DESIGN OF A LOW-COST MOBILE ROBOT FOR MECHATRONICS EDUCATION

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ABSTRACT

During the past few years the development of low cost sensors means that they are now able to be combined together into an integrated unit. This paper describes the recent development of a the first version of a mobile base that means that meaningful research and development can now be carried out into sensor fusion at relatively low cost. The range of sensors developed - infra red, vision, ultrasonic etc - will allow work in new areas of mechatronics education and research to be implemented.

1. INTRODUCTION

Recent developments in mobile autonomous robots indicate that multiple low cost units will supersede the present use of single, multipurpose robots with high cost. This is apparent from the direction that the major applications of mobile robotics, ie underwater autonomous vehicles, space robots, and robots for use in the building and construction industry, are moving. The integration of sensors is needed to allow these robots to be fully informed of their environment, thus making their applications more diverse.

There is a need in robotics/mechatronics education for a low cost robot that can be used for experimentation and research into the integration of sensors and cooperative behaviour between robots. This need has led to the design of such a robot. The initial version proved the concept and has led to the design of a newer version that overcomes some of the problems with the first.

Because of the modular way that the robot is designed it is possible to build a number of them relatively cheaply. Mobile robots for teaching and research currently cost in the region of US$40,000 - 60,000. The mobile base described costs around US$200. A fully integrated robot can be built using the modular design. This can have multiple sensors. It is planned to build at least ten of these robots for less than US$5,000 so that all aspects of sensor fusion and robot cooperation can be investigated.

The ultimate aim of the project is to investigate the behaviour of many autonomous robots operating in a confined area. Robot cooperation is becoming a major area of research, as to work together efficiently robots must not only be aware of their environment but also where they are in relation to their 'colleagues'.

2. THE INITIAL DESIGN

The current robot base is octagonal in shape, 20 cm across flats, with bump sensors along each edge. Extra modules, containing other sensors, can be attached on top of this base so that the configuration can be altered to suit different needs. These are also octagonal in shape - Figure 1.

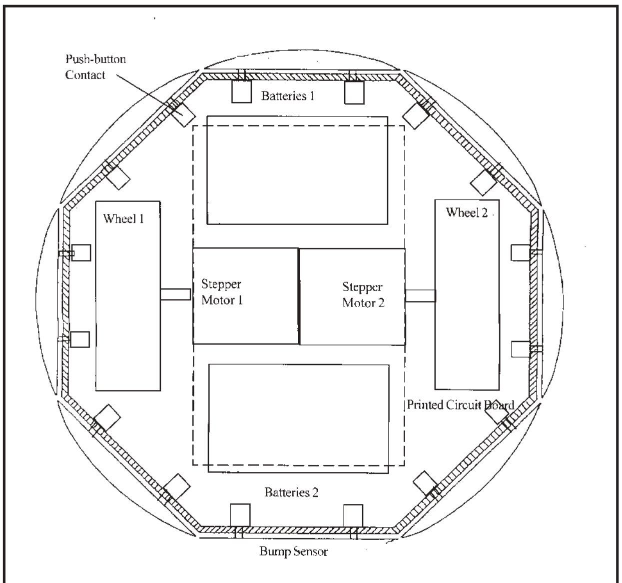

Figure 1: Drawing of original base unit

The base is powered by stepper motors. On board batteries provide around 1 hour of constant use. The base unit has a microcontroller which monitors the bump sensors and controls the direction and speed of the motors.

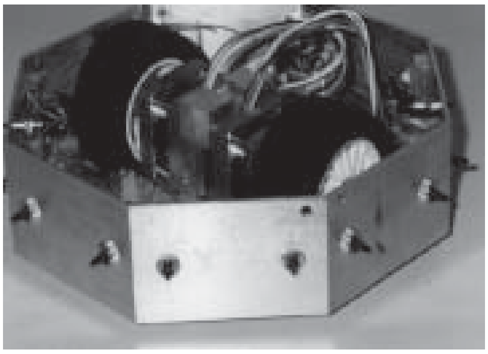

Figure 2: Original base unit showing internal construction and stepper motors

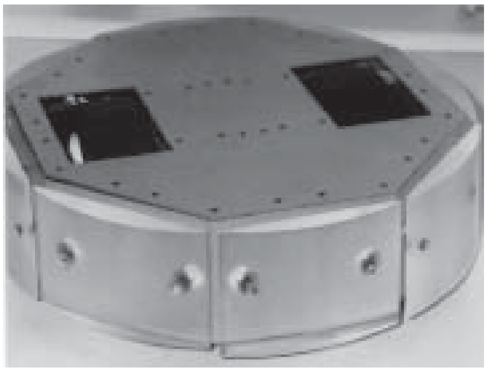

Figure 3: Original base unit showing bump senors

The initial base was machined from a solid block of aluminium -Figures 2 and 3. This was part of a Manufacturing Engineering final year project that was designed in such a way that a rapid prototyping mould could be made after any modifications based on trials had been made. Once the mould has been finalised, at least ten bases would be injection moulded to provide multiple robots for investigating aspects of mobile robot cooperation.

