A Picking Strategy for Circular Conveyor Tracking

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***Abstract* — The automatic part feeding is one of the most crucial task in modern assembly lines. Such a task consists in the separation of parts delivered in bulk and their presentation in a certain amount and orientation at the pick-up location. The traditional Vibratory Bowl Feeder (VBF) is no longer suitable for the modern plants which require high velocity and increasing flexibility. In this work the Ars FlexiBowl™ has been identified as one of the most interesting flexible feeders. A proper path planning algorithm is proposed for Adept Robots in order to take full advantage from this feeder. A robot workcell is used as experimental setup in order to prove the usefulness of the proposed algorithm.**

Keywords—robotics; path-planning; flexible feeder; system calibration.

I. INTRODUCTION

The industrial automation and its optimization play a crucial role in the ever-continuing effort to improve the factory production processes. Several approaches have been proposed to address performance improvement problems, mainly in terms of product quality [1-4] and process productivity [5-9]. However in the last years one of the main issues is the flexibility of the assembly lines. As the matter of the fact the automation is usually a way to lower the cost of labor by achieving and optimizing flexibility and a proper degree of automation.

Basic assembly production strategies can be classified as: manual, dedicated and flexible assembly systems. Dedicated automation consists in serial production with large batch sizes, high productivity and almost no flexibility. The traditional approach adopted to increase flexibility consists in configuring manual assembly system using human operators. Such an approach leads to a great decrease of productivity and to fluctuations in the quality level [10]. In order to solve this problem, in the last few years innovative automated flexible automated assembly systems have been developed and implemented. Those systems, by means of programmable manipulators and vibratory bowl feeders, allow achieving the best tradeoff between flexibility and productivity ensuring a suitable quality level [11].

The most commonly used equipment for singularization and orientation of parts is the vibratory bowl feeder (VBF). Such system is affected by several drawbacks: it a passive orientating system; it is not reliable for small parts; and it is dedicated to feeding only one particular part at a time [12]. In order to overcome these problems, several innovative feeding systems have been proposed. Some researchers tried to add innovative features to the traditional VBF. In order to solve the problem of small parts in [13] a general purpose automatic feeding system, developed for high speed assembly of small parts is presented. This feeding system is functionally uncoupled, leading to minimization of problems in system tuning, parts damage and noise emission.

As far as the problem of part orientating is concerned, several solutions have been implemented. The compact belt system proposed in [14] is capable of feeding complex shape parts using modern sensor technology for part recognition, a standard non-active orientation blade, and a novel method for handling cylindrical parts. In [15] a programmable feeder equipped with electro-pneumatic cylinders and stepper motors is presented. This system is capable of identifying the parts with the wrong orientation and actively re-orientating them into the right one. Moreover in [16] a novel design and development approach for feeding asymmetrical cylindrical parts is proposed. This design incorporating active orientating capability is aimed at 100 percent feeding efficiency.

An innovative approach consists in introducing computer vision systems in order to guarantee both flexibility and short setup activities for part changes. In [17] a vision guided robot able to determine the position of randomly fed products by a recycling conveyor system is proposed. In [18] a feeding/measuring system for dimensional verification of small metallic subassemblies is presented. This system has been applied to assembly processes of the eyeglasses industry. Following the same approach, a new concept of flexible automation is proposed in [19][20]. The fully flexible assembly system (F-FAS) makes it possible to predict its efficiency, throughput and unit direct production costs, correlating such values with the system production variables.

Looking at the feeders on the market, one of the most used flexible feeding systems is the Flexfactory AnyFeeder™. Such a compact system addresses flexible feeding needs for various bulk goods and replaces dedicated feeders. On its surface, the parts are identified by the vision system and picked by the manipulator. If the parts have a wrong orientation the surface can vibrate in order to change it. The bottleneck of AnyFeeder is that only one of these operations can be performed at a time.

However, recently ARS proposed a new product called FlexiBowl™. The feeder is designed to handle a wide array of loose small parts including parts of different shapes and materials. Thanks to its rotating platform, the FlexiBowl™ (combined with a vision system) can simultaneously perform the three main operations above mentioned so as to accept and feed new parts significantly speeding production [21]. Such a system has only one drawback, since a circular conveyor tracking is not implemented in many robots, the whole robotic workcell cannot work continuously. Indeed the need of stopping the feeder rotation for each picking operation introduces an unjustifiable waste of time.

