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Robotic Gift Wrapping — or a Glance at the Present State in Santa's Workshop

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Abstract: This work presents a robotic implementation of Christmas gift wrapping. Handling paper is a challenging task for an industrial robot as it easily tears and folds in unexpected ways. In this application, a dual-arm industrial robot with simple two-finger grippers was used, and the robot was programmed using a standard position-based approach. The wrapping was accomplished with the help of plastic spatulas, and although the speed of the final wrapping was slower than an average human, the gift wrapper application became a success on its tour around Sweden during the Christmas commerce 2015.

Keywords: Industrial robots, robot control, gift wrapping

1. INTRODUCTION

Industrial robots are becoming increasingly popular for automating manufacturing tasks. Traditionally they have been position-controlled and performed tasks such as welding, painting, and packetizing. The introduction of external sensing, such as vision and force, have extended the set of tasks that can be robotized, by making it possible for robots to be aware of their environment.

A common place to find industrial robots is within the automotive industry. The car parts look exactly the same each time, they do not easily deform, and the physical interaction is predictable. An opposite to stiff car parts is paper and other soft materials, which are more challenging to manipulate because of deformation and unexpected folding. For these reasons, industrial robots do not usually handle tasks involving paper folding. This work, however, is about a robotic gift wrapper that automates the wrapping of Christmas presents during a PR campaign, see the robot cell in Fig. 1.

Gifts are most commonly wrapped using human labor, but there are automated solutions using special purpose machines available, e.g., Cpack Pendle Ltd (2016) and Mani and Patil (2015). Such special purpose machines are useful if a large number of standardized packages should be wrapped. It might, however, be difficult to change the process or the package size and, of course, to use the machine for other tasks. Letting a standard robot do the gift wrapping instead, it should be possible to both

Fig. 1. The gift wrapping cell together with the two first authors of this paper.

handle different sizes and use the robot for other tasks as well. Origami, the art of paper sculpture, is a similar task to gift wrapping, and it has been considered with robots before. In (Balkcom and Mason, 2008) a single robot arm together with a fixture on a table was used for performing origami, and in (Namiki and Yokosawa, 2015) two robot arms equipped with multi-degrees-of-freedom fingers were used. The latter setup further used external sensing, both vision and force. Another dual-arm example was presented by ABB Robotics (2015), where simple grippers and a fixture on the table were used to fold paper airplanes. Another related application is folding of towels, and one such approach is presented in (Maitin-Shepard et al., 2010), where a PR2 robot was used to identify grasp points on towels and subsequently fold these towels in a series of grasp-and-place actions.

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[2] The authors are members of the LCCC Linnaeus Center and the eLLIIT Excellence Center at Lund University.

2. GIFT WRAPPING

2.1 Problem description

The GiftWrapper application was commissioned as a Christmas commercial for a consumer electronics retailer in Sweden. The robot traveled to 18 different stores and stayed one day at each location and wrapped gifts, with an on-location setup time of 1–2 hours every day. The event was entirely intended as entertainment for the customers and not to optimize gift wrapping. The robot was a dual-arm ABB YuMi with standard electric grippers and no external sensing. During the packaging, the customer placed the bought items in a cardboard box of standardized measurements, a sheet of paper was also manually placed in a fixture in front of the robot and then the box was put on top of the paper. The robot would then fold and tape the paper around the present and finish by attaching a gift bow given by the customer.

The application had a number of challenges. First, the weight of the boxes varied and despite careful folding the boxes could slip several centimeters during the wrapping process. Secondly, paper is an organic material that folds unexpectedly when deformed and tears when pulled to hard. Without external sensors the robot had to adjust the position of the box during the wrapping by squeezing it between the arms to put it in a known position, and the robot also had to hold the package in place. The robot had a collision detection system, that would stop the robot when too large torques were needed to reach a target position. With access to the low-level control signals it is possible to estimate contact forces using the motor currents (Linderoth et al., 2013), however, the methods available in the commercial YuMi was not deemed sensitive enough to avoid tearing of the paper.

The YuMi robot, the material and the table was available less than one week before the beginning of the tour, while initial designs and testing were carried out using a previous model a month in advance.

2.2 Robot

The ABB YuMi is a dual-arm robot where each arm is redundant with seven degrees of freedom. The arms were equipped with two-finger grippers. A soft padding was attached to the inside of each finger to make it possible for the robot to grip the paper in a reliable way. The robot could be taught using a lead-through programming mode, as well as using standard robot programming techniques, i.e., online using the teach pendant or offline in a simulation environment. The simulation environment could, however, only simulate the robot motion, and not any interaction with the environment or the dynamics of the present and the paper.

