MOTION PLANNING FOR A CUCUMBER PICKING ROBOT

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Abstract: This paper presents an approach to automatic collision-free motion planning for a cucumber picking robot. A functional model of the robot developed at IMAG is described. The objectives of automatic motion planning are outlined as well as the main components of a program generating collision-free trajectories. A first result of an off-line motion planning experiment is presented and discussed. *Copyright © 2000 IFAC*

Keywords: agriculture, robotics, path planning, inverse kinematics, heuristics, collision detection

1. INTRODUCTION

Greenhouse crop production is generally characterised by a high demand for human labour. To be more specific, the manual harvesting of soft vegetable fruits represents a significant percentage (50%) of total production costs. Harvesting requires a large input of human labour. Moreover, in the Netherlands labour costs are high. Therefore, automated harvesting of vegetable fruits is desired (Bontsema *et al.*, 1999).

In 1996, IMAG began research on the development of a modular harvesting robot for vegetable fruits (Van Kollenburg-Crisan e.a., 1997). The task of designing robots for agricultural applications raises issues not encountered in other industries. The robot has to operate in a highly unstructured environment in which no two scenes are the same. Both crop and fruits are prone to mechanical damage and should be handled with care. The robot has to operate under adverse climatic conditions, such as high relative humidity and temperature as well as changing light conditions. Finally, to be cost effective, the robot needs to meet high performance characteristics in terms of speed and success rate of the picking operation. In this project these challenging issues have been tackled by an interdisciplinary approach in which mechanical engineering, sensor technology (computer vision), systems and control engineering, electronics and software engineering partake.

This paper reports on one particular aspect of the cucumber picking robot, i.e. the motion planning for the manipulator of the picking machine. First, the harvesting robot will be described in some detail. Then, secondly, the components of a program that automatically generates collision free motions for the cucumber picking robot are presented together with the results of an off-line motion planning experiment performed in MATLAB.

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2. THE HARVESTING ROBOT

In figure 1 a functional model of the harvesting robot is shown. It consists of an autonomous vehicle used for coarse positioning of the harvesting machine in the aisles of the greenhouse. This vehicle uses the heating pipes as a rail for guidance and support. It serves as a mobile platform for carrying power supplies, a pneumatic pump, various electronic hardware for data-acquisition and control, a camera vision system for detection and localisation of cucumbers and a 7 DOF manipulator for positioning of the end-effector. The manipulator consists of a linear slide on top of which a Mitsubishi RV-E2 manipulator with an anthropomorphic arm and a spherical wrist is mounted. The manipulator has a steady-state accuracy of ±0.2 mm and meets general requirements with respect to hygiene and the operation under adverse greenhouse climate conditions (high relative humidity and temperature of 21°). Limitations were put on the geometrical and physical properties of the manipulator because it has to deal with dense and rather fragile canopies. Also the amount of space between the rows of the crop is limited. The manipulator carries an end-effector. This end-effector contains two parts: a gripper to grasp the fruit and a cutting device to separate the fruit from the plant. On top of the end-effector a small camera is mounted. It is used to obtain high resolution sensory information for fine motion control of the end-effector.

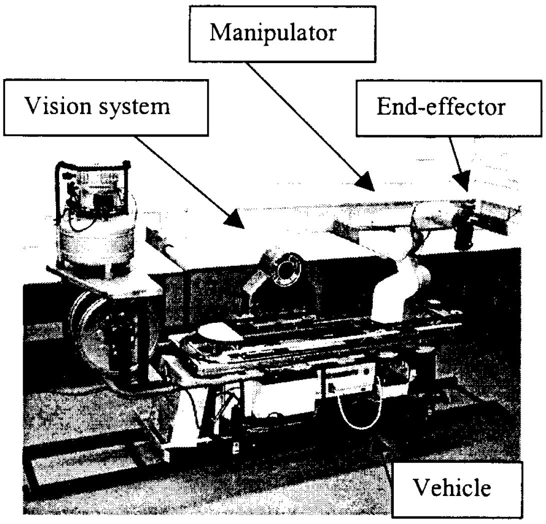

Fig. 1. A functional model of the cucumber harvest robot

During the harvesting operation, the task of the manipulator is to position the end-effector at grasping distance near the fruit. Once the fruit has been separated from the plant and thoroughly secured by the end-effector, the manipulator moves the end-effector with the fruit to the storage crate. Then, the fruit is released by the end-effector.

Motion planning heavily leans on real-time acquisition of sensory information of the environment. To facilitate automated harvesting of the fruits, a new high-wire training system for cucumber cultivation was developed. Compared to traditional cucumber cultivation, the main advantage of the high-wire training system for automated harvesting is the open structure of the canopy. In the high wire training system it is easier to detect, locate and approach the fruits. Still, the harvesting robot has to operate in a highly unstructured environment in which no two scenes are the same.

