Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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Real-time simulation of impact for the aerospace industry

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Summary

This report is based on a presentation held at the EUROMECH'99 conference 'Impact in Mechanical Systems', June 30, July 1-2, 1999, Grenoble, Frqance. The first author attended the EUROMECH conference on a grant received from LAG-ENSIEG, France.

The aim of the EUROMECH'99 conference has been to bring experts on the mathematics of impact in mechanical systems from both the Mechanical Engineering and the Robotics-Systems-Control fields, in order to exchange new ideas and information on problems related to modelling and feedback control of impacting systems.

The presentation of NLR is part of the NLR contribution to the European Community project INTAS 96-2138. One of the aims of the INTAS project is to bring together researchers from (the former) Eastern Europe and researchers for Western Europe in the area of mathematics of impact in mechanical systems.

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A.A. ten Dam and J. Kos

National Aerospace Laboratory NLR
Mathematics Department, ICT Division
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Tel: +31 20 511 3447, 3494, Fax: +31 20 5113210
E-mail: tenDam@nlr.nl. Kos@nlr.nl

Abstract
In this paper a number of issues on impact in mechanical systems are presented. Emphasis is on modelling, simulation and control in a real-time setting for aerospace applications.

Keywords: Contact, Real-time simulation, Impact, Robotics, Aerospace industry.

1 Introduction

This paper presents an overview of selected industrial projects in which NLR is involved and in which modelling, simulation and control of impact mechanics plays an essential role. Industrial designs of systems are usually driven by operational requirements. Based on these requirements, critical items are identified and feasibility studies are executed, supported by simulation studies. These simulation studies require mathematical models of all components of the system under consideration. At NLR we aim at generic models suitable for use in training as well as engineering simulators. As a consequence, proper responses of the models are crucial for humans to perceive a simulator as if it were part of the real world. Therefore, the mathematical models for impacting systems must behave very much like the systems would do in the real world.

The remainder of this paper is as follows. In section 2 an overview of some issues in contact mechanics is given. In section 3 the European Robotic Arm is described. Section 4 outlines our research on modelling of multiple point impacts in mechanics using the illustrative example of a dextrous gripper. In section 5 wheeled vehicles are presented. Some introductory notes on the mathematical approach can be found in section 6. Concluding remarks can be found in section 7.

2 Some issues in contact dynamics

From a mathematical point of view, interactions of mechanical systems with their environment fall into the class of hybrid systems, or non-smooth dynamical systems. Simulation of impact mechanics is by no means a trivial task, and the list below - see also [1,8] - gives an idea of the difficulties that have been encountered and for which solutions have been derived at NLR.

1. Study of wellposedness of impact dynamical systems, i.e. properties of solutions to obtain a unified treatment of contact problems across boundaries of application domains, and for enabling real-time simulation [2,4].
2. Study of impact between two rigid bodies via macroscopic laws that relate the motion after and before the shocks [3].
3. Develop new models of contact-impact laws for specific applications using

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engineering competence available in an organisation [7].

4. Investigate the complex dynamics of vibro-impact systems that may model systems with clearances. An example of such a system is ERA on the International Space Station [6].
5. Study of numerical algorithms to integrate systems subject to unilateral constraints. Simulation of non-smooth mechanical systems is known to be liable to numerical instabilities. A procedure for real-time simulation has been developed at NLR [5].
6. Design control strategies to improve the behaviour of mechanical systems subject to repeated impacts with the environment. Control of constrained robotic manipulators is part of ongoing research [7].
7. Transfer of knowledge to industry [7].

3 Robotic Manipulators

In hostile environments such as space, a large number of operations will be executed autonomously by robotic manipulators. The European Robotic Arm (ERA) is an example of a slender robotic system [6]. In ERA's operational use on the International Space Station, ERA will amongst others transfer payloads on the space station and hand over payloads to other robotic manipulators. Two main issues exist in foreseen operational scenarios: the transition from no contact to contact with a target object when this target object is part of a flexible structure, and the re-orientation of a payload attached to its environment.

These operations must be performed with care as contact of ERA with its environment may induce motions that are difficult to control. Examples are oscillatory behaviour of ERA, and undesired motions of parts of the space station. Clearly, any such effects due to compliant motion must be avoided, especially since power resources for control may be scarce. Moreover, the making of contact may not damage any of the systems. Via real-time simulation studies, operational scenarios are verified. Evidently, these simulation studies require real-time capabilities of all models that are part of the system. The real-time simulator of ERA consists of validated models, making the simulator suitable also for astronaut training purposes [9].

4 Dextrous grippers

As soon as the International Space Station is fully operational, the need for complex manipulation operations will grow. Since space is a hostile environment to humans, automation of the handling of small objects such as wiring cables, units and instruments is advantageous. In many space organisations these ideas have resulted in studies in which a (space) robot is equipped with articulated multifingered hands, i.e. a dextrous gripper, much like a human hand.

A dextrous gripper offers many design challenges, and at NLR we are looking into modelling, simulation and control of multiple impacts as an extension of our work on impacts with a single point of contact.

5 Wheeled vehicles

As an aerospace laboratory NLR has since long been working on dynamic models for aircraft. In the last decade, motivated by acquired capabilities of design and training in the field of robotics, generic models of a wide range of wheeled vehicles have been made. Of special interest is the interaction of a vehicle with accidented terrain. The mathematical models are realistic models of mechanical systems, comprising for example, elasticity and damping of the tyre, wheel suspension, chassis stiffness characteristics, and roll, pitch and yaw motions. The latter motions are important also for application to planetary rovers on rocky surfaces.

6 Mathematical Models

All applications presented above involve mechanical systems subject to environmental constraints. The similarities of the mathematical models of these systems make it worthwhile to study these systems in their full genericity. At NLR, we advocate a system theoretical framework where characteristics of specific physical systems are taken into account as late as possible. In this framework, collision models are based on maps between so-called contact and release sets. In this mathematical setting trajectories of an impacting mechanical system consist of concatenated path pieces of the unconstrained system, where the collision map is used to deal with the local behaviour in case of collisions. We have found that this way of working supports shorter development times, easier transfer of knowledge to industry, and also provides us with mathematical models that can be incorporated in object-oriented software [7], which in turn supports knowledge transfer to industrial environments.

7 Concluding remarks

Training and engineering simulators for the European Robotic Arm, dextrous grippers, and wheeled vehicles offer challenges in modelling, simulation and control with respect to impact mechanics. Especially the real-time requirements give rise to specific problems for which solutions have been found at NLR.

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