

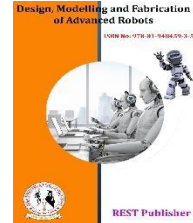


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# Ultrasonic Sensor-Based Work Holding Devices for Enhancing Safety and Accident Prevention

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**Abstract:** This paper presents the design ultrasonic sensor-based work holding system aimed at significantly enhancing industrial safety and accident prevention in machining and fabrication environments. Traditional work holding devices, such as vices and clamps, rely on manual inspection and mechanical force, which can be prone to human error, leading to improper workpiece seating, slippage, and catastrophic tool or part failure. The proposed system integrates an array of ultrasonic sensors to non-invasively and continuously monitor the proximity, secure seating, and potential movement of the workpiece relative to the holding jaws. A microcontroller processes the sensor data, providing real-time feedback to the machine operator and, crucially, generating a mandatory interlock signal to prevent machine operation unless the workpiece is confirmed to be held securely within pre-defined safety tolerances. This intelligent system minimizes the risk of accidents caused by improperly secured workpieces, promotes a safer working environment, and contributes to enhanced operational efficiency and compliance with safety regulations.

**Key words:** Ultrasonic sensor, work holding, safety interlock, accident prevention, machining safety

## 1. INTRODUCTION

Work holding is a fundamental aspect of manufacturing and fabrication, ensuring a workpiece remains stationary and precisely oriented relative to a machine tool during operations like milling, turning, and grinding. The integrity of the work holding system is directly linked to both machining quality and operator safety. Failure of a work holding device be it due to insufficient clamping force, incorrect component seating, or dynamic slippage can result in the workpiece becoming a dangerous projectile or causing a tool crash, leading to severe personnel injury and costly equipment damage. Current industry standards for safety in work holding primarily rely on operator vigilance, regular maintenance checks, and mechanical safeguards. However, these methods do not account for instantaneous changes or subtle, critical errors in setup that are often precursors to accidents. A significant challenge in coal yards, for example, is the generation of airborne dust particles during handling, which poses serious environmental and health risks; similarly, in machining, an unsecured workpiece poses direct physical risks. An effective dust suppression system plays a vital role in reducing airborne dust, just as an intelligent work holding system is crucial for enhancing operational safety in machining. This research proposes a move toward proactive, automated safety features in work holding using ultrasonic sensor technology. Ultrasonic sensors are low-cost, robust, and excel at non-contact distance measurement, making them ideal for monitoring the gap between the holding jaws and the workpiece surface in real time. The core innovation lies in creating a safety interlock that leverages this data to prevent machine start-up, thereby actively mitigating the risk of accidents before they can occur.

## 2. LITERATURE REVIEW

The application of sensors and automation for industrial safety is an expanding field. Previous studies have highlighted the importance of active monitoring systems over passive safety measures.

### 2.1 Sensor Technology in Industrial Safety

Various sensor technologies, including proximity sensors, force sensors, and vision systems, have been explored for enhancing safety in industrial contexts. Ultrasonic sensors offer a reliable, cost-effective alternative for non-contact distance sensing in harsh environments. They utilize sound waves to measure distance, making them highly effective

for confirming the presence and secure position of a workpiece. Furthermore, ultrasonic sensors are noted for their robust functionality in the presence of dust, smoke, or high humidity, making them suitable for typical factory floor conditions.

## 2.2 Work Holding and Safety Interlocks

The concept of a safety interlock is well-established in manufacturing, often used to prevent access to moving parts (e.g., machine door interlocks) or collision avoidance. The integration of ultrasonic distance measurement directly into the clamping logic presents a significant advancement for work holding. By establishing a tight, verifiable range of acceptable proximity, the system can reliably determine if the part is fully seated and secured before machine operation is permitted. This proactive approach to accident prevention is critical for minimizing human error and improving overall worker safety

## 3. DESIGN

The proposed work holding device is designed around a standard hydraulic or pneumatic vice, enhanced with an integrated ultrasonic sensor array and control module.

### 3.1 System Components

The primary components of the ultrasonic sensor-based work holding system include:

- **Work Holding Vice/Fixture:** A standard work holding mechanism (e.g., a hydraulic vice).
- **Ultrasonic Sensor Array:** Multiple ultrasonic sensors are mounted strategically within the fixed and moving jaws, positioned to direct their beams toward the contact surfaces of the workpiece.
- **Servo Motor:** The system will utilize a pneumatic air vane motor, coupled with a fan to generate an air blast that aids in clearing chips from the sensing area. The air motor (pneumatic motor) converts compressed air or gas energy into mechanical rotational motion.
- **Microcontroller Unit (MCU):** An embedded controller (e.g., Arduino or Raspberry Pi) to read, process, and interpret the distance data from the sensor array.
- **Safety Interlock Relay:** An electromechanical relay or solid-state switch connected to the machine control (CNC or conventional) to function as the Start/Enable signal interlock.
- **User Interface (HMI):** A simple display and warning light system for real-time feedback.

