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Contribution of Shape Memory Alloys Elements in Designing Underwater Smart Structures

Shape memory alloys (SMA) have generated a lot of new ideas in engineering. Application is however so far limited to clamps and springs. With respect to smart structures sensing as well as control has to be included. While sensing looks to be relatively feasible control is the big challenge. This paper describes some related a smart structure idea using SMAs and discusses the challenges which need to be solved before these ideas can be realised.

Keywords: *shape memory alloys, underwater robots, actuators, artificial intelligence*

1. Introduction

The transformation process between martensite and austenite is known for decades. Practical use of the resulting shape memory alloys (SMA) has been limited to switching between these two phases only and have resulted in clamps, switches or springs.

Smart structures proposed since the late eighties consider more than just this 'on-off' stage. Briefly spoken they include sensing, actuation, and control which allows the structure to smoothly adapt to various conditions. The large deflections and forces which SMAs can generated have made them highly interesting as actuation devices. Furthermore, they have damping properties which are much above those known for conventional metallic materials. Their ability to remember shape has given them the final kick of magic in engineering minds.

However trying to realise that kind of ideas requires a good description of the constitutive behaviour as a control input.

This paper starts presenting an idea of SMA application. A description of an underwater robot related smart structure idea using SMAs follows from which the relevant SMA aspects to be clarified and their way of achievement are discussed.

At last, conclusions are drawn with regard to the consequences in realising the smart structures considered.

2. Analysis

Underwater technology for natural resource exploration as well as construction and inspection of underwater facilities becomes more and more important. Unmanned underwater vehicles, both remotely controlled (ROV) and autonomous (AUV) are used today by both science and industry to perform numerous tasks in submarine regions. Equipped with sensors and manipulators, unmanned underwater vehicle can assist human diver and in many cases take their place in underwater operations.

The marine underwater environment is very demanding to any sort of technical equipment. The corrosive properties of the salt water make it necessary to use only high-quality material. Because once deployed to deep submarine regions any sort of machinery is very difficult to maintain and repair, the technology used in these regions has to be as simple, robust and reliable as possible. For autonomous operating vehicles, i.e. vehicles without a cable connection to a supply ship, there is an additional need to operate very energy efficient, as battery capacities are limited.

Figure 1. Micro-AUV

On the other hand, the remote control of grippers and other actuators over large distances and with only a limited and 2-D overview of the area of operation pose a real challenge to ROV operators. With the currently available systems, it is very difficult to regulate for example the gripping power of a underwater robot arm. Highly qualified and trained operators are necessary for this task, limiting the usability of ROVs in many cases. For AUVs, the autonomous force-sensitive handling of objects is even more demanding. Force and pressure sensor arrays and the respective control software needed to provide a force-feedback to the robot add considerable complexity to the system and contradict the need for simpler and more reliable systems.

Why we can positionate SMAs in the world of smart materials and structures?

A widely accepted understanding of "smart" is that the material possesses sensing, actuation and control capabilities. SMAs can sense temperatures as a function of change in damping, stiffness, electrical resistivity and deflection. It is specifically the latter aspect which has made SMAs highly interesting since it is the actuation function built into this material. However the link between the mentioned sensing function or any other sensor signal such as a strain gauge and the actuation function is not very clear. These inherent sensing and actuation functions are therefore not able to fully interact in a control loop without any help from outside. SMAs themselves may therefore not be considered as a smart material in the strict sense. However they are specifically good elements as actuators and partially even sensors for smart structures.

Figure 2. Robotic underwater snake

Using intelligent SMAs to build "smart" actuators, i.e. to implement a low-level reactive behaviour directly in the actuator level, a force-sensitive gripping and even reflex-like behaviour can be implemented in a very simple and elegant way, without the need for additional sensor arrays. The smart gripper of a robotic arm may "feel" when an object slips and in a reflex-like behaviour decide on a very local level, i.e. without having to bother the main process-control of the robot, to increase the force of the grip in order to hold the object tight.

