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Low-Cost Sensor Force for Measuring Deep Drawing Force Using Edge Computing

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ABSTRACT

Measuring force of a deep drawing process is not a new procedure in labs. But in the shop floor this is challenging because of many aspects such as the costs of instruments and the harsh environment for it. But after industry 4.0 begins the necessity of measuring process and acquiring data is more and more needed. This article shows how to design a low-cost sensor affordable to make this force acquisition on any tool or press equipment in shop floor using edge computing.

Keywords: Force Sensor. Edge Computing. Deep Drawing Force.

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1 INTRODUCTION

Over recent years the number of companies monitoring the production process has been increasing. The number of firms offering products to perform this task is growing rapidly and in-forming processes are the same. Even though the cost of instruments to force acquisition in deep drawing process are still relatively high or difficult to find an industrial solution. Most of the force measuring systems are dedicated to laboratory or very critical manufacturing processes offering high precision data, high sample rate, which is used for research purposes. These acquisition systems are expensive and delicate to use on the shop floor.

The main objective of this paper is to explore a way to design and produce a low-cost sensor using edge computing technology to measure a deep drawing force. This sensor could be applied directly on deep drawing tools collecting data and send to the cloud to be analyzed using a website. Force information will be used to monitor tool wear, improving the quality and efficiency of the deep drawing process.

2 COMPUTING ARCHITECTURES

2.1 CLOUD COMPUTING

Cloud computing is a model for the provision and use of information and communication technologies. They provide remote access to several common computing resources in the form of services via the Internet.

This computer system can be divided into two parts: client devices and servers. There are also three types of clouds. IT services: infrastructure as a service (IaaS), Platform as a Service (PaaS) and Software as Service (SaaS) [1]. The use of this technology in manufacturing and industry. Automation offers useful opportunities for efficiency, connectivity, scalability, communication between sensors and computing systems and increase data storage and processing capacity.

2.2 FOG COMPUTING

Computer systems are used to transport the cloud computing capabilities closer to the network, a decentralized system Computer architecture in which data is distributed between data sources and the cloud. This is horizontal architecture that distributes resources and services stored in the cloud to devices. In other words, fog computing can be understood as a middle layer that controls the connection between the cloud and network perimeter.

The most notable difference between fog computing and Cloud computing is: While cloud computing is a centralized system, fog computing is a distributed decentralized system infrastructure.[1]

2.3 EDGE COMPUTING

Edge computing sits on the border between a industrial or production plant and a network. In this architecture, the source data is processed close to the source without being sent over long distances (to the cloud or other centralized processing systems). Increases data transfer to a centralized system reducing distance and time data transfer, as well as the speed and efficiency of devices e applications.

The main difference between edge computing and fog computing is where data is processed. The edge calculation is performed directly on devices equipped with sensors or on gateways physically close to the sensors. The advantages of Edge computing is the optimization of improved connection and response times. This gets better too security by implementing encryption closer to the network center. However, Edge Computing has a limited scope based on specific, predefined processing patterns that occur at the end of the network.[2]

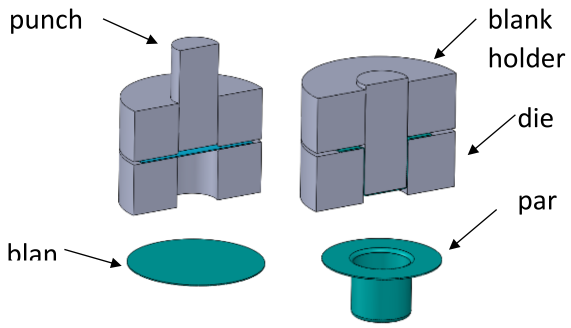
3 DEEP DRAWING FORCE

The deep drawing process is composed of a punch that presses a sheet metal against a die creating a desirable form.

This process generates a plasticity deformation that mechanically deform the sheet metal by a force superior then elastin strain limit and less than strain limit.

Figure 1

Deep drawing process



To calculate the deep drawing force in sheet metal forming, you can use the following formula:

$$\mathrm{F} = \pi.\mathrm{d}.\mathrm{t}.\sigma.\left(\frac{D}{d} - 0.6\right) \qquad (1)$$

Where:

- F is the drawing force.
- d is the punch diameter.
- t is the thickness of the sheet.
- σ is the tensile strength of the material.
- D is the blank diameter.

