Flexible Automated Depalletizing: an Unwrapping Robot to Remove Plastic from Palletized Goods

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***Abstract*—Despite being a crucial step of the intralogistic flow, pallet unwrapping, i.e., the removal of the plastic film that protects the items stored on pallets, has not been satisfactorily automated yet. However, automated solutions may improve workplace safety and work efficiency. The automated solutions available on the market are usually bulky machines that lack flexibility. In this work, we describe an unwrapping robot mounted on a small-footprint mobile base, hence easily relocatable, that can unwrap pallets even when the knowledge of the profile is affected by some uncertainty.**

***Index Terms*—Logistic Automation, Depalletizing, Robotic Physical Interactions**

I. Introduction

Parcels stacked on pallets are usually tightly wrapped in plastic to stabilize them during storing or shipping and protect them from the potentially damaging effects of adverse environmental conditions. The removal of the plastic film, which we refer to as *unwrapping*, is the preliminary and necessary operation to make the items accessible for manipulation. Despite the general trend towards the robotization of intralogistic processes, unwrapping is particularly far from complete automation in the current industrial scenario, due also to the perception and control challenges that it poses.

It is emblematic that even the most advanced integrated solutions for warehouse automation—see, e.g., TATO-20R depalletizer by MAS PACK[1]—require the presence of human operators to execute the unwrapping task.

In the literature, robotic cutting is often executed under human-robot shared control [1]. Typical applications are surgical procedures and nuclear decommissioning. Targeting the meat industry, [2] designs a method that relies on a complex model of the beef shoulder for cutting soft materials with two autonomous robotic manipulators. Instead, in the case of automatic precision-cut of metallic pieces, the accurate knowledge of the environment allows for precise positioning of the cutting end-effector [3]. Active force control has been proposed for autonomous cutting tasks of uncertain profiles [4]. However, force control may, in general, have stability issues and requires high bandwidth [5]. The injection of extra flexibility by allowing online deviations of a pre-planned trajectory based on the proximity with the environment has been exploited in the literature in order to increase the robustness to uncertainties of different robotic tasks [6], [7].

(a) Experimental setup: plastic only on the *lateral* surface of the pallet.

(b) Experimental setup: plastic on both the *lateral* and the *top* surface.

Fig. 1. Pictures of the system during unwrapping task execution. On the left, the robot unwraps a pallet in which the plastic covers only the lateral surface; on the right, the robot unwraps a pallet in which the plastic partially covers also the top surface.

Besides the challenges involved, sporadic execution is another reason underlying the scarce automation of the unwrapping task. A human operator can be assigned to different tasks, carried out between the two unwrapping-task executions. However, with the recent pandemic outbreak, a higher push towards complete warehouse automation has risen, to guarantee physical distancing. This additional motivation sums up to the improvements of safety and working conditions that would result from the adoption of automated unwrapping solutions —while, of course, reducing the physical strain, automated unwrapping would avoid the need for ladders and prevent the risk of static electric shocks while manually handling the plastic[2].

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[1]http://www.maspack.com/en/product/tato-r-400-bpm/

[2]https://www.bwintegratedsystems.com/docs/default-source/literature/material-handling/robotic_unwrapper_hr.pdf?sfvrsn=d3fbe398_4

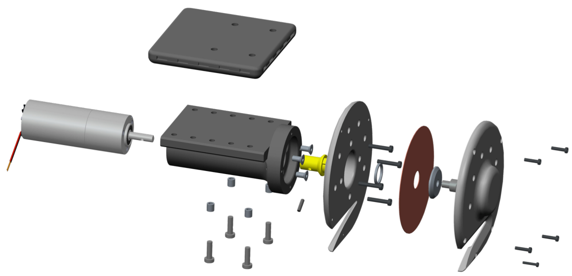

Fig. 2. Exploded view of the cutting end-effector. The cutter is attached to the robot via a flange. The actuation is composed of an electric motor with a planetary gearbox. The circular blade, with a diameter of 60 mm and a thickness of 0.6 mm, is protected by a frame.

Among the examples on the market MSK[3] fully automatic unwrapping machine is composed of a portal frame under which the palletized items are placed. A large metal structure cuts the wrapping film. Hence, a rolling cylinder winds the sheet, which is eventually suctioned under the machine. The BWContainer Systems automatic unwrapper[4] consists of a robotic arm of considerable size that melts the plastic with a hot air gun. A mechanism for removing the open plastic sheet is integrated. Suitable items are bulk glass or plastic bottles, and aluminum or steel cans. No labels, tags, tapes, and the like are allowed in the cutting region. The VARO unwrapping machine[5] works with single-item cuboid pallets, introduced inside a metal case where a custom cutting end-effector cuts the stretch film on the top and lateral surfaces. Eventually, there are unwrapping systems that apply solely to specific objects. Among these, the automatic unwrapper by Autorema[6] and the CSW-Multifeeder series[7] are designed for packets of end-cans.

In conclusion, the solutions available on the market are usually bulky machines that work on very specific pallets. Thus, they may lack flexibility.

