International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 4 April. 2026, pp: 233-236 www.ijaem.net ISSN: 2395-5252

Designing An Automated Mold Recovery Model Using Ai Technology for Product Defect Analysis

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Date of Submission: 03-04-2026 Date of Acceptance: 14-04-2026

ABSTRACT
In modern industrial production, quality control and the handling of defective products play a crucial role in ensuring the reliability and reputation of a business. However, in reality, many current inspection systems still rely on manual operations, which not only increases processing time but also carries the risk of errors. Given this situation, the application of automated control technology combined with artificial intelligence in identifying and handling defective products is considered an effective solution, opening up prospects for improving productivity and optimizing production processes.
This paper utilizes AI technology in product defect analysis and applies it to an automated mold return model to research and build a simulation model capable of automating the product inspection and sorting process, thereby contributing to the development trend of smart production lines.

1. An overview of industrial automation

In the context of rapid scientific and technological development, automation has become an inevitable trend in the industrial sector. Automation not only helps increase labor productivity but also contributes to improving product quality, reducing production costs, and increasing the competitiveness of businesses in the global market.

Industrial automation is understood as the use of control systems such as computers, robots, and high-tech equipment to operate and control production processes with minimal human intervention. These systems can include automated production lines, programmable logic controllers (PLCs), supervisory control and data acquisition systems (SCADA), and modern industrial robots.

Currently, automation is developing rapidly in conjunction with the Fourth Industrial Revolution. Technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data, and cloud computing are being integrated into production systems, creating smart factories. As a result, production processes can be optimized, monitored remotely, and errors can be predicted before they occur.

The applications of automation in industry are diverse, ranging from automotive, electronics, and food manufacturing to textiles and energy. For example, in the automotive industry, robots are used for high-precision welding, painting, and assembly. In the food industry, automated packaging lines help ensure hygiene and increase production speed.

Alongside its immense benefits, automation also presents several challenges, such as high initial investment costs, the need for highly skilled personnel, and the risk of replacing some unskilled workers. However, in the long run, automation remains an inevitable path for businesses to achieve sustainable growth.

In Vietnam, automation is gradually being widely applied in many industries. The government and businesses are focusing on investing in technology and training human resources to keep up with global trends.

In summary, industrial automation currently plays a crucial role in improving production efficiency and promoting economic development. In the future, with the continuous advancement of science and technology, automation will develop even more strongly and become the core foundation of modern industry.

2. AI technology and mold recall models apply AI technology in product defect analysis

Artificial intelligence (AI) is a crucial field of computer science, focusing on creating systems capable of performing tasks that require human intelligence, such as learning, reasoning, recognition, and decision-making. Key branches like machine learning, deep learning, and natural language processing have contributed to AI's increasing intelligence and widespread application. In the industrial sector, AI plays a key role in manufacturing automation, enabling robots to operate accurately, reducing labor costs, and increasing productivity. Furthermore, AI is used for predictive maintenance, product quality control through computer vision, and

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optimizing supply chains and control systems. In the future, the development of AI in industry will be closely linked to its integration with the Internet of Things (IoT), leading to the creation of smart factories, expanded intelligent automation, the development of collaborative robots, and the efficient exploitation of big data.

Automated mold rework models utilizing AI technology for product defect analysis are an advanced solution in modern industrial manufacturing, aiming to improve quality and optimize the manufacturing process. Mold rework is the process of adjusting, repairing, or perfecting a mold after detecting deviations or defects in the product, especially common in industries such as plastic injection molding and metal casting. When integrated with AI, the system can collect and analyze data from the production process through technologies such as computer vision to detect surface defects, dimensional errors, or shape defects. Simultaneously, machine learning and deep learning algorithms help the system "learn" from previous defect data, thereby predicting the cause of the defect and suggesting mold adjustments automatically and accurately.

Beyond simply detecting errors, this model offers real-time feedback, shortening testing time, reducing production costs, and minimizing reliance on human experience. In the context of Industry 4.0, AI-powered automated mold feedback models can integrate with intelligent manufacturing systems, creating a closed loop process from detection – analysis – adjustment – inspection. This allows businesses to improve productivity, enhance product quality, and increase competitiveness in the market.

3. The main device uses a model design

The system utilizes various automation devices, each performing a crucial function to ensure accurate, stable, and efficient control, monitoring, and operation. Below are some of the main devices in the model:

Figure 1: Equipment used in the model

The Mitsubishi FX3U PLC is the central controller of the entire system. The FX3U PLC can read and write signals from sensors, push buttons, cameras, and send control signals to motor drivers, relays, and actuators.

Cameras play a crucial role in capturing images for surveillance or computer vision processing. They connect directly to the computer via USB, allowing for real-time image processing using specialized software or vision solutions.