Approaching the cucumber during the picking operation is considered to be a two stage process. First, with a camera system mounted on the vehicle, the cucumber fruits are detected and their location is determined. These low resolution images are used for positioning the end-effector in the neighbourhood of the cucumber. Once the end-effector has arrived in the neighbourhood of the cucumber, then secondly, using the camera system mounted on top of the end-effector, high resolution information of the local environment of the cucumber is obtained for the final accurate approach of the cucumber.

The motions of the manipulator need to satisfy the following requirements. Motions should be performed in minimum time so as to satisfy the overall cycle time of 10 seconds available for one picking action (Bontsema et al., 1999). The system should position the tool centre point with an accuracy of 1 mm. Collision avoidance strategies should prevent collisions of the manipulator, end-effector and harvested fruit with the crop, the greenhouse construction and the robot itself (such as the vehicle and vision system) during the harvesting operation. To assure the quality of the harvested fruits, constraints will be imposed on the travelling speed and accelerations during various portions of the motion path.

3. MOTION PLANNING FOR A 7 DOF MANIPULATOR

Figure 2 illustrates the components of a program that automatically generates collision free motions for the cucumber picking robot.

Collision free motion planning relies on 3D information about the structure of the robot as well as the workspace in which the robot has to operate. So, the first step in collision free robot motion planning is the 3D *world description acquisition*. This description is based on sensory information such as machine vision and a-priori knowledge about for instance the kinematic structure of the harvesting robot, contained in a database. With this information, during the *task definition* phase, the overall task of the robot is planned. It is decided which final position and orientation of the end-effector result in

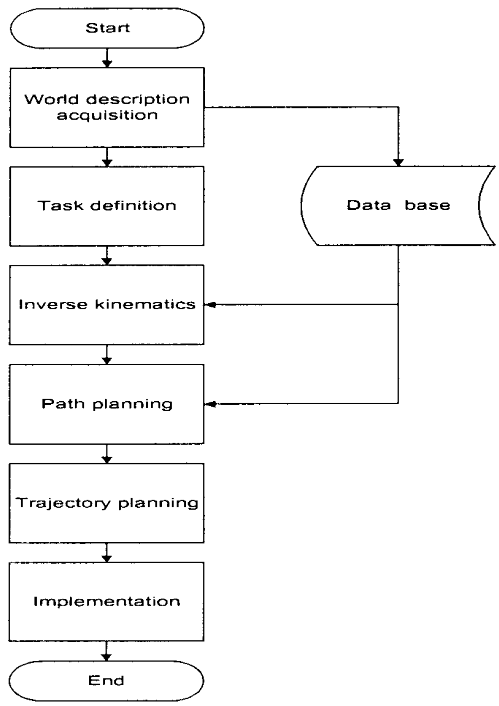

Fig. 2. A program for automatic generation of collision-free motion paths

the best approach of the cucumber. Also specific position and orientation constraints are defined during this phase. In the *inverse kinematics* phase the goal position and orientation of the end-effector, defined during *task definition*, are translated into the goal configuration of the manipulator in terms of a translation on the linear slide and 6 rotations of the joints. This information is used by the *path planner*. The *path planner* uses a search technique to find a collision-free path from the start configuration of the manipulator to its goal configuration. The search for collision-free paths occurs in a search space that is different from the 3D world space. In the motion planning system of the cucumber picking robot the search space is the so called configuration space. In case of the 7 DOF manipulator it is a 7 dimensional space spanned by the combination of 1 translation and 6 rotations. Once the collision-free path planning has been completed successfully, the *trajectory planner* converts the collision-free path into a trajectory that can be executed by the manipulator. Typically, the path planning process is concerned only with collision-free configurations in space, but not with velocity, acceleration, smoothness of motion. These factors are handled by the *trajectory planner* (Herman, 1986). The output of the *trajectory planner* forms the motion commands to the servo mechanisms of the robot, i.e. the actual *implementation* of the motion. Some components of the motion planning system will be described hereafter in more detail.

3.1 World description

The machine vision based world description acquisition for the cucumber picking robot is described in a paper by Meuleman *et al.* (2000). As stated above, also a-priori knowledge about for instance the structure of the robot is needed for collision-free motion planning. Figure 3 shows a 3D model of the Mitsubishi RV-E2 manipulator implemented in MATLAB. The model was originally developed in COSIMOD, a commercially available software package for modelling 3D structures, and then converted to MATLAB. The model is used for evaluation of motion strategies and serves as a basis for the collision detection.

