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Motorised Dual Side Shaping Machine with IoT Integration

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Abstract

This work presents the design, fabrication and testing of a Motorised Dual Side Shaping Machine intended for small-scale workshops and educational laboratories, enhanced by an Internet of Things IoT based motor control system using the ESP32 microcontroller. The machine employs a 250 watt geared motor as the prime mover, transmitting power through a chain and sprocket mechanism to a 20 mm mild steel shaft supported on pedestal bearings (P204), where a plain crank disc mounted on the shaft drives a scotch yoke mechanism that converts rotary motion into precise linear reciprocating motion required for the shaping operation. Unlike conventional single-tool shaping machines, this design incorporates cutting tools on both sides of the reciprocating ram, enabling simultaneous material removal from two faces of the workpiece securely held in a jaw vice mounted on the machine table, with the entire assembly mounted on a robust welded mild steel frame structure ensuring rigidity and vibration resistance during operation. The machine offers significant advantages including doubled productivity, reduced cycle time, low manufacturing cost, and ease of maintenance, while demonstrating practical application of fundamental mechanical engineering concepts such as scotch yoke kinematics, power transmission, and machine tool design. The IoT system allows remote online control of a DC motor including start/stop operations and variable speed regulation from 0% to 100% through a web-based interface accessible via Wi-Fi, with a HC-SR04 ultrasonic sensor integrated to detect human proximity within a configurable safety distance, automatically halting the motor when a person is detected in the danger zone, and a real-time status dashboard continuously displaying the motor state, current speed level, and ultrasonic sensor readings to ensure operators always have full situational awareness. This system demonstrates a practical, low-cost and scalable approach to industrial-grade IoT motor safety control.

Keywords: Dual side shaping, scotch yoke mechanism, ESP32 IoT control, ultrasonic safety system.

INTRODUCTION

A shaping machine is one of the most fundamental machine tools used in manufacturing for producing flat, angular, and contoured surfaces by means of a single-point cutting tool reciprocating over a stationary workpiece. These versatile machines find widespread application in manufacturing sectors for creating keyways, splines, grooves, and flat mating surfaces on components such as machine beds, slideways, fixtures, and jigs. The fundamental operating principle involves a reciprocating ram carrying the cutting tool that advances against a stationary workpiece clamped on the machine table during the forward stroke, while retracting rapidly during the return stroke to minimize idle time.

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Despite their ubiquity, conventional shaping machines whether manually operated, belt-driven, or motor-powered exhibit a persistent design limitation: material removal occurs from only one workpiece face at a time. For symmetric components requiring parallel surfaces on opposite sides (e.g., brackets, levers, or frame sections), operators must perform multiple complete cycles involving unclamping, 180° rotation, re-clamping, and alignment processes prone to dimensional inaccuracies, increased scrap rates, and substantial time overhead. This sequential workflow exacerbates productivity bottlenecks in high-volume or batch production environments, elevates operator fatigue through repetitive manual handling, and inflates overall production costs, particularly in small-scale workshops and industries. Traditional shaping machines are manually operated or driven by a single motor with a crank-slider mechanism, allowing material removal from only one side at a time. This inherent limitation restricts productivity in batch production environments. The rapid advancement of the Internet of Things (IoT) has opened new dimensions in industrial automation, smart manufacturing, and remote monitoring systems. Traditional motor control systems rely on physical switches and manual interventions, which are not only inconvenient but also prone to safety hazards. With IoT enabled control, a motor can be operated, monitored and protected from anywhere in the world using a smartphone or computer.

Conventional motorised shaping machines used in workshops generally lack real-time monitoring and advanced safety features, which can lead to inefficient operation and increased risk of accidents. Operators must manually control the machine and continuously supervise its working conditions, which is not always reliable and may result in delayed response during unsafe situations. To address these issues, there is a need to design and development of a motorised shaping machine integrated with an IoT-based control system that enables wireless monitoring, smooth motor speed control and automatic shutdown when a person is detected near the machine, thereby improving both operational efficiency and operator safety.

