Advances in Mechatronic Education using Micromouse as a Teaching Tool

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Abstract

This paper considers the use of robotics projects, such as Micromouse in teaching mechatronics. Micromouse integrates the basics of electronic and control engineering with mechanical and software engineering and is a perfect example of the integration of disciplines needed in the teaching of mechatronics.

The introduction of this design projects into the final year project stream of the City Polytechnic of Hong Kong's diploma and honour's degree courses has not only raised the awareness of mechatronics within the department and also Hong Kong, but also inspired the students to work in a more coordinated and group mode than if more traditional projects had been used.

1. Introduction

Micromouse, as an exercise in the design and implementation of an integrated mechatronics application, has been around since 1979, see Fig 1. However it is only during the past six years that it has been taken seriously enough by the academic community, and considered as an ideal project for diploma and degree students.

Micromouse is a small autonomous microprocessor controlled robot vehicle that has to navigate its way through an unknown maze. The main challenge for the contestant is to impart to the micromouse an adaptive intelligence to explore different maze configurations and to work out the optimum route for the shortest travel time from start to finish.

The maze consists of 16 x 16 squares 18cm x 18cm. The passageways are 16.8cm wide. The walls are 5cm high, white on the sides and red on the top. The floor of the maze is black. The start of the maze is in one corner; the goal is the centre four squares.

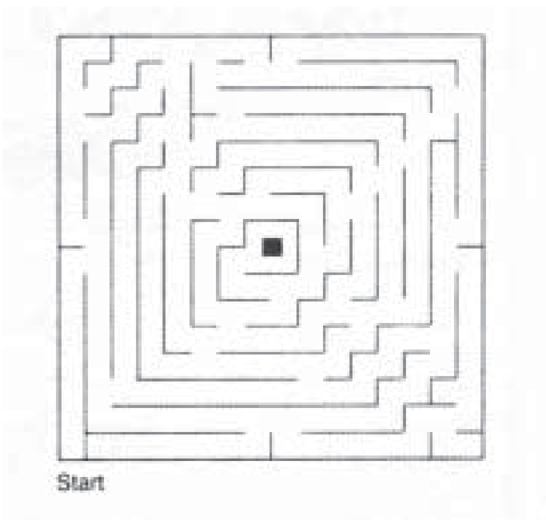

Fig 2: Typical maze layout

1972: Le Mouse 5000 - sponsored by Machine Design - distance event
1977: IEEE Spectrum announce Amazing Micromouse Maze Contest
1979: First US contest, National Computer Conference, New York - 'pass- through' maze
1980: First UK contest, London Computer Fair - 'centre-goal' maze
1980: New Technology Foundation, Tokyo - first Japanese contest
1985: Tsukuba, Japan - First World Championships
1987: First Singapore contest
1988: First Taiwanese contest
1990: First Hong Kong contest
1991: First Robot 'Olympics' - Glasgow, Scotland
1991: Second World Championships, Hong Kong
1993: Third World Championships - London

Fig 1: History of Micromouse Contests

USA:	MIT, Rensselaer Polytechnic Institute, California State Univ Long Beach
Canada:	McGill U, Waterloo U
UK:	Paisley U, East London U, Glasgow U, UMIST, IC, Herriot-Watt U, Strathclyde U
Finland:	Tampere U
Germany:	Darmstadt U, Kaiserslautern U
Australia:	Monash U, Macquarie U, Queensland U, USQ, Wollongong U
New Zealand:	Auckland U, Central Institute of Technology, Massey U
Singapore:	NUS, Nanyang U, Ngee Ann Polytechnic, Singapore Polytechnic
Japan:	200+ universities, technical institutes etc
Taiwan:	Taiwan National U
Philippines:	Univ of Philippines
Hong Kong:	City Polytechnic of Hong Kong, Hong Kong University of Science and Technology, Chinese University of Hong Kong, Hong Kong Baptist College, Hong Kong University, Morrison Hill TI, Chai Wan VTC, Tsing Yi VTC

Fig 3: Educational Institutions using micromouse

Fig 2. Structure of the maze

The mice have physical restrictions; they must be no more than 25cm x 25cm in width and length. However there is no restriction on height - except gravity!

The scoring procedure is quite complicated, rewarding efficient maze exploration algorithms, and penalising inefficient ones. It is not only speed that determines the winner; reliability and intelligence are also taken into account. For example, if a mouse is touched in anyway, then it is heavily penalised.

The combination of easily defined goals, plus a scoring system that rewards efficient and reliable design makes micromouse an ideal student project.

