Optimal Trajectory Planning for a Robotic Manipulator Palletizing Tasks

Fabio Parisi
Electrical and Information Engineering
Polytechnic University of Bari
Bari, Italy
fabio.parisi@poliba.it

Agostino Marcello Mangini
Electrical and Information Engineering
Polytechnic University of Bari
Member IEEE
Bari, Italy
agostinomarcello.mangini@poliba.it

Maria Pia Fanti
Electrical and Information Engineering
Polytechnic University of Bari
Fellow IEEE
Bari, Italy
mariapia.fanti@poliba.it

I. Extended Abstract

Robotics is one of the Industry 4.0 enabling technologies, adopted and declined under different perspectives and in particular Robotics manipulator are used in industries for many different tasks like machining [1], handling and pick-and-place, palletizing, welding, painting and cooperation with humans in specific tasks.

In many industrial applications, the robots are used to perform a set of tasks and the tasks sequencing and how the robot moves between them greatly influence the overall performance of the application [3].

This contribution deals with the problem of palletizing objects from a pre-determined storage area to a delivery area. In the storage area the objects are stacked in columns, while in the delivery area the robotic manipulator has to pose the objects in horizontal levels, one over another.

A robotic manipulator has to move a finite number of objects from a starting pre-determined geometric configuration (storage area) to an ending different pre-determined configuration (delivery area).

The starting geometry is configured by disposing the objects to be moved in a set of columns, where the objects are stacked one on the other. The distances between the columns has to take into account also the geometry of the gripper on the end-effector; the manipulator can grip every object only in a single fixed configuration (see for instance Fig. 1). The ending object configuration is obtained by disposing the objects in a certain number of levels, one over another. At every level, the objects position is shifted of an half of the length referring to the previous one and the next one. The final configuration is similar to the construction of a wall made of bricks.

All the objects have the same geometry, and the robotic manipulator can handle only one object for each transfer operation, starting from the initial position and ending to the final position. The manipulator will perform this global task in a number of sub-tasks depending on the geometric configuration of the problem.

The problem we want to solve is to compute the optimal sequence of actions for moving objects from the starting to the ending configurations in order to minimize the length of the travelled paths.

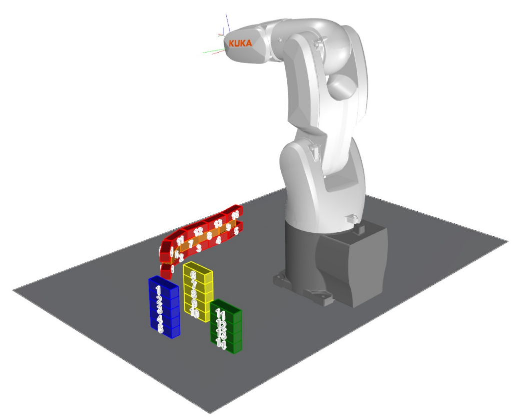

Fig. 1. Geometry configuration

II. The Matematical Programming Formulation

A time-indexed formulation of the problem is proposed where the decision variables are the pick-up and delivery operations in the discrete-time instants, in which the operations are scheduled ([2]). In order to schedule the operations in discrete time periods, we assume that the handling times are integer parameters in the time-indexed formulation. Moreover, we assume that each operation is performed in one time interval, even if not all the operations have the same durations.

The solution of the ILP problem presented in [2] is tested by two strategies: i) an off-line simulation framework is specified; ii) a real case study is performed.

In order to solve the problem, a geometric configuration is set as it is shown in Fig. 1. The parameters and variables are specified as follow:

- the objects to be moved are $n = 14$;
- $S = \{S_1, ..., S_i, ..., S_{14}\}$ is the set of objects in the initial positions;
- $E = \{E_1, ..., E_j, ..., E_{14}\}$ is the set of the ending positions;
- the moving process is discretized in $t = 14$ time intervals;
- the starting positions are configured in $c = 3$ columns;
- the ending positions are configured as in Fig. 1, where the objects are positioned in $f = 3$ levels, with $l_1 = 5$,

$l_2 = 5$ and $l_3 = 4$;

- d_{ij} are the elements of the distance matrix D. To compute the elements of the matrix, each sub-task trajectory is structured so that collisions are avoided.

Moreover, the following parameters and variables describe the generic positions and configurations of the objects:

- $l_{lb}(w) = \sum_{v=1}^{w-1} l_v + 1$ for $w = 2, ..., f$ denotes the first time interval in which the object can be positioned in level w;
- $l_{ub}(w) = \sum_{v=1}^{w} l_v$ for $w = 1, ..., f$ denotes the last time interval in which the object can be positioned in level w.

The time-indexed formulation of the problem considers a planning horizon that is discretized into n time units (t.u.). In addition, a time-indexed binary variable is defined as follows:

$$y_{i,j}^t = \begin{cases} 1 & \text{if the object is moved from } S_i \text{ to } E_j \text{ at time } t \\ 0 & \text{otherwise.} \end{cases}$$

The aim is finding the sequence of the moves of the manipulator that minimizes the length of the travelled path.

Hence, the objective function can be defined as follows:

$$D_{tot} = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{t=1}^{n} d_{i,j} \cdot y_{i,j}^t \quad (1)$$

The ILP is the following:

$$\min D_{tot} \quad (2)$$

subject to:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} y_{i,j}^t = 1 \quad \text{for } t = 1, ..., n \quad (3)$$

$$\sum_{i=1}^{n} \sum_{t=1}^{l_1} y_{i,j}^t = 1 \text{ for } j = 1, ..., l_1 \quad (4)$$

$$\sum_{i=1}^{n} \sum_{t=l_{lb}(w)}^{l_{ub}(w)} y_{i,j}^t = 1 \text{ for } j = l_{lb}(w), ..., l_{ub}(w),\ w = 2, ..., f \quad (5)$$

$$\sum_{j=1}^{n} \sum_{t=1}^{n} y_{i,j}^t = 1 \qquad \text{for } i = 1, ..., n \quad (6)$$

$$\sum_{t=1}^{k} \sum_{j=1}^{n} y_{i,j}^t - \sum_{t=1}^{k+1} \sum_{j}^{n} y_{i+1,j}^t = 1 \quad \text{for } k = 1, ..., n \quad (7)$$

$$y_{i,j}^t \in \{0, 1\} \text{ for } i, j, t = 1, ..., n. \quad (8)$$

III. Results

The outputs of the solution are described by the decision binary variables that identify the sequence of the manipulator moves in each interval time. Then, the result is reported in Table I and the minimum path to perform all the movements is given by the ILP objective function $D_{tot} = 19.222m$.

The theoretical solution of the problem is tested in an experimental set up involving a KUKA KR3 R540 robot (figure 2). The programming phase is performed by using the online approach directly on the workcell. With the KUKA teach pendant (SmartPAD), the exact geometry and travel set modelled in the simulation environment is replicated, in order to compare the simulation with the real experimentation.

TABLE I
Optimal Solution

Time intervals	Starting position	Ending position
1	11	5
2	12	3
3	13	2
4	1	1
5	14	4
6	6	8
7	2	7
8	3	6
9	7	9
10	8	12
11	9	14
12	10	13
13	4	10
14	5	11

Fig. 2. Start phase of the experimentation

The speed used for every movement is $sp = 0.4m/s$. This setting, together with the low height of the bricks, make neglect-able the robot dynamics.

The obtained results reported in Table II take into account also the time needed to grip and release the objects. However, the experimental results are consistent with the theoretical solution obtained by the ILP problem.

TABLE II
Experimental Results

Path length (m)	Time (s)
19.222	48.05

References

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