The main goal of this work consists in adding new features into the control unit of Adept robots in order to optimize the usage of feeders like FlexiBowl™. For this purpose a robotic workcell made up of an Adept SCARA robot, its vision system and a FlexiBowl™ is presented. Particular path planning algorithms, implemented in the robot control unit, allow achieving a circular conveyor tracking. In this way the robot is able to pick parts on the fly from the circular moving feeder without the need of stopping its rotation. The use of such a feature can be employed in several industrial plants where circular conveyors are used in order to optimize the layout of (machines involved in) the production lines.

In the next section the Ars FlexiBowl™ working principle is illustrated. In section III & IV the layout of the whole system is proposed together with a suitable use of the reference frames and the system calibration. Finally, in section V and VI the experimental result and the conclusion are presented.

II. FlexiBowl Working Principle

As above mentioned the Ars FlexiBowl™ is a rotating feeder. Its working principle is illustrated in Fig. 1. Without lack of generality a clockwise rotation sense is assumed. The feeder surface is "virtually" subdivided into four areas: In the first one the parts are loaded on the FlexiBowl™, usually by a conveyor; when the parts are in the second area, a properly mounted camera take a picture of the parts in order to find their position; successively, in the third area, the parts are picked by the robot; if one or more parts are not pickable due to their orientation or proximity, in the fourth area a pulse generator device can be enabled.

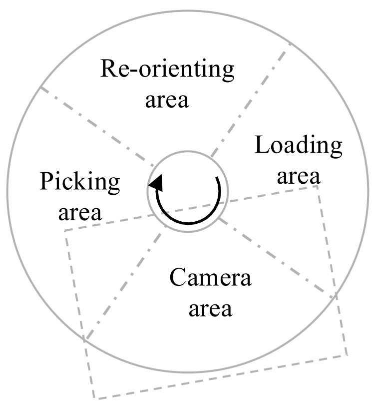

Fig. 1. The FlexiBowl surface subdivision in four areas

In order to highlight the advantage of the proposed path planning algorithm, a timetable analysis is discussed in order to compare the traditional and the novel employing methods.

A. *Without Circular Conveyor Tracking*

Let us define t_r the time the FlexiBowl takes to perform a complete rotation, t_s the time the FlexiBowl™ is stopped to allow the robot to take the parts, and t_p the mean time the robot needs to pick the reachable parts from the FlexiBowl™. (In general case we can suppose that $t_r < t_s$ and $t_s = t_p$). The time t_s is proportional to the number of parts to pick and inverse proportional to the robot speed. Conversely the time t_r is independent from these parameters. However the time t_r should be set properly. On one hand it should be set as small as possible, because during the rotation the robot is waiting. On the other hand the rotation speed should be limited. Indeed it is important to take into account that the parts on the FlexiBowl™ are already recognized by the vision system, and a jerkily or fast motion can induce a relative motion between the parts and the feeder surface. If this happen, the robot will not be able to pick the parts. Moreover in case of small relative motion, a bad picking operation can damage the part or the end-effector in case of unwanted contact. Therefore the time t_r cannot be neglected with respect to t_p. Hence the time taken to the robotic system to pick the parts, for each complete feeder rotation, is equal to $t_r + t_p$.

B. *With Circular Conveyor Tracking*

When using circular conveyor tracking, some differences can be seen in the system workflow. As the matter of the fact, if the robot system is able to pick the object while it still is moving, the FlexiBowl™ can keep moving, hence t_s can be set to zero. In this case the t_r should correspond to a larger amount of time, allowing the robot to take the objects. In case of uniform distribution of the object on the FlexiBowl™, t_r can be set equal to t_p. Therefore the time taken to the robotic system to pick all the object is equal to t_p.

Fig. 2. The robotic workcell

C. Method Comparison

By comparing the two approaches, the main advantages of the second one appear evident:

- The time taken to the FlexiBowl™ to perform a full rotation is masquerade by the time taken to pick and place the object. This lead to a lower time consumption.
- The FlexiBowl™ rotation speed is set to a lower value, preventing any relative motion between objects and FlexiBowl™, and hence avoiding any problem in the pick operation.

III. System Layout

The algorithm implementation has been carried out through the robotic workcell illustrated in Fig. 2. The robotic work cell is made up of one Adept Cobra 600 SCARA robot, one Basler A631 firewire camera and one Ars FlexiBowl™ feeder developed by Ars Automation.

