Intentionally impacting deformable material

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***Abstract*— We envision modern robots performing impulsive tasks like kicking a ball. However, safely generating impacts with robots is challenging due to discontinuous velocity and high impact forces. If not accounted for, they can make the controller unstable or damage the robot. In our recent work, we showed how to control impacts with rigid bodies safely, however, not all objects are rigid. We here generate impacts with deformable contacts, incorporating constraints imposed by the hardware. Therefore, we learn the shock-absorbing soft dynamics. Real-robot experiments with Panda validate our approach.**

I. Introduction

Many classic robot control schemes avoid making contacts or approach contacts with close-to-zero velocities, thereby reducing the set of physically possible movements. A new line of research in modern robotics instead aims for generating intentional impacts when making contacts. Recently, we proposed an impact-aware control scheme [1] that safely maximizes pre-impact velocities with respect to hardware and other limits, assuming rigid contacts and relying on a single-step ahead prediction. In our current work [2], we address the control and constraint formulation for intentional impacts subject to *deformable contacts*. Soft material implies the existence of deformation and deformation dynamics, which need to be accounted for. On the one hand, control approaches must model these dynamics and consider a reasonable long preview horizon. On the other hand, the softness will consume large parts of the kinetic energy and therefore allows higher pre-impact velocities. We here aim to generate intentional impacts with a soft material whose deformation dynamics are learned, and therefore we are optimizing the pre-impact end-effector velocity.

II. Approach

When impacting soft material, the robot has to limit its pre-impact end-effector velocity to prevent damaging hardware. When evaluating the effect of the pre-impact end-effector velocity for soft contacts, the deformation dynamics must be taken into account, describing the system behavior after making contact.

Contact forces are functions of surface deformations. Hence, our approach is to learn the contact model based on exploratory penetration data. Next we formulate an optimization problem in order to maximize the pre-impact velocity $\dot{\mathbf{x}}$. It incorporates the learned deformation dynamics and the robot's hardware limits:

$$\max \quad \dot{\mathbf{x}} \tag{1}$$

subject to hardware constraints and deformation dynamics

Solving this optimization problem in every iteration and tracking its solution with the end-effector enables to generate maximum impacts with soft contacts. It is important to note that our approach does not require exact knowledge of impact location or impact timings, as is the case for related works. Further note that our approach is perfectly suited for position-controlled robots [2].

III. Real-Robot Experiments

Our approach applies to two distinct scenarios: (i) soft material attached to the end-effector that makes contact with a rigid environment and (ii) a rigid end-effector that contacts and a soft environment.

The experimental platform is a Panda manipulator from FrankaEmika which is controlled at 1 ms update rate based on our exisiting QP-control framework [3]. The robot's hardware limits on joint position, joint velocity, joint acceleration, joint torque, and joint torque-derivative, are specified on the manufacturer's website[1].

The video shows experiments with a soft dice object and a deformable sucker attached to the end-effector. We observe high pre-impact velocities and achieve precise force-tracking subject to soft material without violating hardware limits: `https://youtu.be/juynq6x9JJ8`

IV. Conclusion

We learn a contact force model for deformable contacts based on exploratory penetration data with impacts. Based on the modeled deformation dynamics, we plan task-space trajectories for intentional impacts. The control scheme includes hardware constraints and operates at 1 KHz. With this approach, pre-impact velocities are maximized without damaging the robot.

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References

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[1] `https://frankaemika.github.io/docs/control_parameters.html#constants`