IOP

Precision Technology

Overactuated systems

SENTER IOP

Exploring overactuation in motion systems

Subject:
Overactuation as an integrated design principle in motion systems

Purpose:
To explore the possibilities of overactuation, significantly reducing the weight of motion systems

Market application:
Aerospace, robotics, pick & place systems for assembly, wafer scanners, printers

Potential use:
Damping and prevention of vibrations and distortion in precision motion systems

Research period: July 2001 - June 2005

Total budget: : EUR 546,000, funded by IOP

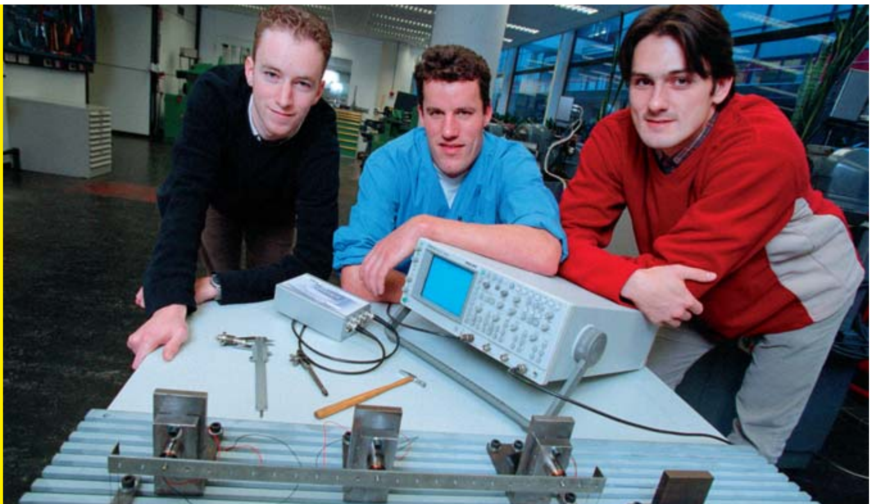
Research institute: Eindhoven University of Technology

Project leader: Maarten Steinbuch

At the Eindhoven University of Technology three PhD students from different sections are co-researching the possibilities of overactuation in motion systems. They believe that an integrated overactuated design approach will have advantages over traditional vibration control solutions, such as piezo systems in so-called 'smart structures'.
Using more actuators than are actually needed for the 'rigid-body' motion task, with less power each, in combination with closed-loop control, could reduce the overall weight of a construction considerably. This idea has not been researched before, since until now all focus in vibration reduction has been on using smart structures. 'I am convinced that the principle is applicable when micro- and nanometre accuracy is required.'

'The traditional solution to reduce vibrations in motion systems is to add stiffness to the construction; in doing so, its weight is increased', says Professor Maarten Steinbuch, head of the Control Systems Technology group at Eindhoven University of Technology. 'In this project we want to investigate whether overactuation is a valid alternative. Our aim is to realise a weight reduction of a factor of two.'
This is especially attractive in application areas where weight plays an important role, as in aerospace. But also in medical systems such as MRI and CT scanners, pick & place robots in the electronics and automotive industry, and printers.

The three PhD students of the project team on overactuated systems. From left to right: Maurice Schneiders, Jeroen van der Wielen, Jurai Makarovic. At the front, the first one-dimensional prototype



Complete set-up for overactuated research

Flexible beam: an overactuated system with movement in one direction

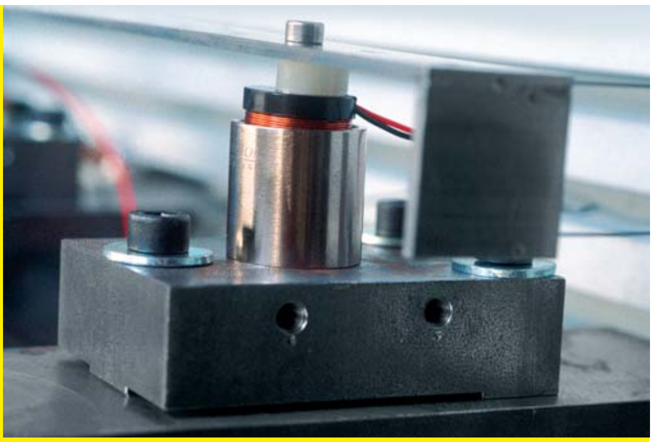
Domino effect

When high demands are made on precision, one of the main aspects that limit performance is the presence of vibrations. Motion systems are normally designed following a common set of rules. Maarten Steinbuch explains: ‘First, the mechanical design takes care of the stiffness of the construction, traditionally by adding weight. Secondly, actuators are responsible for the movement of, say, a robot arm. At the place where high precision is needed, sensors do the measuring. Finally, a control loop should influence the dynamic behaviour and makes corrections when needed.’
Adding weight is a passive way of increasing stiffness and thereby solving vibration problems. But this has a negative impact on the amount of energy needed to make the movements; it increases temperature and generates a range of other problems. ‘It’s like a domino effect.’
Well-known vibration control solutions often make use of adaptations after the mechanical design has been completed. ‘For example adding so-called ‘smart structures’. In that case, sensors and actuators placed at specific points of the construction take care of active damping.’ But these are specifically designed for use in stable, stationary systems.

