CAU Mountain&Sea 2025 AdultSize Extended Abstract

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Abstract. This paper presents the lessons learned by the CAU Mountain&Sea team during our preparation for the RoboCup 2025 Humanoid Adult Size Soccer competition. We provide detailed insights into the technical strategies employed to enhance robot performance, including advancements in locomotion, vision-based perception, and real-time decision-making. Our experiences also highlight key innovations in humanoid robotics, including sensor fusion, adaptive control architectures, and reinforcement learning for improved task execution. These lessons aim to contribute to the broader field of robotics by showcasing both the challenges and solutions encountered in the context of competitive humanoid soccer.

1 Lessons We Learned

1. **Balancing Predefined and Learned Behaviors is Crucial for Stability and Adaptability**: Our experience highlights the need to carefully balance predefined motion sequences and learned behaviors. Tasks that require high adaptability, such as walking across varying terrains, benefit from data-driven approaches like deep reinforcement learning (DRL). DRL allows the robot to learn optimal gaits through trial and error in simulation, leading to more dynamic and resilient locomotion. On the other hand, simpler but critical actions such as standing up and kicking require high reliability and repeatability. These are best handled with predefined motion sequences, as they ensure consistent execution without the unpredictability of learned models. Future improvements could involve hybrid approaches, where reinforcement learning is combined with model-based optimization to improve both adaptability and reliability, ensuring smooth transitions between different motion types.
2. **Sensor Fusion is Essential for Robust Perception and Localization in Dynamic Environments**: Our current localization primarily relies on vision-based detection, using deep learning models like YOLOv5 and traditional tracking methods such as particle filters. However, we have observed that vision alone has limitations, particularly under conditions of occlusion, lighting variation, or fast motion. Future enhancements could involve implementing Simultaneous Localization and Mapping (SLAM) techniques and

probabilistic filtering methods like Kalman Filters or Partially Observable Markov Decision Processes (POMDPs) to improve real-time decision-making under uncertainty.

3. **Modular and Adaptive Behavior Control Enhances Performance and Scalability**: Currently, our robot's decision-making is structured using a finite state machine (FSM), which effectively manages simple behaviors by defining clear states and transitions. However, FSMs can become rigid and difficult to scale as the complexity of behaviors increases. To improve flexibility and decision-making, we are exploring behavior trees (BTs), which provide a hierarchical and modular way to structure actions, making it easier to handle complex behaviors dynamically. Additionally, reinforcement learning (RL)-based policies could help optimize real-time decision-making in unpredictable scenarios.

2 Major Problems

1. **Enhancing Robot Intelligence for Adaptive Decision-Making**: In highly dynamic game environments, robots must make rapid, context-aware decisions to respond effectively to evolving situations. This requires integrating multiple aspects of intelligence, including perception, planning, and control, to handle challenges such as ball tracking, opponent movement prediction, and real-time obstacle avoidance. One of the key challenges is ensuring that robots can process visual data efficiently and convert it into actionable strategies within milliseconds. To achieve this, we aim to develop advanced decision-making frameworks that leverage machine learning, reinforcement learning, and probabilistic modeling. Additionally, improving multi-agent coordination is essential. Robots need to assess their teammates' and opponents' positions in real time, enabling dynamic role-switching and strategic play adaptations to maximize performance.
2. **Optimizing Robot Gait for Speed, Stability, and Energy Efficiency**: Efficient locomotion is a fundamental requirement for humanoid soccer, impacting not only the robot's speed but also its ability to maintain balance, recover from disturbances, and execute precise movements during gameplay. Developing an adaptable gait pattern that optimizes stability across different field conditions (such as variations in surface friction) is crucial. This involves incorporating reinforcement learning-based gait optimization, biomechanical modeling, and real-world testing to refine movement efficiency. Additionally, the transition between walking, running, and sudden stopping needs to be smooth to avoid unnecessary energy consumption or instability. By fine-tuning motion control algorithms and integrating real-time feedback from sensors, we aim to enhance gait reliability, allowing the robot to maintain agility while conserving energy during extended gameplay.

3 Plans for RoboCup 2025

1. **Vision System Enhancements**: We aim to develop an advanced vision system capable of more precise and reliable object detection and tracking under varying field conditions. This will include improvements in detecting and tracking the ball, field lines, goalposts, and opponents. To enhance ball tracking, techniques such as predictive modeling and Kalman filters will be employed to compensate for occlusions and rapid movement. This will ensure continuous tracking, even when the ball is partially hidden by other players. Field line detection will be further optimized to improve localization accuracy. By leveraging the relative position of field markings, the robot can enhance its understanding of its position on the field, leading to more stable navigation and strategic positioning. Additional improvements may include the integration of deep learning-based vision models and multi-sensor fusion to enhance the robot's ability to perceive and react to dynamic game scenarios with greater accuracy and speed.

4 Current Status

We have developed advanced motion and vision system for booster T1 robot for high-performance gameplay in the RoboCup Humanoid Adult Size Soccer competition. This system enables robots to perform precise detection and tracking of key objects, including the ball, field lines, goalposts, and opponents. Utilizing deep learning-based object detection and predictive tracking algorithms, they can maintain continuous awareness of their surroundings, even under challenging conditions such as occlusions and rapid ball movements.

In terms of action execution, the robots can perform a range of complex maneuvers, including approaching the ball with optimized walking gaits, dynamically adjusting their position based on real-time game scenarios, and executing accurate kicks with varying force levels to strategically target the goal. These capabilities are supported by an adaptive control system that ensures stability and responsiveness during gameplay.

With these advancements, we are well-prepared for our participation in the competition, focusing on further refining the robots' decision-making, coordination, and overall gameplay efficiency to compete at a high level.