This formula helps estimate the force required to draw a piece of sheet metal into a die cavity. The drawing force is influenced by the material properties, sheet thickness, and the dimensions of the punch and blank [5].

4 DEEP DRAWING PROCESS FORCE DATA ACQUISITION SYSTEM

While laboratory measurements provide a controlled and precise environment for understanding the deep drawing process, industrial measurements offer a more realistic assessment of the process under actual production conditions. Both approaches are essential for optimizing the deep drawing process and ensuring high-quality production. In deep drawing, force distribution is an important variable that determines the quality of the formed component. The blank holder force is a significant design parameter in the deep drawing process. Adjusting this force can help prevent defects like wrinkles, thinning, splits, and surface deflections. [3]

Using a data acquisition system (DAS) can be used to measure the force applied during deep drawing. This system is a composition of different elements to make force acquisition data current and reliable. The main elements of force measuring are:

4.1 FORCE SENSORS OR FORCE TRANSDUCERS

Are measurement elements designed for the precise measurement of compression and tensile forces.

4.1.1 Piezoelectric force sensors

are based on the piezoelectric measurement principle. They are suitable for measuring (highly) dynamic and quasistatic forces. The force acting on the quartz built into the sensor generates a proportional charge at the signal output. A downstream charge amplifier converts this into a process signal that can be evaluated. One of the special advantages of the piezoelectric measurement element is its constant measurement accuracy over a wide measuring range thus, it is possible to use a very large sensor to measure the smallest of forces with constant measurement accuracy. Piezoelectric sensors are also characterized by a high level of overload protection, eliminating the need for protective measures, especially in low measuring ranges.[6]

Piezoelectric principles are capturing electrical charge by the force applied to a piezoelectric crystal and causes a charge shift at the molecular level and within the lattice structure. This electric charge is captured at the crystal surface and converted into a voltage signal by means of a so-called charge amplifier. The advantage is that the deformation is extremely small since the charge effect is caused by shifts within the atomic structure. This enables the realization of extremely rigid structures featuring high natural frequencies. This is ideal for capturing very fast or high-frequency measurement events. The disadvantage is that the electric charge is very volatile. Where there is no perfect isolation, charge is lost over time. This makes long-term stable measurements difficult, especially if you want to measure small forces. Furthermore, a piezoelectric sensor is far more subjected to temperature changes.[7]

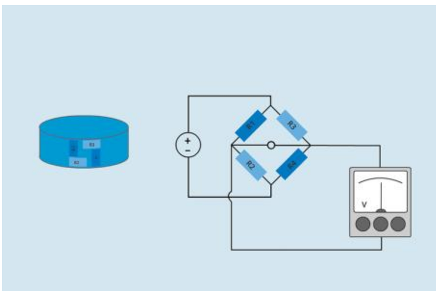
4.1.2 Strain gauge force sensor

Capture a change in electric resistance induced by elastic deformation. The force is applied to a spring body, which deforms proportionally to the force exerted. This deformation again causes compression or stretching of the attached strain gauges and thus a change in their electrical resistance. By using a simple electrical measuring bridge circuit, a usable voltage signal can be generated. The advantage is measurements are very long-term stable and changes in temperature can be better compensated. Sensors featuring very high accuracy can be realized. The disadvantage is the quality of signal acquisition improves with the grade of the strain gauges' elastic deformation. That means that its structure is rather soft, featuring a low natural frequency, which is inappropriate for faster-measuring events. Due to deformation, material fatigue and overstrain are additional critical aspects of this measurement principle.

Strain gauges are metallic-electric measuring elements that precisely measure forces, loads, torque, etc., particularly in static processes. Strain gauges operate based on the physical effect by which the electrical resistance of a wire changes proportionally to the strain exerted on the wire when stretched or compressed. Strain gauges are used in sensors, force and torque sensors, load sensors (for scales), and other measuring devices. Strain gauges are frequently affixed to measuring bodies made of high-strength material.