In underwater applications such "smart" actuators on the basis of SMAs are particularly useful because:

- They help to simplify the technology, which is an important feature in underwater applications where maintenance operations are difficult and systems have to work reliably during long-term missions;
- They avoid unwanted interferences of forces created by water pressure with the measurements of the force sensor arrays.

- The temperature of the underwater environment, in particular in the deep-sea, is always low. In such an environment, the SMA actuators can be cooled by natural means, making the application of SMA actuators very energy effective

Apart from grippers, there are a number of application for SMA based actuators in the underwater environment. These include the actuators for robotic arms and other moveable parts, as well as the development of new, bio-inspired locomotion principles, such as fins and flaps that use linear movements to propel underwater vehicles in a fish-like manner.

The DFKI Robotics Lab in Bremen has extensive experience with underwater applications (Figure 1 and 2). Among others, the lab developed a Micro-AUV for operation in narrow and confined fluid-filled spaces (like tanks) and a snake-like autonomous underwater vehicle (Figure 3). The SME based actuators proposed to be developed will be used to further develop and improve these applications with smart robotic grippers and energy-efficient linear locomotion modules

Figure 3. Design-study for an robotic underwater fish

3. Factors to be considered.

The problem considered is that of constructing an underwater vehicle /manipulator system. Although the vehicle, the manipulator and their coupling may be dealt with in a standard way, modelling of the whole system is quite difficult, due to the necessity of taking into account the presence of hydrodynamic effects of the surrounding fluid.

A basic idea, here, is that of simplifying the situation as much as possible, by concentrating only on the phenomena which affects the dynamical properties of interest. Besides hydrodynamics effects, we should take into consideration also the interaction with the environment due to contact between the force sensitive robotic grippers and an object. In this way, keeping also into account experimental and theoretical results presented in the literature, we should obtain a, satisfactory, workable model of the underwater vehicle/manipulator system.

The cinematic control problem should also be considered. The considered system is always redundant, due to the DOF provided by the vehicle, but different movements that give rise to the same position and orientation of the force sensitive robotic grippers may have greatly different cost in terms of energy and execution time. In general, it is preferable to perform fast motion of small amplitude by means of the manipulator, while the vehicle keeps its position, and to employ the vehicles mobility only for performing slow, gross motions. This allows to distribute the motion between vehicle and manipulator in accordance with specific requirements.

Taking in consideration the problem of dynamic control of the underwater system, it is obvious that several classical approaches can be used. Sliding mode control, adaptive control and output feedback control schemes can be inferred and analysed from the point of view of stability and error dynamics. Another interesting contribution is the application, to the control problem at issue, of a so-called virtual decomposition based control scheme. Adopting this approach, the serial chain structure of the underwater vehicle is exploited to reduce the complexity of the control problem and to facilitate implementation. An adaptive/integral control law can be developed by designing part of the compensation action in the inertial reference frame and part in the vehicle-fixed reference frame. External disturbances like ocean current and restoring forces can be handled easier in this way, facilitating and improving convergence of the adaptation mechanism.

4. Conclusion

Various activities are going on towards SMA actuated smart structures. Progress over the past is promising which can be specifically related to understanding and analytically describing SMAs' constitutive behaviour as well as manufacturing SMA reinforced composites. However the high complexity of SMA constitutive behaviour will require consideration regarding the following:

- The different models being around need to be consolidated. This may be achieved through intensive discussions on workshops supported by benchmark tests and round robins;
- Agreed standards for testing SMAs need to be established which will allow better comparison of the experimental data being around;
- Databases of widely accepted experimental results are required to validate the various models of SMA constitutive behaviour as well as demonstrating the variety of essential parameters involved;
- Numerical codes which can be implemented as modules into standard FE codes.

Based on such achievements control algorithms for SMA actuated smart structures can be better designed than this is possible so far. Further knowledge is required regarding strain rate and temperature effects which are all interacting between each other.

Altogether the past activities have proven that SMA is still a potential element within smart structures. The way to achieve this seems quite long but compared to the development cycles in aluminium alloys or composites there does not seem to be much of a difference. Maybe the 'impatience' just results from the partially much shorter development cycles in completely other engineering areas

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