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Detection of Stainless Steel Corrosion Based on Convolutional Neural Network

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Abstract

The development of the stainless steel pipe industry in Indonesia has shown significant growth, driven by increasing demand across sectors such as construction, oil and gas, food and beverage, and automotive. Despite its advantages in corrosion resistance, stainless steel pipes remain vulnerable to corrosion due to the reduced composition of essential metals during the manufacturing process. Corrosion-related damage can have serious impacts on safety and operational costs, while manual inspection methods are often considered inefficient and inaccurate. This study aims to develop a web-based corrosion detection system using the Convolutional Neural Network (CNN) method. CNN was chosen for its ability to effectively extract image features and its widespread use across various fields such as healthcare, transportation, and manufacturing. By leveraging a CNN model, the system can automatically classify pipe conditions as either 'corroded' or 'not corroded' through image analysis. The results of this research are expected to make a meaningful contribution to the monitoring of stainless steel pipe corrosion in a faster, more accurate, and efficient manner, offering an alternative to conventional methods.

***Keywords**: Corrosion, Stainless Steel, Convolutional Neural Network (CNN), Image Detection.*

1. Intriduction

The development of the pipe industry in Indonesia has experienced significant progress in line with the increasing demand across various sectors, such as construction, oil and gas, and manufacturing. Stainless steel pipes, with their advantages of corrosion resistance and high strength, have become the main choice for use in various industries such as construction, oil and gas, food and beverage, pharmaceuticals, water treatment, and automotive [1]. Technological innovations that improve efficiency and reduce production costs not only impact a single aspect but also provide overall positive effects for the development of the stainless steel pipe industry [2]. However, as the need for stainless pipes and their installation grows more complex, managing stainless steel pipe corrosion becomes increasingly crucial. The use of stainless steel in Indonesia's construction and manufacturing industries continues to rise, showing a positive trend in the adoption of this material.

The problem of stainless steel pipe corrosion can have major impacts on safety, performance, and operational costs. Pipe damage, such as corrosion, occurs because of production processes that use a mixture of materials or metal elements in manufacturing stainless steel to reduce the use of primary raw materials like chromium or nickel. Such reduction can decrease stainless steel's corrosion resistance, particularly in terms of its durability against rust, as the proportion of key elements that provide anti-corrosive properties becomes insufficient [3]. Corrosion monitoring of pipes is still often carried out manually. However, manual inspection requires significant time and cost, and sometimes the results of identifying pipe damage may not be accurate. Therefore, a more effective monitoring approach is needed. Corrosion damage to stainless steel pipes remains a major problem in industries such as construction, manufacturing, oil and gas, and water treatment, which require more efficient monitoring approaches [4].

One solution to overcome pipe corrosion problems is by implementing a CNN model in a web-based monitoring system. The use of CNN models is adopted because many researchers have already utilized them successfully. Based on these studies, the author proposes a web-based monitoring system using advanced analysis methods such as Convolutional Neural Networks (CNN). CNN is one of the most popular methods in deep learning. CNN works to extract features from image data and reduce its dimensions without altering the main characteristics of the image. CNN consists of neurons equipped with weights and biases. Each neuron receives inputs and processes them by performing dot product operations [5]. CNN has been successfully applied in various fields in Indonesia, such as healthcare, agriculture, transportation, security, e-commerce, manufacturing, and education, improving accuracy and decision-making effectiveness.

Considering the need for a more efficient and effective corrosion monitoring system, the author is interested in raising this issue as a final project under the title "Detection of Stainless Steel Corrosion Based on Convolutional Neural Network". This research is expected to contribute to the development of a reliable stainless steel pipe corrosion monitoring system.

2. Literature Review

2.1. Website

In general, a website is a collection of digital pages that provide information in various formats, such as text, images, animations, and other media, accessible through the internet worldwide. Initially, websites were developed as an information medium using the concept of hyperlinks to make it easier for users to navigate different online resources. Thanks to multimedia concepts, websites can deliver information in various forms, including text, images, audio, and video [6].