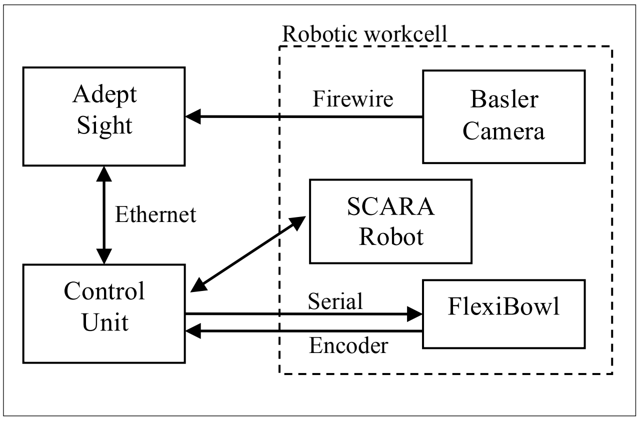

Fig. 3. The experimental setup modules and connections

The whole experimental setup is schematically depicted in Fig. 3, and comprises the above mentioned robotic workcell, the Adept control Unit, and the AdeptSight vision system running on a PC directly communicating with the robot controller by means of an Ethernet bus.

The Adept Cobra Scara Robot has been chosen because it is one of the slower manipulators for pallet fulfilling. In fact the results achieved by means of this robotic workcell can be improved by simply employing a faster robot like the Adept Quattro [22].

The Vision System is employed to detect the object on the FlexiBowl™. For this purpose the camera is fitted perpendicular to the feeder moving surface in order to identify the horizontal coordinates of the detected parts. Since the parts are on a moving surface, the image acquisition is a critical task. Indeed the picture has to be taken simultaneously with the FlexiBowl™ angular position acquisition. Such information allows the controller to achieve the part position by simply reading the actual encoder value (signal). In the next section the reference frames needed for this purpose are illustrated together with their transformation matrices. On the contrary, the image processing task is usually not critical. Indeed there is always enough computing time before the parts arrive in the robot reachable workspace (picking area).

In Fig. 4 are depicted the Robot Reference Frame (X_R, Y_R, Z_R), the Camera Reference Frame (X_C, Y_C, Z_C) and the FlexiBowl™ Reference Frame (X_F, Y_F, Z_F). The vision system identifies the position $\boldsymbol{p}(\rho, \varphi)$ of the object, in polar coordinates, both with its symmetry main axis γ.

$$\boldsymbol{p}_F = \begin{Bmatrix} \rho\cos\varphi \\ \rho\sin\varphi \\ 0 \end{Bmatrix} \tag{1}$$

$$\boldsymbol{T}_{part,F}(\rho, \varphi, \gamma, \alpha_0)\ ? \tag{2}$$

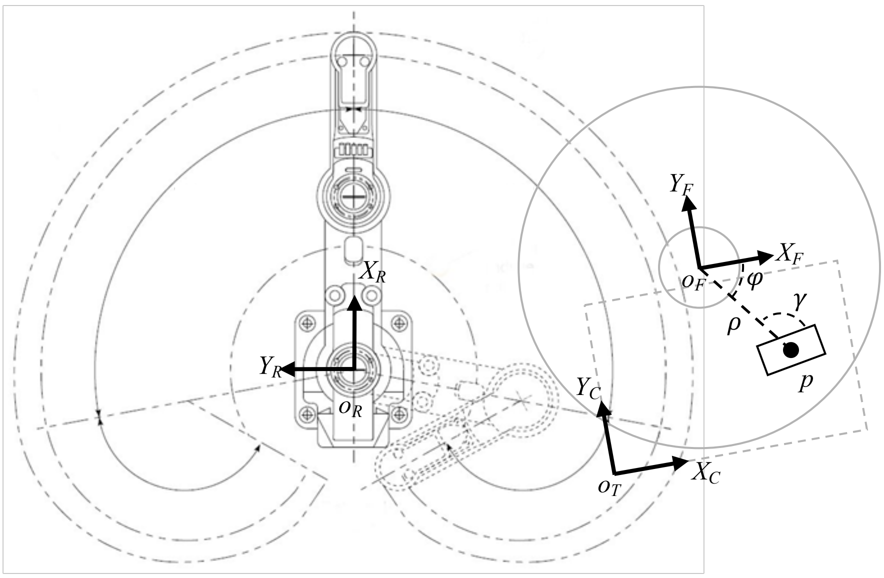

Fig. 4. The workcell layout with the system reference frames

Let us denote with $\boldsymbol{T}_{i,j}$ the 4x4 transformation matrix that describes the i reference frame with respect to the j reference frame, with $\boldsymbol{T}_x(d)$ the 4x4 elementary transformation matrix that defines a translation along the x axis of d mm, and with $\boldsymbol{R}_z(\alpha)$ the 4x4 elementary transformation matrix that defines a rotation around the z axis of α degrees.