2. Micromouse in education

Although many educational institutions have students doing micromouse projects, see Fig 3, at the moment very few educational institutions around the world have anything that can be described as a coordinated programme of micromouse development. Perhaps the leading proponent of this is Ngee Ann Polytechnic in Singapore [1].

The programme starts with the top 200-250 students being given a demonstration. Interested students then apply to join the Micromouse project stream, and the top 10% (18 to 20 students each year) are selected. A two week solid training programme follows (software, solving and search theory, hardware and sensor design etc). Every student builds everything from scratch, code is not reused; however students' software design efforts are transferred at the flowchart level. As in any successful student project programme, the top students have outstripped their supervisors. The supervisors keep close contact and follow the students work, but now the top students assist the lecturers with the detailed aspects of Micromouse! The best students have also created their development tools.

City Polytechnic of Hong Kong follows another approach, which follows the more 'free-wheeling' aspects of Hong Kong society when compared to Singapore. In this programme, described in detail below, students are free to follow their own ideas, but must work within departmentally set guidelines.

California State University at Long Beach, CSULB, in the United States also has a long running programme. They have around twelve students at any one time based in the Computer Science and Engineering Department.

MIT in Boston, USA has always been at the forefront of micromouse design, especially because Dave Otten, a research engineer in the Laboratory for Electronic Engineering Systems (LEES) has won more international micromouse contest than anyone else! Their latest approach is to ask students on a robotics short course at MIT to build a micromouse using Lego parts. This approach is, in itself not new, with one of the first mice using Lego in 1980[2]. In fact, some of the mice from 1993's course were so successful that they ran in the 1993 APEC contest in Boston.

Finally, there is the Japanese approach. This originated with delegates from the New Technology Foundation, a government funded body set up to encourage the awareness of informatics in schools and colleges, doing the rounds of micromouse contests in the early 80s. Then they ran the first major world contest in Tsukuba in 1985, where the Japanese mice thrashed the competition[3]. Since then they have encouraged the growth of micromouse clubs around Japan, and these now number nearly 200. The annual Japanese contest regularly attracts over 100 entrants.

3. The engineering challenge

Micromouse is essentially a totally autonomous robot that has to solve a very particular task, ie map an unknown maze and then find the quickest path to the centre of that maze. For the fastest mice this means controlling around 1kg mass moving at up to 3m/sec with a positional accuracy of +/- 1mm in a 9 sq m area! The individual parts of the mice are inherently very simple and easy to assemble; however the integration of these parts into a unit that can solve the control problem above is not that easy - and this is the challenge to the students.

The control problems are probably the most difficult to solve. It seems indicative of the trend, in EE courses especially, that both classical and modern control theory has been relegated to a specialist final year option. This means that most students are only learning the fundamentals of control theory whilst trying to implement a sophisticated application of that theory, with consequent results!

There are basically four parts to a micromouse. First the sensors; these can be infra-red, looking either down on the walls or at the sides of the walls, laser, ccd array (vision) or ultrasonic. Secondly, the motors can be brushed dc, brushless dc, servo or stepper. Thirdly, the processor can be anything available, form microcontrollers like the 80196 to simple 8-bit processors such as the Z80. Finally the software can be written in anything from C++ through assembler to Quick Basic. Normal algorithms can be used or even fuzzy logic or neural networks.

This great diversity of implementation means that every mouse is different! The potential combinations are nearly infinite - which is why micromouse is an ideal project to teach the integration of electronic, mechanics and control/software ie mechatronics.

4. Micromouse at CPHK

The Department of Electronic Engineering (EE) at CPHK runs three bachelors' with honours degree level, one masters' level and the remnants of two diploma (senior technician engineer) level courses. It has around 55 academic staff and 1300 students. The final year of the degree and diploma courses have a project element that runs for the whole academic year. The project also forms and integral part of the masters' degree.

For the past four years micromouse has been a major project area involving up to 16 of the 400 final year students. The interest is distributed across all courses, see Fig 4.

At the beginning of micromouse at CPHK the mice followed the simple configuration of stepper motor and IR sensors looking at the tops of the walls. The motors were slow, usually bought from a local electronic 'flea market', with little documentation - but cheap! The sensors were also from other applications that happened to be in departmental stores. This approach, whilst useful in getting micromouse off the ground in a virgin environment, did not make for mice that could compete on the world stage. However the second mouse built at CPHK did reach the middle successfully, and did compete in a number of international contests, even becoming both the Australian and New Zealand champion in 1992.