A USB to RS485 converter is a communication device used to connect a computer or PLC to industrial equipment using the RS485 communication standard, typically Modbus RTU. This device is used to connect stepper motor drivers, RS485 sensors, HMI displays, or other expansion modules to a computer for monitoring and control.

Stepper motors are motors that rotate in small angular increments, enabling precise positioning without the need for feedback encoders. Stepper motors work by controlling each coil inside according to a series of pulses from the driver, thereby creating smooth and precise rotational movement.

Pneumatic cylinders are linear actuators that operate using compressed air pressure. When compressed air is supplied, the piston inside moves, creating a pushing or pulling force depending on the design. Combined with solenoid valves and relays, the cylinder can operate fully automatically under PLC control.

A stepper motor driver is an intermediary that receives control signals from the PLC (pulse/direction signals) and supplies precise current to the motor phases. The driver determines the smoothness, torque, and accuracy of the motor through microstepping levels. Adjusting the current and pulse frequency appropriately helps the motor operate stably, reduces vibration, and achieves high accuracy in positioning systems.

A screw and linear guide is a mechanical drive system used to convert rotational motion from a motor into translational motion with very high precision. Thanks to the use of recirculating bearings, friction is significantly reduced compared to conventional screws, resulting in smoother movement, higher load capacity, and good repeatability. The accompanying guide rail ensures straight movement without vibration or misalignment.

A relay is a device used to switch electrical loads on and off using a control signal from a PLC. Relays function to isolate the voltage between the control circuit (typically 24 VDC) and the power circuit (AC 220V or higher DC). With their simple design and high reliability, relays are an indispensable component in any automation system.

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4. The working principle of AI-powered automated mold recovery models

When the system starts operating, the conveyor belt carries the mold to the sensor's detection position, and the conveyor belt stops. Motor-cylinder assembly 3 then moves forward, picks up the mold, and drops it into the chute. Next, the product is moved to the product processing area. A camera scans the product, and AI identifies whether it is defective. If the product is defective, motor-cylinder assembly 3 moves forward, picks up, and drops the defective product into the defective product storage area. If the product is not defective, motor-cylinder assembly 3 moves forward, picks up, and drops the product into the mold. The sensor detects the product's impact, and the cylinder assembly pushes and pulls the product and mold to the desired position. Next, cylinder assembly 1 picks up and drops the product into the standard product storage area, and cylinder assembly 2 picks up and drops the mold onto the conveyor belt. The conveyor belt then carries the mold to the sensor's detection position, and the process repeats.

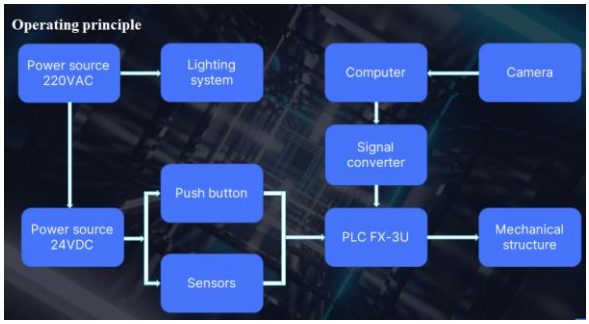

Figure 2. Operating principle of the model


Figure 3. Mold return model upon completion

The AI model was developed using PyCharm software with the Python programming language. The problem consists of the following components:

*** Import libraries:**

```
import sys
import os
import pathlib
import torch
import cv2
import numpy as np
import time
from pymodbus.client import ModbusSerialClient
```

sys: Manage system parameters, for example, sys.path to add library paths.
os: Working with paths, folders, and files.
pathlib: Supports object-based path manipulation.
torch: The PyTorch library is used to load and run the YOLOv5 deep learning model.
cv2: OpenCV is used for image processing, camera reading, drawing rectangles, and displaying the results.
numpy: Array manipulation, fast arithmetic calculations.
time: Measuring time, delay, and steady-state conditions.
pymodbus.client.ModbusSerialClient: Connecting and controlling the PLC via Modbus RTU protocol.

*** Path configuration:**

```
# ================ CẤU HÌNH ĐƯỜNG DẪN ================
BASE_DIR = os.path.dirname(os.path.abspath(__file__))

# Thư mục chứa YOLOv5
YOLOV5_DIR = os.path.join(BASE_DIR, 'yolov5')

# Nếu YOLOv5 chưa có trong sys.path thì thêm vào
if YOLOV5_DIR not in sys.path:
    sys.path.insert(0, YOLOV5_DIR)

from yolov5.utils.augmentations import letterbox
pathlib.PosixPath = pathlib.WindowsPath  # Fix lỗi đường dẫn trên Windows
```

- BASE_DIR: Get the current directory path containing the script file.
- YOLOV5_DIR: The folder contains the YOLOv5 source code.
- Add YOLOV5_DIR to sys.path if it's not already there, so Python can import YOLOv5 modules.
- letterbox: This function is used to resize images while maintaining aspect ratio, and is necessary for YOLOv5.
- pathlib.PosixPath = pathlib.WindowsPath: Fixes path compatibility issues when running on Windows.

