information such as alerts and machine operation status is clear at a glance, the production line schedule can be fully grasped, the operation efficiency can be evaluated, and full utilization of resources can be ensured. Nowadays, most of this technology is designed with managers as the center, but the specialized application software and system are expensive. If it is to be directly used in the current inspection of hole saw caps, the method must be changed to meet the current situation of use. Therefore, the traditional production process should first be digitalized. Collecting the inspection data during the production process also allows the operator to make judgments on any unexpected situation arising in the process by quickly referring to the production history to find the problem points. Moreover, the problem of the time-consuming search of cumbersome paper materials can be alleviated to improve efficiency.

3. Results

The goal of this study is to combine the environmental data during the manufacturing process of hole saw caps and the measured data of hole saw caps into a common database system. During the manufacturing process, data are collected as follows. First, turn on the no-fuse switch to supply power to IPC, communication modules and operating equipment. Next, open the user graphic control interface and input the IP location, port, and timeout time. Then touch the button to connect to the Modbus gateway, input various parameter settings, and press the button to bring up the pop-up window to confirm the successful saving of settings. Press the start button to connect to the first station of raw material cutting and pin delivery, and store the current captured data in the database. In the delivery process of the first station, before the raw materials are transported to the cutting station, the humidity condition is evaluated to prevent the humidity from affecting the processing task. If the humidity exceeds the set value, the graphic control interface displays a fault, and the three-color indicator light of the first station turns red. After the humidity returns to normal, press the troubleshooting button to display the troubleshooting window; the three-color indicator light will turn yellow. After waiting for the prescribed troubleshooting time, the system returns to the operation of the motor of the first station, the three-color indicator light becomes green, the window displays the current status, and the flow proceeds to the process of the second station for object grinding. The prototype hole saw cap is transported to this station for further grinding. During transport, the transport motor of the second station is started. In addition, the humidity value is stored and sent to the second station for processing. If the humidity exceeds the set value when the product is transported to the second station, the same operation as that at the first station is performed. After pressing the troubleshooting button, it is again necessary to wait for the prescribed troubleshooting time before the conveyor motor starts running again. The third station is the inspection station of hole saw caps. Before transport, the humidity must not exceed the set value for the motor to start. If the humidity is still higher than the set value, press the troubleshooting button at this time. The conveyor motor will activate after the prescribed troubleshooting time. During the final inspection, attention must be paid to the temperature change to avoid thermal expansion and contraction of the metal, which affect the accuracy of the measurement. When transporting hole saw caps to the inspection station, first record the temperature. If the temperature exceeds or falls below the set value, place the current hole saw caps in the first station. It is judged that it is easy to measure inaccuracy, the number of hole saw caps is recorded in the data table, and the number of faulty caps (NG) is increased by 1. If the hole saw cap is acceptable, the number of acceptable caps (OK) is increased by 1. After the hole saw cap arrives at the inspection station, record the completion time and the time taken on the data sheet, and judge whether the set target production number is reached. After the production of the work order is completed, we can browse the corresponding production history by touching the Machine Data tab of the graphic control interface, as shown in Fig. 3. We can switch to the Inspection Database tab to enter the hole saw cap measured data into the data table, as shown in Fig. 4.

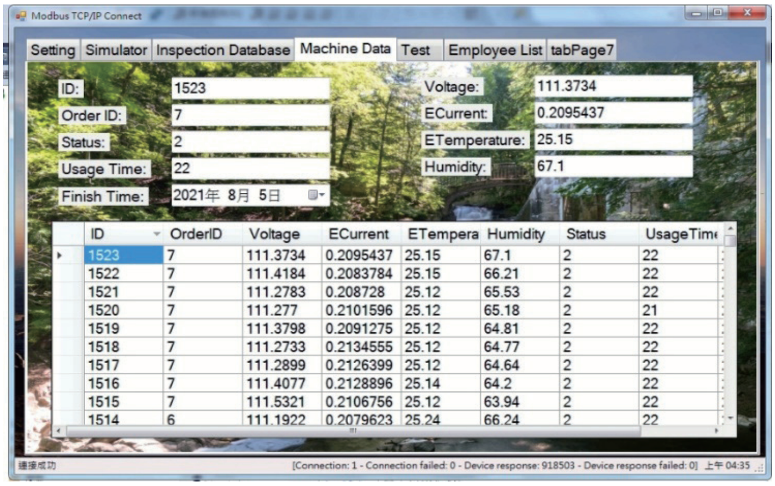

Fig. 3. (Color online) Production history of hole saw caps.

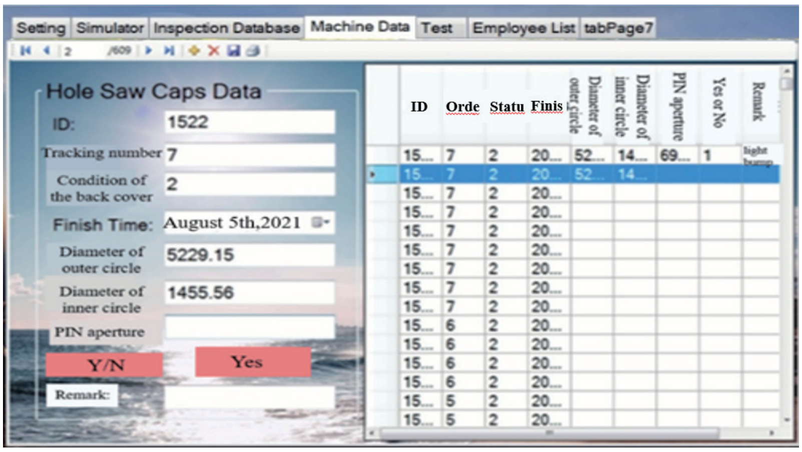

Fig. 4. (Color online) Measured data of hole saw caps.

