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ROBOTIC MANIPULATION OF DEFORMABLE OBJECTS

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Abstract:
This work focuses on the ability of robots to manipulate objects whose shape can alter due to external forces. The task is to propose control schemes that can autonomously manipulate deformable objects. In order to cope with the object flexibility extra sensors are required, in this case we consider force and vision sensors. A dual arm robot is considered as the test platform and two proof of concept applications are envisaged. These applications center around the idea of meat separation: a task that requires both accurate positioning and force control in contact with a highly deformable object. In order to analyze the pros and cons of respective schemes, a global simulator which takes into account the dynamics of the robot, multi-arm control and object flexibility, is imperative. Furthermore preliminary experiments are conducted using force/vision controllers on semi rigid-objects.

Keywords: *Dual-arm Robots, Force and Vision controllers, Manipulation of deformable objects*
Collaborations : ANR, ARMS PROJECT

1 Introduction

Until recently robots have been confined to tightly controlled industrial environments. These robots, generally a single-arm structure, execute repetitive and monotonous tasks with a degree of accuracy and efficiency to match any human worker. Typically these tasks are defined off-line by an operator who moves the robot via a small control panel. However, there has always been a desire to apply robotic solutions to more diverse tasks. In order to do this, two important considerations must be taken into account. Firstly the working conditions cannot be a priori completely known and are liable to evolve in an unpredictable manner. Secondly most environments both industrially and domestically have been designed with humans in mind, therefore in order to function efficiently the robot should ideally have a human-like structure i.e. two dexterous arms [1].

1.1 State of the Art

Dual-arm cooperative manipulators are two serial robots controlled simultaneously to complete a common task. The attraction of dual-arm systems is that they can execute sophisticated tasks that would be very difficult or sometimes impossible for a single arm robot [2]. In these tasks the usage of a multi-arm system has many advantages. For example carrying objects where a load is very heavy and would require the single arm manipulator to be very large. Using a cooperative system the load can be distributed among several smaller robots. Similarly if the object is of an unwieldy, awkward or deformable composition, the single arm robot may struggle to manipulate it.

In order to allow the robots to interact with a dynamic environment, extra sensors can be used. Force and vision sensors have been shown to be of great benefit when it comes to the robotic execution of everyday tasks [3]. The traditional position control schemes require an exact knowledge of the surroundings which is not always possible. Thus force feedback is becoming a more attractive option. There are two main advantages of having a force feedback on the robot: (1) the ability to precisely control a force exerted by the robot, (2) the detection of any unwanted collisions in the workspace. Applications are found both in industry: assembly, deburring, polishing, grinding etc. and in service robotics where human interaction is expected i.e hospitals, homes etc [4]. The vision sensors are generally used to construct a visual servoing scheme. This consists of using a feedback system in order to control the location of an end effector relative to a desired frame. It has been shown to provide a flexible, stable and reactive mode of control for robot manipulators [5]. By using a visual feedback supplementary information can be extracted from the environment that would be impossible to know simply from the robot's state.

1.2 Objectives

The objective of this work is to show that by using a combination of force and vision controllers, robots can complete complicated tasks in an evolving environment. This work specifically targets the manipulation of deformable objects. Integrating the aforementioned techniques in a controlled coherent manner is not a trivial task, yet in doing so certain tasks can be accomplished that until recently would not have been possible with standard robotic manipulators. In order to validate the advocated solutions, two demonstrative target applications are proposed :

A.1 Cutting a beef steak in a domestic environment: In a domestic environment, for instance at a dinner table, a beef steak is to be separated by a dual arm system. In this particular case the vision system must locate the plate, the steak and their relative positions. After they have been successfully identified the robotic arms, equipped with a knife and fork, will move to the steak and separation is completed using force feedback.

A.2 Industrial separation of beef muscle: The ARMS project[2] aims to contribute to the increasing mechanization of the meat industry, desirable due to the hazardous working conditions. In this scenario a multi-arm system is designed to process meat. One robotic arm is equipped with a knife and cuts the muscle while the robot has a gripper thats pulls and tears in order to perform the separation. The closed chain is completed by an deformable object i.e. the meat muscle that is to be processed. The vision system must recognize the line of separation while both arms are controlled in force and position to ensure a successful cut.

2 Methods

2.1 Visual Servoing: Where to go?

The visual servoing algorithm locates the robot end effectors, ${}^{c}\mathbf{T}_t$[3], and also the desired object, ${}^{c}\mathbf{T}_o$. Since the object is deformable, there is no way to know offline the evolution of the desired position. On the other hand it is possible to use the robot's internal joint sensors to calculate its location. However, instead by supplementing this information with vision, all calculations can be conducted *in the camera frame*. This means that the actual camera location can be eliminated from the control law, leaving just the relative position ${}^{t}\mathbf{T}_o$ bewteen the pieces.