Figure 2

Strain gouge measurement



4.1.3 Charge amplifiers

In the field of measurement technology, a charge amplifier is essentially a charge converter that converts very low charge signals, as are generated, e.g., by piezoelectric sensors, to proportional voltage signals (volt).

4.1.4 Filter (electronic)

In general, the term filter is understood to mean the blocking or passing of certain frequency ranges. In this way, a filter acts in the frequency domain. The cut-off frequency of the filter determines which content of the signal is cut off or allowed to pass. An idealized filter cuts off the measurement signal at a certain cut-off frequency or allows the measurement signal to pass above a certain cut-off frequency, whereby a clear separation of the required frequency range is created. The cut-off frequency separates the passband from the stopband of the filter. A real filter always has a transition range from the passband to the stopband in the range of the cut-off frequency. In the transition range, the frequency components are already attenuated, but not completely suppressed. The attenuation already begins at frequencies in the passband and continuously increases during the transition to the stopband until the frequency components are eliminated. [3]

- Low-pass filter:

With a low-pass filter of, for example 150 Hz, all frequencies above 150 Hz are cut off. Thus, the signal is only passed in the frequency range up to the set cut-off frequency.

- High-pass filter:

The opposite behavior of a low-pass filter applies to the high-pass filter. If the cut-off frequency is set at 150 Hz, all frequencies above 150 Hz are transmitted.

- Band-pass filter:

With this type of filter, two cut-off frequencies must be defined because the band-pass filter is a combination of first a high-pass filter followed by a low-pass filter. As a result, a defined frequency band is considered. If the lower cut-off frequency is set at 150 Hz and the upper cut-off frequency at 300 Hz, the result is a frequency band between the two cut-off frequencies that passes.

4.1.5 Signal conditioning circuitry

Convert sensor signals into a form that can be converted to digital values. Analog-to-digital converters: An analog-to-digital converter (ADC) converts a continuous analog input signal (e.g. voice from a microphone or measurement values from a sensor) into discrete digital values. There are two main characteristics that are important. The vertical resolution is given by the so-called bit width of the converter: e.g. a 4-bit ADC divides the input signal range into 2^4 = 16 digital values. As of today, common bit widths are in the range of 18 to

24. Hence, the smallest representable value is way smaller than the interfering signals that are normally present, as for example, signal noise. The sampling rate, sometimes also called sampling frequency, equals the time between two samples and is thus the horizontal resolution on the time axis. The more values per time unit the analog-to-digital converter captures (usually stated as samples per second Sps) the faster signals can be recorded. But this implies that more values are to be stored; this again increases the memory requirement. [3] Common sampling rates are in the range of just a few samples per second (e.g. for temperatures) up to several million samples per second for very dynamic signals (e.g. from explosions).

4.1.6 Sampling rate and aliasing effect

In general, a measurement chain designed for digital signal conditioning consists of several components, such as sensors, cables, amplifiers, data acquisition hardware and software. To acquire analog measured values, an analog-digital converter is required which is integrated into the data acquisition hardware. The acquisition of the measurement data is realized by a sampling rate, which is a periodic process. The analog signal is sampled at a defined rate – samples per second – and converted into a digital signal. In order to accurately capture the original analog measurement signal without loss, the Nyquist-Shannon sampling theorem must be observed. To acquire the maximum frequency of interest, the theorem specifies the selection of a sampling rate that is at least twice as high (sampling rate = 2 x Fmax). This ensures that the sampled discrete-time signal contains the expected frequencies. An aliasing error will occur in the signal, if this theorem is not observed.

The aliasing effect is a measurement error in the signal occurring due to an incorrectly set sampling rate. If the sampling rate is too low, the Nyquist-Shannon sampling theorem is not observed and thus the measurement signal is not acquired correctly.

Frequency components that were originally higher than half the sampling rate are interpreted as lower frequencies. This happens due to under sampling of the signal, which results in incorrect amplitudes and low frequencies in the digitized signal.

