Overstress Avoidance on Flexible Object Manipulation

Alberto Zafra-Navarro, Rosario Aragüés, Gonzalo López-Nicolás

Afiliación: Robotics, Computer Vision and Artificial Intelligence (Ropert)
Instituto de Investigación en Ingeniería de Aragón (I3A)
Universidad de Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, Spain.
Tel. +34-976762707, e-mail: 876628@unizar.es

Abstract

Handling deformable objects remains a major challenge due to the complex physics involved. This work presents an enhanced multirobot control system that incorporates a physically-safe control barrier function. This system ensures the structural integrity of deformable objects during manipulation, by using a finite element analysis. The proposed method dynamically adjusts control actions to avoid overstressing configurations.

Introduction

Many tasks in the manufacturing sector are performed manually. Often, these tasks can cause discomfort or injuries, they may be unpleasant and even hazardous for human workers. In this context, collaborative robots (cobots) are designed to work alongside humans, sharing workspaces and tasks. Its integration to the industry can improve the quality of life of their human colleagues.

Modeling and control of systems with collaborative robots are key areas in robotics [1], especially in the industrial and healthcare sectors. These fields face significant challenges when the working environment or the objects to be manipulated are deformable, such as the case of the textile, food, and medical industries. Specifically, the simulation and definition of dynamic models play a crucial role in the development and optimization of algorithms for shape control and manipulation of flexible objects using multi-robot systems. This requires investigating and designing behaviours in virtual environments before implementing them in the real world. Such an approach not only reduces development time and costs but also enhances the precision and efficiency of the robots. Therefore, control strategies that involve flexible objects might have an enormous impact on our society, bringing a huge amount of possibilities.

Several works have tackled the problem of flexible object manipulation [2]. Nevertheless, it is not common to consider the effects that the manipulation may have on the flexible body. This means that the object's integrity might be compromised during deformation tasks. In other words, the system may have planned the task based on performance but not based on the items' safety. Thus, leading to overstressing configurations that would tear down the manipulated objects.

To avoid this problem, accurate physics modeling is a must. Hence, it is required to account for both the internal and external forces present on the body during manipulation. Some common techniques used for modeling deformable objects are Mass-spring systems, Position-based dynamics (PBD) and Finite Element Methods (FEM). Generally, FEM is the standard computational method for providing a physically accurate description of the object. This is because, despite being difficult to achieve real-time performance, having such accuracy is necessary in critical applications. As a result, some works have introduced FEM-based models within their control algorithms [3], [4].

Overstress Prevention

Our approach aims to improve a multirobot transportation control system, introducing a higher layer of control that ensures the safety of the deformed object. Within this algorithm two well-differentiated subdivisions can be found.

The first part contains the standard 3D controller applied for transporting the flexible object [5]. The second part comprises a control barrier function (CBF) that applies the desired restrictions to our model. These restrictions are based on the physical properties of the non-rigid body and enforce the internal forces of the model to be within a safety margin. To achieve this, first the system has to compute the current stresses present within the object and represent them as a numerical scalar value also known as the von Mises stress. Then, by combining the current stress and the 3D controller output a prediction of the deformation gradient is obtained.

This process is shown in Figure 1 (left) where the block diagram of our control system is shown.

Finally, the control actions are optimized by minimizing the difference between the desired action (the control action proposed by the 3D controller) and the feasible action that avoids plastic deformations on the object. The results of applying this system can be discerned in Figure 1 (right) where a basic simulation is presented. An elastic object was deformed with a constant force until reaching its failure. It can be seen that, while the standard 3D controller continues stretching the non-rigid body, our system stops the actions when a maximum feasible deformation is reached. In our case, the boundary conditions have been simplified in this illustrative example taking into account only the nodal displacements instead of the complete von Mises stress.

Conclusions and future work

This work addresses a limitation in current robotic systems for deformable object manipulation: the lack of internal force consideration during planning and control. By incorporating finite element analysis, we introduced a CBF that ensures the manipulated object's structural safety.

Our approach enhances an existing 3D control scheme by enforcing stress constraints derived from von Mises stress analysis, enabling the system to predict and avoid overstressed configurations. Future work will focus on a real-time physical implementation and extension to complex, dynamic environments.

