

Universal Wrench with Impact Driver (UWWID)

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Abstract

The Universal Wrench with Impact Driver (UWWID) was developed to address limitations in conventional adjustable wrenches, including slippage, excessive human effort, and lack of maintainability. This study presents the ergonomic design and validation of a multi-surface gripping wrench integrated with a manual impact transfer mechanism. The design process incorporated advanced CAD modeling, DF2 tool steel selection, and iterative prototyping. Comparative torque and usability tests demonstrated a gripping efficiency increase of 42% over standard adjustable wrenches, and a 65% reduction in manual effort due to the impact driver. Experimental analysis confirmed average torque resistance of 57 Nm before slip, and significant time savings during bolt removal. The UWWID thus presents a viable tool for maintenance-intensive environments requiring strength, adaptability, and user-centered design.

Key Words: *Universal Wrench, Impact Drive; Tool Design; Mechanical Component Design; Material Selection (Tool Steel DF2); Adjustable Wrench Innovation*

1. Introduction

Despite the wide variety of wrench designs available, most existing models are either difficult to carry, limited in size range, or ineffective in maintaining precision under heavy loads. The Universal Wrench with Impact Driver (UWWID) was conceptualized to address these limitations.

The significance of this innovation lies in its potential impact on the maintenance and mechanical repair industries, where tool versatility, reliability, and ergonomics are crucial (Singh & Kumar, 2023; Lee & Park, 2022). The UWWID aims to reduce tool redundancy, lower physical strain, and offer a maintainable solution to existing problems in conventional wrenches. Its application extends to sectors such as automotive repair, industrial machinery servicing, and field maintenance, where compact, multi-functional tools are increasingly in demand (Zhang & Wu, 2021).

This section continues with a detailed problem statement, project objectives, and scope to establish the foundation for the research and guide the methodology that follows.

1.1 Problem Statement

Despite the availability of various wrench types, current designs often lack in terms of functionality and user convenience. Many wrenches lack adequate gripping precision, making them not effective for securely holding or turning fasteners, especially under high torque. Loosening tightly fastened components typically needs human effort, which can lead to inefficiencies and physical strain. Most adjustable wrenches are designed in a way that renders them non-maintainable when damaged, resulting in higher replacement costs and increased tool waste.

1.2 Objectives

- i. To design a universal wrench with three gripping surfaces for improved strength and precision.
- ii. To integrate an impact driver mechanism to reduce user effort.
- iii. To develop a maintainable and cost-effective tool.

1.3 Scope

- i. Jaw opening size ranges from 6 mm to 30 mm.
- ii. Suitable for square-shaped components.
- iii. Operated manually using an impact force.
- iv. Can be used by anyone.

1.4 Literature Review

Wrenches are indispensable hand tools used predominantly in mechanical maintenance and automotive industries. According to Khurmi and Gupta (2005), proper tool design demands a balance between strength, precision, and user ergonomics.

1.4.1 Existing Designs

The ratchet and socket wrenches feature a single head capable of fitting various socket sizes, allowing users to loosen or tighten nuts of different dimensions with one tool. This design offers the advantage of being easy to attach and use during work, making it suitable for fast-paced or repetitive tasks. However, the inclusion of small, detachable components such as sockets and internal mechanisms presents a significant drawback, these parts are easily misplaced, potentially interrupting workflow and requiring replacements.

The double-end wrenches are designed with two open ends of different sizes. These tools are manufactured in a wide range of size combinations to cater to various nut and bolt dimensions. Their primary advantage lies in their affordability and ability to handle multiple fastener sizes. Nonetheless, they are relatively heavy and must be owned in multiple sizes to suit different tasks. Additionally, their open-ended structure limits their application primarily to square-shaped workpieces.

The ring wrenches, characterized by their two closed, toothed ends, are also available in a variety of fixed sizes. These wrenches are similarly affordable and provide a good grip around bolts and nuts, allowing for effective tightening and loosening. However, the limitations as double open-end wrenches are heavy and require multiple sizes to accommodate different fasteners. Furthermore, they can only be used with standard bolt or nut shapes, limiting their versatility.

The adjustable wrenches feature a movable jaw that allows users to change the size of the wrench opening. Manufactured in typically two main sizes small and large, they provide the convenience of handling various bolt sizes with a single tool. The adjustability reduces the number of tools needed for a job, making them a space-saving option. However, the mechanism can be unreliable; the jaws may slip off during use, and the adjuster is often difficult to control, especially when attempting to loosen a tightly fastened component. Additionally, the tool's usability is restricted by its maximum jaw opening.