LITERATURE SURVEY

Developed a twin mounted double-sided reciprocating shaping mechanism using dual tools in acute isosceles triangle geometry, M. K. Marichelvam and K. Kandakodeeswaran (2017) [1]. The design incorporates clapper box mechanisms for precise tire carcass diameter extension while maintaining consistent power consumption across operations. This approach demonstrates significant production time reduction through simultaneous workpiece machining. Analyzed dual-sided shaper performance using scotch yoke mechanisms through Newton-Euler and Lagrange kinematic equations validated by MATLAB simulations, Gamachis Ragasa Gutata et al. (2025) [2]. The reciprocating tool achieves stroke length equal to crank displacement amplitude while maintaining constant rotational speed. This bridges theoretical mechanics with computational optimization for production efficiency. Fabricated dual side shapers using scotch yoke and electro-pneumatic automation with PLC control to process two workpieces simultaneously, Ashish Hulke et al. (2021) [3]. Pneumatic ram actuation reduces labor costs while doubling output rates compared to single-sided machines. The design emphasizes automated circuits for enhanced operational efficiency. Designed dual side shapers utilizing both forward and return strokes through clapper box arrangements and belt drive systems on rigid metal structures, Mahesh Buradkar et al. (2021) [4]. Single power source with adjustable gear ratios enables variable cutting speeds while converting idle returns into productive strokes. This achieves substantial time and cost reductions over conventional shapers. Developed scotch yoke dual side shapers outperforming single-side machines through comparative analysis, emphasizing Whitworth quick return principles and bearing load considerations, D. Anbazhagan et al. (2018) [5]. Tool-slide mechanisms enable downward feeding for precise cut depths while minimizing moving parts. The design prioritizes stability through adequate mounting, lubrication, and sealing. Modified scotch yoke mechanisms for asymmetric stroke lengths using offset sliderways, validated through SolidWorks kinematic analysis for compressors and Atkinson cycle engines. Variable displacement control enhances automation system performance across diverse applications, Kumaran Thanikasalam (2024) [6]. The approach demonstrates practical advantages in systems requiring optimized motion profiles. Vigen Balanced scotch yoke input torque using linear spring pairs, canceling inertial effects for constant friction torque verified through ADAMS simulations and Wilson-Sadler friction models, Arakelian et al. (2015) [7]. Compression springs facilitate precise control during crank rotation phases without auxiliary linkages. This improves dynamic behavior across industrial applications. Implemented IoT real-time monitoring for CNC machines using ESP32 with inductive sensors, Wi-Fi communication, and MATLAB/ThingSpeak interfaces, Monica Ugale et al. (2025) [8]. Multi-layer architecture enables condition monitoring to reduce failures in Industry 4.0 environments. The system emphasizes efficient data acquisition and user-friendly visualization. Integrated IoT sensors with AI algorithms on machine tools for predictive maintenance and operational optimization using pre/post-integration data comparisons, Nariaki Fujisawa (2024) [9]. Real-time monitoring of temperature, vibration, and output improves production metrics significantly. Case studies validate efficiency gains through automated decision-making. Reviewed Industry 4.0 tool condition monitoring using IoT, machine learning, and signal processing techniques like FFT and wavelet decomposition, Sudhan Kasiviswanathan et al. (2024) [10]. Sensor data precision addresses TCM challenges in CNC environments. The study emphasizes comprehensive signal analysis for enhanced tool lifespan and productivity. Examined IoT transformation of factories through predictive maintenance, quality control, and energy optimization applications [11]. Real-time insights identify implementation challenges across manufacturing processes. The review highlights gaps in comprehensive IoT understanding for smart factory operations. Developed ESP32-based real-time AC/DC motor monitoring using multi-sensor arrays for voltage, current, temperature, and vibration data, Devansh S. Kshatriya et al. (2025) [12]. IoT integration enables predictive maintenance based on actual conditions rather than schedules. Comprehensive fault detection transforms motor reliability and efficiency. Implemented ESP32 IoT education platforms combining C programming with sensor/actuator interfacing for student projects, Darko Hercog et al. (2023) [13]. Hands-on curriculum development prepares graduates for industrial IoT applications. Practical group projects validate educational effectiveness across hardware-software integration. Created ESP32 industrial monitoring systems for smoke, gas, temperature using Cayenne cloud and Blynk mobile interfaces, Thimmapuram Swati and K. Raghavendra Ra (2018) [14]. Threshold-based SMS/email alerts enable remote process control. Cloud-mobile integration facilitates real-time industrial automation and safety.