A website is a set of interconnected web pages consisting of multiple related files. Its structure usually begins with a main page or homepage at the top of the hierarchy, while other pages, known as child pages, fall below it. These pages often include hyperlinks for easier navigation between them. Websites function as internet platforms that connect documents, both within local and global networks. These documents are called web pages, where hyperlinks allow users to move between them (hypertext), whether within a single server or across different servers worldwide. Web pages are accessed using browsers such as Google Chrome, Mozilla Firefox, Internet Explorer, and others [6].

Websites are platforms that serve as media for delivering information and promoting products to make them more widely recognized by the public. They are internet-based applications containing multimedia documents—such as text, images, audio, animation, and video—accessed through the HTTP protocol (Hypertext Transfer Protocol) using browser software. Websites serve multiple functions, such as promotion, marketing, information sources, educational media, and communication tools [7].

In short, websites present information on the internet in multiple formats such as images, videos, text, audio, and interactive content. They also enable interconnection between documents (hypertext) through links, which are accessed via browsers [8].

2.2. Corrosion

Corrosion is a process of degradation or damage on the surface of metals caused by chemical reactions, especially electrochemical reactions, between the metal and its environment. Generally, corrosion is the oxidation of metals due to exposure to environmental substances such as water vapor, oxygen in the air, and dissolved acidic compounds. In everyday life, corrosion is more commonly known as rusting. The word "corrosion" comes from the Latin corrodere, meaning to destroy or rust metal.

This phenomenon is harmful because it reduces the quality and strength of metal materials. Corrosion can also be described as a redox process, where metals undergo oxidation while other surrounding substances—such as oxygen from the air—undergo reduction. From a thermodynamics perspective, corrosion reflects the effort of metals and their environment to reach a stable equilibrium, marked by the formation of stable compounds like metal oxides. The most common example is rust on iron, chemically known as $Fe_2O_3 \cdot xH_2O$, a reddish-brown solid compound. This process usually involves the oxidation of metal and the reduction of oxygen or nearby electrolytes, categorizing corrosion as an electrochemical reaction [9].

2.3. Pipes

A pipe is a closed channel with a circular cross-section used to transport fluids in full flow conditions [10]. The term "pipe" refers to a hollow tubular structure designed to carry or convey various commodities, such as liquids, gases, steam, or fine powders. Pipes are one of the main components in piping systems, which function to transport fluids from one point to another. Piping systems consist of various elements, including pipes, flanges, fittings, bolts, gaskets, and valves, arranged as a unit to ensure efficient fluid flow [11].

Pipes are hollow cylindrical structures used to transport fluids in the form of liquids, gases, or solids like powders. They are often compared to "tubes," although tubes are typically defined by their outer diameter. Pipes can be made from various materials depending on their application, including iron, copper, brass, plastic, PVC, aluminum, and stainless steel. Their design considers pressure strength, wall thickness, fluid temperature, and material type, factoring in corrosion resistance and mechanical strength. Pipes are used to transport fluids under different pressure and temperature conditions [12].

3. Method

This study uses Convolutional Neural Networks (CNN) to detect corrosion in stainless steel pipes. Several steps are involved in designing the object detection system for pipe corrosion analysis. The system diagram is as follows:

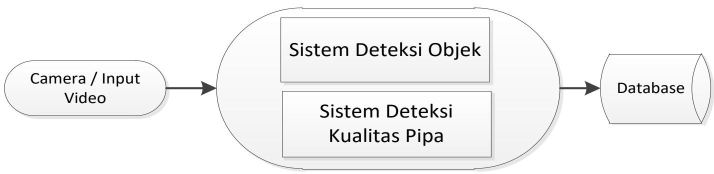

Fig. 1: System Diagram

This flowchart illustrates the process flow in the pipe corrosion inspection system using video-based object detection technology. The steps are explained as follows:

1. Camera/Input Video

This is the initial stage where a camera or other video input device captures footage of a specific area, such as a pipeline inspection path. The camera acts as the visual data source for the system to detect and analyze pipe corrosion. The captured images or videos continuously stream into the system for inspection.