The YuMi robot is an inherently safe robot, which means that it does not need any fence around it, or any other safety measures[1]. The robot have been built in light weight materials, sharp edges have been covered with soft padding, and the power and speed of the motors in the robot is limited. The fact that the robot is safe made it possible to perform the gift wrapping in really close proximity to people on the tour.

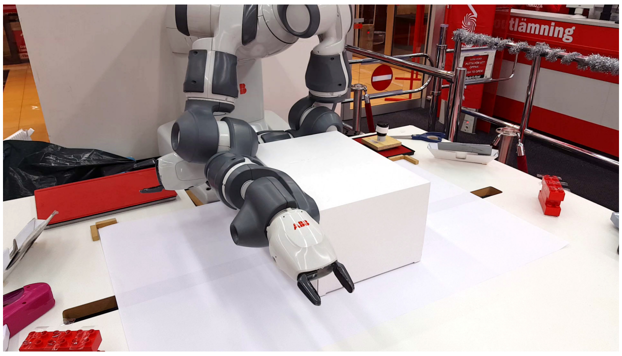

Fig. 2. The initial pose of the robot, where the arms are positioned such that the customer can place the package in a position known to the robot.

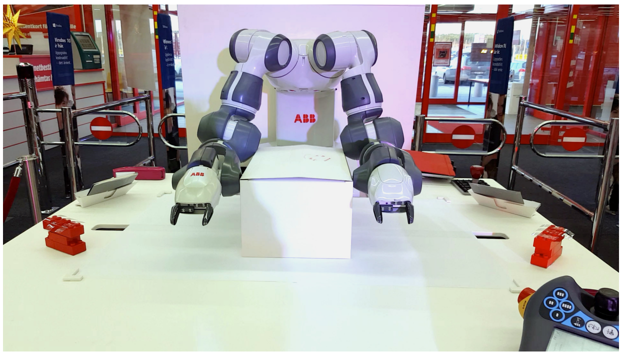

Fig. 3. The position of the package was fixed by squeezing it between the arms.

2.3 Method

The YuMi robot that was used had no external sensing, and the program was therefore completely position-based. Initially the robot kept the arms in a perpendicular position and let the operator (or the customer) place the package in the desired starting position, see Fig. 2. To make sure that the package actually was in the correct start position, both arms were used to push on the package from two sides simultaneously, and thereby giving some robustness to position uncertainties as it was being squeezed between the arms, see Fig. 3. This type of adjustment procedure was repeated two more times during the wrapping process to increase the robustness and the success rate of the application.

The first part of the wrapping was to perform the long side folds, see Fig. 4. While fixing the position of the package using the padded part of one of the arms' wrists, the paper was picked from the table with the other arm. The table top had a horizontal incision which made it possible to slide one of the fingers under the paper and grip the edge of the sheet, see the left photo in Fig. 4. The arm that gripped the paper lifted it up and held it against the package, the fixating arm then switched position to hold the paper, while the arm that picked up the paper released it and instead fetched a piece of tape to fasten the paper to the

[1] The robot itself needed, however, some degree of protection from too curious customers.

Fig. 4. The folding of the long side. Left: The incision in the table top was used to pick up the paper. The left arm fixates the package by holding from the side. Center: The right arm has put the paper on the package and handed over to the left arm to hold it, while the right arm fetches a piece of tape. Right: The right arm attaches the piece of tape to the package.