In Fig. 4, starting with the highlighted data raw of ID 1523, the measured outer diameter, inner diameter, and pin–hole diameter of hole saw caps are sequentially input. Press the save tool bar to save, and the save confirmation window pops up, as shown in Fig. 5.

After successful storage is confirmed, the data table displays the measured data, as shown in Fig. 6, in which the data field showings NULL means that the measured data has not been input. The system can continue to operate at this time, and the data can be input when the production quantity target is reached. This completes the overall process of the inspection database system of hole saw caps.

4. Discussion

In view of the results of this research, there are still some deficiencies in our development of the inspection database system for hole saw caps that must be improved in the future. In the

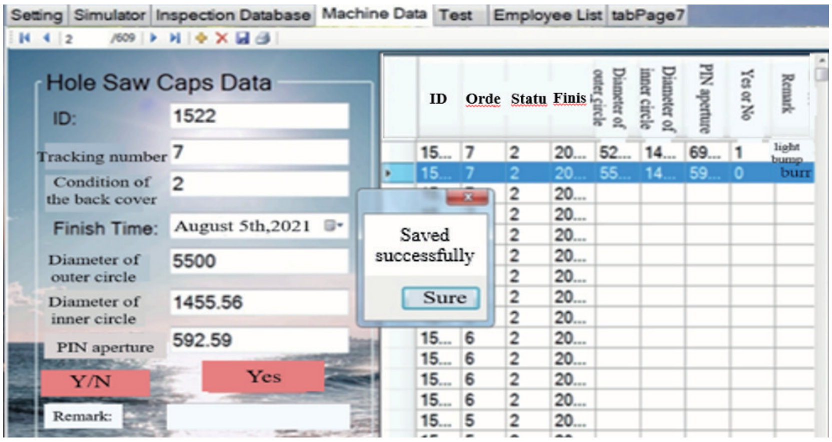

Fig. 5. (Color online) Measured data saved successfully.

	E...	Tem...	Humidity	Status	Usage	ID	FinishTime	Diameter of outer circle	Diameter of inner circle	PIN aperture	Y/N	Remark
601	0	25.12	63.94	2	22	1515	2021-08-05	NULL	NULL	NULL	NULL	NULL
602	0	25.14	64.2	2	22	1516	2021-08-05	NULL	NULL	NULL	NULL	NULL
603	0	25.12	64.64	2	22	1517	2021-08-05	NULL	NULL	NULL	NULL	NULL
604	0	25.12	64.77	2	22	1518	2021-08-05	NULL	NULL	NULL	NULL	NULL
605	0	25.12	64.81	2	22	1519	2021-08-05	NULL	NULL	NULL	NULL	NULL
606	0	25.12	65.18	2	21	1520	2021-08-05	NULL	NULL	NULL	NULL	NULL
607	0	25.12	65.53	2	22	1521	2021-08-05	NULL	NULL	NULL	NULL	NULL
608	0	25.15	66.21	2	22	1522	2021-08-05	5500	1455.56	692.59	0	burr
609	0	25.15	67.1	2	22	1523	2021-08-05	5229.15	1455.56	692.68	1	light bump

Fig. 6. (Color online) Input measured data to data table.

process of discussion with collaborating manufacturers, we learned that the ultimate goal is to build a complete MES in the factory area and to provide the overall production history of hole saw caps while standardizing the production process. The information of the production process can be used to accurately calculate the time required for hole saw cap fabrication from raw materials to packaging and delivery, so that parts can be prepared precisely. The stock of parts in the warehouse can be managed to meet production needs, as well as to ensure the product has a certain yield. Considering the existing structure, it will be highly challenging to achieve the goal of the database system of the production and inspection of hole saw caps in a short period of time, because the MES covers a wide range of fields. Not only the manufacturing process in the factory area but also order collation and planning at the commercial level must be innovated. Therefore, the first of the future improvement projects related to this study will be the improvement and strengthening of the database system during the production and inspection of hole saw caps and to further move towards the realization of the MES.

5. Conclusions

We used Modbus TCP/IP gateways to effectively expand sensors that support RS-485 communication and Zigbee communication modules to control the conveyor motor and record environmental data during transport along a production line. A Wi-Fi bridge adapter is employed to overcome spatial limitations by converting Ethernet signals into Wi-Fi signals in accordance with the site requirements. A graphical control interface designed in C# is used to connect to the Modbus gateway's IP address. The measured data of hole saw caps, voltage, current, humidity, operational conditions during transportation, and other relevant data are written into a shared MSSQL database. Corresponding data tables are created in the database to handle various types of sensor data and system operation status. The measured data of hole saw caps can be imported into the production history. Users can quickly switch between internal subpages to review the measured data of hole saw caps and the environmental conditions during processing. In the case of abnormal measurements, the transport operation of hole saw caps can be promptly stopped, and the environmental monitoring data and shutdown position during the production process can be immediately accessed to identify the source of the problem and reduce the time and cost of maintenance. The current production line status is presented through a graphical interface to track the production progress in real-time.

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