Mechatronics

Overactuation is the use of actuators and sensors which actively influence the stiffness. Maarten Steinbuch gives an example: ‘You can compare it to a table. From a mechanical viewpoint, with an infinite stiff tabletop three legs would be enough. However, when the tabletop is made of less stiff material, you would need more legs to support it.’ Or turned around: the more legs, the less stiff the tabletop can be. ‘In the case of motion systems, there is of course the added complexity of movement.’
In the IOP project, which started in 2001, the research is conducted by three PhD students from two departments in the university: Precision Engineering and Control Systems Technology in the faculty of Mechanical Engineering, and Electromechanics and Power Electronics in the faculty of Electrical Engineering. ‘This is in line with the mechatronics design philosophy: a multidisciplinary systems approach. As a university we want to stimulate this type of cooperation.’
In the first phase of the project, literature is researched and models are developed. Based on this, a concept for further development is chosen in which different strategies of overactuation are investigated.
Currently, in the second phase, a one-dimensional prototype with movement in one direction has been built: a beam with low stiffness and several actuators. Maarten Steinbuch: ‘We just started validating our model, which implies a great number of tests and measurements.’ Design questions such as where to place the actuators and the sensors need to be answered. Actuators are responsible for generating the required forces to realise the movement. In the experiments voice coil actuators (Lorentz actuators) are used.
The findings from this phase will be applied in the third part, when a three-dimensional set-up is planned. Finally, the results will be documented in recipes on how to use the knowledge gained. ‘With a precision measured in micrometers and half the

Light weight actuator used in the prototype

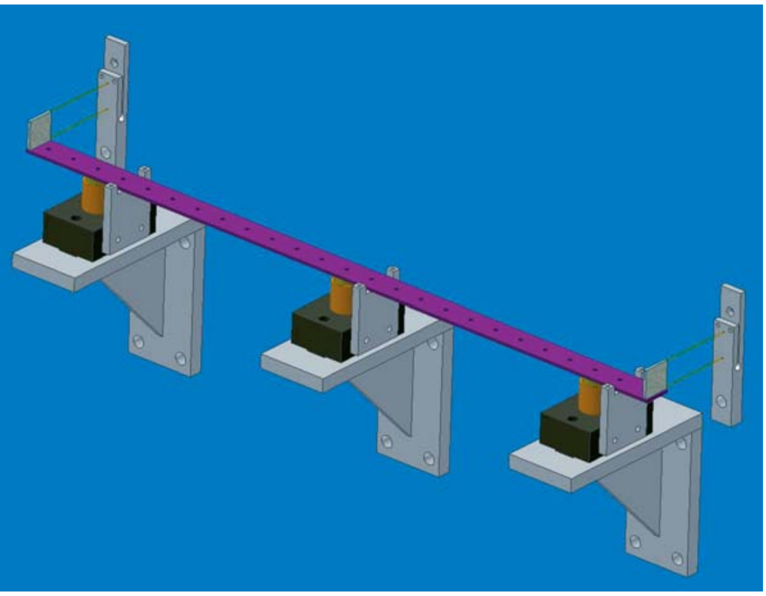


weight of a traditional construction, we want to prove that overactuation is a viable alternative. I am convinced that the same principle is applicable when nanometre accuracy is required.'

Industrial involvement

Maarten Steinbuch has a background in industry, having worked at Philips Research and the Philips Centre for Industrial Technology (CFT). For this reason he is sensitive to the need for industrial relevance and attainability. 'In the back of my mind, I constantly compare our findings with how this would work in practice.' The IOP project is one of the first research projects he started as a professor at the university. 'At CFT I have learned the importance of a multidisciplinary approach, and the importance of avoiding islands of thought.'

This practice is also fostered by involvement of different industries with an IOP project. In order to stimulate knowledge transfer between research institutes and companies, industrial user groups are formed with interested companies. 'This is a big added value for us', says Maarten Steinbuch. 'The members of this group play an important role, bringing expertise and specific technical knowledge. By asking the right questions at our meetings, they clarify the essence of the problem. That is extremely helpful for our PhD students.' In order to build good contacts with the companies, the three PhD students visited most of them at the start of the project.



Design of an overactuated simple beam structure

Informal atmosphere

Henk Huisman is senior design engineer in power electronics at the Centre for Concepts in Mechatronics. This company designs and develops industrial production devices such as multiple-beam wafer-dicing machines and assembling devices for the pharmaceutical and food industries. 'We have a lot of expertise on precision mechanics and electronics, and we find this interesting research because the demands of accuracy and light weight are, at first sight, extremely conflicting.' The added value he brings to the project is his personal knowledge. Besides his input in the regular meetings, he was able to help one of the PhD students with the design of the control loop for the actuator. 'That was very useful, and it shows the informal atmosphere between researchers and industry.' He introduced one of his colleagues as an extra member to the user group because of his expertise on precision mechanics.