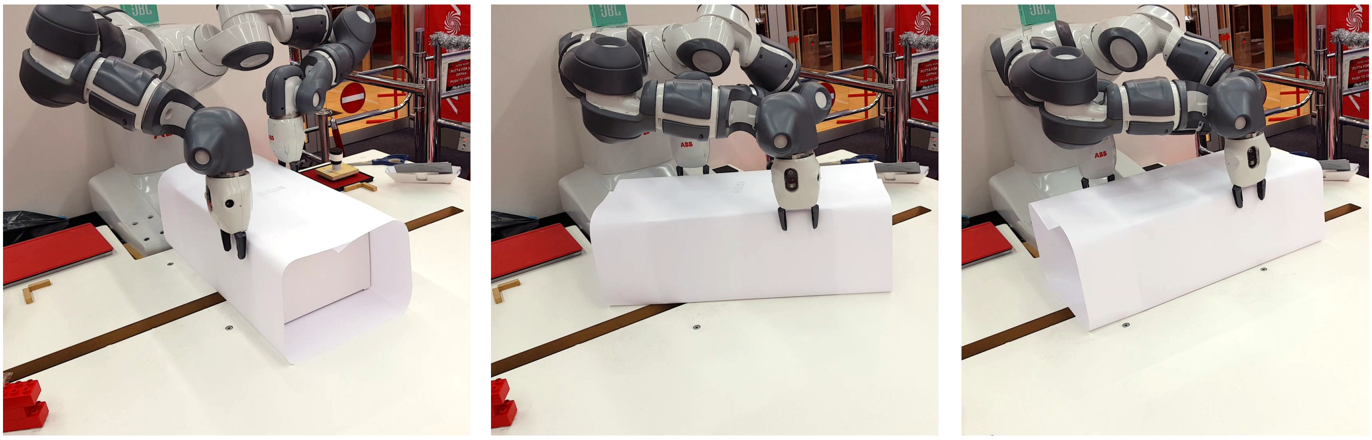

Fig. 5. The package was rotated using both arms such that the robot could reach the short sides. The initial configuration of the package is displayed in the left photo, and the final configuration in the right photo, while the middle photo shows an intermediate configuration.

package, see the middle and the right photo in Fig. 4. This procedure was repeated for each side of the package.

The next part of the wrapping consisted of rotating the package 90 degrees, such that the short side became reachable for the robot, see photos in Fig. 5. The rotation was performed using both hands, and the position of the package was adjusted in a similar manner as in the beginning of the wrapping process.

The short sides of the package were folded using a plastic spatula. One arm fixated the box using three contact points, the elbow, the finger tip and the tool tip while the other used the same type of spatula to fold the side. The plastic was compliant enough to allow some position uncertainty while smoothing wrinkles in the paper. The width of the spatula further added robustness in the folding, as it enabled the robot to perform folds also when the package had slipped away from the nominal position, in contrast to using the thin fingers to fold the paper where an error of just a few millimeters resulted in failure. The fingers were further fragile and using them for folding made the fingers break or the safety system to stop the robot, as the contact with the stiff table easily generated larger forces than the fingers or the safety system could tolerate. Since paper has a natural flexibility, the folding required multiple swipes with the plastic spatula to hold.

The folding of the short side is displayed in Fig. 6. First, one arm held the package in place and used its spatula to hold down the paper on the side, see the left photo in Fig. 6. The other arm then used its finger tips to perform the initial folds by pinching the paper, to create the side flaps as can be seen in the left photo in Fig. 6. The folding arm then picked up a spatula and used it to fold these side flaps around the package by swiping over the paper, see photos in Fig. 6. The short side fold was finished by lifting the lower flap from the table, once again making use of the incision in the table top, handing it over to the holding arm, and picking up a piece of tape to attach it to the package. The tape was firmly attached to the package by moving one arm to the opposite side to fixate the package, see the photos in Fig. 7.

The short side fold procedure was performed in the same way for both short sides of the package. An adjustment phase was added between the folding procedures, as the package usually slided somewhat during the folding of

Fig. 6. Folding of the short side flaps. Left: One arms holds down the paper on the short side using the spaula while the other arm uses the fingers to pinch the paper to fold the side flaps. Center and right: The spatula was used to fold the short side flaps by swiping over the paper.

Fig. 7. The folding of the short side. Left: The incision in the table top was used to pick up the bottom flap. Center: The lower flap was handed over to the holding arm to enable the taping. Right: The holding arm was moved to the other side of the package to fixate it when the tape was attached.

the first short side. The wrapping was finished with a stamp, see Fig. 8, and by putting a gift bow on the package, see Fig. 9. The bow was handed to the robot, preferrably by the customer whos gift was being wrapped, and it thus became a collaborative part of the wrapping process between the robot and the customer. Finally, the finished gift was pushed towards the customer using the soft padding on the wrists.

Taping Handling and attaching tape to the package was a difficult problem, mainly due to the fact that the robot only had two fingers in each hand. Using a standard tape dispenser was not possible, both because the robot was unable to pull off the tape from the dispenser, and because the tape then would have ended up in a position in the fingers that would have made it in practise impossible to attach it to the package in any good way. The solution used was therefore to manually prepare pieces of tape with an appropriate length in a position that made it possible for the robot to grip them in a way that suited the two-finger gripper, see Fig. 10. An option could have been to construct an automatic tape dispenser that would deliver the pieces of tape.