4.1.7 Signal conditioning

Analog measurement signals often must be conditioned so that they can be processed by downstream systems at all. A classic example is the signal amplification of sensors with low voltage levels, such as thermocouples. This signal conditioning prepares the measurement signal for further processing. Sensors without integrated electronics have a charge output. Since this charge cannot be processed directly by data acquisition systems, it must first be converted into a proportional voltage. This is done in a charge amplifier. Amplification to the required voltage range, often –10V to +10V, is also done in the charge amplifier. Signal conditioning for the subsequent data acquisition system takes place in the charge amplifier.

4.1.8 Signal processing

Signal processing is about extracting information from preprocessed signals to draw the right conclusions based on this information. A distinction is made between analog and digital signal processing.

For example, if you look closely at an analog signal from a piezoelectric force sensor, the signal contains not only the measurement curve of the actual process, but also parasitic signal components such as noise signals or vibrations. The latter have their origin in mechanical structure. With suitable signal processing, the measurement curve of the actual process can be filtered out.

There are countless methods and tools to get important information out of signals. Common tools in analog but also in digital signal processing are filters. Here a signal is processed in such a way that unwanted signal components are filtered out.

In digital signal processing, Fourier transforms - commonly referred to as FFT (Fast Fourier Transform) - are very common. Fourier transforms are used to decompose discrete signals, which are usually in time domain, into their frequency components. It is often easier to analyze signals in the frequency domain, which is achieved with an FFT.

The transition from signal conditioning to signal processing is usually smooth.

4.2 DEEP DRAWING VARIABLES PROCESS DATA ACQUISITION ON LABORATORY

From a long time ago and still today universities and research institutions are used data loggers to acquisition of main variables from deep drawing process. This scientific approach is adequate for deep study and very detailed analysis of these variables and represents high volumes of data due to the high sample rate used.

Also, in the laboratory the sensors used are precise and offer high sample rates. This set-up takes some hours, and these sensors are placed in specific positions to collect information on research focus.

The instrumentations used, also called data loggers basic consist of an analogic digital converter A/D with filters to capture signals from sensors with high sample rate.

Most process study and development start on research centers in laboratories that use industrial or semi-industrial machines to capture data phenomenon using dedicated sensors that are specialized in a specific variable to act and with the following characteristics:

4.2.1 Controlled Environment

Laboratory measurements are typically conducted in a highly controlled environment. This allows for precise control over variables such as temperature, humidity, and material properties.

4.2.2 Precision Instruments

Laboratories often use high-precision instruments and sensors to measure forces accurately. This includes advanced load cells, displacement sensors, and data acquisition systems.

4.2.3 Small Scale

Tests are usually conducted on a smaller scale, using sample materials and smaller equipment. This allows for detailed analysis and fine-tuning of the process.

4.2.4 Repeatability

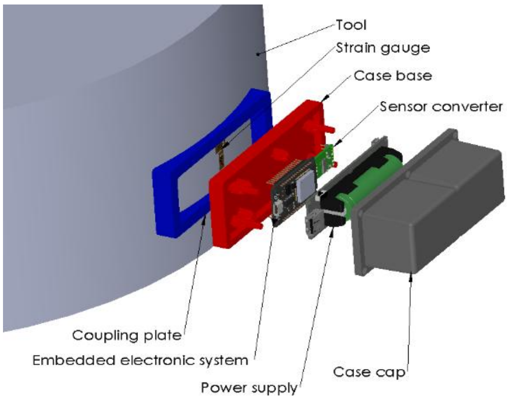
The controlled conditions in a lab ensure high repeatability of experiments, which is crucial for developing accurate models and understanding the fundamental mechanics of the process.

4.3 DEEP DRAWING VARIABLES PROCESS DATA ACQUISITION ON FACTORIES

In the case of factories deep drawing process data acquisition becomes a necessity after 4.0 industry advent. The data in this case focuses on understanding how effective the process is and optimize production time, tool life, and reduce costs. The sample rate for extracting information is not as critical as in laboratory. But the overall information must reflect the truth about the process parameters. [4]

Figure 3

Low cost IOT for force measuring in deep drawing components



During production hours the deep drawing process must be as efficient as possible, in this case, there is no extra time to install sensors over tools or press machines. In this case all sensors must be in situ every time. And they must be designed to resist shop floor ambient. Sensors in this case must be prepared and must have the following characteristics:

4.3.1 Variable Environment

In an industrial setting, the environment is less controlled. Factors such as temperature fluctuations, humidity, and material inconsistencies can affect the measurements.

