IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.102 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 12, December 2024

DOI: 10.17148/IJARCCE.2024.131218

MULTISOURCE DATA FUSION AND CHANNEL ATTENTION CNNS FOR EFFECTIVE FAULT DIAGNOSIS OF INDUSTRIAL ROBOTS

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Abstract: Industrial robots are prone to failure due to harsh working environments, which affects movement accuracy. The fault diagnosis of industrial robots has become an indispensable part of robot collaborative maintenance in intelligent manufacturing. Most existing diagnostic methods only use a single data source, and the diagnostic accuracy will be affected due to signal acquisition errors and noise interference. This paper proposes a multi-source data fusion and channel attention convolutional neural network (MD-CA-CNN) for fault diagnosis of multi-joint industrial robots. The network takes the time domain data and time-frequency domain data of the vibration signal, torque signal, and current signal of the six joints of the robot as input. Then, we realize the diagnosis of the faults by using a Softmax Classifier layer after the two parts of feature extraction and feature fusion. In addition, a channel attention mechanism is developed. It acts on the two parts of feature extraction and feature fusion, respectively. It assigns weights to different source data and weights to time-domain and time-frequency domain features.

Keywords: 360 degree camera, Tensor flow, Digital Image Processing, Conveyer Belt

I. INTRODUCTION

In an increasingly industrialized world that moves towards the concepts established by the thematic of Industry 4.0, it makes no sense to have highly dynamic and versatile equipment, such as industrial robots and controllers, performing continuously the same tasks thought lifecycle without receiving new inputs and different configuration from the outside world. Industrial robots have long been used to automate manufacturing processes to improve productivity, quality, and safety. Therefore, it is meaningful to study a highly accurate fault diagnosis method for industrial robots to arrange appropriate maintenance strategies and reduce maintenance costs. In the industrial field, there are three main ways to diagnose equipment faults: knowledge-based, model-based, and data-driven. Knowledge-based diagnostics require expert experience to identify the status of the device. These new concepts have led many engineering companies and schools to develop and search for new solutions to overcome some of the challenges ahead.

II. METHODOLOGY

The design methodology consists of two main components; Hardware (That describes the system's physical components) and Software (Which instructions are encoded on the computer). The block diagram of the system.

The objects are randomly placed on a running conveyor belt, a USB camera installed on the top of the conveyor allows to identify and follow the objects along the conveyor until they reach the point of capture. The conveyor is powered by a Variable Frequency Drive (VFD) and the speed can be adjusted according with the created algorithm. When the objects reach the point of capture, an articulated robot pick up the objects in the current position and inclination. Multiple objects could be tracked simultaneously, and the speed of the conveyor is automatically adjusted to guarantee that all the objects will be picked up. In the model training stage, the processed data are randomly divided into three independent datasets, i.e., training set, validation set, and testing set, in the ratio of 7:2:1.

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The structure of the MD-CA-CNN model was determined by pre-experimentation. The proposed MD-CA-CNN model is trained, evaluated, and optimized offline using the training and validation set samples and their corresponding labels. The loss function is computed, and the model weights are updated according to the backpropagation principle. The test set samples are used to test the accuracy of the MD-CA-CNN model after training.

In the fault diagnosis stage, the trained MD-CA-CNN model is deployed, and the robot field data is collected as input to the model using the same time window length as the data preprocessing stage to obtain the output results. Then, the diagnostic results are used to provide decision support for maintenance. In the data preprocessing stage, a sliding window method segments the data along the time dimension. The sliding window method is a commonly used data enhancement method in fault diagnosis, which can significantly increase the number of training samples. The structure of CNN mainly consists of alternating convolutional layers, nonlinear layers, pooling layers, and fully connected output layers. Convolutional layers are the most important part of CNN. Each convolutional layer contains multiple convolutional kernels. Unlike the traditional fully connected layer, the convolutional layer performs convolutional operations through convolutional kernel.