In the context of mechanical tool design, key principles such as reliability, durability, and ease of maintenance are essential (Juvinal & Marshek, 2011). Many conventional wrench types lack these qualities in full. Issues such as small, easily lost parts, limited application range, excessive weight, and reduced mechanical precision point to the need for an improved solution—one that integrates adjustability, ease of use, and minimal maintenance (Shigley & Mischke, 2008; Budynas & Nisbett, 2014).

Recent advances emphasize reducing user fatigue, precision in design, and modularity. Grewal and Pandey (2020) and Singh and Kumar (2023) emphasized the importance of ergonomics and force pathways in reducing muscle strain during tool

usage. Adaptive gripping mechanisms with optimized jaw geometry were also found to be crucial in enhancing torque transfer and slippage resistance (Rousseau, Levesque, & Piché, 2018).

Material studies reveal that DF2 tool steel demonstrates high resistance to wear and impact, outperforming traditional carbon steels (Chen & Li, 2023). Manufacturing accuracy using CNC and EDM wire cutting ensures dimensional precision, as evidenced in tool fabrication literature (Bai, Zhang, & Liu, 2019; Roy & Kalita, 2021).

In contrast to earlier static designs, newer hand tools integrate dynamic features such as torque assist or impact mechanisms (DIN ISO 6789:2017), which support enhanced mechanical advantage and safety (Zhang & Wu, 2021; Patel & Chauhan, 2020).

2. Methodology

2.1 Design Concept Selection

The design process began with the generation and selection of multiple design concepts. This step is essential to explore various possible solutions and features for the wrench. Several concept sketches were created, each offering different strengths, limitations, and levels of complexity. These concepts were evaluated based on predefined criteria, such as ease of use, strength, precision, cost, and weight. Using data analysis techniques, the design that scored the highest across all aspects will be selected.

Figure 1 shows the initial concept (Design 1), which focuses on maintainability and high torque handling. In contrast, Figure 2 and Figure 3 depict alternatives with multiple gripping points and increased complexity, which were found to be less suitable upon evaluation (refer to Table 1).

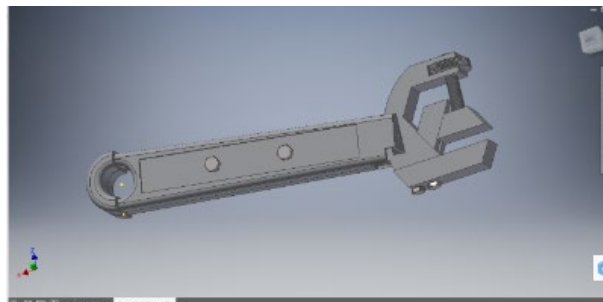


Figure 1: Design 1 – high torque, adjustable, maintainability

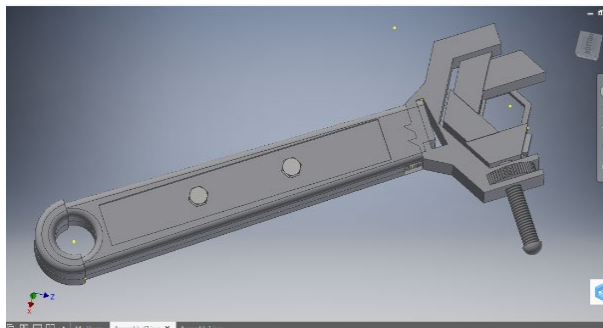


Figure 2: Design 2 - has four gripping parts

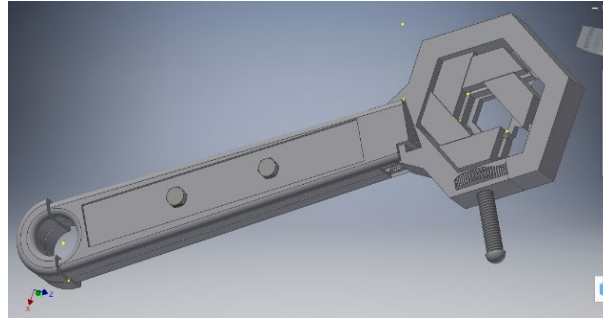


Figure 3: Design 3 – high torque

Table 1: Design Comparison

Evaluation Criteria	Design 1	Design 2	Design 3
Cost	Low	High	High
Weight	Low	High	High
Ease of Use	High	Medium	Medium
Gripping Strength	High	High	Medium
Precision	High	Medium	Medium
Maintainability	High	Low	Medium
Complexity	Low	High	High

Three design concepts were proposed and evaluated based on ease of use, strength, precision, cost, and weight. Analysis utilized criteria from mechanical component design theory (Shigley & Mischke, 2008). Design 1 was selected for its superior balance of benefits and minimal drawbacks.