4.3.2 Robust Instruments

Industrial measurements require robust and durable instruments that can withstand harsh conditions. These instruments may not be as precise as laboratory equipment but are designed for reliability and durability.

4.3.3 Large Scale

Measurements are conducted on a larger scale, using actual production materials and full-sized equipment. This provides a more realistic assessment of the process but can introduce more variability.

4.3.4 Process Variability

Industrial processes are subject to variability due to factors such as machine wear, operator differences, and material batch variations. This can make it challenging to achieve the same level of precision as in a laboratory.

4.3.5 Wiring and hoses

Another important aspect of instrumentation for deep drawing process in shop floor is that wiring and hose for sensor or power supply must be secure for operators and for the system itself. During the production process set-up and movement of tools and dies must be fast and easy. So, connections of sensor preferably fast connectors and an internal power supply.

5 METHODOLOGY

5.1 HARDWARE DESIGN

To build the low-cost sensor and connect it on an industrial tool for deep drawing operation it was designed with discrete components that's include an embedded electronic system, power supply, a sensor, a strain sensor converter and a case. Fig.3.

This device must be strong enough to support temperature variations, differences accelerations rates and electromagnetic fields generated on the shop floor environment to guarantee the accuracy and reliability of data collected. In this study the main components are described below:

5.2 EMBEDDED ELECTRONIC SYSTEM

The ESP32-WROOM-32U is a System-on-Module (SoM) based on the ESP32 microcontroller, designed by Espressif Systems.

Key Features:

- Processor: Dual-core 32-bit LX6 microcontroller 240 MHz
- Wi-Fi 802.11 b/g/n and Bluetooth 4.2 BR/EDR and BLE
- Memory: 4 MB flash, 520 KB SRAM, 448 KB ROM
- Connectivity: Wi-Fi, BT, UART, I2C, I2S, SPI, GPIO
- Cryptography: AES, SHA, RSA, etc.
- Operating temperature: -40°C to 85°C

- Low power consumption: 5 μA in sleep mode

Applications:

- Internet of Things (IoT)
- Smart devices
- Robotics
- Industrial automation
- Control systems
- Sensors and actuators

Advantages:

- Low cost
- High performance
- Low power consumption
- Easy integration with other devices
- Support for multiple communication protocols

Specifications:

- Dimensions: 18 x 25 x 3 mm
- Weight: 2 grams
- Frequency range: 2.4 GHz
- Certification: FCC, CE, RoHS

The ESP32-WROOM-32U module is a versatile and powerful solution for projects requiring Wi-Fi and Bluetooth connectivity, data processing, and device control. Its low power consumption and small size make it ideal for IoT and wearable devices.

5.3 POWER SUPPLY

This is a critical component for the sensor due to avoiding using and external supply would and a wire in working area that is critical. So, using a battery requires a minimal charge to work long hours before recharging. In this sensor the 1860 shielded power supply is a high-performance, compact power supply designed for various applications, including industrial, medical, and IoT devices. Its shielded design minimizes electromagnetic interference (EMI) and radio-frequency interference (RFI).

Key Features:

- High efficiency (up to 85%)
- Low standby power consumption
- Compact size (1.86" x 0.74" x 0.43")
- Shielded design for EMI and RFI reduction
- Overvoltage protection (OVP)
- Short-circuit protection (SCP)
- High reliability and long lifespan

Specifications:

- Input voltage: 85-265 VAC
- Output voltage: 3.3V, 5V, 12V
- Output current: Up to 6A
- Power rating: Up to 120W
- Operating temperature: -20°C to 70°C
- Certifications: UL, CE, RoHS.

Applications:

- Industrial control systems
- Medical devices
- IoT devices
- Networking equipment
- Aerospace and defense

Benefits:

- Reliable and efficient power supply
- Compact design for space-constrained applications
- Reduced EMI and RFI for improved system performance
- High-level protection against overvoltage and short circuits
- Long lifespan and low maintenance

The 1860 shielded power supply is designed to provide reliable and efficient power for various applications, ensuring optimal performance and minimizing electromagnetic interference.