*** Modbus model path and address**

```
# ================ ĐƯỜNG DẪN MODEL ================
MODEL_KHUON_PATH = os.path.join(BASE_DIR, 'model', 'SPVR3.pt')
MODEL_NG_PATH = os.path.join(BASE_DIR, 'model', 'NGVR6.pt')

# ================ ĐỊA CHỈ COIL ================
COIL_M554 = 553  # Địa chỉ coil NG (M554)
COIL_M555 = 554  # Địa chỉ coil GOOD (M555)
```

- MODEL_KHUON_PATH và MODEL_NG_PATH: The path leads to two YOLOv5 models, one for product mold recognition and one for non-product (NG) inspection.

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- COIL_M554 và COIL_M555: The PLC coil address is used to control the GOOD/NG signal.

*** Connecting Modbus RTU to PLC**

```
# ================ KẾT NỐI MODBUS RTU ================
client = ModbusSerialClient(
    port='COM5',
    baudrate=19200,
    bytesize=8,
    parity='N',
    stopbits=2,
    timeout=1
)
client.unit_id = 1  # Slave ID của PLC

if not client.connect():
    print("❌ Không thể kết nối Modbus. Kiểm tra cổng COM hoặc kết nối vật lý.")
    exit()
```

- Initialize a client to connect via Modbus port 5.
- baudrate, bytesize, parity, stopbits, timeout: Modbus communication parameters.
- unit_id: PLC Slave ID.
- Check the connection; if it fails, exit the program.

*** Coil control function**

```
# ================ HÀM GHI COIL ================
def dieu_khien_coil(coil_address, state):
    try:
        result = client.write_coil(coil_address, state)
        if result.isError():
            print(f"⚠️  Ghi coil lỗi tại địa chỉ {coil_address}")
        else:
            ten = "M555 (GOOD)" if coil_address == COIL_M555 else "M554 (NG)"
            print(f"✅ Đã ghi {ten}: {state}")
    except Exception as e:
        print(f"❌ Lỗi khi ghi coil: {e}")
```

- Write the ON/OFF signal to a specific coil address.
- state = True/False: Turn the coil on/off.
- Print success or error messages.

*** Load the YOLOv5 model**

```
# ================ LOAD MÔ HÌNH YOLO ================
print("🔄 Đang load mô hình KHUÔN và NG...")

yolo_khuon = torch.hub.load(
    YOLOV5_DIR,
    'custom',
    path=MODEL_KHUON_PATH,
    source='local'
)

yolo_ng = torch.hub.load(
    YOLOV5_DIR,
    'custom',
    path=MODEL_NG_PATH,
    source='local'
)
yolo_ng.conf = 0.20
```

- Use torch.hub.load to load the YOLOv5 model from the local directory.
- yolo_khuon: Product mold identification.
- yolo_ng: Identifying defective (NG) products, conf = 0.2 means the detection probability threshold is 20%.

*** Open camera**

```
# ================ MỞ CAMERA ================
cap = cv2.VideoCapture(1)
if not cap.isOpened():
    print("❌ Không mở được camera.")
    exit()
```

- cv2.VideoCapture(1): Open camera number 1.
- Check if the camera is successfully turned on.

*** Waiting variable stabilizes**

```
# ================ BIẾN CHỜ ỔN ĐỊNH ================
last_state = None
last_change_time = None
stable_state = None
DELAY_SEC = 4.0  # thời gian chờ ổn định (giây)
```

- last_state: Previous status (GOOD/NG/NONE)
- last_change_time: The moment the state changes.
- stable_state: Current stable state.
- DELAY_SEC: The waiting time for the stable state before coil recording.

*** Main loop**

```
# ================ VÒNG LẶP CHÍNH ================
while True:
    ret, frame = cap.read()
    if not ret:
        print("⚠️  Không đọc được khung hình.")
        break
```

- Continuously reading frames from the camera.
- If it can't read the message, exit the loop.

*** Unleash resources**

```
cap.release()
cv2.destroyAllWindows()
client.close()
```

- Release the camera, close all OpenCV windows..
- Close the Modbus connection to the PLC.

5. Conclude:

After research, the authors designed a product transport and mold return system capable of precisely controlling product position using stepper motors and lead screws; collecting product image data and training an AI model to distinguish between good and defective products; integrating the two systems into a complete automation process; and simulating real-world product inspection and sorting operations. The system operates stably, with high accuracy and no errors. The research results provide an important foundation for further development of a more complete system in the future.

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