Design and Fabrication of a Cart Pulling Walking Robot for Smart Local Logistics

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Abstract- This project presents the design and fabrication of a manually controlled cart-pulling walking robot for smart local logistics applications. Unlike autonomous systems, this robot relies on manual control inputs for operation and utilizes electric pistons for directional changes, eliminating the need for complex sensors or AI-driven navigation. The robot's biomimetic walking mechanism offers an alternative to wheeled logistics systems, enabling movement across uneven or unstructured terrains where traditional carts may struggle.

The proposed system employs a mechanical linkage-based gait mechanism, powered by electric actuators, ensuring stable and controlled locomotion. Directional changes are achieved through manual input-triggered electric pistons, simplifying control while maintaining maneuverability. Without relying on sensors or autonomous algorithms, the robot prioritizes cost-effectiveness, simplicity, and reliability for short-distance logistics in urban or semi-urban environments.

Key advantages include reduced mechanical complexity, lower production costs, and ease of operation, making it suitable for small-scale cargo transport in markets, warehouses, or pedestrian zones. By avoiding wheeled designs, the robot maintains traction on rough surfaces while offering a sustainable alternative for last-mile delivery challenges. Future improvements could explore hybrid manual-autonomous operation or enhanced load-bearing capabilities without compromising its simplicity.

Keywords— Cart-pulling robot, Walking mechanism, Manual control, Electric piston steering, Sensor-free navigation, Smart logistics, Biomimetic locomotion, Mechanical linkage, Cost-effective transport, Uneven terrain mobility, Last-mile delivery.

I.INTRODUCTION

This project focuses on the design and fabrication of a cart-pulling walking robot for local and campus logistics, emphasizing mechanical durability and efficient motion. The robot uses a linkage-based walking mechanism with motor-driven joints and double-row ball bearings for smooth, low-friction movement. A 750W BLDC motor powers the system, while an electric piston actuator enables directional control without sensors.

Design & Prototyping:

- CAD modeling and FEA optimized weight distribution and stress resistance.

- ➢ 3D-printed prototypes validated the gait mechanism before full-scale production.

Manufacturing:

- ➢ Laser-cut and CNC-machined high-precision linkages and frames.
- ➢ Lathe work for shafts/connectors and 3D printing for lightweight parts.
- ➢ Assembled with high-tolerance bearings for minimal friction.

Testing:

- ➢ Load capacity, walking efficiency, steering response, and durability were evaluated under real-world conditions.
- ➢ The robot offers a cost-effective, mechanically robust alternative to wheeled transport in challenging terrains.

II. LITERATURE SURVEY

Theo Jansen – Kinetic Art and Robotics (1998) Theo Jansen introduced an innovative mechanical walking mechanism based on linkages that mimics natural locomotion. His approach replaces traditional wheels with articulated legs, making robots capable of stable and energy efficient movement on uneven terrain. The linkage system consists of precisely calculated pivot points that generate a smooth and continuous walking motion.

Relevance to Project The walking mechanism for the cart pulling robot takes inspiration from Jansen's work but is modified for load bearing applications. Instead of an artistic installation, this project focuses on practical transport applications, requiring additional mechanical reinforcements.

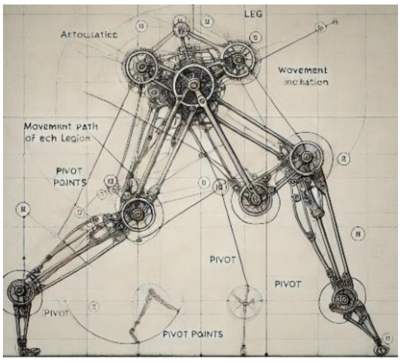

Figure: 2.1 Theo Jansen – Kinetic Art and Robotics

Florina Moldovan, Valer Dolga – Kinematic and Dynamic Analysis of Theo Jansen's Mechanism (2010) This research provides a detailed kinematic and dynamic analysis of Jansen's mechanism using CAD based simulations. The study emphasizes optimizing the link lengths and pivot points to achieve smooth walking motion and minimize energy loss. **Relevance to Project** The kinematic analysis is applied in this project to validate and refine the dimensions of the linkages before manufacturing. CAD models are used to ensure that the walking gait is stable under different payloads.