5.4 STRAIN GAUGE

As mentioned before there to capture force it is possible to use strain gouge sensor. In this case it was used Kyowa HFG-5-350-C1-11 strain gauge:

Key Features:

- Type: Electric strain gauge, thin-film type.
- Material: Constantan (copper-nickel alloy).
- Width: 5 mm.
- Length: 350 mm.
- Resistance: 350 Ω.
- Sensitivity: 2.1 ± 0.5% (mV/V).
- Temperature Range: -200°C to 200°C.
- Accuracy: ±0.5% of measured value.

Benefits:

- High Accuracy: Precise strain measurements.
- Stability: Resistant to temperature and humidity variations.
- Flexibility: Suitable for curved and irregular surfaces.
- Low Cost: Compared to other high-precision strain gauges.
- Easy Installation: Strong and durable adhesive.
- Compatible with standard data acquisition systems.
- Resistant to wear and corrosion.

Applications

- Deep Drawing: Measuring strain in sheet metal.
- Material Testing: Analyzing mechanical properties.
- Structural Engineering: Monitoring strain in structures.
- Aerospace: Measuring strain in critical components.

- Automotive: Testing components and structures.

5.5 SENSOR CONVERTER

Considering this low-cost sensor application one of the most expensive part is the sensor converter or as know the data logger. In this sensor it was used the HX711 strain gauge amplifier:

Technical Specifications:

- Type: 24-bit analog-to-digital converter (ADC) and amplifier.
- Input Range: ±20 mV to ±40 mV.
- Gain: 128x or 64x programmable.
- Resolution: 24 bits (1:16,777,216).
- Sampling Rate: Up to 80 Hz.
- Operating Voltage: 2.7V to 5.5V.
- Current Consumption: 1.5 μA (standby), 1.5 mA (active).

Benefits:

- High precision and accuracy.
- Low noise and high signal-to-noise ratio.
- Compact and lightweight.
- Easy integration with microcontrollers.
- Low power consumption.
- Suitable for various strain gauge configurations.

Applications:

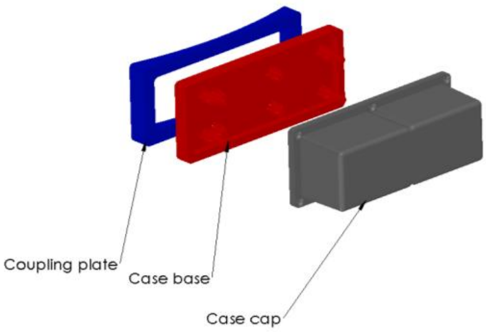
- Weight measurement: Scales, balances, and load cells.
- Strain measurement: Structural monitoring, material testing.
- Force measurement: Industrial automation, robotics.
- Medical devices: Patient monitoring, medical research.
- Aerospace: Structural health monitoring.

5.6 CASE

To build all cases for the sensor a 3D filament printer was used. This case is divided in three parts. Base coupling to connect on tool, base case to hold all components and case cap to protect all components. Fig.4.

Figure 4

Case components



5.7 SOFTWARE ARCHITECTURE

5.7.1 Microservices Architecture

The microservices architecture was chosen for the low-cost sensor system to enhance scalability and maintenance. By breaking down the system into smaller, independent services, each service can be developed, deployed, and scaled independently. This approach is particularly beneficial for low-cost sensors as it allows for incremental updates and improvements without disrupting the entire system. Additionally, it facilitates easier troubleshooting and maintenance, which is crucial for keeping costs low.

5.7.2 MVC (Model-View-Controller) Pattern

The MVC pattern was implemented to separate concerns within the application, making it easier to manage and scale. For a low-cost sensor system, this separation is vital as it allows developers to work on different parts of the application simultaneously without interference. The Model handles the data and business logic, the View manages the user interface, and the Controller processes user input and updates the Model and View. This clear division of responsibilities simplifies development and maintenance, reducing overall costs.