Year	90/91	91/92	92/93	93/94	94/95
HDEE	2(4)	2(4)		2(4)	*
HDCE		4(8)		*	
BEngEE	2(2)	4(4)	6(6)	5(5)	2(2)
BEngCE			1(1)		1(1)
BScIT			1(1)		
MScEE			1(1)	1(1)	

First number = number of projects ie mice

Number in () = number of students

* Course discontinued at CPHK - see text

Fig 4: Number of students taking micromouse projects by course

Since these early days the mice have changed dramatically. The introduction of special Japanese stepper motors that deliver 2000 g.cm of torque at 5,000 pps, weighing only 200 g, and working at 2.4 V has revolutionised the speeds available. However, most of the recent mice have used dc motors. In an evolution similar to that for the stepper motors, early dc motor designs used low cost motors designed for the toy market. The latest designs use ironless pm motors. The gearing has also changed from that used in mobile toys to near-frictionless, precision gear boxes. Batteries have also evolved from NICads to NiMH cells.

All these technological changes have, however, introduced new problems. First, it is no longer possible for the students to blame the components for poor performance! Dc motors are more difficult to control, needing, at the minimum, simple closed loop control, unlike the dead-reckoning used by simple stepper motor mice.

NiMH batteries do not have the same discharge characteristics as NiCad batteries, although they do store twice the charge, and are slightly lighter. This means that extra power control hardware must be used.

Finally, the evolution of sensor technology has also introduced new problems. Initially, top mounted IR sensors were considered adequate; but as more sensors were introduced to try and cope with 'racing turns' and 'diagonal runs' the number of ports available on the processor became the limiting factor. So side mounted sensors are now used, both IR and laser. These involve new techniques which have to be learned.

At the same time advances in ccd cameras have led to vision systems being used on mice. At CPHK a low cost 'intelligent camera' has been developed for machine vision use. This takes the signals from a ccd array, passes them through an ADC, and then directly into video RAM[4]. Not only is the unit small, but it also consumes small amounts of power. It also means that some video processing is possible using the microcontroller built into the camera.

This year, a preliminary project shower that it was possible to map the maze from just four points using a machine vision approach. Unfortunately it is still necessary to employ IR sensors as the mouse must move to these four locations without all the information from the camera being available. Also the angle of view of the camera means that the four closest walls cannot be seen by it.

Some years ago a generic chassis was developed which allows all students to get working on the control aspects as soon as possible. Early experience showed that EE students were not very good at building mechanical hardware. The simple chassis [5] costs about US$5, and is designed to be chopped about by the students to take whatever drive mechanism they need. As this chassis can be easily mass produced it has also been used for a number schools' projects - see below. The chassis also allows any number of pc boards to be attached, and can also be used for both side facing and top mounted sensors - Fig 5.

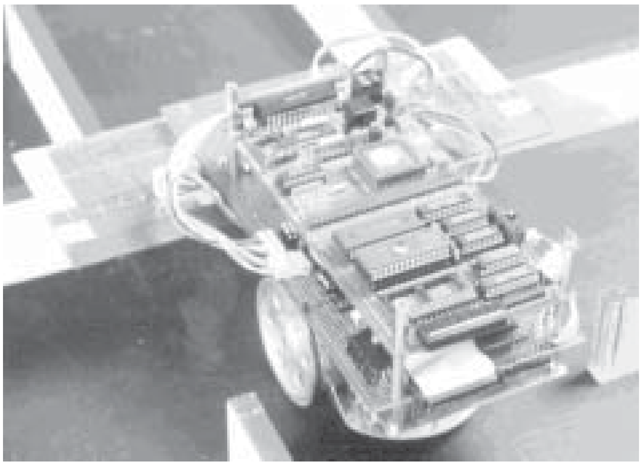

Fig 5. A view of the generic chassis used at CPHK

One area where little in-house innovation has been attempted is in the maze solving software. The 'intend to centre' algorithm is the one used by most Hong Kong mice. Calculating the quickest path is also another algorithm where 'standard' algorithms are used.

However attempts have been made to introduce new concepts into this area. An initial project using fuzzy logic for maze exploration and path planning showed some possibilities in this area, and will form the basis for further work. Similar work with neural networks is also underway.

The opening of a dedicated Micromouse Laboratory in 1993 meant that a full size maze could be kept permanently erected for students to work on year-round. This laboratory is also open in the evenings and on weekends so that part-time students can also work there. Another maze is available for competitions, so that no disruption occurs at those times.