II. Contribution

In this paper, we describe an autonomous unwrapping robot, shown in Fig. 1, that has been first introduced in [8]. The robot is composed of a perception module, an impedance-controlled robotic manipulator mounted on a mobile base, a custom cutting end-effector, and a suitable planning strategy. Compared to the state-of-the-art solutions, our robot is lighter and can be mounted on a reduced-footprint mobile base. Hence, it can be easily relocated to maximize warehouse efficiency. Furthermore, even if at the present state we unwrap cuboid pallets (which, anyway, characterize a large part of all practical applications), the system is intended to handle arbitrarily shaped pallets. The main contribution of such a solution is twofold: on one side, the robot is equipped with a custom cutting device, designed after extensive experimental evaluation of existing cutting tools with different working principles; on the other side, the robot is provided with a Cartesian impedance and trajectory planning strategy to effectively execute the cut of the wrapping film without damaging the goods, accounting for uncertain knowledge of the environment. Furthermore, in this work, the possibility of integrating online force feedback at a planning stage in order to trigger proper reactions is discussed.

III. System Description

In this section, we provide a description of the unwrapping system.

A. Hardware

The robot is composed of a 7-degrees-of-freedom robotic manipulator[8] equipped with a custom end-effector (see Fig. 1(a) and Fig. 1(b)). The end-effector is composed of a concealed and actuated circular blade (see Fig. 2). The protection prevents any contact between the blade and the underlying objects, facilitates the engagement of the plastic film, and is safe to be used in a human-robot shared environment. The actuation of the blade enables a more effective cut. The mobile base on which the robot has been mounted uses a lidar for self-localization and an RGB-D camera for detecting the extents of the pallet. A suction system to remove the plastic could be integrated as in the state-of-the-art solutions.

B. Planning and Conrol

Pure position control, making the robot stiff during the physical interaction, is not the most suitable solution to guarantee the integrity of the objects. Our robot is controlled with a Cartesian impedance control law. Uncertainties, due, e.g., to noise and estimation errors coming from the perception module, reasonably affect our knowledge of the pallet size and position. Cuboid pallets, being the majority of the overall shipped pallets, are considered at this stage. The pallets are supposed to be wrapped either on the lateral surface (see Fig. 1(a)) or both on the lateral and top surfaces (see Fig. 1(b)). In the most complex case, the one in Fig. 1(b), the robot end-effector moves downward to reach the top surface of the pallet, then forward to engage the plastic film and cut it. At the edge of the pallet, it rotates and continues the cut downward. Suitable planning of trajectory and impedance ensures that the plastic film is actually engaged despite the uncertainties, e.g., that, during the first motion, the cutter touches the pallet surface and that the forces exerted on the wrapped items stay bounded. Sensor feedback, especially force feedback, may be used at a planning stage to adjust the cutter trajectory on-the-fly.

IV. Experiments and Discussion

In [8], the proposed trajectory and impedance planning has been tested on 26 trials, 13 in which the plastic was only the lateral surface of the parcels (see Fig. 1(a)), and 13 in which the plastic partially covered also the top surface of the pallet

[3] https://www.msk.de/loesungen/defoliersysteme/defolierer-paletten/

[4] https://www.bwpackagingsystems.com/docs/librariesprovider2/fleetwoodliterature/robotic-unwrapper-unbagger-english.pdf?sfvrsn=12

[5] https://www.varomachinery.com/non-food/packaging/unwrapping-system/

[6] https://autorema.com/en/can-making-industry/

[7] https://www.youtube.com/watch?v=pnLEEi9ZY5I

[8] https://www.franka.de/technology


(a) (b) (c)
(d) (e) (f)

Fig. 3. Photo sequence of the unwrapping of a cuboid pallet using reactive planning. The cutter starts above a region free of plastic in 3(a). Hence, it moves downwards until it senses a contact with the surface in 3(b). The contact triggers the stop of the descending motion and the beginning of a forward motion. The cutter slips on the surface of the objects until it senses the force exerted by the engaged plastic film, in 3(c). Hence, the blade is actuated and the plastic cut. When the plastic on the edge of the pallet exerts a force on the cutter, in 3(d), the cutter rotates of 90 degrees, in 3(e). After completing the rotation, the cutter moves downward finishing the cut of the plastic along the lateral surface of the pallet. (3(f)).

(see Fig. 1(b)). The results showed 100% of success in the scenario of Fig. 1(a) and 76.92% in that of Fig. 1(b).

From experience acquired in [8], it seems beneficial to confer some awareness of the current task execution status to the robot planner. Specifically, preliminary experiments suggest that the percentage of success may be increased by using online force feedback in the planning. For instance, because it could be possible to rotate the cutter at the right moment in the case of Fig. 1(b). Bad timing of the cutter rotation due to inaccurate estimation of the pallet edge was the main cause of failure in the previous results. Figure 3 shows a preliminary experiment in which a reactive planning strategy for cuboid pallets has been adopted.

Moreover, if an unexpected collision is detected, a reactive planner might trigger an emergency policy, the simplest one being stopping the robot and calling for human assistance. Finally, it could also be possible to detect the loss of the engagement with the plastic film by sensing a reduction of the external forces on the cutter under a certain threshold.

This work described an unwrapping robot composed of a robotic arm mounted on a mobile base and equipped with a cutting custom end-effector, and a perception system to acquire information of the pallet to unwrap. Impedance law allows controlled physical interactions with the environment, while proper planning ensures effective task execution and bounded forces on the underlying items. In the future, extensive tests using force feedback at a planning stage will be carried out in realistic environments. Irregularly shaped pallets will be tackled, and the recognition of plastic-free regions of the parcels will be automated. A prismatic joint may be added at the base of the arm to augment its vertical workspace.

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