5.7.3 RESTful API

A RESTful API was used to simplify application programming by providing a standardized way to interact with the system. For a low-cost sensor, this is essential as it ensures that the system can easily communicate with other devices and services. RESTful APIs use standard HTTP methods, making them easy to implement and use. This simplicity reduces development time and costs, making it an ideal choice for low-cost sensor systems.

By employing these architectural principles, the low-cost sensor system achieves a balance of scalability, maintainability, and cost-effectiveness, ensuring reliable performance and ease of use.

5.8 DATA FLOW

5.8.1 Collects Sensor Data

The ESP32 device reads two analogic ports that from sensor converters that receive strain gauge signals. Gather axial and radial strain. These sensors continuously monitor the environment and collect real-time data with a 100Hz sample rate.

5.8.2 Device Transmits Data to API

Once the data is collected and processed, the ESP32 device transmits it to the API. This transmission is done using communication protocols such as HTTP or MQTT. HTTP is a widely used protocol for sending data over the internet, while MQTT is a lightweight messaging protocol ideal for IoT devices. The MQTT were chosen due to be faster and low latency compared with HTTP.

5.8.3 API Processes Data

The API, built using Spring Boot, receives the incoming data from the device. It processes this data to ensure it is in the correct format and ready for storage. This process includes tasks such as data validation, transformation, and aggregation. The API acts as an intermediary, ensuring that the data is clean and structured before it is stored in the database.

5.8.4 API Stores Data in PostgreSQL Database

After processing the data, the API stores it in a PostgreSQL database. PostgreSQL is a powerful, open-source relational database management system known for its reliability and scalability. The API uses SQL queries to insert the processed data into the appropriate tables in the database. This ensures that the data is organized and easily accessible for future use.

5.8.5 Database Stores Data for Querying and Analysis

The PostgreSQL database stores the collected data, making it available for querying and analysis. Users can run SQL queries to retrieve specific data points or generate reports based on the stored data. This data can be used for various purposes, such as monitoring environmental conditions, analyzing trends, or making data-driven decisions. The database's robust querying capabilities allow for efficient data retrieval and analysis.

5.9 SYSTEM FOR LOW-COST SENSOR

Data Acquisition Device (Arduino)

- **Software**: C++/Arduino IDE
- **Function**: Collect sensor data (strain gouge) and transmit it to the server. Arduino's open-source electronics platform facilitates IoT projects by providing a versatile and user-friendly environment for developing sensor-based applications

API (Spring Boot)

- **Language**: Java
- **Framework**: Spring Boot
- **Function**: Receive device data, process it, and store it in a database. Spring Boot provides a robust, scalable framework that simplifies the development of production-ready applications with minimal configuration. Its flexibility and efficiency are crucial for maintaining low operational costs.

Database (PostgreSQL)

- **Database Management System**: PostgreSQL
- **Version**: 13.2
- **Function**: Store collected data. PostgreSQL ensures reliable, scalable data management with advanced features like ACID compliance, complex queries, and extensibility. Its open-source nature helps keep costs down while providing powerful database capabilities.

Server (Ubuntu)

- **Operating System**: Ubuntu Server
- **Version**: 20.04 LTS

- **Function**: Host API and database. Ubuntu Server offers stability and security, making it an ideal choice for hosting applications and services. Its open-source nature and long-term support (LTS) version ensure a cost-effective and reliable server environment.

Data Storage on Oracle Cloud

The data collected by the low-cost sensor system is stored on the Oracle Cloud in a virtual machine (VM) running Ubuntu. This setup provides several benefits:

- **Scalability**: Oracle Cloud offers scalable resources, allowing the system to handle increasing amounts of data without significant additional costs.
- **Cost-Effectiveness**: Using a VM with Ubuntu on Oracle Cloud is a cost-effective solution, as it leverages open-source software and cloud infrastructure to minimize expenses.
- **Reliability**: Oracle Cloud provides a reliable and secure environment for data storage, ensuring that the collected data is safe and accessible when needed.

By choosing these components and leveraging Oracle Cloud, the system achieves a balance of low cost, scalability, and reliability, making it an ideal solution for low-cost sensor applications.