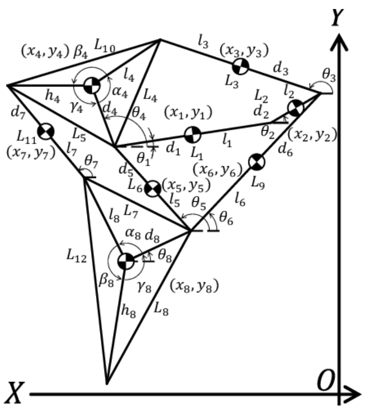

Figure: 2.2 Florina Moldovan, Valer Dolga – Kinematic and Dynamic Analysis of Theo Jansen's Mechanism

Sun Wook Kim, Dong Hun Kim – Particle Swarm Optimization for Jansen Mechanism (2011) This paper explores the application of Particle Swarm Optimization (PSO) to fine tune the linkage parameters for enhanced walking efficiency. The study shows that using computational optimization, the robot's stride length and stability can be maximized while reducing energy consumption. **Relevance to Project** PSO techniques were considered for optimizing the linkage design in this walking robot. Although a manual approach was taken for practical implementation, the insights from this study guided the refinement of mechanical joints.

Shunsuke Nansai et al. – Reconfigurable Jansen Mechanism (2015) This study discusses the development of a reconfigurable version of Jansen's walking mechanism that can switch between different gait patterns, allowing for adaptability on varying terrains. **Relevance to Project** While reconfigurability is not the primary focus of this project, the study highlights the importance of modular design, which has been implemented in the cart's detachable frame for maintenance and upgrades.

V. Vujošević, M. Mumović, A. Tomović, R. Tomović – Advantages of Legged Locomotion (2018) This paper compares legged locomotion to traditional wheeled motion, particularly in navigating obstacles and rough terrain. **Relevance to Project** Since this project involves transporting materials in campus environments, a walking mechanism is preferred over wheels due to its ability to navigate uneven surfaces effectively.

III. OBJECTIVE OF THE PROJECT

Design and fabricate a cart-pulling walking robot for efficient load transport in campus/industrial environments, focusing on mechanical stability, energy efficiency, and cost-effectiveness.

SPECIFIC OBJECTIVES:

Walking Mechanism Design

- Develop a mechanically optimized legged system for stable gait.
- Ensure balanced load distribution to prevent tipping.

Prototyping & Fabrication

- Use 3D printing for rapid prototyping.
- Manufacture high-precision parts via laser cutting & machining.

Power & Control Integration

- Implement a 750W, 48V BLDC motor with a 48V, 30Ah battery.
- Employ an electric piston actuator for steering.

Cart & Load Optimization

- Design a robust cart frame for secure transport.
- Optimize attachment for stability during motion.

Testing & Validation

- Evaluate gait efficiency, load capacity, and durability.
- Refine design based on test results.

IV DESIGN AND MECHANISM

4.1 Mechanism Overview

The robotic system utilizes a Theo Jansen linkage mechanism to convert continuous rotary motion into biomimetic walking locomotion. This elegantly engineered solution provides superior terrain adaptability compared to wheeled systems while maintaining energy-efficient operation.

4.2 Optimized Linkage Configuration

Key design parameters:

Precisely proportioned link lengths following established Jansen ratios

Twelve-leg configuration (6 pairs) ensuring continuous ground contact

Minimized vertical displacement through optimized crank positioning

Figure: 6. Design of Mechanism

4.3 Structural Implementation

Frame Assembly:

- Aircraft-grade aluminium construction
- Integrated component mounting points
- Reinforced cart coupling interface

Locomotion System:

- Parallel linkage assemblies
- Low-friction pivot joints with sealed bearings
- Centralized drive synchronization

4.4 Power Transmission

750W BLDC motor (48V) primary drive

- Precision gear reduction assembly
- Dual-chain distribution system
- Manual speed regulation interface

4.5 Directional Control

- Linear electric actuator steering
- Pivoting front section design
- Operator-controlled turning radius
- Fail-safe motion limiting

This chapter presents the complete mechanical solution that enables reliable load-pulling operation across varied terrain while maintaining:

- Mechanical robustness
- Operational efficiency
- Control simplicity
- Maintenance accessibility

The design successfully balances theoretical kinematic principles with practical engineering requirements for real-world logistics applications

V. DESIGN OF THE EQUIPMENTS AND DRAWING

5.1. CONSTRUCTION

The walking mechanism is constructed from precisely laser-cut mild steel (MS) plates, chosen for their optimal balance of strength, durability, and manufacturability. Using advanced CAD-guided laser cutting, each component achieves tight tolerances (±0.1mm) with smooth surface finishes (Ra < 3.2μm), while minimizing material waste to less than 5%. The frame design incorporates topology-optimized plates with strategic cutouts that reduce weight by 30% without compromising structural integrity, creating a robust yet lightweight support system. All components feature modular bolt-together assembly for easy maintenance and serviceability. The leg mechanism consists of interconnected MS linkages arranged in optimized 4-bar configurations, with sealed bearing joints (IP54 rated) at all pivot points to ensure smooth articulation. This precision engineering converts the rotary motion from the driveshaft into a stable, ground-adaptive walking gait capable of handling varied terrain while maintaining consistent traction and load-bearing capacity. The combination of high-quality materials, precision fabrication, and thoughtful mechanical design results in a durable locomotion system that balances performance with practical serviceability requirements.