$$\boldsymbol{p}_R = \boldsymbol{T}_{C,R} \cdot \boldsymbol{T}_{F,C} \cdot \boldsymbol{p}_F \tag{3}$$

This allows defining the “goal frame”:

$$\boldsymbol{T}_{goal} = \boldsymbol{T}_{part,R} = \boldsymbol{T}_{C,R} \cdot \boldsymbol{T}_{F,C} \cdot \boldsymbol{T}_{part,F} \tag{4}$$

$$\boldsymbol{T}_{part,F} = \boldsymbol{R}_z(\varphi + \alpha - \alpha_0) \cdot \boldsymbol{T}_x(\rho) \cdot \boldsymbol{R}_z(\gamma) \tag{5}$$

Where: ρ and φ are the polar coordinates of the point $\boldsymbol{p}$, α is the actual encoder value in degrees while α_0 is the encoder value at the position identification. Finally γ is the angle between the part main symmetry axis and the $\boldsymbol{p}_F - \boldsymbol{o}_F$ vector. The angle γ can be set equal to a predefined angle in case of circular parts.

The matrices $\boldsymbol{T}_{C,R}$ and $\boldsymbol{T}_{F,C}$ are given by the calibration procedures, and hence are calculated once. The values ρ, φ and γ defines the point P, hence are calculated by the vision task for each object; α_0 identifies the angular position of the FlexiBowl™ with the objects are identifies by the vision system. Only the parameter α changes its value, due to the rotation of the FlexiBowl™, hence the values of the matrix $\boldsymbol{R}_z(\varphi + \alpha - \alpha_0)$ has to be updated as fast as possible during the picking of the moving object.

IV. System Calibration

The aim of the calibration procedure consists in finding the matrices $\boldsymbol{T}_{C,R}$ and $\boldsymbol{T}_{F,C}$ which identify the position of the camera in robot reference frame and the FlexiBowl™ in the camera reference frame respectively. The calibration allows the vision system to express the detected object position in the robot reference frame. The calibration procedure is made up of two phases. The aim of the first one consists in finding the camera position together with the millimeter/pixel ratio. In this phase the user is requested to place an object by means of the robot on the FlexiBowl™. After the detection of the object by the vision system, the same object has to be displaced in a second position on the FlexiBowl™. When the object has been detected for the second time, it is possible to measure the distance between the two locations both in pixels and in millimeters. The two distances give the requested ratio. Moreover, since the coordinates of the two points are known in the two measurement units, it is possible to compute the matrix $\boldsymbol{T}_{C,R}$. Such a matrix allows identifying the position of the objects detected by the camera in robot reference frame.

$$\boldsymbol{p}_R, \boldsymbol{q}_R \ \& \ \boldsymbol{p}_{Cpx}, \boldsymbol{q}_{Cpx} \tag{6}$$

$$r_{mm/px} = \frac{|\boldsymbol{q}_R - \boldsymbol{p}_R|}{|\boldsymbol{q}_{Cpx} - \boldsymbol{p}_{Cpx}|} \tag{7}$$

$$\emptyset = \angle(\boldsymbol{q}_R - \boldsymbol{p}_R) - \angle(\boldsymbol{q}_C - \boldsymbol{p}_C) \tag{8}$$

$$\boldsymbol{T}_{C,R} = \boldsymbol{T}_{p_R,R} \cdot \boldsymbol{R}_z(\emptyset) \cdot \boldsymbol{T}_{p_C,C}^{-1} \tag{9}$$

