Mission Design for Service Robots

Elias Xidias[1], Nikos Aspragathos[2] and Philip Azariadis[1],

[1] Department of Product and Systems Design Engineering, University of the Aegean, Syros, Greece,
[2]Department of Mechanical Engineering & Aeronautics, University of Patras, Greece,
{xidias, azar}@aegean.gr
asprag@mech.upatras.gr

Abstract. This paper considers the mission design problem for a service robot which is operating in a partly known indoor environment. A service robot is requested to serve a set of work stations in the environment providing transport and delivery tasks while avoiding collisions with the obstacles during its travel. The objective is to determine the optimum sequence of the work-stations visited by the service robot exactly once assuring that the robot's path through the work-station is collision free. The problem addressed in this paper combines two computationally hard problems: the task scheduling problem and the motion planning between the successive work stations.

Keywords: service robot, mobile manipulator, indoor environment, multi-goal, motion planning, bump-surface, genetic algorithm

1 Introduction

In recent years, service robots (SRs) are of immense interest due to their capability to perform complex tasks in many fields such as automated transportation systems in offices, hospitals and libraries [1]. The purposes of automation are both to save time and manpower and to improve the service quality. Since the personnel of a market store or of a library are always assigned several tasks at a time as a result of saving the expenses. It makes the quality of the service lower. In this paper, we propose an intelligent service robot to assist us in dealing with several matters (e.g. placing books on a bookshelf). Here, a SR (i.e. a mobile manipulator) is requested to serve all the work-stations cluttered in a semi-structured environment in order to perform pickup and place tasks while moving safely during its travel. The objective is to determine the minimum total travel-time required by the robot to serve all work stations in the environment.

The attainment of this objective necessitates the solution of two known combinatorial optimization problems: (a) motion planning [2], and (b) vehicle routing and scheduling planning [3]. Both of them are known to be intractable. Motion planning and task scheduling issues are often studied separately. So far, the integration of these problems has been studied by few researchers in [4], [4] and [4] for industrial applications. In [4], an Autonomous Guided Vehicle (AGV) is demanded to serve timely (providing delivery tasks) as many work stations in a 2D industrial environment as possible. The proposed methodology consists of two phases: First, the vehicle's environment is mapped onto a 2D B-Spline surface embedded in 3D Euclidean space using a robust geometric model. Then, a modified genetic algorithm is applied on the generated surface to search for an optimum legal path that satisfies the requirements of the vehicle's mission. However, this work considers only one moving AGV and does not take into account the corresponding kinematics constraints. In [5] a methodology is presented for modeling and controlling a flexible material handling system (MHS), composed of AGVs, suitable for flexible manufacturing systems. The AGVs incorporate artificial intelligence and mobile robotics techniques in order to calculate their paths. The MHS makes use of a decentralized navigation control and a distributed Petri net in order to achieve higher flexibility and autonomy. However, the method is not globally optimal because the generated paths are not taking into account the task scheduling procedure. In [6], a set of AGVs is requested to serve all the work stations cluttered in a 2D industrial environment. Each AGV starts from its depot, passes through a number of work stations (from each one exactly once) and returns back to its depot. The objective is to determine the minimum total travel-time required by the AGVs to serve all work stations in the 2D environment. It must be noticed that, every work station is allowed to be served by only one AGV. Furthermore, the number and the sequence of the work stations which is served by a vehicle are not predetermined. In order to achieve this goal, they utilize the concept of Bump-Surfaces to perform a global search of the solution space in order to ensure an optimal routing-scheduling and motion planning for the set of AGVs moving in the given 2D environment. Then, the entire problem is formulated as an optimization problem which is resolved using a modified GA.

In this paper, we present an approach which combines some of the positive characteristics of several previous approaches with new ideas to generate an approach that provides an effective solution to the problem of mission design of a SR moving in an indoor environment. The advantages of the approach are: (a) The SR' path is generated by taking into account the environment's geometry, the depot location, the number and location of predefined stations and the scheduling algorithm. (b) The generated path is smooth and collision-free. (c) The integration of path and velocity planning provides the optimal or near optimal solution for the whole system. In addition, a time optimal algorithm is presented for motion planning of the manipulator for pick and place objects at the stations. The key-element of the approach is the representation of the workspace through a single mathematical entity using the Bump-Surface concept presented in [7]. The entire problem is formulated as a constrained global optimization problem which is resolved using a Genetic Algorithm (GA) [8].