One of the other participants of the industrial user group is Gert van Schothorst, group manager at the Philips Centre for Industrial Technology (CFT). 'With a group of ten people within the Mechatronics Research department we are working in the area of machine dynamics. We focus on the design of precision motion systems, with the aim of minimising the occurrence of vibrations and distortions.' The idea of using overactuation has been around for some time at CFT, but much research is needed before it can be used in practice, and it is more suitable to do that research in an academic environment. He sees cases where the idea might be very useful: 'The past year we did an internal development project on motion stages for large area processes. For instance, in new display technologies, patterns are printed on large glass substrates of 1.5 by 1.8 metre. Later on in the process, displays are cut from these glass plates, for instance for mobile phones, laptops or car navigators. The extreme required accuracy of this motion stage combined with printing movements of about 2 metres is a big challenge, and makes it at an attractive potential application for overactuation.'

Members of the industrial user group

ASML
Assembléon Netherlands
CCM Centre for Concepts in Mechatronics
De Koningh
Dutch Space
Nyquist
Philips Centre for Industrial Technology (CFT)
Te Strake
Thales Nederland
TNO TPD

Contact information on overactuated systems

Department of Eindhoven University of Technology, Department of Mechanical Engineering
Prof. Dr Ir Maarten Steinbuch, section Control Systems Technology
Telephone +31 40 247 54 44
E-mail m.steinbuch@tue.nl

Project team on overactuated systems

John Compter
Roëll van Druten
Elena Lomanova
Jurai Makarovic
René van den Molengraft
Piet Schellekens
Maurice Schneiders
Maarten Steinbuch
Jeroen van der Wielen

IOP Precision Technology

Precision technology is needed when products are to be built with high demands on the accuracy of their shape or size, and also when products or parts need to be positioned with high precision. Examples are laptop computers (especially data storage), cd players, dvd recorders, optical and medical instruments, space engineering and mobile phones. Further miniaturizing makes it impossible to build these functions in a purely mechanical way; a multidisciplinary systems approach is needed.

The IOP program in this field of technology started in 1999. Currently 16 projects have received grants for research on one of three central themes.

- In the field of systems-oriented design, subjects for research include design topics such as piezo actuators, precision movements in vacuum and high algorithmic mechanics. These topics all have movements with great speed and/or high precision.
- The second theme covers the constant raising of the precision of production processes by improving process control or using new production techniques. Not only conventional methods like precision machining are included but also new technologies such as lithographic etching, the use of laser or X-ray bundles and chemical vapour deposition.
- Micro system technology is the third area in this IOP program. Sensors and actuators coupled with a control system are of interest here. Examples are wet chemical etching and packaging of MST devices like an optical chip to a glass fibre.

Further questions on IOP Precision Technology

Contact dr. Casper Langerak, program manager
Telephone +31 70 373 53 12
Telefax +31 70 373 56 30
E-mail c.j.g.m.langerak@senter.nl
Website www.senter.nl/iop-pt

IOP

An innovation-driven research program (IOP) awards grants to innovative technological research projects at universities and other non-profit research organizations. Through this approach, the Dutch government wants to make the research world more accessible to the business community and improve and intensify contacts between the two. A precondition is that projects must fit in with the long-term research needs of the business community. The program stimulates interaction between the research world and business community through the latter's involvement in research projects, knowledge transfer and network activities. Major efforts are made to ensure that each completed program leads to lasting co-operation between the Dutch research institutes and business community with a view to fulfilling technological developments.

Business participation

In order to build a bridge between research and industry, an IOP provides opportunities for companies to take part in innovative research. The possibilities are as follows:

- Joining an industrial user group.
  As the most direct means of knowledge transfer, joining an industrial user group means close involvement in one or more projects. The business is kept up to date on the latest research developments, and, in some cases, can contribute practical experience that steers the course of the research work.
- Taking over patents or licenses that have resulted from IOP projects at universities and non-profit research institutes.
- Providing work experience placements for researchers, so that new know-how is passed on to the business quickly and can be tested in and adapted to practical conditions.

Colophon

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Senter The Hague
Juliana van Stolberglaan 3
P.O. Box 93144
2509 AC The Hague
The Netherlands
Telephone +31 70 373 50 00
Fax +31 70 373 51 00

General information:
Telephone +31 70 373 52 77
E-mail info@senter.nl
Internet www.senter.nl

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TU/e

The Eindhoven University of Technology is driven by research and focused on design in selected areas of technology. It provides engineering, postgraduate design, teacher-training programmes, and post-academic courses.

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