2. Object Detection System
   At this stage, the object detection system analyzes the video captured by the camera. This technology uses computer vision algorithms, particularly CNN, to recognize and detect pipe surface conditions in the video. Each pipe appearing in the footage is identified and automatically inspected for corrosion. This detection allows the system to identify defects or irregularities in pipes that require attention.
3. Pipe Corrosion Assessment System
   Once the object (pipe) is detected, the corrosion assessment system evaluates whether the pipe meets the required corrosion standards. This system typically inspects each pipe passing through the inspection line and provides real-time assessments. This ensures that corrosion data is always accurate and up to date.
4. Database
   Data generated from the corrosion assessment system is stored in a database. The database serves as an organized storage for information on pipe corrosion, inspection times, and other relevant data. It can be accessed by managers for analysis, reporting, or decision-making. Storing data in a database also enables further processing, such as identifying corrosion trends.

The detection system applies the Single Shot Detector (SSD) algorithm for detecting single objects, in this case, pipes.

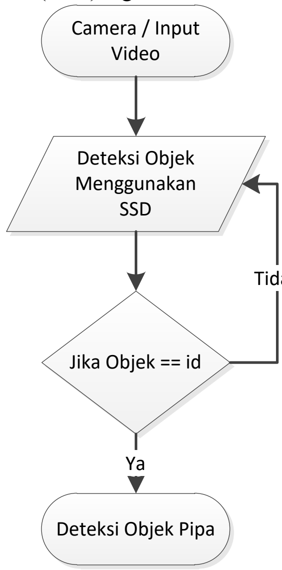

Fig. 2: Object Detection Flowchart

Single Shot Detector (SSD) is one of the most popular object detection methods in computer vision, particularly due to its ease of implementation, good accuracy, and relatively high computational efficiency. SSD allows object detection in a single pass through the neural network, differentiating it from other methods requiring multiple stages.

The SSD model training process involves:

1. Dataset Collection
   A dataset consisting of stainless steel pipe images, including categories such as defects, rust, or other damage. Images are taken from various angles and manually annotated.

2. Data Preprocessing
   a. Image Augmentation: Techniques such as rotation, flipping, or adding noise to increase data variation.
   b. Normalization: All image data is normalized to have uniform pixel values, usually scaled between [0,1].
   c. Resizing: Images are resized to match the SSD input size, i.e., 300x300 pixels.

3. SSD Model Architecture
   This model uses a base architecture such as VGG16 as the backbone. It combines multiple CNN layers to generate bounding box predictions at different image scales.

4. Model Training
   a. Parameter Initialization: Initial weights are set using pretrained weights.
   b. Loss Function: SSD applies a combination of bounding box regression loss and object label classification loss.
   c. Batch Training: Data is trained in batches; here, 16 images per batch are used to accelerate training..

4. Result

The results of this research are presented in the following explanation:

1. Initial Menu Display

Fig. 3: Website Display

This website is designed to facilitate users in automatically detecting corrosion through images. The user interface is made simple and intuitive, with several menus and buttons that have the following functions:

a. Dropdown Menu
This menu allows users to select the image input source, either through a webcam or by uploading a file from the device. This choice determines the input method used in the corrosion detection process.

b. Choose File
This feature enables users to manually select an image from their device. The selected image will be processed by the system to detect corrosion.

c. "Upload & Detect" Button
After an image is selected, users can press this button to upload it and start the automatic corrosion detection process. The system will run an AI-based analysis model to detect and display results on the right side of the screen.

d. "Clear Screen" Button
This button clears the previous detection results from the screen, allowing users to start a new detection process without visual interference from the previous session.

e. "About Application" Button
This button displays information about the application, including technical explanations such as the use of the Convolutional Neural Network (CNN) method in analyzing and identifying corrosion from images.