2 Mission Design Problem: General Assumptions and Notations

Consider a SR moving in a library environment, in which obstacles (either static or moving) exist. Here, moving obstacles correspond to customers, employees and to any other moving object such as another SR, in the library environment. The set of determined stations $\hat{\mathcal{S}} = \{\mathcal{S}_1, \ldots, \mathcal{S}_m, \ldots, \mathcal{S}_M\}$, $M \geq 1$, represents the desk and the bookshelves where the SR should pick up or place books. A typical example of such dynamic scenario. The overall requirements that must be taken into account are: (**i**) In order to simplify the representation of the SR' environment, we construct a 2D environment $\mathcal{W}$ by the projection of the initial 3D environment in the u_1u_2-plane. (**ii**) The SR is a mobile manipulator, where the mobile platform is represented by a rectangular-shaped body with two rear wheels and two directional front wheels with a limited steering angle [2] and a PUMA 560 is mounted in the center of the top of the mobile platform. (**iii**) The SR it is equipped with range-sensors encircled around it. The set of sensors defines a region ***RS***, which is encircled by a circle of radius r_s located in the middle of the robot's body. The set of sensors measures in real-time: the location, the geometry and the instantaneous speed vector (velocity and direction) of the obstacles which are detected by the sensors. (**iv**) The SR is moving only forward with variable velocity in the interval $\left(0, v_{\max}\right]$. (**v**) A SR's path always starts from the library desk (depot), goes through all the stations (each station should be served only once) and terminates at the library desk. (**vi**) Each station $\mathcal{S}_m$ is associated with a feasible region, which is represented by a circle, in which the mobile platform can be located to perform a pick and place task without violating the constraints of the manipulator and of the environment (obstacles). (**vii**) The moving entities are represented by circular disks. (**viii**)The dynamic constraints of the SR are ignored. (**ix**)The static obstacles, such as walls and bookshelves, have fixed and known geometry and location.

In the following of this paper, an approach is presented for the determination of the optimal path for a service robot distributing books and putting them in the right bookshelves taken into account the robot and environment constraints as well as the aforementioned requirements.

2.1 The workspace model

For the representation of the SR' workspace we adopt the method based on the Bump-Surface introduced by Azariadis and Aspragathos [7]. The Bump-Surface concept is a method that represents the entire workspace by using a B-Spline surface embedded in a higher dimension Euclidean Space. The construction of the Bump-Surface S is based on a control-points net with variable density depending on the required path-planning accuracy, i.e., denser the grid, higher the accuracy. In addition, due to the flexibility of the B-Spline surfaces we can capture the desired accuracy by taking advantage of their ability for local and global control [9].

3 Optimal Mission Design

In this section an integrated approach is presented for optimal multi-target mission planning of a mobile platform in partly known environments cluttered with known static obstacles and unknown moving ones, as well as the motion planning of a manipulator mounted on the platform and performing manipulations at the target locations.

3.1 Mission design in static environment

The main objective of this Section is to simultaneously determine the schedule and the path for a SR taking into account only the static obstacles of the environment and the dimension of the mobile platform. Following the results from [6], the mission design problem for the static environment is formulated as an optimization problem given by

$$\begin{aligned}&\min\left(t_p\right)\\&\text{subject to } k_i \le k_{max}\ ,\ i=1,\ldots,N_c\end{aligned} \tag{1}$$

where t_p is the time required for the platform to travel along $\mathbf{R}(s)$. The minimization of problem (1) with respect to the control points $\mathbf{p}_i$ leads to a collision-free path for the platform, which satisfies all the requirements.

A modified GA has implemented to deal with the mission design problem in the static environment. A mixed integer and floating-point representation was selected for encoding of the variables [6].

3.2 Avoiding moving obstacles

Once the global path $\mathbf{R}(s)$ has been created, the robot starts to move along this path in order to serve the stations. If the SR detects a moving obstacle entering in the ***RS*** region another algorithm is activated to modify the initial trajectory. In this part of the paper the algorithm introduced in [10] for the deviation from the initial path is presented in brief.

At every point $\mathbf{R}_i, i=1,\ldots,N_c$ (which correspond to the time instance t_i) of $\mathbf{R}(s)$, the SR using the set of the onboard range-sensors checks if any of the moving obstacles are entered in the region ***RS*** . If there are no moving obstacles in the region ***RS***, then the robot moves to the next point $\mathbf{R}_{i+1}$ of $\mathbf{R}(s)$ without modifying its motion. If SR detects a moving obstacle then, taking into account the necessary information of the onboard sensors, it is able to compute the relative velocity $v_{ro}(t_i)$ between the SR and the moving obstacle. By computing the $v_{ro}(t_i)$ we can determine if a collision occurs (for details see [10]). If $v_{ro}(t_i) \le 0$, the SR is moving away from the moving obstacle and no maneuvers are needed. If $v_{ro}(t_i) > 0$, the SR is moving towards to the moving obstacle. In this case, the SR motion should deviate from the initial path in order to avoid collision with the moving obstacle.

