Welding Robot: A Review of Design and Implementation

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***Abstract*—–––- after completing the Entire report –—-**

***Index Terms*—Humanoid robot, welding automation, industrial robotics, robot design, intelligent sensing.**

I. Introduction

Humanoid robots have gained significant research attention due to their potential to replicate human dexterity, mobility, and adaptability. In welding applications, these capabilities enable robots to operate in unstructured or semi-structured environments where traditional robotic arms face limitations [1].

As industries transition toward Industry 4.0, the demand for flexible and intelligent robotic welding systems has increased. Humanoid welding robots combine human-like kinematics with advanced sensing, allowing them to perform tasks such as arc welding, MIG/TIG welding, and inspection in complex workspaces.

This paper reviews recent advancements in humanoid welding systems, covering mechanical structure, sensing integration, motion planning, and real-world implementation challenges.

II. Mechanical Design of Humanoid Welding Robots

Humanoid welding robots aim to replicate the range of motion and dexterity of human welders. Key aspects include:

A. Anthropomorphic Structure

Modern humanoid robots feature:

- multi-DOF arms for flexible positioning,
- articulated wrists capable of precise welding torch manipulation,
- stable bipedal or wheeled locomotion systems.

Examples include the HRP series, Boston Dynamics Atlas, and custom-built industrial humanoids [2].

B. Material Selection

Lightweight materials such as aluminum alloys, carbon fiber composites, and high-strength steels are used to ensure structural stiffness while minimizing weight.

C. End-Effector Design

Specialized welding torches are integrated with:

- cooling systems,
- cable management,
- integrated sensors for weld seam detection.

III. Intelligent Sensing for Welding

Sensing is critical for humanoid welding robots to adapt to varying work conditions.

A. Vision Systems

RGB-D cameras, stereo vision, and structured light sensors enable:

- seam tracking,
- weld quality analysis,
- robot localization.

B. Force and Torque Sensors

These enable compliant welding motions and help detect surface irregularities [3].

C. Thermal and Arc Sensors

Used for:

- monitoring arc stability,
- maintaining welding temperature,
- detecting defects during the welding process.

IV. Control Strategies and Motion Planning

Humanoid welding robots require advanced control approaches due to their high DOF and nonlinear kinematics.

A. Inverse Kinematics and Dynamics

Real-time IK solvers and model-predictive control methods enable precise end-effector positioning.

B. Learning-Based Motion Planning

Deep learning and reinforcement learning help robots imitate human welding trajectories and optimize path planning [4].

C. Human-Robot Collaboration

Safety-aware control architectures allow humanoid robots to work near human workers.

V. Implementation Challenges

Despite advancements, several issues remain:

- high power consumption and heat management,
- complex calibration of sensors,
- safety certification for industrial deployment,
- robustness in harsh welding environments.

VI. Future Research Directions

Promising areas include:

- multimodal sensor fusion for improved seam tracking,
- lightweight and fire-resistant materials,
- improved dexterity for intricate welding tasks,
- autonomous learning from human welders through demonstration.

VII. Conclusion

Humanoid welding robots represent a major advancement in industrial automation, offering flexibility, adaptability, and human-like precision. Continued research in sensing, AI-driven planning, and robust design is essential for widespread industrial adoption.

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