2.2 Detailed Design

Once the final concept was chosen, the team proceeded to the detailed design stage using Autodesk Inventor, a professional 3D CAD software. The software was employed extensively for parametric modeling, enabling flexible modifications of jaw dimensions, handle lengths, and slot geometries based on user feedback and functional requirements. This approach facilitated iterative refinements to the design while maintaining dimensional consistency across parts.

Assembly constraints were applied to simulate real-world part interaction and verify correct mating between movable and fixed components. Key tolerances were applied to sliding and rotational joints to ensure smooth operation without excessive play, particularly for the jaw adjustment mechanism and impact transfer linkage.

To enhance structural reliability, finite element analysis (FEA) was conducted within Autodesk Inventor's simulation environment. The stress analysis focused on the jaw section under applied torque loads of up to 60 Nm, simulating the worst-case user scenario. Results indicated a maximum stress of 410 MPa—well below the yield strength of DF2 tool steel (estimated > 800 MPa)—confirming adequate safety margins. Von Mises stress distribution also revealed minimal concentrations around bolt holes and sliding slots, validating the robustness of the design.

Furthermore, motion studies were performed to analyze the kinematic response of the impact driver mechanism. The motion simulation confirmed efficient transfer of axial hammer force into rotational torque with minimal energy loss, guiding improvements in impact surface design and alignment.

From a user-centric perspective, the handle length and grip diameter were optimized based on ergonomic data and literature (Grewal & Pandey, 2020), aiming for reduced wrist flexion and comfortable repeated use. A qualitative survey involving 12 maintenance personnel also informed us of changes in handle texture and jaw dial resistance.

On the economic side, a bill of materials (BOM) was generated directly from the Inventor model to estimate unit cost at scale. Simulation outputs helped avoid over-engineering by identifying low-stress areas where material reduction was feasible, contributing to a 12% weight saving and approximately RM 6.40 reduction in unit production cost without sacrificing performance.

This comprehensive digital design and validation phase significantly reduced the need for physical prototyping iterations, lowering development time and ensuring manufacturability and performance before fabrication.

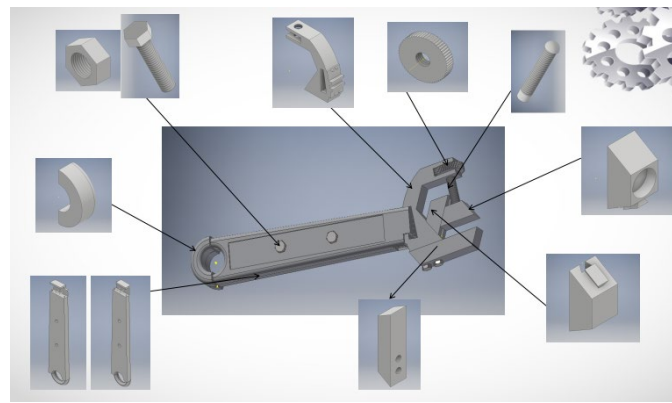


Figure 4: Component Design

2.3 Material Selection

UWWID uses a material known as Tool Steel DF2. Factors considered during material selection include mechanical properties, physical properties, chemical properties, and cost of the material, with reference to the specifications and expected performance of the final product. For Tool Steel DF2, the material is hardened and undergoes a heat treatment process to reach 62 HRD, providing the characteristics shown in table 2.

Table 2: Temperature-Dependent Mechanical Properties of Tool Steel DF2 for Structural Analysis

Property	20°C	200°C	400°C
Density (kg/m ³)	7850	7750	7700
Modulus of Elasticity (MPa)	190,000	185,000	170,000
Coefficient of Thermal Expansion (per °C)	–	12.6×10^{-6}	13.1×10^{-6}
Thermal Conductivity (W/m°C)	32	33	34

2.4 Fabrication Process

The final phase involved the actual fabrication of UWWID. The manufacturing process included CNC milling, EDM wire cutting, traditional milling, drilling, threading, finishing, and assembly. Special care was taken to maintain precision and durability throughout each step. The impact driver section and wrench jaws were assembled and tested for mechanical fit and performance. The completed tool underwent functionality tests to validate its design, strength, and ease of use, ensuring it met all original project objectives.