Suppose that at time t_i the SR is moving towards the moving obstacle, i.e. $v_{ro}(t_i) > 0$, then, in order for the SR to avoid getting trapped in obstacles' concave regions and bypass any blocking obstacle, the geometry of the moving obstacle it should be modified. The modified obstacle derived from the union of its traces, at the time interval $\left[t_i, t_{i+M}\right]$, where t_{i+M} is the time instance where the SR collides with the obstacle. Then, the Bump-Surface is used in order to determine a “new” path $\mathbf{R'}(s)$ for the SR where the initial point is $\mathbf{R}_i$ and the final point is $\mathbf{R}_{N_c}$. The local path planning problem is solved using a GA [8]. Finally, the SR is moving to the point $\mathbf{R'}_1(s)$, which corresponds to the time instance t_{i+1}, and repeats the above procedure. It must be noticed that, in order to ensure that the SR has a smooth motion the following condition is incorporated:

$$\min(\theta(t_{i+1}) - \theta(t_i)) \tag{2}$$

where $\theta(t_i)$ is the SR’s orientation at time t_i and $\theta(t_{i+1})$ is the SR’s orientation at time t_{i+1}.

3.3 Manipulator motion planning

This section presents a method for solving the motion-planning problem for the onboard manipulator operating in a 3D environment cluttered with static obstacles. When the platform arrives to a station $\mathcal{S}_m,\ m = 1,...,M$ stops and starts to execute a predefined task, such as to take a book from the box and put it into the bookshelf.

Using the Bump-Surface the manipulator’s workspace is represented by a 3D surface embedded in $\Re^4$, which represents both the free-space and the forbidden areas of the robot’s workspace. A global optimization problem is then formulated considering simultaneously the task-scheduling and the collision-free motion planning of the manipulator among the obstacles. The optimization problem is solved using a Genetic Algorithm (GA) with a special encoding that considers the multiplicity of the Inverse Kinematics [11].

In order to take into account the shape of the manipulator a set of probabilistic points $a_\nu^n, \nu = 1,...,N$, defined in the initial 3D environment, is selected on the surface of each n-link (n=2,…,6) according to the requested accuracy (e.g. higher accuracy is achieved using a big number of N), where N is the overall number of probabilistic points. Thus, following the results from [6] the minimization of the following objective function,

$$Flat = \sum_{\mu=1}^{2+\mathcal{R}+\tau} H_\mu \tag{3}$$

with respect to the joint variables $\theta_\mu \in \Re^6, \mu = 1,...,2+\mathcal{R}+\tau$, satisfies the requirement for collision-free robot's configurations, where H_μ is the “flatness” of the image $a_\nu^n(s)$ on S (see [6]), $2+\mathcal{R}+\tau$ is the total number of configurations between the initial and final configuration, μ is a robot configuration, τ corresponds to the configurations between the successive configurations resulting from linear interpolation of the joint variables and the number $\mathcal{R}$ is the intermediate configurations between two successive task-points specifies the trajectory of the robot while moving between the initial and final configuration.

The total travel time t_{total} needed to move the manipulator from the pick a book point to the place a book point through the intermediate configurations is given by

$$t_{\text{total}} = t_A + t_{\mathcal{R}} + t_B \tag{4}$$

where t_A is the time spent by the manipulator to travel from the pick configuration to the first intermediate configuration, $t_{\mathcal{R}}$ is the time spent by the manipulator to travel from one intermediate configuration to another one and t_B is the time spent by the manipulator to travel from the last intermediate configuration to the final configuration corresponding to the *place point* (for details see [11]) .

Thus, the multi-objective function is given by,

$$E_M(\boldsymbol{\theta}) = w_1\ t_{\text{total}}(\boldsymbol{\theta}) + w_2\ Flat(\boldsymbol{\theta}) \tag{5}$$

expresses the total cycle time obtained taking into account the initial and final configurations and the $\mathcal{R}$ intermediate configurations and simultaneously ensures that collision avoidance while the manipulator moves between these configurations, where w_1 and w_2 are weight factors with $w_1 + w_2 = 1$ and $w_1, w_2 \geq 0$.