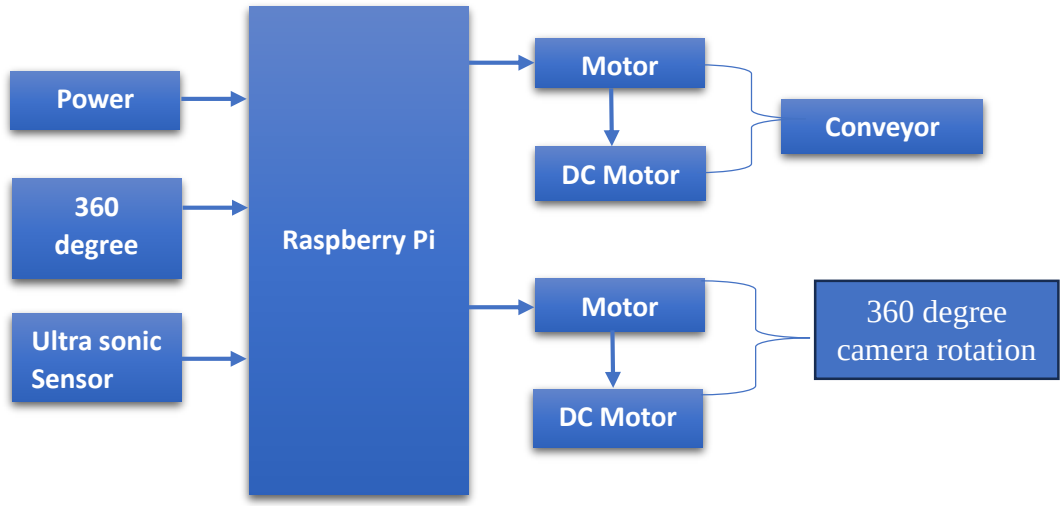

Figure 1: Block diagram of conveyer belt

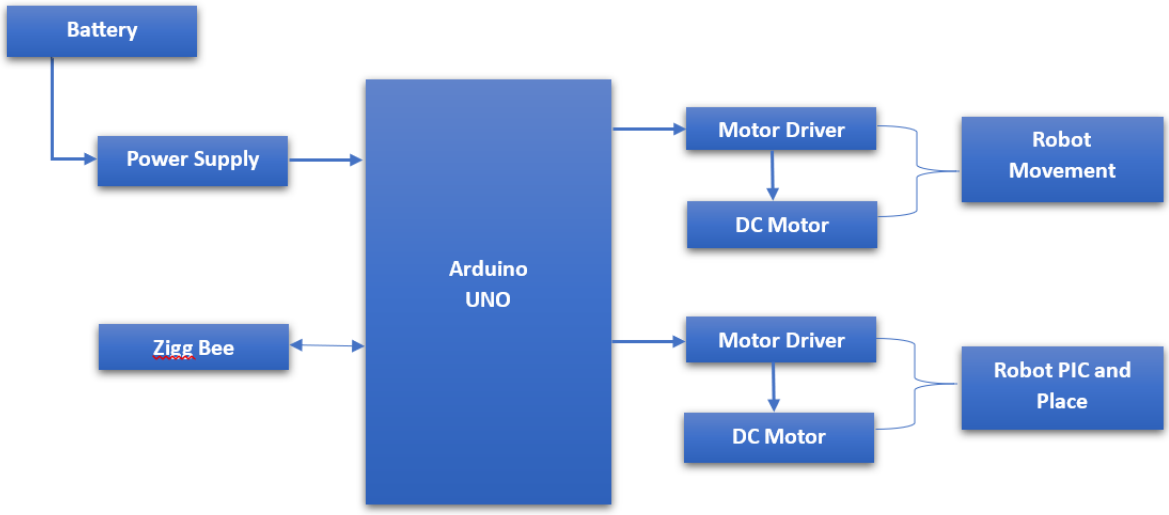

Figure2**:** Block diagram of multisource data fusion and channel attention CNNS for effective fault diagnosis of Industrial robots

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III. IMPLEMENTATION

APPROACH

The total system is divided into 3 modules- Database creation, Training the dataset, Testing, sending alert messages as an extension.

1. Database creation
a) Initialize the camera and set an alert message to grab the attention of the students.
b) Get user id as input
c) convert the image into gray scale, detect the face and
d) Store it in database by using given input as label up to 20 frames.

2. Training
a) Initialize LBPH face recognizer.
b) Get faces and Id's from database folder to train the LBPH face recognizer.
c) Save the trained data as xml or yml file.

3. Testing
Load Haar classifier, LBPH face recognizer and trained data from xml or yml file.
a) Capture the image from camera,
b) Convert it into gray scale,
c) Detect the face in it and
d) Predict the face using the above recognizer.