2. Webcam Menu Display

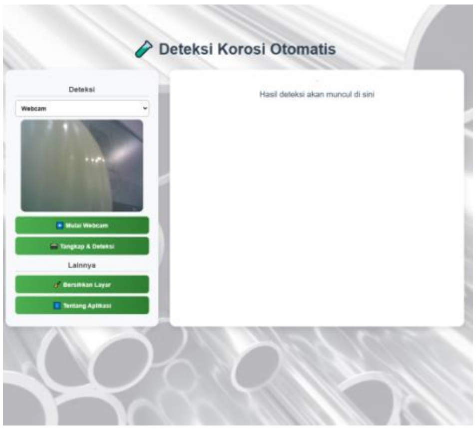

Fig. 4. Website Detection Mode Using Webcam

This display shows the application interface when the user chooses the image input method via webcam. This feature provides convenience in capturing images directly without having to upload files from the device. The functions of each element available are as follows:

a. Dropdown Menu
The dropdown menu at the top allows users to select the input method, either Upload or Webcam. In this view, the user has selected Webcam as the input source.

b. Camera Display
After selecting the webcam, the screen shows a live preview from the device's camera. This preview helps users ensure that the object or corroded area is clearly visible before running detection.

c. "Start Webcam" Button
This button is used to activate the device's camera and start real-time image capturing.

d. "Capture & Detect" Button
Once the camera preview is active, this button allows users to capture an image from the webcam preview and automatically run the corrosion detection process on the image using the available AI model.

e. "Clear Screen" Button
Just like in file upload mode, this button clears the previous detection results from the screen so users can start a new process without old results remaining visible.

f. "About Application" Button

This button provides additional information about the concepts, technologies, and methods used in the application, such as the implementation of Convolutional Neural Networks (CNN) for corrosion analysis and identification from images.