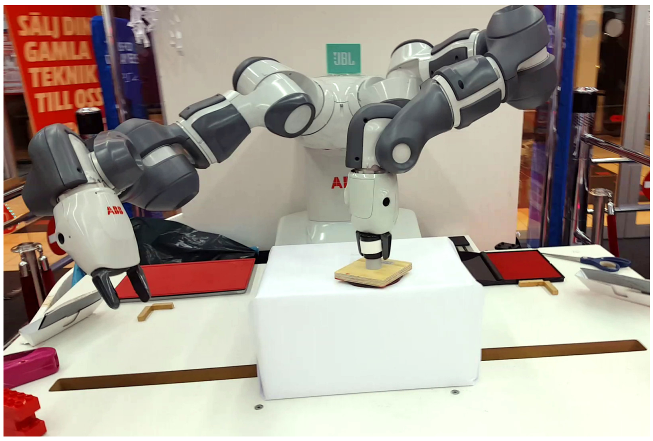

Fig. 8. The wrapping procedure was finished by stamping the present.

Getting the tape to release from the fingers was another difficulty, as the pieces of tape had a tendency to stick to the padding on the inside of the fingers. The strategy used to solve this problem was the one illustrated in Fig. 11. The fingers was approached to the package such that the

Fig. 9. A gift bow was attached to the package.

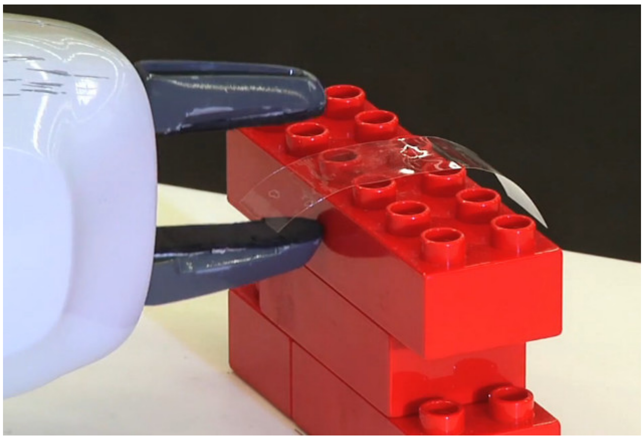

Fig. 10. The robot picked prepaired pieces of tape.

free end of the tape could stick to the package. Before the tape made contact with the paper, the gripper was slightly opened, and once in contact, the position of the gripper was rotated such that only the finger facing the non-sticky side of the tape was in contact with the package, with the tape in between. By sliding the finger along the package, the tape was both firmly attached to the paper, and it was forced to release from the other finger. This process could render large forces to the package, and the other hand was therefore used to fixate the package. To make sure that the piece of tape was attached in a satisfying way, the fingers were used to slide back and forth over it after the intial slide motion used to get the tape to release from the fingers.

Fixating the position during wrapping The weight of the package could vary quite much, depending on what the customer wanted to be wrapped. This meant that the same maneover of the robot affected the package quite differently, mainly due to different friction forces between the package and the table top, and it was therefore important to fixate the position of the package. The dual arm capability of the robot was extensively used, with one arm to perform the actual folding and the other to perform the fixation. To achieve a robust and satisfying hold of the package, multiple contact points were used. Sometimes, both the finger tips, a point on the wrist, and the elbow were used to get a three-point grip, see photos in Fig. 6.

3. RESULTS AND DISCUSSION

The final program wrapped a package in 2 minutes and 40 seconds, a video can be found online (Stolt and Stenmark, 2016), which is rather slow compared to a human. The robot was performing all free-space motions with its maximum speed, while all actions in contact with the paper were rather slow. The slow speed was needed to not tear the paper apart in case the robot gripped the paper slightly wrong. By being slow, the paper and the package could tolerate small errors in a way that did not damage the paper.

The current implementation can only handle one size of packages. The initial plans for the project involved other package sizes as well, but the short amount of programming time, including the design of the work cell and material testing, was the reason for not accomplishing this goal. The wrapping strategy that was used could futher not be used on packages that were much smaller than the size of the one that was used, as the robot needed to be able to reach the package with the elbow to be able to satisfactorily fixate it. The reach of the robot was quite limited, as it did not have any possibility to move its torso. Assuming that the package is large enough for the robot to be able to reach all relevant positions, a more general approach could be to relate all positions to the package. The actual robot positions could then be generated with respect to the package size.