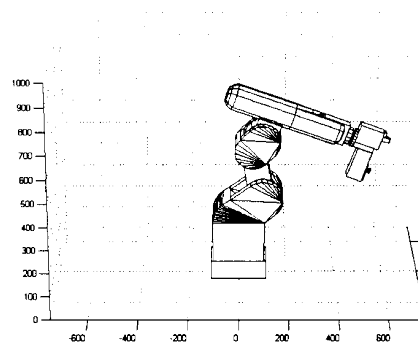

Fig. 3. A 3D CAD-model of the Mitsubishi RV-E2 manipulator

3.2 Inverse kinematics

The inverse manipulator kinematics deals with the computation of the set of joint angles and translations that result in the desired position and orientation of the tool centre point (Craig, 1989). In case of the 6 DOF Mitsubishi RV-E2 manipulator an analytic solution of the inverse manipulator kinematics was obtained by Van Dijk (1999). Solution of the inverse kinematics of the 7 DOF manipulator, i.e. the Mitsubishi RV-E2 manipulator mounted on a linear slide, is still subject of research. Since the linear slide introduces redundancy in the kinematic chain, a straightforward analytic solution does not exist. Numerical ways of solving the inverse kinematics problem for the 7 DOF manipulator are currently investigated.

3.3 The path planner

A collision-free path planner essentially consists of two important components: a search algorithm and a collision detection algorithm. The search algorithm explores the search space, i.e. configuration space, for a feasible trajectory from the initial configuration to the goal configuration of the manipulator. The feasibility of each step in the search space is checked by a collision detection algorithm. This algorithm checks for collisions of the manipulator with other structural components such as the fruits, stems but also the vehicle.

In this research a best-first-search A*-algorithm was implemented for searching a feasible path in the configuration space (Pearl, 1984; Kondo, 1991; Russell and Norvig, 1995). The 6 dimensional configuration space of the RV-E2 manipulator was discretized by means of a fixed grid structure. The A*-algorithm searches a path from the start grid point to the goal grid point while minimising a cost function. This cost function includes the cost of the path so far and an optimistic estimate of the cost from the current position to the goal. In this way, the A*-search strongly resembles dynamic programming. The A*-algorithm is both complete and optimal. Completeness of the algorithm assures that the algorithm finds a solution if one exists (Russell and Norvig, 1995).

For collision detection an algorithm was implemented based on the ideas reported by Boyse (1979). This algorithm evaluates the intersection of surfaces of the robot model with the surfaces of other structural components in the workspace. Calculating the intersection of two surfaces essentially boils down to determining the intersection of all the edges of one surface with the other surface. All in all, collision detection is a computationally intensive task. Therefore, collision detection in a real-time application such as the cucumber robot, requires a trade-off between the desired accuracy of the collision detection and the available calculation time. The accurate CAD-model of figure 3 contains 600 triangular and rectangular surfaces. Collision checking with this model did not yield a feasible solution in terms of calculation time within a MATLAB environment. A factor 15 reduction in calculation time could be achieved by replacing the accurate manipulator model by a less accurate model built from so called oriented bounding boxes (OBB). This 3D OBB-model of the manipulator consisting of only 36 surfaces is shown in figure 4. Clearly, with the OBB-model some accuracy was offered for the sake of calculation speed. For the current investigations it was considered justifiable.

Not only the increasing performance of computer hardware but also results of research on computational geometry obtained throughout the last decade offer opportunities for reducing the calculation time of the collision detection task described here. State of the art collision detection algorithmes use a sequential approach. They start with a computationally inexpensive coarse collision detection using an inaccurate model. Then, if a possible collision is detected, using more accurate models, a more precise collision detection is performed (Lin and Gottschalk, 1998).

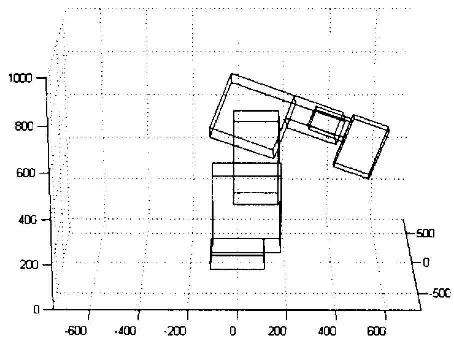

Fig. 4. An oriented-bounding-box (OBB) model of the RV-E2 manipulator.

4. A MOTION PLANNING EXPERIMENT IN MATLAB

To illustrate the approach, results of a simplified collision-free motion planning experiment are presented.