This proposed system uses Viola Jones algorithm for face detection which uses modified Haar Cascades for detection. Raspberry Pi is the main component in the project. We will be using USB webcam to capture photos. We can access Raspberry Pi's console either by using SSH in laptop or by using Keyboard and mouse with the display device like TV connected to Pi. Firstly, the algorithm needs a lot of positive images and negative images to train the Haar cascades classifier. Positive images are images with clear faces where negative images are those without any faces.

Haar Cascades:

Each feature is represented as a single value obtained from the difference of the sums of pixels in white rectangle from the sum of all pixels in the black rectangle. All different possible sizes and locations of classifier is used for calculating of plenty of features. As the number of classifiers increase the arithmetic computations seems to take a long time. To avoid this, we use the concept of Integral Image. In Image Processing Integral image is a data structure which is summed area table and algorithm for quickly and efficiently generating sum of values in a rectangular grid subset. Integral image is derived by using the formula.

Integral image :

To solve the complexity of the number of classifiers applied for calculation we use Ad boost machine learning algorithm, which is inbuilt in OpenCV library that is cascade classifier, to eliminate the redundancy of the classifiers. Any classifier which has a probability of 50% of more in detection is treated as weak classifier. The Sum of all weak classifier gives a strong classifier which makes the decision about detection. Although it is very vague to classify with one strong classifier we use the cascade of classifiers. Classification takes place in stages, if the selected region fails in the first stage, we discard it. We don't use the classifiers on that region which is discarded. The region which passes all the stages i.e. all strong classifiers is treated as the detected face. Detected Faces are passed to the Face recognition phase. In this phase we use Local Binary Patterns algorithm for face recognition. Local binary patterns are simple at the same time very efficient texture operator which assigns the pixels of the image by comparing with the adjacent pixels as threshold and which results in a binary result.

The detected integral image is subjected to this Local binary pattern which results in decimals are represented as histogram for every integral image. Face recognition is extremely vulnerable to the environment changes like brightness, facial expressions and position. Face pre-processing is the module which reduces the problems that makes the picture unclear to recognize the face such as less brightness and contrast problems and noise in the image and make sure the facial features always be in a constant position.

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In this project we use histogram equalization for face pre-processing. For efficiency we use separate pre-processing which is histogram equalization for left and right face. So histogram equalization is done three times, firstly for the whole face and the other two for side fac

IV. HARDWARE AND SOFTWARE DESCRIPTIONS

- Model: Raspberry Pi 3 Model B+
- Memory: 8GB
- Clock Speed: 2.4GHz
- General Purpose Input Output (GPIO) pins: 40-pins
- Full-size HDMI
- 4 USB 2.0 ports
- Camera Serial Interface (CSI): camera port for connecting a Raspberry Pi camera
- Display Serial Interface (DSI): display port for connecting a Raspberry Pi touchscreen display
- Power Source Connector (PSC): To enable the external power source.
- Operating Voltage: 12V

It is capable of performing various functionalities such as surveillance system, military applications, surfing internet, playing high definition videos, live games and make databases. The device is implemented using a Raspberry pi 3B board and their specifications are as follows.

Raspberry Pi is a credit-card sized computer manufactured and designed in the United Kingdom by the Raspberry Pi foundation with the intention of teaching basic computer science to school students and every other person interested in computer hardware, programming and DIY-Do-it Yourself projects.

The Raspberry Pi is manufactured in three board configurations through licensed manufacturing deals with Newark element14 (Premier Farnell), RS Components and Egoman. These companies sell the Raspberry Pi online. Egoman produces a version for distribution solely in China and Taiwan, which can be distinguished from other Pis by their red coloring and lack of FCC/CE marks. The hardware is the same across all manufacturers.

The Raspberry Pi has a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor, Video Core IV GPU and was originally shipped with 256 megabytes of RAM, later upgraded (Model B & Model B+) to 512 MB. It does not include a built-in hard disk or solid- state drive, but it uses an SD card for booting and persistent storage, with the Model B+ using a MicroSD.

The Foundation provides Debian and Arch Linux ARM distributions for download. Tools are available for Python as the main programming language, with support for BBC BASIC (via the RISC OS image or the Brandy Basic clone for Linux), C, Java and Perl.

As of February 2014, about 2.5 million boards had been sold. The board available online in India at a price of Rs. 3000.