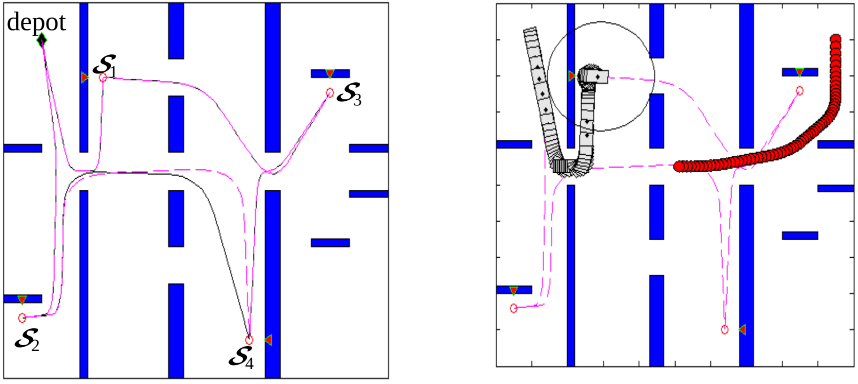
For the optimization of the multi-goal motion planning problem a modified Genetic Algorithm is selected [11].

4 Experiments

All simulations are implemented in Matlab and run on a Core 2 Duo 2.13 GHz PC. Due to space limits, we present in this section only one experiment.

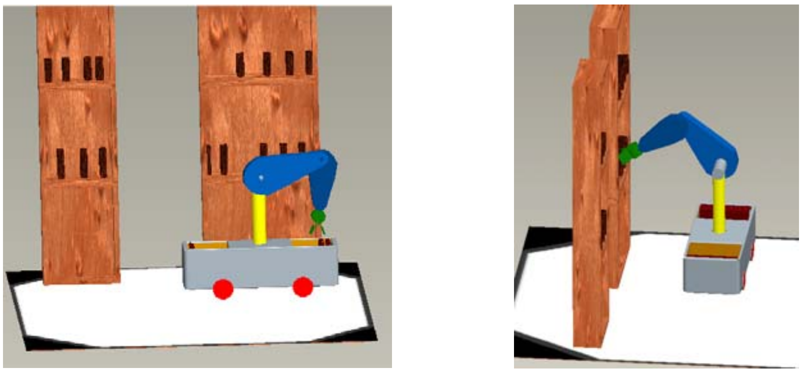
Test case: The representative experiment corresponds to a library scenario shown in Fig.1, which is cluttered with narrow corridors, static and one circular moving obstacle. It assumed that the moving obstacle is moving with constant velocity $\left|v_{obs}\right| = 0.5$ and the SR is moving only forward with variable velocity in the interval $\left(0, 0.5\right]$.The SR has to travel between a depot and 4 work stations. The number of the unknown control points between the stations is set equal to 5. Thus the overall number of the unknown control points $\boldsymbol{g}_{\omega}$ is $N_b = 25$. The solution path is shown for the in Fig. 1(a). The magenta dashed curve shows the final path and the black curve shows the initial path, i.e., the path derived by taking into account only the static obstacles and the dimension of the platform. The SR passes through the stations depot-$\boldsymbol{\mathcal{S}}_1$- $\boldsymbol{\mathcal{S}}_3$- $\boldsymbol{\mathcal{S}}_4$- $\boldsymbol{\mathcal{S}}_2$-depot. Fig. 1(b), shows a time instance of the proposed motion of the SR. The rectangular object (grey color) presents the mobile platform where the black dot represents the onboard manipulator and the red circular disk represent the moving object. The black circle represents the ***RS*** area. Fig. 2 shows the SR in front of the bookshelf (station $\boldsymbol{\mathcal{S}}_1$) where the manipulator gets a book from the box and put it in the bookshelf.

As can see from the above example the proposed method is able to schedule the motion of a SR and simultaneously to produce collision free motion for the onboard manipulator in complicated environments with narrow corridors and rooms. The generated solution path satisfies (in a near optimum way) all the established mission design criteria and constraints. Furthermore, one should bear in mind that we assumed that the mobile platform is car-like robot; hence its motion is bounded by kinematic constrains (e.g. an upper bounded steering angle) therefore the motion of the platform is acceptable.



(a) (b)

Fig. 1: (a)**:** The Solution path (color magenta) and the initial path (back color. (b) A time instance of the SR's motion and the obstacle's motion.



(a) (b)

Fig. 2: **(a)** The manipulator taking a book from the box. **(b)** The manipulator putting a book on the bookshelf.

5 Conclusions

A novel approach for motion planning of a SR in a dynamic environment has been presented in this chapter. The overall problem has been resolved be applying the Bump-Surfaces in order to represent the entire environment with a single mathematical entity. With this representation one is able to formulate the current mission design problem as a constrained global optimization problem in order to compute a valid path for both the mobile platform and the manipulator. The latter problem is resolved using a Genetic Algorithm.

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