2.2 Force Controller: What to do?

When the robot reaches its desired position it must apply a force, either to cut the object, $\mathbf{f}_c$, or to pull at the object, $\mathbf{f}_p$. Again if the object is perfectly known it would be possible to apply forces simply by controlling the position of the pull. However since the material properties are unknown this is impossible. Furthermore, in the case of flexible objects not only must the force be controlled but a relationship should be enforced between it and the desired position ($\mathbf{X}^d$). This relationship is known as an Impedance Controller after the well known impedance relationship: $\mathbf{f} = \mathbf{Z}\dot{\mathbf{X}}^d$.

3 Simulation and Experimentation

Simulation

The force vision controllers are tested both in simulation and by experimentation. The simulator allows us to control two Kuka lwr 7-DOF robots by applying a torque to each joint. The goal of the simulator is to complete the separation of a deformable body using a dual-arm system. The simulation steps can be explained with the aid of Figure 1, and can be decomposed into three modules.

Module 1. Controller: The controller is written in Matlab and Simulink. Using the outputs (simulated vision primitives and reaction forces) of the real world simulator, the controller generates a joint torque, from a desired trajectory. This torque is then passed back to the simulator causing the robot links to move.

[2] http://arms.irccyn.ec-nantes.fr/

[3] $\mathbf{T}$ is the homogenous transformation matrix representing the position and orientation between two frames

Module 2. Dynamic Simulator: The simulator comprises of a separable deformable object and two robots. Within the simulator's environment the object and robots can interact. The robots can be controlled via. joint torques and as an output the simulator gives the visual scene and the robot state.

Module 3. Finite Element Model (FEM): The deformable objects are modeled using Finite Element methods. This means that the object body is discretized into a mesh like structure. The connections between the nodes of the mesh have properties that affect the object behavior. In this simulation the object properties are similar to those of beef muscle. After the object has been modelled correctly, a vibration analysis is carried out. This analysis permits us to calculate the deformation of the object in response to external forces using what is known as the modes of the object.

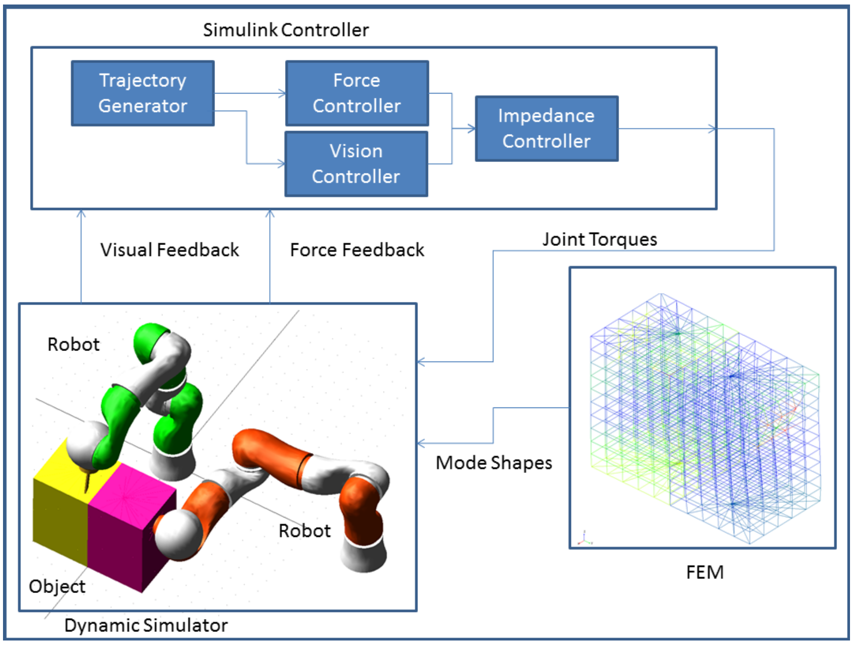

Figure 1: Simulation procedure

Experimental Work

In parallel to the simulation test, certain experiments are run in order to validate previous results. Figure 2 shows an overview of a typical experimental setup. The goal of the experiment is move the tool to the object i.e. reduce the vector $\mathbf{s}$ to zero, where $\mathbf{s}$ represents the difference between the tool frame and the object frame ${}^{t}\mathbf{T}_{o}$. The vector $\mathbf{s}$ is converted first to a Cartesian velocity $\mathbf{V}$ and then into a joint velocity using a Jacobian matrix $\mathbf{q} = -\lambda \mathbf{J}^{+} \mathbf{L}^{+}\mathbf{s}$. The force controller calculates a deviation from the trajectory, $\mathbf{dX}_F$, using the following force control law $\mathbf{K}_e \left(\mathbf{f}^d + \mathbf{K}_f \left(\mathbf{f}^d - \mathbf{f}\right)\right)$. This allows the robot to be sensitive to enviromental collisions and also execute desired force tasks. When the desired frame has been reached, the tool must traverse the object while applying a desired force $\mathbf{f}^d$ normal to the surface. The results are shown in Figure 3.

