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SUMMARY OF DOCTORAL DISSERTATION

Dissertation Title: **Research on Control of a 6 DOF Robotic Arm for Trajectory Tracking Based on Artificial Intelligence**.

Major: Control Engineering and Automation

Code: 9520216

PhD Candidate: **Ngo Xuan Khoat**

Training Course: 2019

Supervisors: **Dr. Luu Hoang Minh; Dr. Ngo Manh Dung**

Training Institution: Ho Chi Minh City University of Transport

1. Research Objectives

This dissertation aims at proposing a new control system for a robot combined with a camera, based on intelligent algorithms to help the robot follow a trajectory and approach the target accurately under the influence of environmental factors and random errors.

2. Research Subjects and Scope

a. Research Subjects

- The 6DOF robotic arm system and Stereo Camera, ROS-based control system for the 6DOF robot

b. Scope of Research

- Research and develop the "Object Bounding" solution for 2D images using the Yolo algorithm. Develop algorithms to improve 3D image quality using the PPF method before using it to estimate the 6DOF of the object, taking into account the computation time for application in the robotic arm (rubber duck grasping) system.

- Investigate and choose a trajectory planning solution for the robot in a 3D environment with fixed obstacles, focusing on the Probabilistic Roadmap (PRM) algorithm and the Artificial Potential Field (APF) algorithm.

- Research and develop trajectory tracking control theory for robotic arms. Specifically, focus on developing the PD Fuzzy gravity compensation algorithm for the UP6 robotic arm and the ROS-based control method to optimize two key evaluation metrics for teleoperated systems: trajectory tracking error and tracking delay.

- Simulate and verify the proposed algorithms using Matlab.

- Experiment on an industrial robotic arm model (Motomini) + Stereo Camera (Intel Realsense D435), Robot controller (YRC1000micro), and ROS-based control software to test the proposed control method.

3. Research Methods

- Analysis: Analyze the impact of computation time on the control process for the robotic system, as the total computation time affects the update rate of control parameters (average update frequency is 40Hz, corresponding to 25ms).

- Survey: Survey the stability of the system using conventional controllers (PD gravity compensation, Fuzzy, Fuzzy-PD) on the UP6 robotic arm.

- Evaluation and Comparison: Evaluate and compare to choose the appropriate solution for trajectory tracking control, trajectory planning, and 3D image processing for 6DOF estimation.

- Simulation: Simulate the proposed controllers on Matlab.

- Experimental Verification: Conduct experiments on the model and evaluate the stability of the algorithms.

4. Scientific and Practical Significance

- **Scientific Significance**: The dissertation has researched, proposed, and tested algorithms for the robot + camera system, including the main tasks of estimating the object's 6DOF, planning the robot's trajectory to approach the object in a fixed-obstacle environment, and controlling the robot to follow the planned trajectory. The main algorithms have been verified through simulations and compared with other methods to demonstrate their advantages. An experimental model was used to verify the correctness of the proposed algorithms.

- **Practical Significance**: The robot + camera system for grasping rubber ducks, as proposed in the dissertation, can be applied in many expanded cases, such as in radioactive environments, medical waste or hazardous waste handling. It can easily be adapted for underwater observation and repair, and particularly in bomb disposal and anti-terrorism scenarios.

5. New Contributions of the Dissertation

- For the Robot + Camera System: The dissertation successfully developed the PPF algorithm for estimating the 6DOF of an object, with the proposed reduction of computation time by bounding the object in 2D images and downsampling the 3D image cloud.

- For Trajectory Planning in a 3D Environment with Fixed Obstacles: The dissertation proposed and improved solutions to overcome some shortcomings of the PRM and APF algorithms. Specifically, with the APF algorithm, an exponential function was used to improve the total potential field, and the lambda step factor was updated based on changes in the total force field to optimize the speed along the trajectory.

- For Controlling the Robotic Arm Using Dynamic Equations: The dissertation proposed a solution to estimate the parameter values of the dynamic equations for the UP6 robot and proposed and simulated two controllers, PD gravity compensation and Fuzzy PD, for the UP6 robot's dynamic equations.

- For Controlling the Robotic Arm Using Kinematic Equations: The dissertation applied ROS-based control to convert the dynamic control problem into a kinematic control problem. Additionally, the inverse kinematics problem was solved using the

Jacobian velocity matrix inversion method to optimize computation time.

6. Structure of the Dissertation

The main content of the dissertation is organized into 4 chapters, along with a conclusion and proposed research directions. The structure is as follows:

- Chapter 1: 6DOF Robotic Arm and Robot-Camera System
- Chapter 2: Trajectory Planning for the 6DOF Robotic Arm in an Environment with Fixed Obstacles
- Chapter 3: Trajectory Tracking Control for the 6DOF Robotic Arm
- Chapter 4: Experimental Model

Ho Chi Minh city, October 18, 2024

Supervisors		**Ph.D candidate**
Dr. Luu Hoang Minh	**Dr. Ngo Manh Dung**	**Ngo Xuan Khoat**