Work with this base unit has shown a number of problems associated with the simple design. These problems and the modifications to the original concept to overcome them are addressed later.

3. MULTIPROCESSOR APPLICATIONS

For multiple sensor fusion, as well as to make the integration of sensors as flexible as possible, thus facilitating the modular approach, the initial base unit is currently being modified to add an external bus structure to the control board. This will use the I^{2}C bus developed for consumer electronics use by Philips [1]. The I^{2}C bus has a simple serial bus structure that is designed to make interfacing relatively easy. ICs communicating with each other on a serial bus must have some form of protocol which avoids all possibilities of confusion, data loss and blockage of information. Fast ICs must be able to communicate with slow ICs. The system must not be dependent on the ICs connected to it, otherwise modifications or improvements would be impossible. A procedure has also to be devised to decide which IC will be in control of the bus and when. And if different ICs with different clock speeds are connected to the bus - the bus clock must be defined - Figure 4.

Current work has shown [2] that the I^{2}C bus is capable of connecting all the proposed modules. Although the bus is relatively slow, up to 400 kb/s, the fact that most of the processing would be carried out locally by the sensor modules, means that only command and control data need be sent on the bus.

The fact that the bus controllers are available 'off the shelf' means that costs can be kept low, whilst the simple design means that low level programming can be used. The development of an hierarchical communications structure should provide the basis for communications at a speed that is adequate for the purpose.

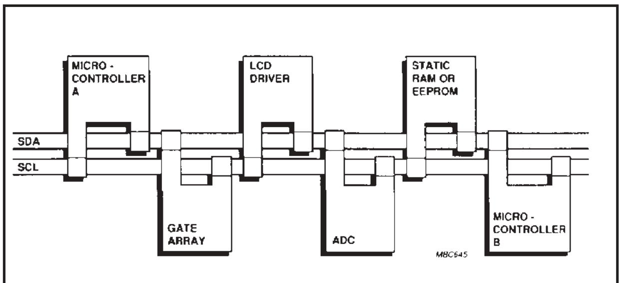

Figure 4: Example of an I^{2}C bus configuration using two microcontrollers

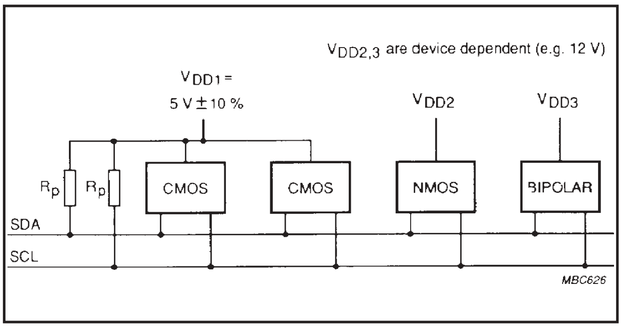

Figure 5: The I^{2}C bus allows different types of devices to be interconnected easily

The I^2C bus supports ICs with any process (NMOS, CMOS, etc) - Figure 5. Two wires, serial data and serial clock carry information between ICs connected to the bus. Each IC is recognised by a unique address and can operate as either a transmitter or receiver. The I^2C bus is a multi-master bus. This means that more than one IC capable of controlling the bus can be connected to it, unlike alternative approaches where one processor is designated the bus controller. Arbitration procedures prevent more than one master controlling the bus at any one time.

A simple hierarchical protocol is used for integrating the sensors. This contrasts to more complex methodologies used by other researchers. Other protocols need large amounts of centralised computing power; this has the disadvantage of making the modular approach in this proposal more difficult and expensive to implement. At the same time, as there are many processors with built in I^2C interfaces, the simple hierarchical approach is much more flexible.

Many microprocessor families are supported by I^2C bus interface chips and some even have versions specially designed for the bus. These include 68000, 80C51 and 8048. This wide range of processors means that the one most suitable for each sensor can be used and they can all communicate on the bus.

4. SENSOR INTEGRATION

The initial base unit can move around the room, in a certain direction, moving away from objects that are hit and avoiding them by rerouting. In the hierarchy of sensors used in such robots the highest priority is given to the bump sensors on the base unit.