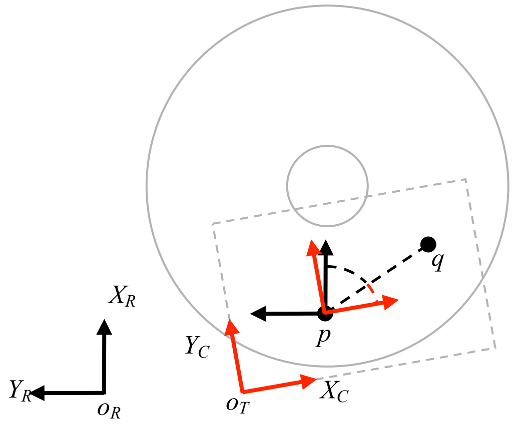

Fig. 5. Camera reference frame calibration

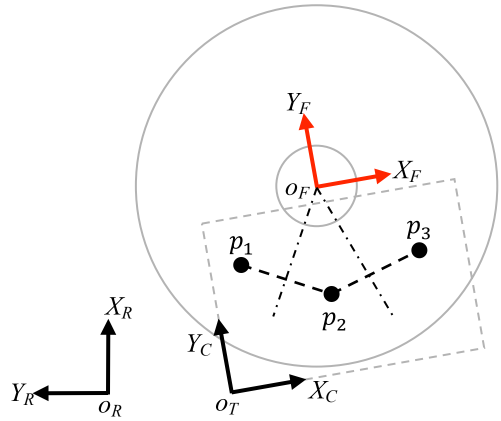

Fig. 6. FlexiBowl reference frame calibration

The aim of second calibration phase consists in computing the matrix $\boldsymbol{T}_{F,C}$. This matrix allows expressing the position of an object on the FlexiBowl™ in the camera reference frame.

Such a result consists in finding the center of the feeder $\boldsymbol{o}_F$ in the camera reference frame. The procedure plans to have only one object on the FlexiBowl™. The vision system takes at least three pictures of the object while the FlexiBowl™ is moving. Without lack of generality, in Fig. 5 the three pictures is taken every forty-five degrees. Given the coordinates of the three points, the equations of the two segments (green lines) which go respectively from the first to the second point and from the second to the third one can be computed. Afterwards two straight lines normal to the two segments and crossing them in their midpoints can be identified (red lines). Finally the intersection of those two straight lines represents the center of the FlexiBowl $\boldsymbol{o}_F$ while the orientation of the reference frame is the same of the vision system.

$$\boldsymbol{T}_{F,C} = \begin{bmatrix} \boldsymbol{I}_3 & \boldsymbol{o}_{F,C} \\ 0 & 1 \end{bmatrix} \tag{10}$$

V. Path Planning

The core of the circular conveyor tracking is the path planning of the robot. The main problem consists in performing the vertical movement to approach the part and simultaneously following the part moving on the horizontal plane of the FlexiBowl™ surface. The problem exists because it is not possible modify the path of the robot when the moving task is executing. Such a problem has been solved exploiting in a particular manner the "continuos path" property of the robot trajectory planner. Such a feature is explained by means of Fig. 6. When the robot has to perform a movement from a location A to a location B crossing a waypoint C, the typical motion law is illustrated in Fig. 6 (a). In order to reduce the task executing time, the continuous path can be used: the robot begin the movement towards the location B before arriving in the waypoint C. In particular, the second movement starts with the beginning of the decelerating ramp of the first one. Fig. 6 (b) shows that when the "continuous path" is enabled the time needed for an acceleration (or deceleration) ramp is saved.

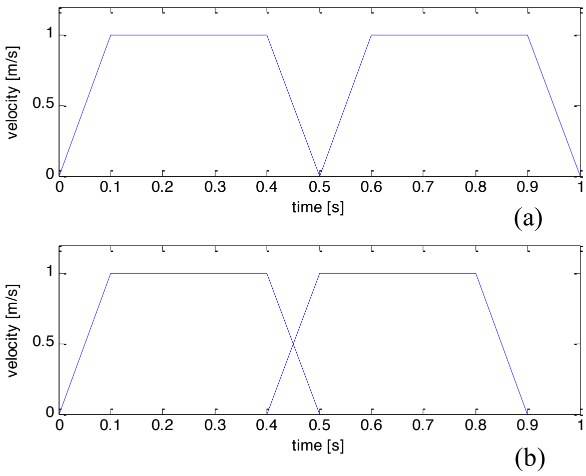

Fig. 7. Continuous Path: disabled (a) and enabled (b)