Raspberry pi 3 model B+

The Raspberry Pi 3 Model B+ contains a wide range of improvements and features that will benefit the designers, developers, and even engineers who are looking to integrate Pi systems into their products. Here are some of the new Pi's specs:

- Quad core 64-bit processor clocked at 1.4GHz
- 1GB LPDDR2 SRAM
- Dual-band 2.4GHz and 5GHz wireless LAN
- Bluetooth 4.2 / BLE
- Higher speed ethernet up to 300Mbps

Power-over-Ethernet capability (via a separate PoE HAT)

The table below shows the specs of the Raspberry Pi 3 B and the Raspberry Pi 3 B+

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EMC Compliance
One feature included with the Raspberry Pi 3 Model B+ is a wireless dual-band LAN that comes with modular compliance certification. For those who are unaware, electronic products cannot be constructed and then released to the market without having some tests done to them (see CE and FCC), and many of these tests look for interference. Testing for interference (also known as EMC) can be incredibly costly and difficult to isolate, but, thanks to the WLAN's modular compliance certification, you can expect significantly lower EMC issues when integrating the Pi into a product.

. *Physical Features*

While the mechanical layout of the Pi has not changed (GPIO location, drill holes, etc.), the PCB itself has clearly undergone some physical changes. The main processor is no longer housed in a plastic package. Instead, it has a metal package, which may be beneficial for those who want to keep the temperature of the Pi as low as possible (with the aid of a heat sink). The top side also shows fewer components, and a four-pin header (used for PoE) has been included in the top right of the PCB.

Web Camera

Web Camera feeds or streams its image in real time to or through a computer to a computer network. Unlike an IP camera(which connects using Ethernet or Wi- Fi),a web cam is generally connected by a USB cable, or similar cable, or built into computer hardware, such as laptops.

L298N Motor Driver
This L298N Motor Driver Module that is shown in fig. 3 is a high-power motor driver module for driving DC and Stepper Motors. This module consists of an L298 motor driver IC and a 78M05 5V regulator. L298N Module can control up to 4 DC motors, or 2 DC motors with directional and speed control.

Power Supply Module
It is used to provide power to all components. It will take 12v input voltage and convert it in three voltages of 3.3,5,12v.

Voltage Regulators
Voltage Regulators are designed to maintain the constant voltage it may include negative feedback or a simple feed forward design. In this model two types of voltage regulators are used one is IC 7805 and LM317. These two regulators are used to maintain the constant voltage.

Transformer
A transformer is a device that transfers electrical energy from one circuit to another through inductively coupled conductors without changing its frequency. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core, and thus a varying magnetic field through the secondary winding. This varying magnetic field induces a varying electromotive force (EMF) or "voltage" in the secondary winding.

Rectifier
A rectifier is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid-state diodes, vacuum tube diodes, mercury arc valves, and other components.

Filter
The process of converting a pulsating direct current to a pure direct current using filters is called as filtration. Electronic filters are electronic circuits, which perform signal-processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones.

Regulator
A voltage regulator (also called a _regulator') with only three terminals appears to be a simple device, but it is in fact a very complex integrated circuit. It converts a varying input voltage into a constant _regulated 'output voltage. Voltage Regulators are available in a variety of outputs like 5V, 6V, 9V, 12V and 15V. The LM78XX series of voltage regulators are designed for positive input. For applications requiring negative input, the LM79XX series is used. Using a pair of _voltage-divider' resistors can increase the output voltage of a regulator circuit. It is not possible to obtain a voltage lower than the stated rating. You cannot use a 12V regulator to make a 5V power supply. Voltage regulators are very robust.

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These can withstand over-current draw due to short circuits and also over-heating. In both cases, the regulator will cut off before any damage occurs. The only way to destroy a regulator is to apply reverse voltage to its input. Reverse polarity destroys the regulator almost instantly.

SOFTWARE REQUIREMENTS

OpenCV (Open Source Computer Vision) is a library of programming functions mainly aimed at real-time computer vision. Originally developed by Intel, it was later supported by Willow Garage then Itseez (which was later acquired by Intel). The library is crossplatform and free for use under the open-source BSD license. OpenCV supports deep learning frameworks TensorFlow, Torch/PyTorch and Cafe.

It has C++, Python, Java and MATLAB interfaces and supports Windows, Linux, Android and Mac OS. OpenCV leans mostly towards real-time vision applications and takes advantage of MMX and SSE instructions when available. A full-featured CUDA and OpenCL interfaces are being actively developed right now.

There are over 500 algorithms and about 10 times as many functions that compose or support those algorithms. Open CV is written natively in C++ and has a template interface that works seamlessly with STL containers.