4 Conclusion

This paper has given an overview of the work realised in this PhD project. As of yet the experimental control schemes have been applied on planar semi-rigid objects. The next step is to introduce irregular objects whose material properties ressemble that of beef. Furthermore the addition of a secondary arm, previously unavailable, to hold or pull the object as the separation is taking place must be introduced. Finally a global centralised control system, that manages the two robot controllers must be designed.

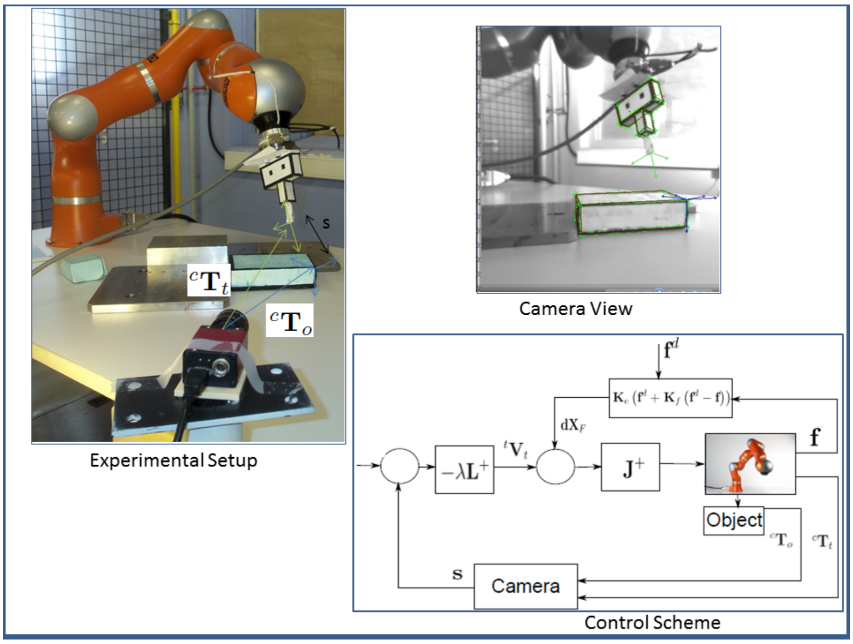

Figure 2: Experimental Setup

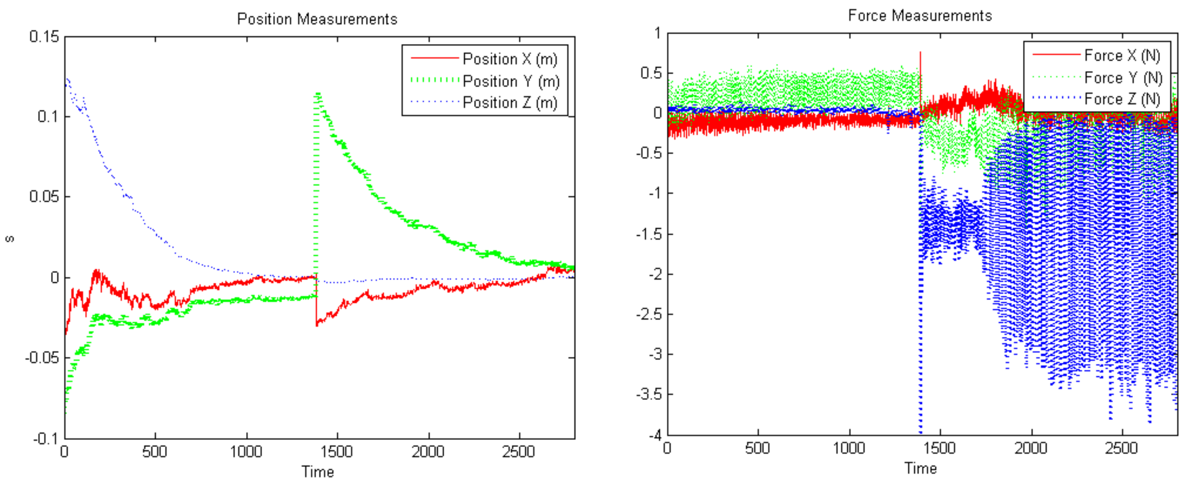

Figure 3: Experimental Setup

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