Figure 5.a shows the RV-E2 manipulator with an obstacle in the workspace: a box. The objective was to steer the manipulator to the opposite side of the box without hitting the box. Figure 6 shows a scan of two dimensions of the configuration space. These two dimensions represent the rotations around the lowest two joints of the RV-E2 manipulator. The black shaded subspace indicates configurations yielding a collision between the manipulator and the box. Also indicated are two configurations marked 's' and 'g', representing the initial and goal configuration for the path planning experiment. Figure 5.a shows the initial configuration. The line connecting the start and goal configuration was found by the A*-search algorithm described before. Figure 6 illustrates that the motion trajectory of the manipulator does not include colliding configurations. Similar graphs can be shown for the other degrees of freedom of the manipulator.

To show the actual motion of the manipulator in the 3D-workspace is a bit difficult on paper. Essentially, the motion consists of an anti-clockwise rotation of the lowest joint while tilting the second and third joint backwards until the box has been circumvented. Then, the second and third joint tilt forward again to reach the goal configuration. Figures 5.a to 5.c try to visualise this motion.

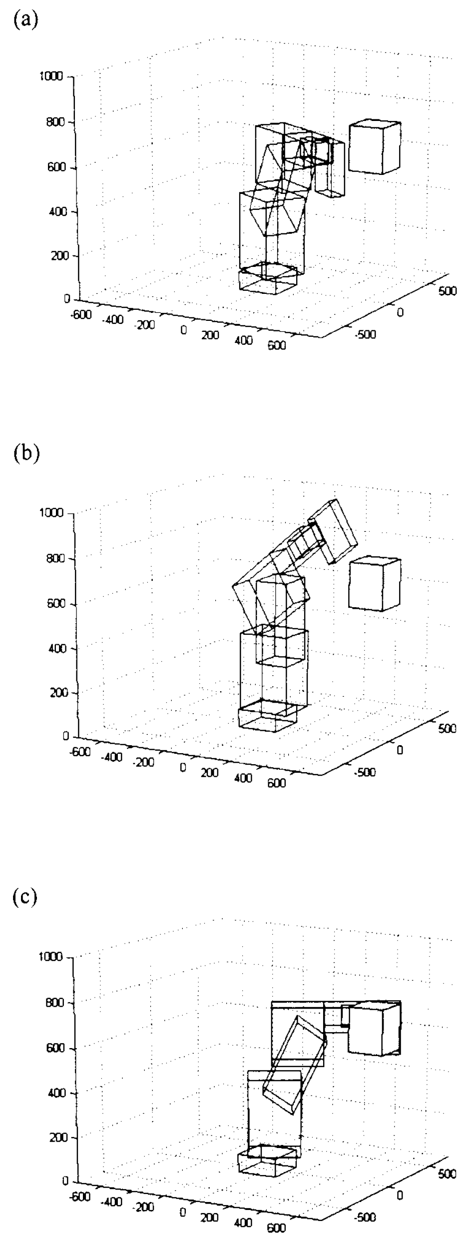

Fig. 5. Three snapshots of the collision-free motion of the RV-E2 manipulator. (a) and (c) are the initial and final configuration respectively.

5. CONCLUDING REMARKS

In this paper an approach to collision-free motion planning for a cucumber harvest robot was outlined. It was shown that collision-free trajectories can be calculated for the 6 DOF RV-E2 manipulator.

Current research focuses on motion planning for the 7 DOF manipulator in a real-time environment. Main topics are the interfacing between the machine vision based world description acquisition and the motion

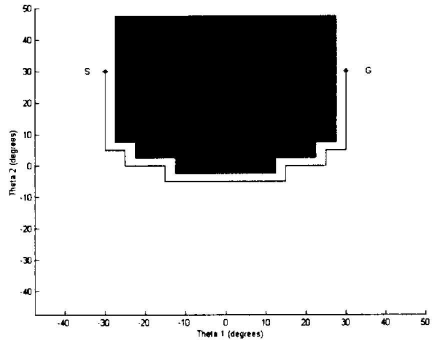

Fig. 6. Two dimensional sub-space of the six dimensional configuration space. The black-shaded subspace expresses configurations with a collision. 's' and 'g' denote start and goal configuration, respectively.

planning software, the solution of the inverse kinematics problem for the 7 DOF manipulator and reducing the computation time needed for collision-free motion planning.

Viable solutions for reducing the computation time needed for motion planning are dedicated faster computer hard-ware, state of the art hierarchical collision detection schemes (Lin and Gottschalk, 1998) and multi-strategy search techniques to explore the configuration space (Herman, 1986; Kondo, 1991).

In the current approach of motion planning, the calculation of collision-free motions and considerations with respect to dynamic behaviour are being dealt with separately. The path planning process is concerned only with collision-free configurations in space, but not with velocity, acceleration and smoothness of motion. These factors are handled by the *trajectory planner* once collision-free motions are available. To achieve a cycle time of less than 10 seconds for one picking action may require an integral approach of motion planning in which obstacle avoidance and time optimal behaviour are treated simultaneously.

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