Sensors in, for and by Mechatronics: a Symbiosis

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Sensors are central to mechatronic systems.

This is so because mechatronic systems are essentially dependent on information. Some of this information is provided *a priori*, via programming of embedded microprocessors, but most is acquired during operation via sensory subsystems. Indeed the functioning of most mechatronic systems is critically dependent on these subsystems. (Machine vision subsystems are, of course, fundamentally sensors and can provide very rich information input.)

But the interrelation of mechatronics and sensor technology is wider than this. Sensory subsystems within mechatronic systems – and *vice versa* – can fulfill a range of purposes: these may be grouped as follows.

- **Sensors embedded within mechatronic systems.**

At the most basic level sensors provide feedback from the actuators which form part of most mechatronic systems, i.e. they are essential for the operation of internal control loops. Standard, off-the-shelf components will often meet this requirement, for example, rotary shaft encoders in the joints of robotic systems.

However, cases often arise in which non-standard, system-specific sensors are needed, and meeting this need is a research task routinely undertaken as part of mechatronic design. Geometrical constraints (and also cost) commonly restrict the use of off-the-shelf transducers and limit design options; but a magnet moving relative to a Hall Effect sensor, for example, can be configured to transduce a wide range of motion-related quantities.

- **Sensing capabilities enhanced by mechatronics.**

There are many situations in which a sensory system alone cannot do the job required, for example visual inspection in a hostile or dangerous environment. Here the mechatronic subsystems are critical to meeting the external sensing objective. A further example is the acquisition of information by touch – tactile sensing – which almost always involves mechatronic control of the interaction between the sensor array and the target object.

- **The use of mechatronics to create 'a sensor'.** Finally there are situations in which mechatronic techniques can be employed within a package which the external user sees as 'a sensor'. The device may be labeled a 'smart sensor' in recognition of its ability to respond or adapt to the phenomenon or quantity being sensed, but fundamentally the device is a measurement system, i.e. an instrument. Its purpose is to provide measurement information and is characterised by a calibrated input-output relationship for a particular measurand. Here the internal mechatronic subsystems may be invisible to the user but their operation is essential to the measurement task.

Hence we have a symbiosis of sensing, measurement and mechatronics. The nine papers introduced below span all of three aspects introduced above, but of course there is much sensory research reported in papers in other sections of this book, such is the closeness of the relationship.

Commencing with a broad view, *Schultz and Billingsley* consider the process of commercial breadmaking from a mechatronic perspective. An holistic approach reveals considerable potential for automation but this is dependent on the fusion of a wide range of information inputs. These include not only traditional (statistical) product data, and the state of (presently) isolated control loops, but also novel sensing of the product as it moves though the plant. Potential sensing solutions for improved oven control, product sensing (e.g. 'brownness') and item tracking are proposed.

A range of specific measurement requirements are enhanced, enabled or entirely performed using mechatronic techniques.

During harvesting of sugar cane, a small but significant proportion of product is lost when it is imperfectly separated from waste leaf material. *McCarthy, Billingsley and Harris* have devised a measurement system for this product loss by observing that it is inherently sensed within the harvester – a large fan is used to pneumatically separate and extract the waste material and there are characteristic vibrations in the blades of the fan when these are impacted by cane billets. Mechatronic techniques are used to transduce this vibration and derive a count of lost billets from the acoustic signal produced.

Measurement of spatial position to decimetre scale is required for robotic operations in field agriculture. *Billingsley* shows that global positioning system (GPS) data from low-cost GPS receivers can be enhanced to yield the required precision if a pair of receivers are used simultaneously and their outputs combined with appropriate embedded processing. Furthermore the technique is shown to be capable of relatively rapid recovery from loss of satellite lock.

'Low-cost' sensing and measurement systems are always desirable, but in some situations the measurement will simply not be made unless a suitably cheap component or system is available. *Stone and Billingsley* tackle one such situation, namely the provision of collision avoidance systems for road vehicles. 'Tailgating' is a common human driving problem in traffic and any automatic collision avoidance (such as a warning, or automatic breaking) requires rapid-response and low-cost measurement of the distance to the vehicle in front. The authors describe a return to 'first principles' to meet the design and cost constraints and report a mechatronic solution to the problem.

Likewise a low-cost 'mechatronic sensor' for the measurement of carbon dioxide gas concentration has been developed as an alternative to the high-accuracy but expensive measurement technique based on infra-red absorption.

Maxwell, Hancock and Tran-Cong demonstrate that traditional 'wet chemistry' (the limewater reaction) may be undertaken using miniaturised components under mechatronic control; and that fluid-mechanical modeling of the reaction cell promises further miniaturisation. The use of low-cost components makes single-mission, sacrificial use feasible and a potential application is the monitoring of delicate horticultural produce during transport.

The measurement of the properties of surfaces, both their shape (profilometry, as above) and texture can be undertaken by contact, and this is necessary in environments where non-contact techniques such as machine vision are impractical. And where contact has to take place, for example as part of a manufacturing process, signals conveying some of the information required may already be available (as it is in the case of sugar cane loss, above). *Xue, Naghdy and Simpson* derive surface finish information during grinding using a combination of direct acoustic sensing and indirect grinding force sensing (from motor current in the grinder). Correlation results embedded in a heuristic model will permit the loop to be closed to provide automatic control of surface quality.

Surface texture, as well as surface position, is also of major practical importance for those of us who have limited vision. To provide this capability *Khodai-Joopari* reports the further development of the 'Robotic Cane', a mechatronic aid for the visually-impared. The device has a small wheeled trolley at the foot of the cane which remains in contact with the ground, hence the surface texture is sensed via changes in the orientation of the trolley relative to the cane as it moves over the surface.

Finally, the broader question of practical tactile sensing in a manufacturing environment is considered by *Tongpadungrod and Brett*. Rather than provide a general-purpose matrix of force sensors, which is usually expensive and susceptible to damage, it is demonstrated that the required tactile information can be achieved with mechatronic systems of lower complexity and improved robustness. A one-dimensional cantilever example is examined with applications to keypad design and measurement systems for the weight and speed of moving objects.