In 1999, the Open CV project was initially an Intel Research initiative to advance CPU intensive applications, part of a series of projects including real-time ray tracing and 3D display walls. The main contributors to the project included a number of optimization experts in Intel Russia, as well as Intel‘s Performance Library Team. In the early days of Open CV, the goals of the project were described as:

- Advance vision research by providing not only open but also optimized code for basic vision infrastructure. No more reinventing the wheel.

- Disseminate vision knowledge by providing a common infrastructure that developers could build on, so that code would be more readily readable and transferable.

- Advance vision-based commercial applications by making portable, performance optimized code available for free – with a license that did not require code to be open or free itself.

OpenCV-Python

Python is a general purpose programming language started by Guido van Rossum, which became very popular in short time mainly because of its simplicity and code readability. It enables the programmer to express his ideas in fewer lines of code without reducing any readability.

Compared to other languages like C/C++, Python is slower. But another important feature of Python is that it can be easily extended with C/C++. This feature helps us to write computationally intensive codes in C/C++ and create a Python wrapper for it so that we can use these wrappers as Python modules. This gives us two advantages: first, our code is as fast as original C/C++ code (since it is the actual C++ code working in background) and second, it is very easy to code in Python. This is how OpenCV-Python works, it is a Python wrapper around original C++ implementation.

And the support of Numpy makes the task more easier. Numpy is a highly optimized library for numerical operations. It gives a MATLAB-style syntax.

All the OpenCV array structures are converted to-and-from Numpy arrays. So whatever operations you can do in Numpy, you can combine it with OpenCV, which increases number of weapons in your arsenal. Besides that, several other libraries like SciPy, Matplotlib which supports Numpy can be used with this.

So OpenCV-Python is an appropriate tool for fast prototyping of computer vision problems.
OpenCV-Python Tutorials

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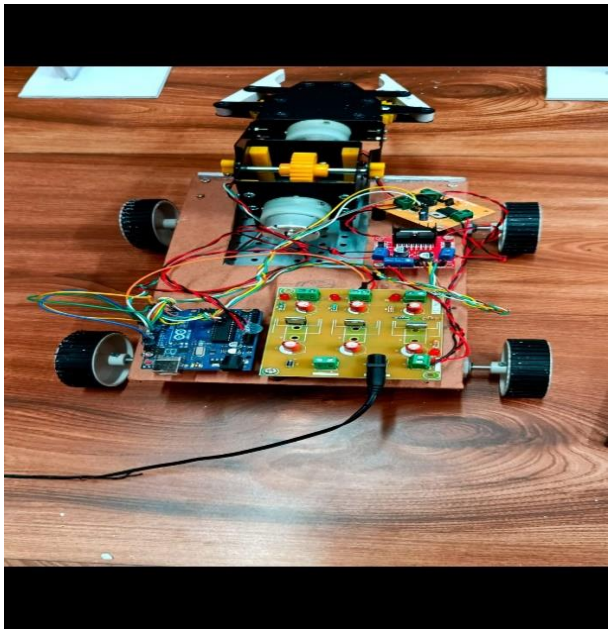
V. RESULT