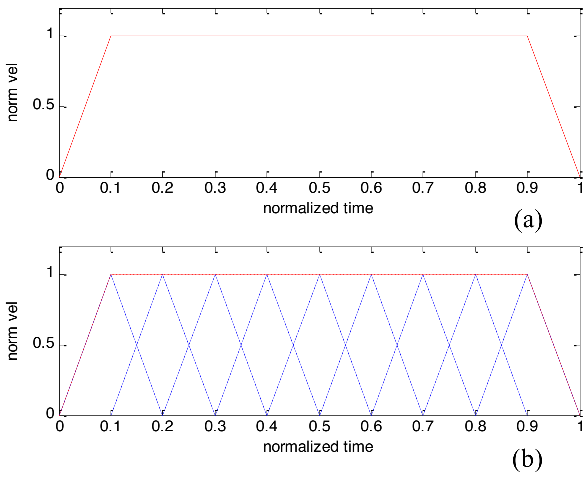

Fig. 8. Trapezoidal velocity profile (a)
and overlap of triangular velocity profiles (b)

The continuous path feature has been used for a different aim in order to pick the parts from the rotating platform of the feeder. Figure 7 (a) shows a typical trapezoidal velocity profile for motion. Exploiting the continuous path feature, the same motion profile is achieved by the envelope of several (properly) overlapping triangular velocity profiles. If the path is straight the effect of the second approach is identical to the first, but in this case the reference position can be updated. This reasoning allows introducing the circular conveyor tracking without modifying (exploiting) the internal trajectory planner. The overlap of triangular velocity profiles is used for the vertical movement planning, while the horizontal movement is achieved by following the part by means of the encoder value.

VI. First Esperimental Results

The proposed path planning has been intensively tested in picking operations. Several tests have been performed without the occurrence of any problem. In Fig. 9, the end-effector path is depicted in polar coordinates. The robot perform the approaching movement following carefully the horizontal part movement.

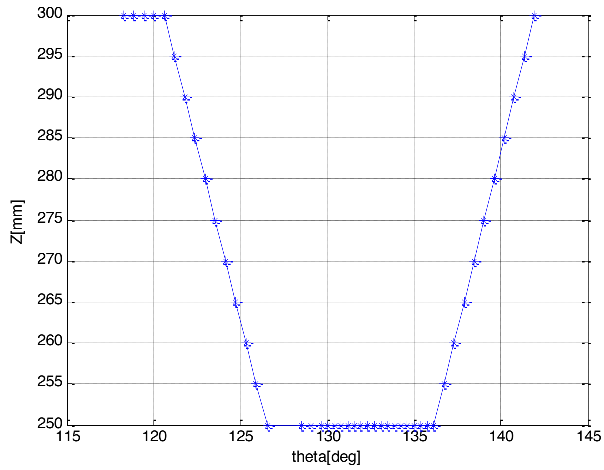

Fig. 9. Picking operation (side view)

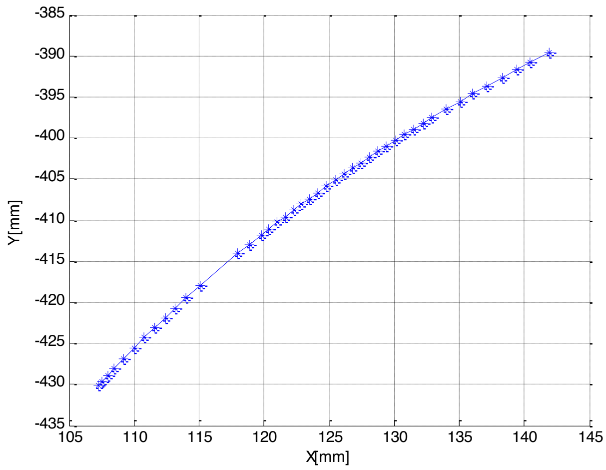

Fig. 10. Picking operation (top view)

Moreover in Fig.10 a top view of the picking operation path is depicted. The horizontal movement is approximately a circumference arc, like the trajectory of the part to be picked. During the intensive tests, the maximum error found in the path following is less the 0.5mm.

VII. CONCLUSIONS

A novel picking strategy for circular conveyor tracking has been presented and then applied to a robotic workcell with a rotating feeder. The method is based on proper motion profiles that allows following properly the parts moving on the rotating bowl. This approach allows employing the robot traditional trajectory planner and can be implemented on each robot control unit. The experimental result proves the effectiveness of the proposed strategy and highlights the possibility of performance improvement of the considered feeder.

The proposed strategy for circular tracking can be employed in those plants where circular conveyor are used to optimize the placement of the assembly/robotic workcells.

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