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Augmented online point to point trajectory planning, a new approach in catching a moving object by a manipulator

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Abstract— **In a structured dynamic environment, due to the known variation of the environment, robot trajectory planning can be performed robots motion starts. Within an unstructured dynamic environment, environment variations are permanent, so that the surroundings information must be acquired in an online action. Likewise the data acquisition, robot trajectory planning must be executed online. In this paper a method for online trajectory planning based on adaptive prediction planning and execution (APPE) is proposed for robotic manipulators considering velocity and torque constraints. A vision-based data acquisition system is used to acquire object positions and velocities. To describe the end-effector trajectories in joint and Cartesian space a set of time polynomial function are used. Initially a primary trajectory is planned and it will be updated in definite time periods. This action will be frequently repeated until catching is occurred. Proposed method has been tested on an experimental setup and the experimental results are presented.**

I. Introduction

Dynamic environments can be classified into two different categories;

1. Structured dynamic environments; which its changes are known or can be predicted beforehand.
2. Unstructured dynamic environments; which its changes are unknown and can't be predicted.

In structured dynamic environments because of the known procedure of variations, the robots trajectory can be planned before the robot begins its motion. If unpredictable variations occurs during the robot motion (unstructured dynamic environment), sensors must be set in the environments to sense the changes[1]. Nowadays using vision systems and image processing is the best solution in detecting environments changes which it has resulted in a new field in motion control named vision based control or visual servoing[2].

Interception of a moving object can be discussed in two different classes based on the object maneuverability[3];

1. Interception of an object with slow maneuvering motion,
2. Interception of an object with fast maneuvering motion.

In the first category a reliable prediction can be made for the objects motion. Subsequently, providing a suitable trajectory is applicable in order to catch the object. Trajectories used for these purposes are planned between robot present conditions and a predicted condition of the object.

Slow maneuvering object also yields the possibility for online trajectory optimization. This paper deals with a method of time optimal point to point trajectory planning for catching a slow maneuvering object[4].

Lin et al. in 1998 reported a method for catching moving objects. His catching plan consists of two different sections named "coarse tuning" and "fine tuning". Robot is taken to a condition neighboring the object using the coarse tuning section and the catching job will be completed using fine tuning[5].

Time optimal trajectory planning gives a solution for catching static objects. Rena et al. presented an open loop minimum time trajectory planning method by considering actuator torque limits using an evolutionary algorithm[6].

In order to find the optimum time to move on a known trajectory, another near time optimal solution to interception problems falls under the category of time optimal control for robotic manipulators moving along a pre specified path. Bobrow et al. showed that the optimal solution is a bang-bang control[7].

Prediction, planning and execution (PPE) method are well suited for intercepting a moving object traveling along a predictable trajectory. Kimura et al. reported a real time ball catching using a PPE technique[8]. This method can't be used for unknown object trajectories. This method can be utilized in an adaptive form where three stages of the PPE technique are repeated as necessary to guarantee the successful completion of the interception task. This method is known as Adaptive Prediction, Planning and Execution or APPE[9, 10]. Namiki and Ishigawa reported a vision based online trajectory planning based on this method to solve a catching problem[11]. Some other method for catching moving objects are presented in [12, 13].

II. Online Trajectory Planning Based on APPE

One common strategy for trajectory planning in robotic systems for unstructured dynamic environments is point to point trajectory planning, which will be operative if the environment changes are sufficiently slow. The target point is predicted frequently and the robot motion path is planned between its present position and the anticipated target position. The path planning procedure will be repeated for every predicted target position until the robot reaches its goal, such

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