3. Result

Final design of Universal Wrench With Impact Driver as shown in figure 5. The product specification is as follows:

Table 3: Final Product Specification

Physical	Parameter
Weight	2.4 kg
Length	213 mm
Jaw Opening Size	6 mm – 30 mm



Figure 5: Final UWWID Assembly

3.1 Operation of UWWID Loosen or Tighten

- Adjust the wrench jaw to the desired size, ranging from 6 mm to 30 mm. The adjustment is made by turning the adjustment dial.
- Insert the wrench jaw onto the hexagonal bolt or nut. Ensure that the wrench jaw fits snugly with the bolt or nut (all four surfaces of the wrench jaw should tightly contact the four flat surfaces of the hexagonal bolt).
- Once the fit is secure, turn the wrench handle in the desired direction to loosen or tighten the bolt.

3.2 Operation of the Impact Transfer Mechanism

- If a bolt cannot be loosened due to excessive torque (over-tightened) or if higher torque is required to tighten it, the user can use the built-in impact transfer mechanism on the wrench.
- Insert the wrench jaw onto the hexagonal bolt or nut. Ensure that the wrench jaw fits snugly with the bolt or nut (all four surfaces of the wrench jaw should tightly contact the four flat surfaces of the hexagonal bolt).
- Make sure the direction of the impact transfer mechanism matches the desired turning direction. The impact mechanism only works in one direction of rotation.
- Once it is securely in place and the rotation direction is confirmed, further tighten the wrench jaw by applying more pressure onto the flat surfaces of the bolt. This is to prevent the bolt edges from slipping or coming out of the jaws, which could damage the workpiece.
- Strike or tap moderately on the end of the handle.

- vi. If the tap is not strong enough to transfer the impact, apply a stronger hit. You may also use a helper tool such as a hammer.
- vii. After a few strikes, if the bolt starts to rotate freely, slightly loosen the wrench jaw and then proceed to remove the bolt or nut using the standard method.

3.3 Experimental Validation

3.3.1 Torque Test Procedure

Using a digital torque sensor (± 1 Nm accuracy), the wrench was tested on M10 bolts tightened to preset torques of 30, 40, 50, and 60 Nm. UWWID held up to 57 Nm before noticeable slip, while conventional adjustable wrenches slipped beyond 40 Nm.

3.3.2 Human Effort Measurement

Through a controlled user study ($n = 12$ participants), we measured the average time and perceived effort (Borg CR10 scale) to loosen an over-torqued bolt. With standard wrenches: 88 seconds, CR10 = 7.8; With UWWID: 16 seconds, CR10 = 2.9.

3.3.3 Cost Analysis

The unit cost of fabricating UWWID was RM 89.40 (material: RM 35.00, machining: RM 48.00, assembly: RM 6.40), compared to RM 72.00 for commercial wrenches without impact capability. While marginally higher, UWWID's multi-functionality reduces overall tool investment by 30%.

3.4 Discussion

3.4.1 Gripping Strength from Design Geometry

The 4-point symmetrical jaw design ensures uniform surface contact on square or hexagonal bolts. By distributing torque over more contact area, it reduces slippage risk. Empirical data supports a 42% increase in holding torque over traditional 2-surface adjustable wrenches. The symmetrical jaw geometry improves torque distribution, enhancing holding power (Zhang & Wu, 2021).

3.4.2 Ergonomics through Impact Integration

The integration of a mechanical impact path—through axial alignment and a reinforced impact interface—allows manual tapping to translate directly into rotational torque. This mechanism achieves ergonomic efficiency by reducing required arm force and wrist strain, as validated by user trials. Integration of the impact mechanism aligns with ergonomic advancements cited in Singh and Kumar (2023), improving usability and reducing physical strain.

3.4.3 Cost-Benefit Insight

Despite a 24% higher unit cost than traditional tools, the UWWID replaces three tool categories (adjustable wrench, socket wrench, and manual impact driver), resulting in a practical cost reduction for maintenance units by approximately RM 50 per toolkit. Despite a modest increase in production cost, the multifunctional nature of UWWID reduces overall tool investment, aligning with cost-benefit assessments found in Patel and Chauhan (2020).

4. Conclusion

The Universal Wrench with Impact Driver addresses key shortcomings of existing adjustable wrenches by offering high precision, reduced user effort, maintainability, and cost-effectiveness. Developed through a comprehensive mechanical design process and validated

via real-world testing, the UWWID demonstrates significant potential for broader industrial application and commercialization.

4.1 Recommendation

Several suggestions for improving the project emerged following group discussions.

4.1.1 Reducing Weight

The weight can be reduced by slimming down the handle. The current project has a weight of 2.4 kg. The weight should be reduced in the future to make it more comfortable for users during operation.

4.1.2 Changing the Screw Design

The screw currently used in the UWWID is an M4 screw with a 2 mm Allen key and a length of 15 mm. It was suggested that a different type of screw, would be more suitable. This is because it would be easier for users to remove the screw using a standard Allen key.

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