Acknowledgement

This work was supported via project REMAIN - S1/1.1/E0111 (Interreg Sudoe Programme, ERDF), and via projects PID2021-124137OB-I00 and TED2021-130224B-I00 funded by MCIN/AEI/10.13039/501100011033, by ERDF A way of making Europe and by the European Union NextGenerationEU/PRTR; and partially funded by Programa de Becas y Ayudas del Instituto de Investigación en Ingeniería de Aragón (I3A) and by Cátedra XX.

REFERENCES

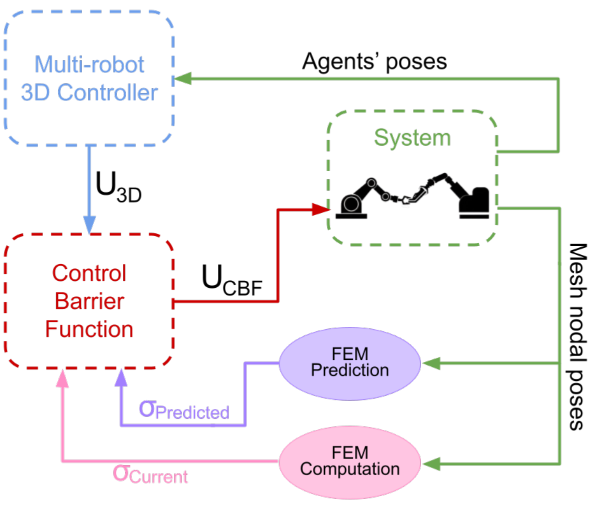
[1]. ZHU, J., *et al.* Editorial: Robotic Handling of Deformable Objects. *IEEE RA-L.* 2022, 7 (3), 8257-8259. doi:10.1109/LRA.2022.3185539.

[2]. YIN, H., VARAVA, A., and KRAGIC, D. Modeling, learning, perception, and control methods for deformable object manipulation. *Science Robotics* 6, eabd8803, 2021. doi: 10.1126/scirobotics.abd8803

[3]. OUAFO FONKOUA, M., CHAUMETTE, F., and KRUPA, A. Deformation Control of a 3D Soft Object using RGB-D Visual Servoing and FEM-based Dynamic Model. *IEEE RA-L.* 2024, 9 (8), 6943-6950. doi: 10.1109/LRA.2024.3416801

[4]. FICUCIELLO, F., MIGLIOZZI, A., COEVOET, E., PETIT, A., DURIEZ, C. FEM-based Deformation Control for Dexterous Manipulation of 3D Soft Objects. *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*. 2018. doi: 10.1109/IROS.2018.8593512

[5]. MARCOS-SAAVEDRA, R., ARANDA, M., LÓPEZ-NICOLÁS, G. Multirobot transport of deformable objects using deformation modes. *4th Workshop on Representing and Manipulating Deformable Objects in conjunction with the IEEE Int. Conf. on Robotics and Automation*. 2024



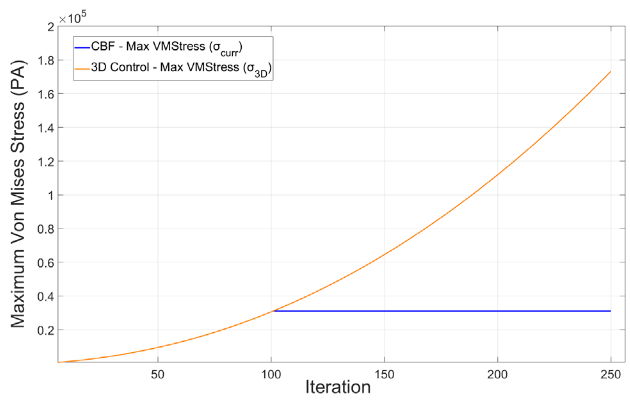


Figure 1. (Left) block diagram of our approach. The 3D controller (in blue) feeds the control barrier function (in red), that combined with the predicted (in purple) and current stress (in pink) is used for computing the control action to be applied in the system (in green). (Right) average von Mises stress comparison between the standard 3D controller (orange) and the improved controller (CBF) in a stretching simplified simulation example.