TECH GC 2025 – INTERACTIVE ROBOTICS REPORT
Team ID: XXXXX
Submission Date: February 13, 2025

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1. Abstract

This report presents an in-depth analysis of our solution to the Interactive Robotics problem statement for CAIC Tech GC 2025. Our objective was to develop a fully integrated robotic control system within CoppeliaSim, emphasizing precision, efficiency, and multimodal user interaction. The project involved implementing advanced robotic control methodologies, object manipulation strategies, and diverse user interfaces, including command-line, graphical, and voice-based control systems. The developed system ensures high accuracy, seamless human-robot interaction, and adaptability for real-world applications. Additionally, we explored optimization strategies for improving performance, latency reduction, and adaptability in various environmental conditions, ensuring the system remains robust under different operational constraints. We also integrated data-driven feedback mechanisms to enhance real-time adjustments and improve response accuracy across different interfaces.

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2. Introduction

The primary aim of this project was to construct a robust robotic arm control framework that enables:

- **Joint Control:** High-precision movement with at least 10% accuracy.
- **End-Effector Control:** Positional accuracy within 1 cm.
- **Object Manipulation:** Dynamic handling and structured stacking of both regular and irregular objects.
- **User Interaction:** A comprehensive suite of interfaces, including CLI, GUI, and voice control.
- **System Scalability:** The ability to extend functionalities for future robotics applications.
- **Cloud-Based Remote Access:** Facilitating remote control and monitoring capabilities.

To achieve these objectives, we leveraged **CoppeliaSim** for simulation, **Python** for scripting, **Flask** for API connectivity, and **React.js** for GUI development. This document provides a detailed breakdown of our methodology, implementation, and performance evaluation, along with additional insights into potential extensions and enhancements for making the system even more adaptive and scalable.

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3. Methodology

3.1 Robotic Simulation Framework

1. **Robotic Arm Selection:**

    - The UR5 robotic arm was chosen for its flexibility and prebuilt compatibility within CoppeliaSim.
    - Configured inverse kinematics to achieve precise joint control.
    - Evaluated alternative robotic arms for future extensions.
    - Developed an adaptive control mechanism to optimize performance in real-time.
2. **Joint Control Implementation:**
    - Applied **inverse kinematics (IK) algorithms** to enable precise arm positioning.
    - Ensured movement accuracy to within 10% of target values.
    - Developed predictive control algorithms to enhance movement smoothness.
    - Integrated real-time motion tracking to fine-tune adjustments dynamically.
3. **End-Effector Positional Accuracy:**
    - Developed a coordinate mapping strategy for real-world Cartesian positioning.
    - Achieved **1 cm precision** through fine-tuned motion constraints.
    - Implemented real-time feedback mechanisms to correct errors dynamically.
    - Tested and refined different grip strengths to improve grasp stability.
4. **Object Manipulation & Interaction:**
    - Integrated grasping, lifting, and structured object stacking techniques.
    - Utilized **collision detection algorithms** to enhance realism and stability in object handling.
    - Incorporated force sensing to improve object grip stability and minimize drop rates.
    - Developed an AI-powered adaptive grasping mechanism to optimize object handling under variable conditions.

3.2 User Interface Development

1. **Command-Line Interface (CLI):**
    - Designed a Python-based terminal control system for robotic operations.
    - Implemented robust error-handling mechanisms to manage invalid inputs.
    - Introduced shortcut commands to improve usability and workflow efficiency.
    - Enabled logging of commands for debugging and analytical purposes.
2. **Graphical User Interface (GUI):**
    - Developed using **Flask + HTML/CSS/JavaScript (jQuery)** for web-based interaction.
    - Incorporated **interactive sliders, buttons, and live status feedback** to enhance usability.
    - Implemented dynamic UI adjustments to optimize user experience based on real-time system states.
    - Integrated WebSockets for real-time status updates and enhanced interactivity.
3. **Voice-Controlled System:**
    - Integrated **Google Speech API** for natural language processing.

    ◦ Implemented **text-to-speech (TTS) feedback** using pyttsx3 to improve user interaction.
    ◦ Conducted noise resilience tests to enhance accuracy in diverse environmental conditions.
    ◦ Developed a hybrid speech recognition model combining cloud-based and offline models for improved robustness.

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4. Implementation Details

4.1 Technologies & Tools

Component	Technology Utilized
Simulation	CoppeliaSim
Programming Language	Python, Flask
Command Interface	Python CLI
Graphical Interface	Flask + HTML + JavaScript
Voice Recognition	Google Speech API + pyttsx3
Communication Middleware	Flask API
Real-Time Monitoring	WebSockets
Data Storage & Logging	SQLite

4.2 System Architecture

Our system is structured into four primary components:

1. **Flask API:** The central hub that processes and routes commands from CLI, GUI, and Voice interfaces.
2. **Robotic Simulation:** CoppeliaSim executes movement logic based on received instructions.
3. **User Interfaces:** A multimodal system integrating CLI, GUI, and voice-based controls.
4. **Data Analytics Module:** Stores and analyzes command execution performance for future optimizations.

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9. Code Repository & Access

The complete source code for this project, including all implementation files for the **Flask API, GUI, CLI, and Voice Control modules**, is available at:

🔗 **GitHub Repository:**https://github.com/DHANASHRI1221/Interactive_Robotics

Repository Structure:

```
/robotics-project
  ├── backend/              # Flask API
  │   ├── flask_server.py
  │   ├── routes.py
  │   └── requirements.txt
  ├── gui/                  # GUI Implementation
  │   ├── templates/
  │   ├── static/
  │   └── app.py
  ├── voice_control/        # Voice Control Scripts
  │   └── voice_control.py
  ├── cli/                  # CLI Commands
  │   └── cli_control.py
  ├── simulation/           # CoppeliaSim Scripts
  │   └── robot_simulation.py
  ├── README.md             # Project Instructions
  └── main.py               # Main integration file
```