The integration of sensors in mobile robots is well documented [3], [4], [5], and, in theory, poses few problems. However, most of the approaches taken by other researchers use large amounts of computing power, usually based around a single, central processor and using a complicated bus structure to communicate between the sensors and the control unit [6], [7]. Others have used 'intelligent' sensors but used high-powered transputer-based processors. [8]

While all of these approaches have their advantages, they all suffer from two major problems; they are expensive and difficult to implement, especially if multiple robot applications are envisaged.

For example, the Yamabico mobile robot developed by Yuta et al at Tsukuba University in Japan [6], [7], whilst being a superb research platform, could not be built in quantity because of the cost. At the same time the robot uses a multibus type approach to connecting all its modules together. Thus a complicated and costly back-plane is required. However the complex design does mean that the development of high level programming language, ROBOL, could be developed.

Other researchers have developed methods of communicating between the sensors and the master processor using a hypercubes [9], parallel processor architecture [10], [11] or asynchronous multiprocessors [12]. Again, all these approaches suffer from the previously identified defects.

During the past few years, work at CityU has resulted in the development of a number of low cost sensors, and a simple method of communication between them, that allows the development of a simpler way of achieving the same goals.

For example, a number of infra red distance sensors have been developed for use with micromouse. This small, autonomous mobile robot is designed to map an unknown maze of 16 x 16 squares and then find the quickest path to the centre goal. A number of undergraduate final-year projects have developed reliable methods of using infra red sensors for both distance and proximity detection [13], [14].

A low cost intelligent vision sensor has also been developed. [15], [16]. This has been further enhanced by undergraduate and MSc students so that it can now be used on a small autonomous robot to provide visual data for machine vision.

Finally, a number of ultrasonic sensors have also been developed for use on mobile robots [17].

The first objective is to build modules for infra red, vision and ultrasonic sensors. These will then be integrated using the I^2C bus, and software developed to integrate the sensors together. The next stage of the project is to design and construct a radio ethernet communications module so that cooperative behaviour can be investigated.

Allied work with robotics at CityU, especially with underwater robots, is indicating that work planned on this proposed project will have an impact on applications elsewhere, especially if a robust cooperative strategy can be developed.

A number of modules are currently being designed. The vision module contains an intelligent ccd array. This is able to sense moving objects and detect their trajectory or direction of movement. Adaptive algorithms using the intelligent ccd array will allow this module to serve a dual role - tracking and position. An infra red sensor module is being designed that will detect both distance and 'warm' objects. Finally, a number of ultrasonic modules are being developed in a related project that could be used for longer distance sensing.

The integration of sensors is a major area of robotics research. The base unit is able to take control of the whole robot and arbitrate through a bus structure. The bus structure allows the separate modules enough local intelligence to control their own environment, whilst not conflicting with the needs of other units. The successful implementation of the integration of the base unit with other sensor units will provide a very powerful teaching and research tool in the mechatronics area.

5. THE SECOND GENERATION BASE UNIT.

A number of problems were found to exist with the architecture of the original design. First the design of the bump sensors left a lot to be desired. They occasionally stuck, especially when the bumpers were struck at a shallow angle. Secondly, the gap between the bumpers, plus the fact that the switch was used as an pivot did not help accurate detection of contact being made. In others words it was unreliable and not very accurate.

At the same time the 20 cm width of the base meant that there was little flexibility in how to use the space. This was especially true when the height - 5 cm - was taken into account.

Consequently a new design is currently being manufactured which is 25 cm across and has a height of 6 cm - Figure 6.

Another potential problem was the fact that there are

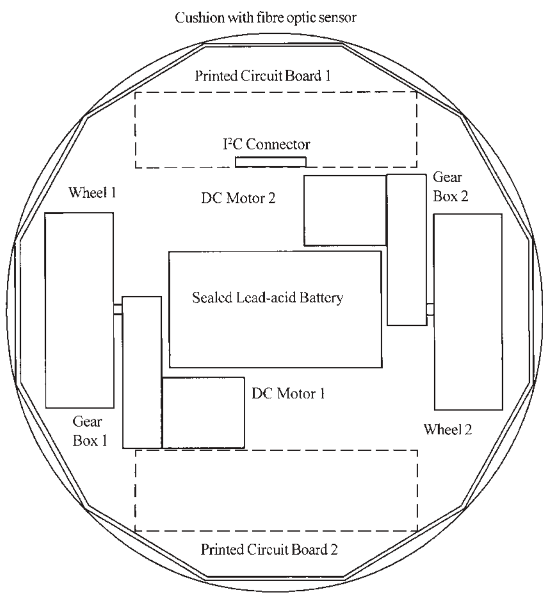

Figure 6: Design of new base unit

only 8 sides to the robot. Experience with ultrasonic and infrared sensors has shown that the angle between adjacent sensors should be 30° minimum to give full 360 ° coverage. The octagonal design had 45°, and this could lead to gaps in the sensor coverage. Thus the new robot will have 12 sides.