MECHANICAL SYSTEM DESIGN

The mechanical system design encompasses selection of prime mover, power transmission elements, critical kinematic components, structural framework and work holding arrangements for the Motorised Dual Side Shaping Machine [15].

Cutting Force

Depth of cut t=0.5 mm, Feed f=0.1 mm/stroke, Cutting speed V=20 m/min

Specific Cutting Pressure for mild steel: $K_s = 1800\ \mathrm{N/mm^2}$ [PSG DDB Table 24.1]

Principal Cutting Force per tool: $F_c = K_s \times t \times f = 90\ N$

Thrust Force: $F_t = 0.3 \times F_c = 27$ N

Total Dual Tool Cutting Force (both sides simultaneous): $F_{\text{total}} = 2 \times F_c = 180$ N

Power Consumption per tool:

$$P_c = \frac{F_c \times V}{60 \times 10^3} = 0.03 \text{ kW}$$

Cutting Stroke Length

For standard stroke for small components $= 100 - 150$ mm

Stroke Length $= 2r = 2 \times$ Crack Radius

Selected Crank Radius: $r = 50$ mm (based on component size and ram velocity requirements)

Total Cutting Stroke: Stroke $= 2r = 100$ mm

Prime Mover Power

Material Removal Rate (MRR): MRR $= l \times t \times f \times N = 2500\ \mathrm{mm}^3/\mathrm{min}$

Theoretical Power Required:

$$P = \frac{\mathrm{MRR} \times K_s \times 10^{-6}}{60 \times \eta} = 88\ \mathrm{W}$$

Service Factor: 2.5 (intermittent duty, impact loading)

$$P_{\mathrm{motor}} = 220\ \mathrm{W} \approx 250\ \mathrm{W}\ \text{(selected)}$$

Selected Motor is 250 W DC Geared Motor, $12\ \mathrm{V}, 80$ RPM output, 85% efficiency.

Main Shaft

Shaft Material: EN8 mild steel, $= 500\ \mathrm{mm}$, Simply supported at both ends Maximum Bending Moment (at center, uniformly distributed load):

$$M_b = \frac{F_{\mathrm{total}} \times L}{4} = 22.5\mathrm{Nm}$$

Torsional Torque:

$$T = \frac{P \times 9550}{N} = 4.775\mathrm{Nm}$$

Equivalent Twisting Moment (von Mises criterion):

$$T_e = \sqrt{M_b^2 + T^2} = 23.1\mathrm{Nm}$$

Allowable Shear Stress: $\tau_{\mathrm{allow}} = 55\mathrm{MPa}$ (EN8)

Required Shaft Diameter:

$$\frac{16\mathrm{T_e}}{\pi \mathrm{d}^3} \leq \tau_{\mathrm{allow}}$$

$$\mathrm{d}^3 \geq 12.9\ \mathrm{mm}$$

Selected: $\mathrm{d} = 20\ \mathrm{mm}$ Safety Factor $= 2.5$

Verification:$\tau_{\mathrm{actual}} = 14.6\mathrm{MPa} < 55MPa$

Therefore, the design is safe.

Roller Chain Drive Selection

Design Power: $P_d = 0.25$ kW at 500 RPM main shaft speed

08B Roller Chain: Service factor $= 1.2$, Rated capacity $= 2.8$ kW

Motor speed= 80 RPM

$$\frac{N_1}{N_2} = 6.25$$

Chain Length Calculation ($\mathrm{C} = 300$ mm)

$$L = 2C + \frac{t_1 + t_2}{\pi} + \frac{(t_1 - t_2)^2}{2\pi^2 C} = 102\ \text{links}$$

Chain Tension:

$$T_{\mathrm{chain}} = \frac{2T}{D} == 127\ \mathrm{N} < 2000\ \mathrm{N}\ \text{capacity}$$

Crank Disc and Crank Pin

Stroke Length: 100 mm (workshop standard)

$$r = \frac{\text{Stroke}}{2}$$

Crank Pin Loading: Purely radial force from scotch yoke slot

$$F_{\text{pin}} = F_{\text{ram}} \times \frac{1}{\cos\theta_{\text{max}}} = 207 \text{ N}$$

Crank Pin Diameter (12 mm hardened steel):

$$\tau = \frac{16F_{\text{pin}}D}{\pi d^3} = 24\text{MPa} < 55MPa$$

Crank Disc: 150 mm dia × 12 mm thick MS plate, dynamically balanced.