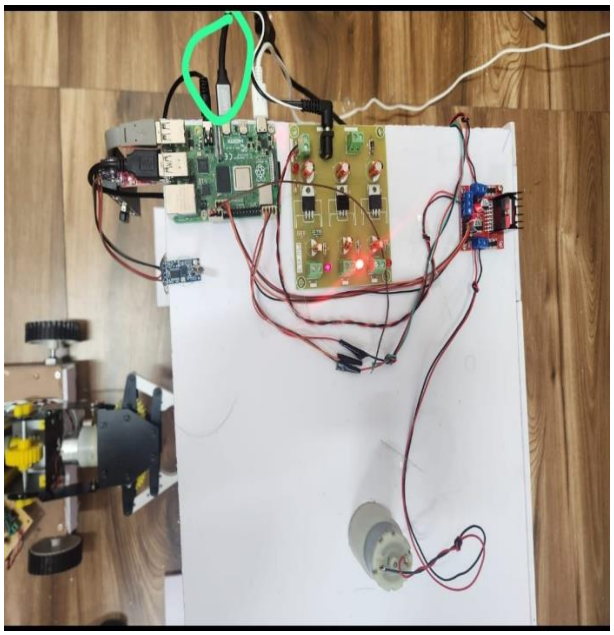


Figure 2:Complete model

Figure 3: Camera showing fault product

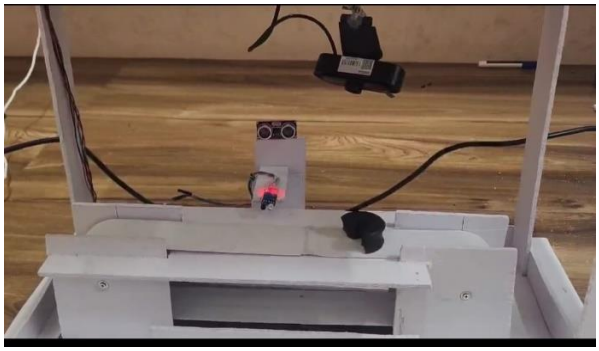


Figure 4: Product moving in conveyer belt

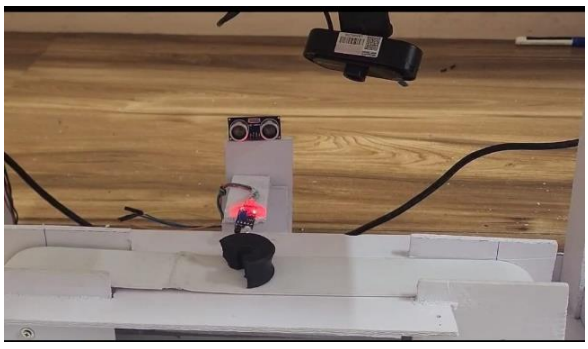


Figure 5**:** IR Sensor detecting the Product

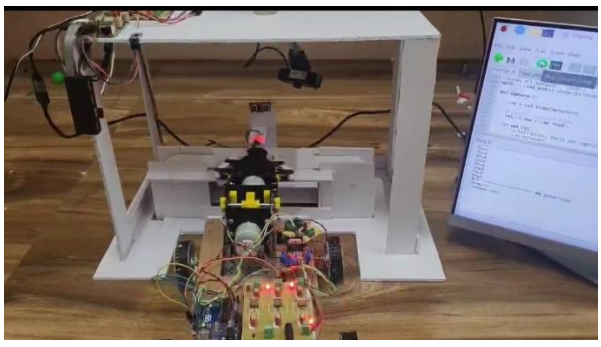


Figure 6: Robot picking the product

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V. CONCLUSION

The development and implementation of the pick-and-place robot successfully demonstrated the automation of repetitive tasks with precision and efficiency. This robot offers significant benefits in various applications, including manufacturing, packaging, and material handling, by improving productivity, reducing human error, and enhancing workplace safety. In this paper, we proposed a multi-joint industrial robot fault diagnosis model based on multi-source data fusion and channel-attention convolutional neural network, namely MDCA-CNN. The model takes the vibration data, torque data and current data of the robot as inputs. The proposed method differs from existing multi-source data fusion techniques in the field of fault diagnosis in the following ways: firstly, the fusion of vibration, current and torque data of robot joints is realized by using CNN channel superposition. Secondly, multiple dimensions of information such as original time-domain signals and time-frequency-domain signals are taken into account, and both 1D-CNN and 2D-CNN are utilized to extract the deep features in both time-domain and time-frequency-domain signals dimensions to obtain more comprehensive fault feature information. Finally, a channel attention mechanism is developed to adaptively assign weights to different source data as well as to time-domain and time-frequency-domain features, thus improving the contribution of important channels to fault diagnosis.We built a testbed to test the performance of the proposed method by diagnosing a variety of six-axis robot RV reducer failures.

ACKNOWLEDGMENT

I would like to express my sincere gratitude to all those who have supported and guided me throughout the course of this project.

First, I would like to thank my project guide and faculty members for their valuable insights, continuous support, and encouragement. Their expertise and guidance were instrumental in the successful completion of this project.

I am also grateful to the technical staff and colleagues who helped with the hardware setup, troubleshooting, and system integration. Their collaborative efforts and suggestions were crucial in overcoming several challenges faced during the development of the project.

A special thanks to my family and friends for their unwavering support and motivation, which kept me focused and driven throughout this journey.

Lastly, I would like to acknowledge the resources and tools provided by the university and the online platforms, which played a significant role in enhancing my learning experience and ensuring the project's success.
This project would not have been possible without the contributions of all these individuals, and I am truly grateful for their support.

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