## 4. WORKING PRINCIPLE AND SAFETY INTERLOCK LOGIC

The system operates by continuously measuring the distance between the sensor and the workpiece surface. The core principle for the safety interlock is based on the Time of Flight (ToF) of the ultrasonic pulse.

### 4.1 Principle of Distance Measurement

An ultrasonic sensor transmits a short pulse of sound at a high frequency and measures the time it takes for the echo to return. The distance ( $D$ ) is calculated using the following formula:

Where:

- $D$  is the distance to the target (workpiece surface).
- $V$  is the speed of sound in the surrounding medium (air).
- $T$  is the total Time of Flight (the time from pulse transmission to echo reception).

### 4.2 Safety Interlock Logic

- **Calibration:** A reference distance is established when a securely clamped, correctly seated workpiece is in place.
- **Continuous Monitoring:** The MCU continuously calculates the measured distance ( $D_{\text{measured}}$ ) from each sensor.
- **Interlock Activation:**
  - If the condition is met for all active sensors, the MCU activates the Safety Interlock Relay, permitting the machine's operational start.
  - If the condition is violated (i.e., the difference exceeds  $\Delta$  for any sensor), the MCU keeps the

Safety Interlock Relay OFF, preventing machine start-up and triggering an immediate visual/audible alert for the operator.

This logic ensures a mandatory electronic hold on the machine operation until the physical security of the workpiece is verified by the sensor array.

## 5. MODELING AND SIMULATION

To validate the proposed system's effectiveness and optimize the sensor placement, Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) simulations will be utilized.

### 5.1 Acoustic-Mechanical Modeling

FEA will be used to model the workpiece, vice jaws, and sensor housing to determine:

- **Vibration Analysis:** The impact of typical machining vibrations on the stability of the sensor readings.
- **Optimal Sensor Mounting:** Identifying mounting locations that minimize sensor interference (cross sensor signal interferences) and maximize coverage of critical contact surfaces.

### 5.2 Environmental and Airflow Simulation

CFD, similar to its use in optimizing mist spray system performance, will be applied to:

- **Chip and Coolant Contamination:** Simulating the airflow (generated by the SS fan blade coupled to the pneumatic motor) around the sensor housing to ensure chips and coolant mist are effectively cleared from the ultrasonic sensor's path, preventing false readings.
- **Signal Integrity:** Modeling the acoustic wave propagation in the presence of coolant mist to predict signal attenuation and determine the required sensor power and sensitivity for reliable distance measurement in a production environment.

The use of these engineering principles and simulations is crucial for optimizing the system's performance and efficiency before fabrication.

## 6. COMPONENTS

The system relies on reliable and durable components:

- **Servo Motor (Electric Motor):** Converts compressed air into rotational motion, used to drive the chip-clearing fan.
- **Ultrasonic Sensor:** A non-contact device for precise distance measurement.
- **Arduino board:** Constructed an open-source electronic development platform consisting of a programmable microcontroller circuit board and software for programming it.
- **Python:** Python is a high-level, interpreted programming language known for its readability and

## 7. CONCLUSIONS

In conclusion, the development and implementation of an ultrasonic sensor-based work holding device represent a significant step toward proactive accident prevention and enhanced safety in modern manufacturing. By utilizing non-contact distance sensing and robust interlock logic, the system establishes a mandatory safety interlock that prevents machine operation unless the workpiece is confirmed to be securely seated and clamped within pre-defined tolerances. The design requires careful modeling and simulation (CFD and FEA) to ensure reliability in harsh operating conditions. This design moves beyond passive safety checks to an active, real-time monitoring system, eliminating human error in setup. The successful implementation of this device will contribute to a safer work environment, reduce equipment damage, and promote responsible industrial practices, mirroring the goals of sustainable safety in other heavy industries. and regular evaluation and monitoring of the system's effectiveness will prioritize the safety of operators and prevent accidents. Ongoing maintenance and updates to the safety features will ensure the system's continued functionality and compliance with regulations. In conclusion, the successful implementation of this sustainable water mist spray system will contribute to a cleaner and healthier environment, enhance workplace safety, and promote responsible practices in the coal industry.

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