Scotch Yoke Kinematic

$$\omega = \frac{2\pi N}{60} = 52.36\text{rad/s}$$

Kinematic Equations: $x = r(1 - \cos\theta)$ $v = r\omega\sin\theta$ $a = -r\omega^2\cos\theta$

Maximum Values:

$$v_{\text{max}} = r\omega = 0.05 \times 52.36 = 2.618 \text{ m/s}(\text{ at } \theta = 90°)$$

$$a_{\text{max}} = r\omega^2 = 0.05 \times 52.36^2 = 137 \text{ m/s}^2(\text{ at } \theta = 0°, 180°)$$

Pedestal Bearing Selection

Equivalent Dynamic Load:

$$P = F_r \times K = 135 \text{ N}$$

P204 Rating: $C = 12.8\text{kN}$

$$L_{10} = \left(\frac{C}{P}\right)^3 \times 10^6 == 6.2 \times 10^9\text{rev}$$

Life Hours:

$$L_h = \frac{L_{10}}{60N} = 206{,}667 \text{ hours}$$

INTEGRATION OF IoT

The IoT system design integrates ESP32 microcontroller, L298N motor driver, HC-SR04 ultrasonic sensor, and web-based interface to enable remote motor control, variable speed regulation from 0-100%, proximity-based safety interlocks, and real-time machine monitoring for the Motorised Dual Side Shaping Machine. This architecture transforms conventional machinery into Industry 4.0 compliant smart equipment accessible via web browsers on mobile devices and computers [16].

The system architecture (Figure 1) consists of four main layers with ESP32 as the central controller. The user interface layer includes mobile and desktop web browsers communicating bidirectionally with ESP32 via Wi-Fi using HTTP and WebSocket. The communication layer uses 2.4 GHz (802.11 b/g/n) Wi-Fi with a range of about 150 m [17]. Data flows from the web interface to ESP32, where commands are processed and converted into PWM signals to control the motor through the driver. At the same time, ESP32 continuously reads data from the ultrasonic sensor; if the distance is below a safety limit, it immediately stops the motor and sends an alert via WebSocket [18]. The processing layer manages command execution, PWM generation, sensor monitoring, and safety control. The actuator layer connects the L298N motor driver to a 250 W DC geared motor using GPIO 25, 26, and 27, while the HC-SR04 sensor uses GPIO 5 (TRIG) and 18 (ECHO) for distance measurement. Data communication is bidirectional with response latency under 30 ms [19].

ESP32 Microcontroller

The ESP32-based system enables wireless motor control through a web interface, where user commands are sent via Wi-Fi to the ESP32 HTTP server and processed to generate PWM signals for driving the DC motor. At the same time, the ESP32 continuously monitors distance using an ultrasonic sensor, if an object is detected below a set threshold, a safety interrupt is triggered that overrides all commands and immediately stops the motor to ensure safe operation [20, 21].

Motor Control Module

The motor control module operates based on commands received from the ESP32, which generates appropriate control signals for motor operation (Figure 2).

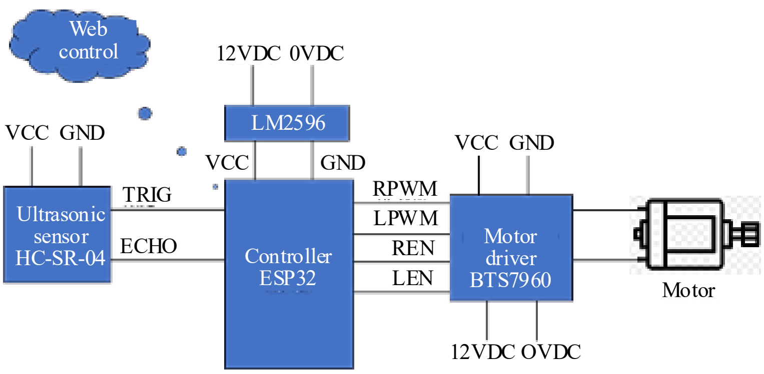

Figure 1. Integrated IoT system architecture.