The initial design had some add-on modules that were 2.5 cm high and some that were 5 cm high. The latest version will only use stackable modules that are 6 cm high - the same as the base.

Next, the new base will be made from acrylic so that the weight will be closer to that for the injection moulded version. The heavy metal base unit slowed the robot significantly and used a lot of power to move.

Finally, the mechanical bump sensors, which caused the problems discussed above, are to be replaced with fibre optic sensors developed for a related project [18], [19]. Three 'rings' of specially treated optical fibres Figure 7 - will be attached to a cushion that covers the outside of the base. This will give 360° continuous coverage, thus overcoming the gaps found in the original. The fibre optic sensors are capable of detecting depressions as small as 0.04 mm, and to within a positional accuracy of 5 mm.

The stepper motors are being replaced with dc motors driven through a gear box. Experience has shown that the extended battery life with dc motors over

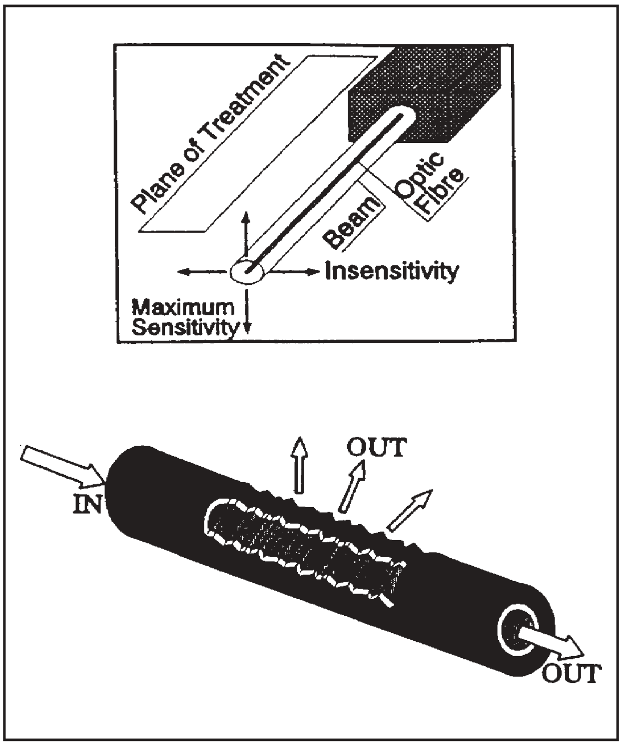

Figure 7: Directionality of measurements and diagram of the sensitised fibre

comes any of the more complicated interface electronics.

6. APPLICATION TO MECHATRONICS TEACHING

The base unit is designed to be used as a teaching tool on a number of courses within the university. A number of final year projects in the Department of Electronic Engineering need such a low cost base, especially for the development of work in robot co-operation and communication.

Also the BEng Mechatronics Degree at CityU, run by the Departments of Manufacturing Engineering and Electronic Engineering, has an 18 month project which is designed to develop prototypes of designs for potential commercial applications. Many of these involve the integration of sensors. Current teaching looks at sensors in isolation - either from each other, or distinct from other elements of the system.

Access to a mobile robot that is designed and built in such a way that simple (or even complex) experiments can be carried out into the development of new sensors, within a system, will overcome the educational problems indicated above.

At the same time, the possession of a number of low cost mobile robots will provide a tool for future development of both teaching and research into robot cooperation and communication.

7. FUTURE PLANS -COOPERATIVE BEHAVIOUR

Cooperative behaviour has come to the fore recently, especially with the introduction of multiple AGVs in industry. A number of approaches have been taken to solving the problem of optimising the performance of many robots in the same workplace, whether this be static robot-arm devices or mobile units. However different strategies are required for small autonomous mobile robots.

The first task in designing a structure for robot cooperation is collision avoidance. This is now such a well researched field , with many differing strategies that it is not planned to spend any time developing this area. The best strategy for the design of robot will be the one chosen after evaluating the performance and capabilities of the robot after the first part of the project, sensor fusion, has been successful.

The main area of future research will concentrate on designing a wireless link between each robot, and then designing the cooperation strategies. A number of researchers have developed wireless links , but most depend on a central “server”. The initial design planned will take this approach, using ethernet-based local area network. However, the final version will probably have a distributed server architecture with the server functions being shared by all the robots.

8. ACKNOWLEDGEMENTS

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