Functional Inspection-on-the-Fly of Deformable Objects using Tactile Perception

L.N. Vishnunandan Venkatesh, Jyothsna Padmakumar Bindu and Richard M Voyles

***Abstract*—Human expertise still dominates assembly of deformable objects in manufacturing as they are constantly inspecting-on-the-fly, using their multi-modal sensing capabilities, unlike robots. This calls for integrating inspection with manipulation routines for robots in manufacturing processes. In this paper, we propose a novel tactile-based inspection-on-the-fly method to identify the states of a deformable object, in our case a Ziplock bag. We use exploratory manipulation to help understand the states of the deformable object and when these state changes occur during these exploratory manipulations. A real time inspection routine is developed wherein we traverse along the zipper contour using reinforcement learning and classify the discovered states of the zipper, sealed and unsealed, with the help of Support Vector Machines. Our inspection-on-the-fly method achieved an accuracy of 92% on a small sample size in inspecting sealed and unsealed states while carrying out exploratory manipulations. The results were extrapolated on rubber-bands in detecting the twists at every point along its surface. Similarly, the proposed method can extend to other complex deformable objects and help robots gain contextual information about the object it is manipulating to achieve purposeful manipulations aimed at accomplishing tasks.**

Keywords— inspection-on-the-fly, exploratory manipulation, deformable objects, tactile, support vector machines, reinforcement learning.

I. INTRODUCTION

Robots have paved their way into many areas of high-volume manufacturing such as automotive final assembly and fabrication processes due to their reliable repeatability and precise manipulations. Many small batch manufacturing processes could largely benefit from the unwavering repeatability of such robots. This is because of the cost of integration, which is generally 4-to-10 times the cost of the robot itself. Integration of robotic methods into small batch manufacturing processes strongly depends on highly trained professionals in software and hardware to simplify the work cell around the robot to eliminate errors – turning the robots, by some accounts, into sophisticated fixed automation.

Humans on the other hand are experts at error handling and manipulation. Humans can relate to many errors from a perspective of knowing when somethings are out of place and what caused the irregularities. This makes integrating humans very adaptable in environments that are unfamiliar, short-run processes.

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Humans employed in fixed automation process undergo extensive training and validation on the procedures they use to complete the fixed automation task. These training methods test the human on task repeatability and task performance accuracy. As humans are experts at error handling, during training we observe our environment as we perform various exploratory manipulations to understand the nuances present in the task. Similar to how a baby learns to walk by performing exploratory manipulations, we humans are constantly performing exploratory manipulations to help us make sense of the states in the environment and achieve our tasks. In short, humans are more adaptable partly because they are constantly inspecting-on-the-fly.

While robots have the ability to detect if a part is present in a process by means of sensors such as light beam sensors, the robot cannot infer if a part of debris has broken the sensor. Hence, we feel it is beneficial to embed robots with a higher ability to inspect-on-the-fly, so they can branch wider "down the food chain" of manufacturing logistics, into smaller batch-size applications.

We are exploring the problem of O-ring installation in manufacturing processes and draw inspiration from the work of Hellman on the closure of Ziploc bags [1]. This paper extends this prior work by proposing a novel method to inspect-on-the-fly the two natural states of a Ziploc bag seal (open and closed) in real-time along the contour of its zipper. Studies in [2][3] shows us that estimating various states through tactile sensing is possible. Understanding the object being manipulated through tactile sensing in terms of its structural properties and other contextual features is a very sought-after research. [4] in an example of an approach that aims at tackling this problem. The proposed purposeful inspection method shall help us in ultimately achieving complete inspection-on-the-fly during the manipulation of a Ziploc bag aimed at transitioning between its states as well as purposeful manipulations.

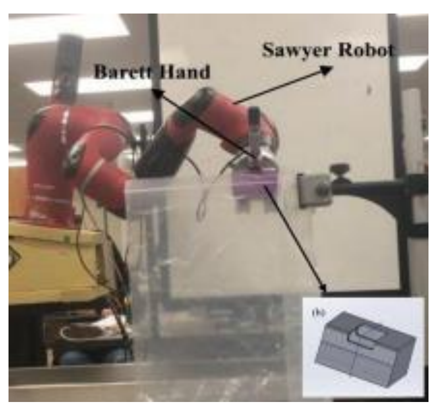

Figure 1. Robot testbed consisting on the SuperBaxter robot and the BarrettHand. b) shows the CAD model for the custom fixture