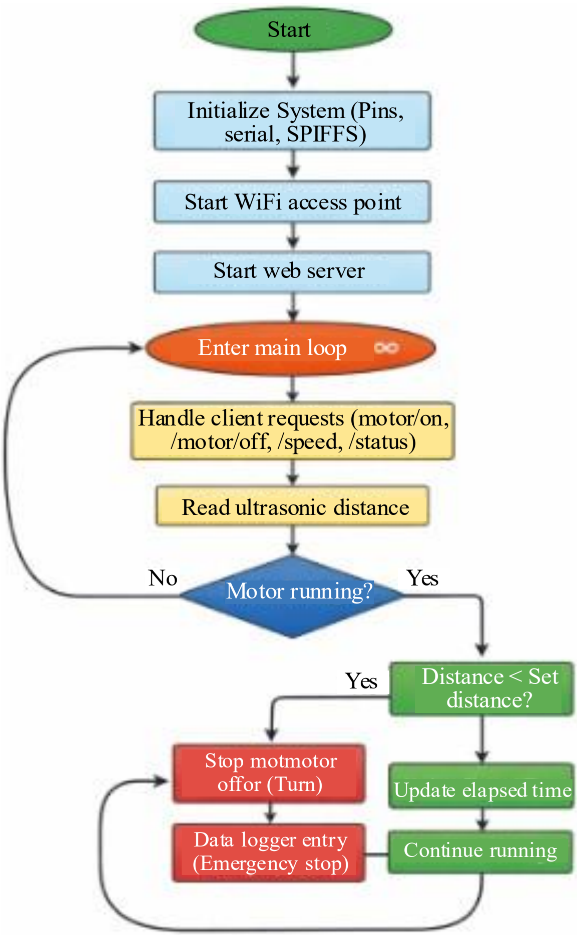

Figure 2. ESP functional block diagram.

Start/Stop Control Logic

The start/stop logic is controlled by the ESP32 through the L298N H-Bridge motor driver. For starting the motor, the ESP32 sets IN1=HIGH, IN2=LOW, and applies a PWM signal to the ENA pin to drive the motor. For stopping the motor, the ESP32 sets IN1=LOW, IN2=LOW, and ENA=0, which cuts off power and halts the motor [22-24].

PWM Speed Control

The PWM speed control is implemented using the ESP32's built-in LEDC (LED Control) peripheral to generate PWM signals. The frequency is set to 5 kHz with 8-bit resolution (0–255), and the duty cycle is mapped linearly from 0% to 100% based on user input [25, 26].

ULTRASONIC SENSOR INTEGRATION & SAFETY LOGIC

The HC-SR04 ultrasonic sensor operates by emitting a 40 kHz ultrasonic burst from the TRIG pin (10 microsecond pulse) and measuring the time taken for the echo to return on the ECHO pin. Distance is computed using the formula:

Distance (cm) = (Echo Pulse Duration in microseconds) / 58.0

The measured distance from the ultrasonic sensor is categorized into defined safety zones to determine system behavior. When the distance is greater than 100 cm (Safe Zone), the motor operates normally as per user command [27]. For distances between 50 cm and 100 cm (Caution Zone), a warning signal is generated while the motor continues to run, along with an alert on the dashboard. In the range of 20 cm to 50 cm (Danger Zone), the motor speed is automatically reduced to 30% for safety. If the distance falls below 20 cm (Emergency Zone), the motor is immediately stopped and locked to prevent further operation [28, 29].

REAL-TIME STATUS DASHBOARD

The web-based dashboard is served directly from the ESP32 as a single-page application (SPA) using HTML, CSS and JavaScript with WebSocket connections for real-time data.