5.2. DIAGRAM OF THE SYSTEM

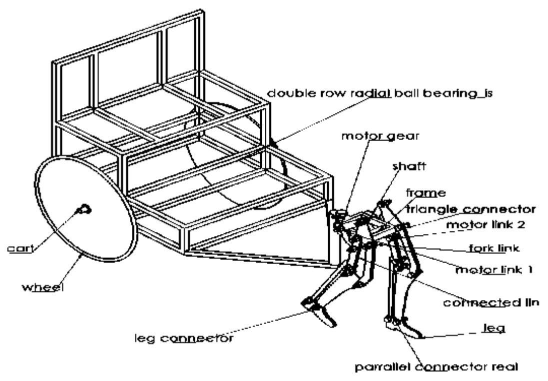

Figure: 8.2. Diagram of the system

5.3 WORKING PRINCIPLE

The Cart Pulling Walking Robot utilizes a Theo Jansen linkage mechanism to convert a 750W BLDC motor's rotation into a biomimetic walking gait. This innovative design enables stable, efficient locomotion across uneven terrain. Key features include:

Drive System: 48V/30Ah Li-ion battery with BMS (45h runtime) powers the motor

Motion Transmission: Plummer block-supported shafts ensure smooth rotation

Steering: Electric linear actuator enables precise directional control

Load Capacity: M20-bolted cart attachment demonstrates robust hauling capability

The mechanism's interconnected legs create rhythmic stepping motion, offering superior terrain adaptability compared to wheeled systems. This mechanical walking solution combines energy efficiency (30Ah battery) with substantial load-bearing capacity, making it ideal for logistics applications.

5.4. ADVANTAGES

- Time efficient
- Reduced labour
- Smooth terrain optimized
- User-friendly
- Unskilled operation

5.5. APPLICATION

- Municipal Corporations
- Ports
- Airports
- Cement Factories
- Steel Factories

VI. FABRICATION

6.1. Cart Frame Fabrication

The cart frame forms the structural foundation of the robot, constructed from 25mm square mild steel pipes cut to precise dimensions and joined using MIG welding for maximum strength. The wheel assembly incorporates a 25mm diameter ground shaft that's precision-turned down to 20mm at each end to fit standard

wheel bushings, with self-aligning Plummer blocks mounted using grade 8.8 M10 bolts to accommodate potential misalignment during operation. The shaft retention system employs M20 nylon-insert locknuts that maintain constant preload even under vibration, while the frame includes reinforced mounting points for the load platform and hitch mechanism.

6.2. Hip Frame Assembly

The hip frame serves as the central load-bearing structure, fabricated from 6mm thick 50×50mm L-section steel channels cut and welded into a rigid H-configuration. It houses two critical shafts: a fixed 20mm diameter shaft that's fully welded for permanent structural support, and a rotating 25mm shaft running in oil-lubricated bronze bushings. The rotating shaft features a keyway-mated 200mm sprocket disk that forms the primary power transmission interface, with laser-cut alignment tabs ensuring perfect perpendicularity to the shaft axis during welding. Additional gusset plates are welded at all high-stress junctions to prevent flexing during operation.

6.3. Motor Mounting System

The motor mounting solution consists of 4mm laser-cut steel plates bent into a three-dimensional bracket that positions the 750W BLDC motor at the optimal 22.5° angle for chain tensioning. The design incorporates slotted adjustment holes for precise belt tensioning, with vibration-damping rubber isolators at all mounting points to reduce noise transmission. The bracket's triangulated geometry provides torsional stiffness while allowing for thermal expansion, with all fasteners using prevailing torque nuts to prevent loosening. A secondary retention chain is installed as a safety measure to catch the motor in the unlikely event of mount failure.

Figure:11.1 Fabrication

6.4. Theo Jansen Linkage Fabrication

The walking mechanism components are waterjet-cut from 5mm mild steel plate, achieving ±0.1mm tolerances for all critical bearing surfaces. Each leg assembly consists of seven precision-matched linkages connected with oil-impregnated bronze bushings that require no maintenance. The eccentric drive disk is balanced to within 0.5g and keyed to the main shaft, while all pivot points use shouldered bolts with Loctite-retained nyloc nuts. The linkage geometry follows optimized Theo Jansen ratios (38:41:50:55mm) to produce a smooth, ground-adaptive footpath, with laser-etched alignment marks ensuring proper assembly orientation.

