

Team ZETIN Extended Abstract

Title

A Hybrid Humanoid Platform Strategy: Predictive Visual Servoing and Dual-Arm ZMP Compensation for Soccer Behaviors

Minseong Kim, Namgyun Kim, Seongwoo Kang, Gyuri Jo, Seohyeon Kim, Taehwan Kim, Se-eon Seong, Jimin Lee, Jihyeon Lee, Jonghee Jeong, Min Jo, Hyeonjeong Ju

Abstract

This abstract presents the humanoid robot system developed by Team ZETIN for the RoboCup Humanoid League. We adopted a hybrid architecture combining the Mobilio TRON1 commercial lower-body platform with a custom-designed upper body to prioritize match-level performance over hardware development.

The system addresses two critical challenges observed in field testing: visual occlusion during close-range interactions and inertial instability during dynamic kicking. We implemented a predictive visual tracking algorithm using an Exponential Moving Average (EMA) velocity estimator, which enables continuous kicking motions even when the ball is momentarily occluded. Furthermore, a dual-arm ZMP compensation mechanism utilizes upper-body inertia to counteract body tilt.

A custom middleware layer bridges the ROS-based behavior planner with the TRON1 locomotion controller, managing protocol negotiation and system initialization. These results suggest that carefully integrating commercial hardware with task-specific perception and control is a practical path for new teams entering the Humanoid League.

1. Introduction

Developing a full-sized humanoid robot involves extensive mechanical engineering and low-level control tuning, which often delays the implementation of high-level gameplay strategies for new teams. Team ZETIN bypassed these hardware barriers by adopting a modular integration strategy.

We utilized the Mobilio TRON1 platform for locomotion, concentrating development efforts on upper-body kinematics, vision processing, and behavior planning. Moving beyond simple reactive sensing, our system incorporates predictive estimation to compensate for sensor latency and tracking loss. This document details the system architecture and specific control strategies tailored for the RoboCup environment.

2. Technical Issues

2.1 Mechanical Design

The robot utilizes the TRON1 lower body for ZMP-based walking. We designed a lightweight custom upper body to minimize rotational inertia while maintaining sufficient range of motion for balancing. The actuation system employs AK-series quasi-direct drive motors, selected for their high torque density and back-drivability. Specifically, AK70-10 actuators drive the shoulder pitch joints, while AK60-6 actuators control the shoulder roll. The neck mechanism uses AK40-10series motors for rapid pan-tilt tracking.

A Nucleo-STM32G474 board serves as the upper-body controller, managing CAN communication and synchronizing kinematic commands with the main computer.

2.2 Communication System

The TRON1 platform operates on a WebSocket-based locomotion interface, whereas the perception and behavior stacks run in ROS. We developed a dedicated middleware node to bridge these distinct protocols. This middleware handles session initialization, command formatting, and the transition sequence (Recovery -> Stand -> Walk), allowing the high-level planner to function independently of the lower-level communication details.

2.3 Vision Recognition and Predictive Blind Kick

Ball detection relies on a deep learning-based object detector. In close-range scenarios, the ball frequently enters the camera's blind spot near the robot's feet, typically causing conventional reactive systems to stall.

We addressed this by implementing a ball velocity estimator using an Exponential Moving Average (EMA, $\alpha=0.3$) filter. When visual tracking is lost, the system extrapolates the ball's position based on its last known velocity vector and proceeds with the kick sequence rather than reverting to a search state. Multi-frame validation logic is applied to filter out transient false detections. Although this predictive approach improves continuity, tracking performance can degrade under abrupt, non-linear ball deflections, which remains a limitation of the current linear model.

2.4 Behavior Planning

The behavior architecture uses an adaptive state machine. The approach velocity is dynamically adjusted according to the ball's estimated speed; the robot approaches

stationary targets aggressively (0.12 m/s) but reduces speed (0.08 m/s) for moving targets to prevent overshooting. Additionally, the yaw alignment threshold tightens dynamically for fast-moving targets to ensure precision.

2.5 Dual-Arm ZMP Compensation

To enhance stability during dynamic maneuvers, we implemented a Dual-Arm ZMP compensation algorithm. Using real-time roll data from the IMU, the arms articulate asymmetrically to generate a counter-moment against body tilt. During the kicking phase, this compensation gain is attenuated to prevent interference with the kicking dynamics. Hard constraints on roll angles are enforced to maintain the robot within safe operating limits.

3. Future Work & Conclusion

Team ZETIN has successfully integrated the core components of a hybrid humanoid system, featuring predictive tracking, inertial balance compensation, and protocol-agnostic middleware.

Future development focuses on three primary areas:

1. **Hardware Finalization:** Full integration of the rectangular foot soles and optimization of surface contact dynamics for grass-like environments.
2. **Algorithm Optimization:** Tuning EMA parameters using real-match datasets to improve prediction accuracy under non-linear ball trajectories.
3. **Advanced Control:** Exploring Deep Reinforcement Learning (DRL) for robust push-recovery and complex falling-and-standing sequences.

At RoboCup 2026, we will evaluate the system under match conditions to validate its stability and adaptability. Our work demonstrates that combining commercial platforms with targeted software engineering is a viable path to achieving competitive performance in the Humanoid League.