3. Upload and Detection Display

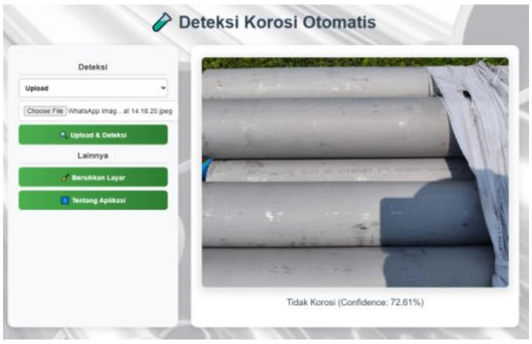

Fig. 5: Upload & Detect 1

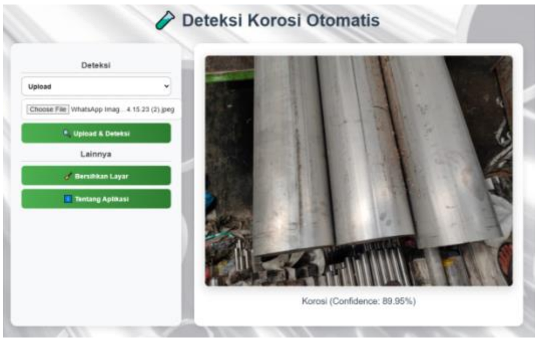

Fig. 6: Upload & Detect 2

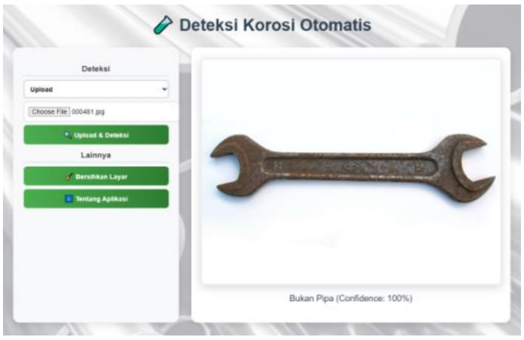

Fig. 7: Upload & Detect 3

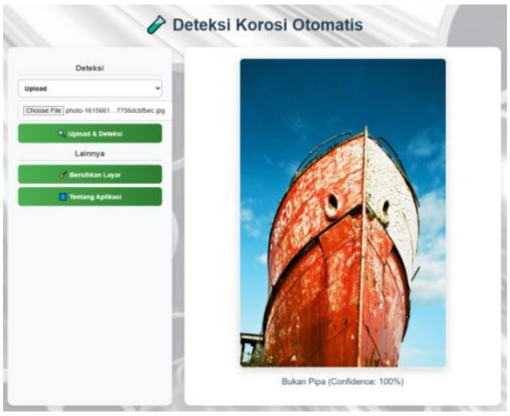

Fig. 8: Upload & Detect 4

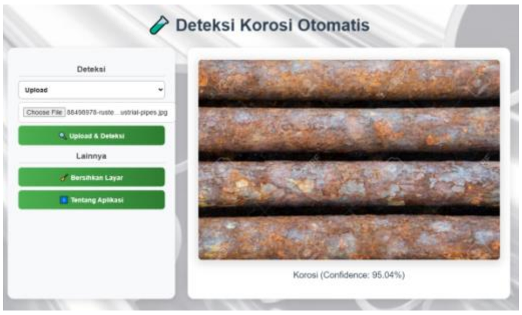

Fig. 9: Upload & Detect 5

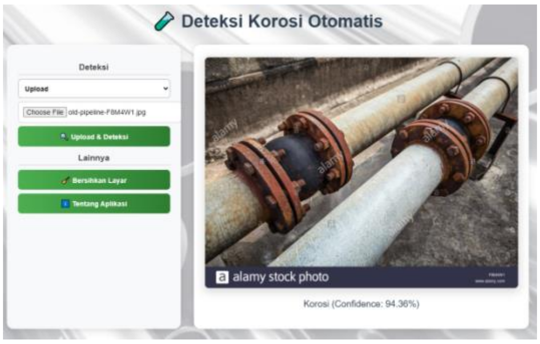

Fig. 10: Upload & Detect 6

This display shows the results when the user utilizes the Upload feature to detect corrosion from an image selected from the device. After the image is uploaded and processed by the system, the detection results are displayed visually along with the confidence level of the detection model.

The key components in this display include:

a. Dropdown Menu (Upload)
The menu is set to the Upload option, allowing users to select an image from their device as input for the detection process.

b. Choose File Field
The user has selected an image named old-pipeline-F8M4W1.jpg, showing a rusty pipe as the corrosion detection object.

c. “Upload & Detect” Button
This button is used to upload the selected file and run the automatic detection process using the AI-based model.

d. Image Display & Detection Results
After the process is completed, the system displays the uploaded image along with the detection results below it. In this example, the system successfully detected corrosion with a confidence level of 94.36%, indicating that the model is highly confident about the presence of corrosion in the analyzed object.

e. “Clear Screen” Button
Used to clear the image and detection results from the screen so the user can start a new process.

f. “About Application” Button
Provides information about the methods and technologies used in the application, including the use of Convolutional Neural Networks (CNN) in visual classification.

4. About Display

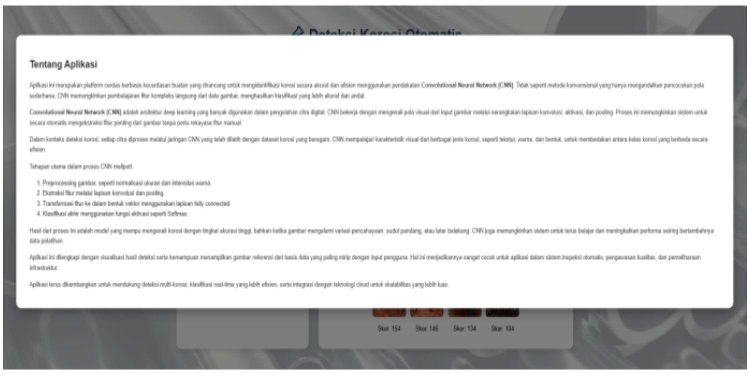

Fig. 11: About Display

This section of the website displays information about the application.

5. Conclusion

The conclusions from this research are as follows:

1. High Efficiency and Accuracy in Corrosion Detection. The system is capable of detecting corrosion quickly and accurately using a deep learning approach, making it suitable for real-time quality monitoring applications.
2. Flexible and Potential for Further Development. With an open architecture that supports integration with other technologies such as IoT and machine learning, this system has great potential to be applied in various industrial environments and continuously developed.

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