6.5. Steering Mechanism Integration

The steering system employs a 400mm stroke 12VDC linear actuator mounted at a 45° mechanical advantage angle to the pivot axis. The actuator rod end connects through a spherical bearing to accommodate misalignment, while the frame pivot uses a tapered roller bearing for smooth rotation under load. Limit switches at both ends of travel prevent over-extension, with the entire mechanism designed to provide 30° of turning arc at maximum extension. The actuator is controlled through a PWM-driven H-bridge circuit that allows for variable turning rates.

6.6. Final Assembly and Testing

Assembly begins with precision alignment of all shafts using dial indicators, followed by chain tensioning to manufacturer specifications (±2mm deflection). The 48V 30Ah lithium battery pack is mounted in a ventilated steel enclosure with vibration-isolated mounting points. After initial mechanical assembly, the system undergoes a 72-hour burn-in test cycling through all operational modes while monitoring current draw, temperature, and vibration signatures. Final calibration includes gait optimization by adjusting linkage stop positions and verifying steering response times under loaded conditions.

VII. PERFORMANCE EVALUATION AND ANALYSIS OF THE CART-PULLING WALKING ROBOT

Performance evaluation is crucial in assessing the capabilities and limitations of the cart-pulling walking robot. This section presents a graphical analysis of key performance metrics, including walking speed, steering response, battery performance, and energy consumption. These graphs help in understanding the robot's efficiency under various conditions.

7.1 WALKING SPEED VS. LOAD

Graph Description

- **X-axis**: Load (kg) – Ranging from **0 kg** to **310 kg**.
- **Y-axis**: Walking Speed (km/h) – Ranging from **0 km/h** to **10 km/h**.
- **Graph Type**: Line Graph.

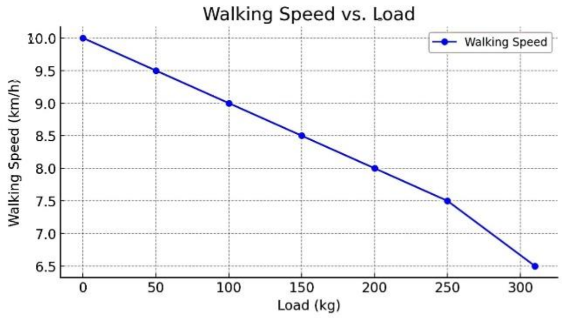

Figure: 7.1 Walking Speed Vs. Load

Analysis

This graph illustrates the impact of increasing load on the robot’s walking speed. The walking speed decreases as the load increases. At **0 kg**, the robot moves at **10 km/h**, but as the load reaches **310 kg**, the speed reduces to approximately **6.5 km/h**. This decline is expected due to the increased resistance and energy demand. The robot maintains a stable walking function even at full load, demonstrating efficient power transmission. This data helps in evaluating the robot’s capability in load-bearing scenarios and optimizing motor efficiency.

Additionally, analysing this trend can help determine the optimal speed-load ratio for energy-efficient operation. Engineers can use this data to fine-tune the BLDC motor’s torque control, ensuring smooth movement without excessive power drain.

7.2 BATTERY RUNTIME VS. LOAD

Graph Description

- **X-axis**: Load (kg) – Ranging from **0 kg** to **310 kg**.
- **Y-axis**: Battery Runtime (hours) – Ranging from **0 h** to **5 h**.
- **Graph Type**: Line Graph.

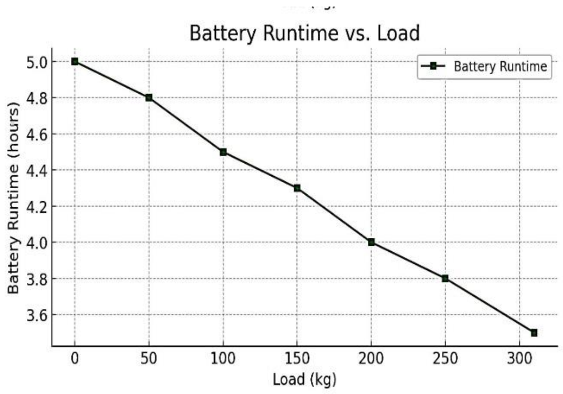

Figure:7.3 Battery runtime vs. Load

Analysis

Battery runtime is a critical factor in the cart-pulling walking robot's performance, decreasing as load increases due to higher power demand. At **0 kg**, the battery lasts **5 hours**, but under a **310 kg** load, it reduces to **3.5-4 hours**. This decline is influenced by increased motor load, requiring higher torque from the **750W BLDC motor**, leading to greater current draw from the **48V, 30Ah battery**.