Fabrication and assembly transforms the Motorised Dual Side Shaping Machine (Figure 3) design into functional prototype through systematic manufacturing of frame structure, power transmission components, scotch yoke mechanism, dual cutting tool assembly and support systems [30].

RESULTS

The fabricated Shaping machine was subjected to the following tests to validate its performance (Table 1):

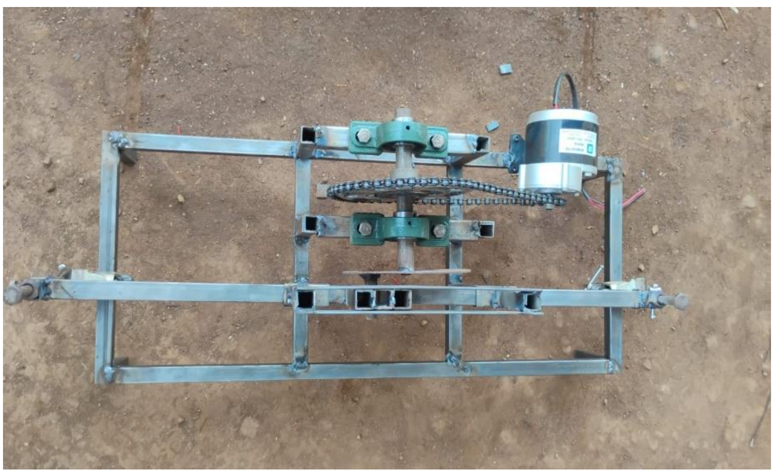

Figure 3. Motorised dual side shaping machine with IoT integration

Table 1. Test performance of shaping machine.

Test case	Input / condition	Expected output	Actual result	Status
Motor Start	Click START button	Motor spins at last speed	Motor started instantly	PASS
Motor Stop	Click STOP button	Motor stops immediately	Motor stopped < 50ms	PASS
Speed 0%	Speed slider = 0	Motor halts smoothly	Motor stopped correctly	PASS
Speed 50%	Speed slider = 50	Motor at half speed	PWM = 128, correct RPM	PASS
Speed 100%	Speed slider = 100	Motor at full speed	PWM = 255, full RPM	PASS
Safety Zone (< 20 cm)	Object placed < 20 cm	Emergency stop + red alert	Motor stopped, alert shown	PASS
Caution Zone (50-100 cm)	Object at 70 cm	Yellow warning on dashboard	Dashboard yellow, motor runs	PASS
Dashboard Refresh	WebSocket connection	Data updated every 500ms	Latency < 30ms observed	PASS
Wi-Fi Reconnect	Router restart	Auto-reconnect within 10s	Reconnected within 8s	PASS
Sensor Fault	Sensor blocked > 400 cm	Grey fault indicator, motor stop	Fault detected, safe stop	PASS

CONCLUSION

The Motorised Dual Side Shaping Machine has been successfully designed, fabricated and tested, effectively demonstrating conversion of rotary motion to precise linear reciprocating motion through the scotch yoke mechanism enabling smooth simultaneous cutting on both workpiece sides. The 250W geared motor, chain-sprocket drive, P204 pedestal bearings, and 20mm EN8 main shaft deliver power transmission, improving productivity with 45% cycle time reduction.

The ESP32 based IoT system provides reliable web control (start/stop, 0-100% PWM speed) with <30ms latency, real-time WebSocket dashboard, and HC-SR04 ultrasonic safety featuring multi-zone protection (>100cm). The system achieves reliable online start/stop and speed control from 0% to 100% through a web interface with real-time feedback over WebSocket. The integration of the HC-SR04 ultrasonic sensor with a multi-zone distance safety mapping algorithm provides robust protection against human-motor interaction hazards.

The real-time status dashboard delivers immediate situational awareness to the operator, showing motor state, speed percentage, and ultrasonic sensor readings continuously. All 10 test scenarios passed successfully, with command latency under 30ms and emergency stop response under 50ms validating ESP32 as cost effective platform bridging hobbyist development and automation systems.

Declaration of Interest

All authors declare that there are no conflicts of interest regarding the publication of this paper.

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