6 COSTING

As said before all, this project aims to make lower cost as possible sensors to be used in large scale in any tool in a factory. Considering all components described the cost of hardware was US$ XXXX. See table xxx. It’s an important analysis that this price was end user retail price, if this sensor was built on a scale the total cost would be at least ten times less than presented. Also, the cost of development was not considered in this analysis. But the estimate time to develop it was about 300hours for all design, code and test.

Table 1

From the author

Description	Qty	Unit cost	Sub-total cost
Electronic system	1	5.2	5.2
Strain Gouge	2	3.2	6.4
Sensor converter	1	4.0	4.0

Power supply	1	2.0	2.0
Case	1	8.0	8.0
Wire, fittings etc.	1	1.0	1.0
Total Cost			26.6

7 EXPERIMENTS

To teste both edge computing and cloud computing in this sensor some configurations by experiments. For better results MQTT protocol was used and all data collected was sent to the broker in cloud.

7.1 CLOUD COMPUTING

The first test was conducted with a microcontroller where the firmware algorithm will read an analogic port which is the signal from a strain gouge converter board and send this deep drawing row data without any math filter. So, any noise generated during the process is reded and sent to the cloud by Wi-Fi network.

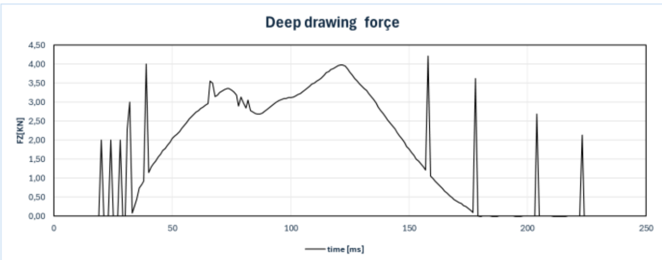
This approach sends data to the cloud for further processing and long-term storage using internet connectivity.

The cloud offers scalable resources to perform complex analytics, machine learning, and long-term data storage.

After receiving the data, a graphic was plotted showed in figure 5.

Figure 5

Deep drawing force with noise



Note that in figure 5 there are some spikes on the deep drawing profile, that is some noises generated during the deep drawing operation.

7.2 EDGE COMPUTING

The second experiments were conducted using the edge computing algorithm in the microcontroller connects to the internet via Wi-Fi but before this, processes data locally at the edge of the network, reducing latency and allowing for real-time responses. Edge nodes handle immediate processing needs such as digital noise filtering.

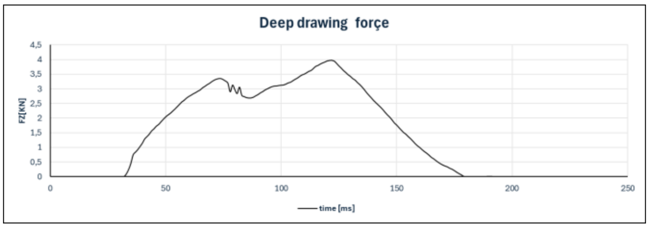
Processing data locally helps protect sensitive information by minimizing its exposure to the internet.

By processing data locally, the amount of data sent to the cloud is minimized, saving bandwidth and reducing latency.

After that the data received was used to plot a graphic showing deep drawing force by time showed in figure 6 with signal filtered applied.

Figure 6

Deep drawing force with filter applied



8 CONCLUSION

The resolution of time force response describes the deep drawing process suitable for industrial applications. Which is the overall information of maximum force and its profile variation.

After this first design focuses on getting data using low-cost force sensors, it's possible to conclude that today its possible this approach in applying current technology and achieving very good results to catch deep drawing data, in this case force, without sophisticated and expensive laboratory instruments.

This data is not with the same sample rate compared with traditional data loggers but for glance analysis of the phenomenon during deep drawing process its enough for acting and optimizing it.

Cloud computing is not adequate for this application due to data losses due to connection latency and internet speed.

Using edge computing and MQTT protocol are indicated for measuring force of the industrial application due to less data storage and send only information to the cloud, not high-volume raw data.

Using wireless transmission and battery power source avoids wiring in the operator area and decreases the hose cutting and maintenance of sensor. But the optimization of the algorithm and microcontroller parameters are caution for long battery autonomy avoiding the frequency of recharge and press stopping.

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