II. METHODS

A. Task Procedure

The procedure consists of 4 steps - a) Grip Calibration b) Contour Following c) Exploratory Manipulation and d) Online State Estimation. Firstly, the 'least contact' gripping force exerted by the BarrettHand digit-fixture gripper configuration for the Ziplock bag under consideration and for each of it's contour states is calibrated. This force is equal to the minimum force necessary to establish contact between the gripper and the Ziplock and no more, to ensure that there is no alteration to the natural state or ground truth during state detection. Then, the gripper goes from the clamped end of the Ziplock to the other in discrete steps along the zipper contour keeping the zipper in the center of the tactile array, such that every point on the contour is covered. We follow the contour using reinforcement learning and to keep the zipper in the center while contour following, we assign a reward of +1 to the center contour state and null reward to any other contour state. Contour state is the vertical position of the zipper contour along the tactile array of the digit in the gripper and can be center, high or low. At every step of this contour following, exploratory manipulation is performed in which we alternatively try to exert an increasing amount of gripping force and exert the calibrated gripping force. At the time when the calibrated gripping force is exerted, tactile image of the zipper contour is recorded which is used for training the unsupervised classifier later or for online state estimation according to the already collected and clustered data. Recording while 'least contact' force is exerted is to check if a state transition has occured. This exploratory manipulation allows us to discover states and transitions between them. Exertion of an increasing gripping force might or might not lead to a state change depending on the initial state and this process is hence stopped after a certain threshold is reached. This threshold is determined by examining the data and selecting a gripping force value beyond which state change can't ignore.

B. Super Baxter Collaborative Robot Testbed

The experiment is setup using a 4 DOF BarrettHand (Barrett Technology, Cambridge, MA) attached to the end of a 7 DOF arm of the bimanual SuperBaxter [5]. The end effector is a gripper configuration consisting of the laterally immobile BarrettHand digit against a custom designed fixture as shown in Fig 1. Manipulation is done through the movement of SuperBaxter arm as well as the movement of the laterally immobile digit. The digit has a joint resolution of 0.005 radians. The fixture complements the surface curve of this digit, allowing smooth sliding of Ziplock in the grip when necessary. Tactile sensing is done using force values recorded from this digit. It has 8x3 rigid capacitive tactels out of which the first 3x3 are used, each having an area of 0.3cm2 and a resolution of 0.01N. The testbed also has a fixed clamp from which the Ziploc is hung at a position known to the robot.

III. RESULTS

We achieved a state identification and estimation accuracy of 92.8% with SVM and 10-fold cross validation, suggesting the classifiers ability to generalize. The testing accuracy with the SVM classifier was 94%. Thus, we can estimate the natural states of a Ziplock with 92% accuracy on average, given the current hardware setup on Ziploc bags of varying weights and sizes, taking an average time of 4.5 minutes. Using our proposed inspection on the fly method Fig 2. we can estimate if any point on a Ziplock is closed or open by means of tactile perception using the robot testbed. These results on Ziplock bags can be extended to other manufacturing application involving deformable object such as O-rings, torlon seals etc. As part of our future work we do plan to use multi sensor modalities with vision integration to help us with the online state estimation and classification and extend our exploratory manipulation methods.

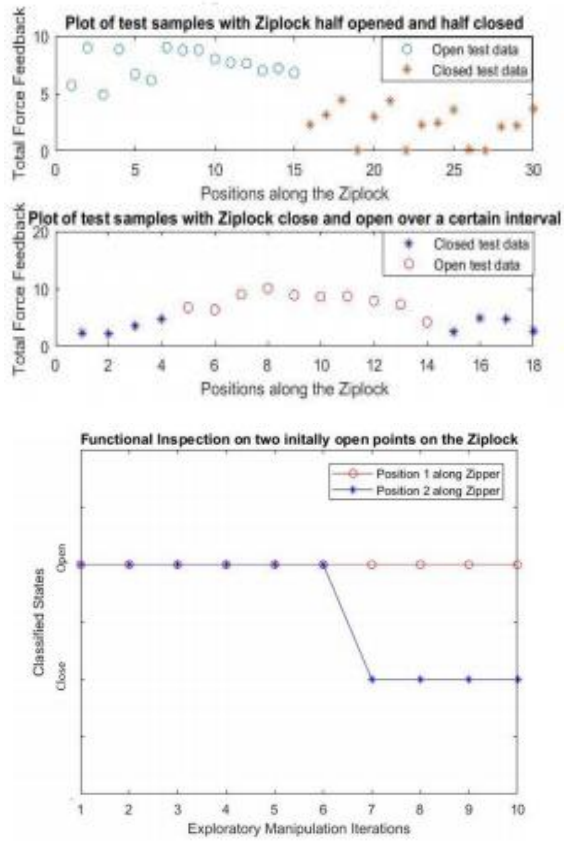

Figure 2. a) Total Force feedback plots of the Ziplock bags under different configurations. b) Plot shows two points on the Ziplock where functional inspection-on-the-fly was carried out. Position 2 along the zipper achieves a state transition as a result of our exploratory manipulations

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