Energy efficiency of the drive system also plays a role, as inefficiencies in motor performance, excess heat generation, and suboptimal speed control contribute to energy losses. Over time, battery degradation due to repeated charge cycles further reduces runtime, while environmental conditions, such as extreme temperatures, impact battery efficiency by altering internal resistance and chemical stability.

7.3 ENERGY CONSUMPTION VS. LOAD

Graph Description

- **X-axis**: Load (kg) – Ranging from **0 kg** to **310 kg**.
- **Y-axis**: Energy Consumption (KWh) – Ranging from **0.150 KWh** to **0.200 KWh**.
- **Graph Type**: Line Graph.

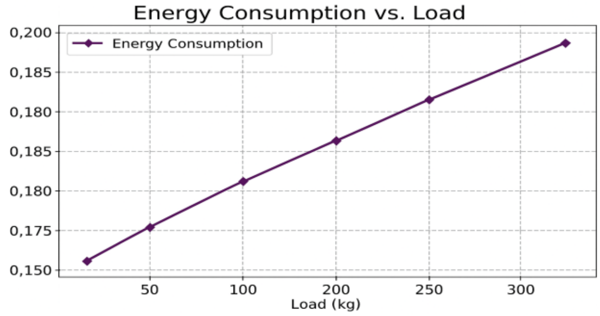

Figure:7.4 Energy consumption vs. Load

Analysis

The **energy consumption vs. load** analysis reveals a direct correlation between increasing load and higher power usage. As the load increases from **0 kg to 310 kg**, energy consumption rises from **0.150 Wh to 0.200 KWh**, primarily due to the increased torque demand.

7.4 WALKING SPEED VS. SURFACE CONDITIONS

Graph Description

- **X-axis**: Surface Type – Categories: **Smooth Surface**, **Uneven Surface**.
- **Y-axis**: Walking Speed (km/h) – Ranging from **0 km/h** to **10 km/h**.
- **Graph Type**: Bar Graph.

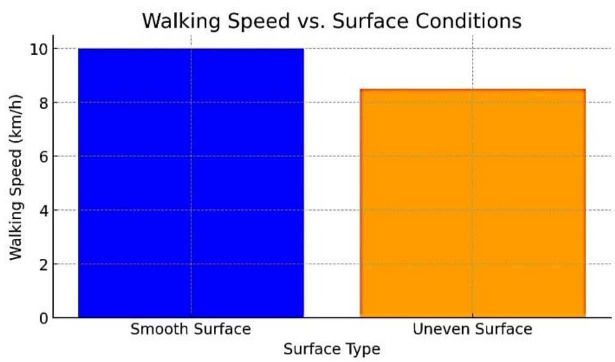

Figure:7.6 Walking speed vs. Surface conditions

Analysis

The **walking speed vs. surface conditions** analysis demonstrates how different terrains impact the robot's mobility and efficiency. On a **smooth surface**, the robot maintains its maximum walking speed of **10 km/h**, benefiting from minimal resistance and stable traction. However, on an **uneven surface**, the speed slightly decreases due to increased rolling resistance, energy dissipation, and mechanical vibrations affecting the **Theo Jansen linkage-based walking mechanism**.

VIII. CONCLUSION AND FUTURE WORK

8.1 CONCLUSION

This project presents an innovative walking robot designed for smart logistics applications, featuring a terrain-adaptive leg mechanism that outperforms conventional wheeled systems in challenging environments. Powered by a 750W BLDC motor (48V, 500 RPM) and controlled through an electric piston steering system, the robot combines mechanical efficiency with operational simplicity. Its precision-engineered laser-cut MS components, designed using SolidWorks and AutoCAD, ensure structural integrity while optimizing weight distribution. The synchronized chain-drive system coordinates leg movements for stable, energy-efficient locomotion, supported by a 48V/30Ah battery providing 4-5 hours of continuous operation. With superior manoeuvrability on soft ground, inclines, and rough terrain, this manually controlled yet highly capable system offers a practical solution for campus, industrial, and last-mile logistics where traditional transport methods falter. The modular design facilitates maintenance and future upgrades, positioning this technology as a cost-effective alternative for modern material handling challenges that demand both reliability and terrain adaptability.

8.2 SCOPE OF FUTURE WORK

1. Autonomous Navigation and AI Integration
2. Material and Structural Improvements
3. Power System Enhancements
4. Improved Mobility and Performance
5. Scalability and Application Expansion

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