Experimental Validation of Reference Spreading for Robotic Manipulation of Unmodeled Objects

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Abstract— **This electronic document is a "live" template. The various components of your paper [title, text, heads, etc.] are already defined on the style sheet, as illustrated by the portions given in this document.**

I. INTRODUCTION

Automation has historically played a crucial role in the logistics industry. Our current way of living depends on autonomous systems for global transportation and warehousing. The growing labor shortage and increasing demand for online retail motivate further developments in the logistics sector [A Dekhne].

A logistical aspect where machines sometimes struggle to compete with humans is object manipulation. Practical examples include order picking or depalletizing. While robots are strong and consistent when manipulating objects, humans are flexible and swift. Robots are held back from faster performance because they must often slow down prior to making contact; establishing contact at a high velocity – an event referred to as an impact – could cause damage to the robot or its environment. On the contrary, humans intrinsically exploit impacts in the form of grabbing, bouncing and hitting.

The field of impact-aware control aims to better equip robots for making contact at high velocities. These impacts are paired with large contact forces that could damage the system. Previous work describes model predictive control using the maximum allowable impact velocity that complies with safety constraints such as limits for the contact force []. This was combined with a compliant cover for the robot that reduces contact forces at impact, facilitating higher feasible impact velocities. Rather than using a soft cover, compliancy may also be achieved by designing a robot with low inertia and high backdrivability as was done in [].

In addition to the large contact forces, the velocity jump at the time of impact is also a subject of interest. Time misalignments between velocity jumps in the reference and in the actual system cause the velocity tracking error to peak[], as is shown in Figure xxx. This error peak results in undesired control effort and should therefore be avoided. In [], the robot's velocities are projected into an impact-invariant subspace based on the expected point of impact. As a result, impact-driven peaks in the velocity tracking error are reduced significantly. It is not always possible to describe a point of impact, however. Often times, impacts occur between surfaces rather than just points. Furthermore, corners of the surface may impact at diverging intervals in uncertain order during what is called near-simultaneous impacts, shown in Figure xxx.

The impact-aware control scheme called Reference Spreading also addresses error peaking caused by misaligned impacts. It operates on the basis of a tracking error that switches once an impact is detected. This concept is best explained at the hand of Figure xxx. The reference is split at the nominal impact time into an ante- and post impact reference. These references are then extended. Initially, the tracking error is based on the extended ante-impact reference, but this is switched to the post-impact reference once an impact is detected. Evidently, this can reduce the error peaking.

Reference spreading can also handle simultaneous impacts. (explanation)

By addressing the peaking error, reference spreading facilitates faster object manipulation, making it interesting to industry if its effectivity can be proven in practice. Reference spreading for object manipulation has already been validated in simulations []. Experimental validations have been limited to interaction with a fixed environment, however []. The goal of this work is therefore to **provide a real-world implementation of reference spreading for practical object manipulation tasks.** To translate the results from simulation to this reality, the following contributions are made:

1. Motion planning for impacts without object models: Generating a reference with velocity jumps that is coherent with the system's dynamics is challenging. One approach maps the ante-impact velocity to the post-impact velocity based on conservation of momentum []. This approach requires a model of the environment, which is feasible in simulations with simplified dynamics, but challenging in reality. Impact-driven velocity jumps could instead be inferred experimentally. In previous studies[], the control gains are reduced to zero upon detection of the impact while inferring an impact map, so that the velocity jump would not results in excessive motor torques. A different model-free motion planning strategy is proposed, which not only produces velocity jumps that are coherent with the system dynamics, but also leverages human intuition to generate fluid motions before and after the impact. (This strategy introduces a human in the loop by means of teleoperation; the operator performs a demonstration, after which a reference can be extracted. During the demonstration, the control gains are relatively low. This mitigates the torque jumps at the time of impact, meaning that the controller does not need to be turned off. The teleoperator instinctively accounts for the low control gains and can perform precise motion tasks despite poor tracking of the controller.)

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words: warehouse, material handling, packaging, transport

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- In your paper title, if the words “that uses” can accurately replace the word “using”, capitalize the “u”; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones “affect” and “effect”, “complement” and “compliment”, “discreet” and “discrete”, “principal” and “principle”.
- Do not confuse “imply” and “infer”.
- The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the “et” in the Latin abbreviation “et al.”.

- The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

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TABLE I

AN EXAMPLE OF A TABLE

One	Two
Three	Four

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an document, this method is somewhat more stable than directly inserting a picture.

Fig. 1. Inductance of oscillation winding on amorphous magnetic core versus DC bias magnetic field

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V. CONCLUSIONS

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

APPENDIX

Appendixes should appear before the acknowledgment.

ACKNOWLEDGMENT

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References are important to the reader; therefore, each citation must be complete and correct. If at all possible, references should be commonly available publications.

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