The resulting present was not perfect in terms of wrapping quality. The robot could not tighten the paper around the package as much as one would have wanted due to the risk to tear the paper apart. The result was therefore often a loosely wrapped package. Another difficulty was to apply the tape in a good way. Both regarding the position and the method to apply it. Applying more tape would probably result in better quality wrapping, but it would increase the already quite long wrapping time.

The programming interface available for the YuMi robot is the same as for a traditional industrial robot. An inherently safe, redundant, and dual-arm robot is, however, in many ways quite different from a traditional robot, which sometimes made it somewhat more difficult to do the programming than it maybe should have been. One example is the positions used to fixate the package with three contact points. These kind of positions were quite tedious to program, as the robot programming language was not designed with these kind of robot positions in mind, as it only focuses on the position and orientation of the tool. More on the programming and the interaction with the robot is presented in (Stenmark et al., 2016).

Working with paper is difficult to automate with an industrial robot. The paper easily folds in unexpected ways, and it is further easy to tear the paper apart if the paper is gripped slightly wrong. Introducing external sensing would be beneficial; with vision it would be possible to see unexpected folds, and force sensing would make it possible to tighten the paper without tearing it apart. External sensing would further make it possible to handle more than one fixed package size, without the need for re-teaching all positions in the program. For the actual project described in this paper, however, the amount of time before the

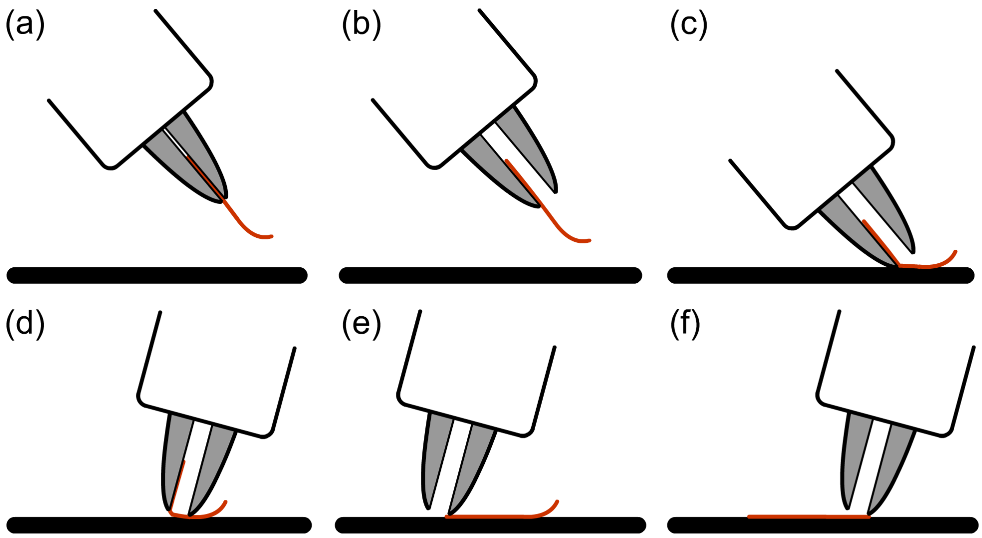

Fig. 11. Illustration of the tape procedure. The robot approaches the package with a tilted orientation, (a), and opens the gripper slightly, (b), before making contact with the package, (c). When in contact, the orientation of the hand is adjusted so that the other finger makes contact, (d), the one which tape is not attached to. By sliding along the package with the "tape free" finger, the tape is forced to release from the finger, (e). To make sure that the tape is fastened to the package, the fingers slide over it back and forth a couple of times, (f).

application should be running was too short to make it possible to integrate any external sensing in the program.

The use of the plastic spatulas actually gave the robot some passive force control capabilities. The compliance of the spatulas made it possible for the robot to apply forces to the paper when performing the folding without the need to know any exact position. The use of the spatulas improved the quality of the folding, and also the robustness as the width of the spatulas contributed to decrease the position accuracy requirements.

The robot went out on a tour to 18 different Media Markt stores around Sweden during the Christmas commerce 2015. The tour resulted in a lot of publicity, including articles in newspapers and appearances in both radio and national television. It thus became a great opportunity to spread the word about robotics to the public.

4. CONCLUSIONS

An implementation of a gift wrapping industrial robot cell was presented. The robot was programmed in a standard position-based way, but by using plastic spatulas it had some passive force control capabilities.

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