5. Invading mice

The success of micromouse in the Department of Electronic Engineering at CPHK has led to its adoption by many other educational institutions in Hong Kong. The original plans for the new mechatronics degree at CPHK, run by the Department of Manufacturing Engineering(ME) [6], originally envisaged a micromouse project as part of the electronic engineering input. However, due to lack of resources this has not been implemented. This has not stopped ME students from getting involved in micromouse though. The standard chassis has been redesigned by one set of ME project students so that it is lighter, stronger and easier to fabricate.

At least once a year CPHK arranges a series of micromouse workshops for local schools. A summer activity camp for local schoolchildren, run by the EE Department also features an elementary experiment based on one of the standard chassis. These activities have meant that a number of schools are now taking up micromouse in a more structured way. It is hoped that sponsorship will soon be forthcoming to allow kits to be made available at low cost.

The annual Micromouse Contest always attracts a large crowd of school children and their teachers, as well as lots of publicity in the local press. This high profile means that a number of schools who are not taking up micromouse formally still support activities through the school's electronics or computer club.

One major change, that will affect the number of students involved in micromouse projects, is the decision by a new Vocational Training Council (VTC) college to adopt micromouse as a compulsory second year project for all EE diploma students. This course is the successor to those moved from CPHK in the preceding years (see Fig 3). Some 20 groups of students will be building mice over a 9 month period. To encourage this new course the next annual contest will be held at the college concerned.

6. Implications for education and industry

Micromouse impinges upon the students' training in many areas. The obvious one in the use of a simulated real life situation or problem. This allows them to come into contact with the sort of engineering problems faced in the 'real world' instead of the more theoretical simulation employed much too frequently at this level.

Micromouse also gives the students real problems to solve; and they have to be solved within a set time - around 40 weeks in CPHK's case, and within real budgets - around HK$1000. These extra disciplines mirror in some way the precosses involved in an industrial/commercial envirorment.

The integration of software, electronics and mechanical design along with the problem solving techniques involved in maze searching and solving algorithms, makes these type of projects unique,.which is why they are so popular, as well as useful in teaching mechatronics.

However, within the Hong Kong context, other aspects arise. Most of the students buy the parts for their projects from one of three street markets that specialise in selling used, or 'stock lot', electronic products. Thus, although the Micromouse Laboratory carries a stock of dc and stepper motors, gears etc, the students have to validate their purchases, and, in most cases, measure the specification, as data sheets are not usually available. This gives the students good practice in areas of electronic and electrical engineering that they may have glossed over in their other academic work.

Being an EE department means that students do not get a good grounding in motors and drives. The necessity of having to measure motor characteristics to compute the most efficient use means that large gaps in the students' more formal education are being filled.

At the same time, the fact that they are members of a team, with regular discussion between ‘competing’ groups, also gives an added dimension to development work that can be missed in a more traditional approach. Finally, the contests that are held locally, regionally and internationally each year provide an added incentive in the way of travel and prizes.

Each year Hong Kong has a local contest, usually attended by around a dozen teams. As the VTC, and other institutions introduce micromouse into their curriculum these numbers will increase.

Fig 6. Winners of the 1993 Hong Kong Micromouse Contest

The winner from Hong Kong has, in recent years, also attended contests in UK, Australia, New Zealand and Singapore. This added cross-fertilisation of ideas has meant that some technologies not considered in Hong Kong have been adopted, with interesting results.

Any education programme that aims to be useful to the local industry that supports it has to have a balance between academic and practical work. In an Asian environment, especially one based essentially on Chinese culture, emphasis is usually given to the rote learning of bookbased knowledge.

One of the objectives of tertiary engineering education is to overcome years of pre-conditioning, and to get the students to think together and to work together. At the same time, introducing experimental work into the curriculum that will be useful training for industry is also important.

The changing face on Hong Kong industry during the past decade has meant that this experience is not now part of everyday life. In the 60s, 70s and 80s, Hong Kong's main employment came from light, low tech, manufacturing. In the 90s this has mostly moved to southern China.

Hong Kong is moving towards a management, financial and skills centre for the Pearl River delta. This means that engineering education has to be more aware of these roles.

Group based projects, such as micromouse, coupled with inter-disciplinary ones such as robot ping pong, are one method of meeting these challenges.

The fact that vocational colleges and schools are also participating in mechatronics-based project work will enhance the appreciation of evolving and integrating technologies.

The only other country to take micromouse seriously, Japan, did so because its government saw exactly the same opportunity and need. Unlike Japan, however, Hong Kong has no centrally imposed curriculum or financial or technical support for setting up micromouse clubs. It is only the interest of members of staff at these institutions that allows such activities to flourish.

As southern China moves into higher technology manufacturing, it is clear that the same needs will arise there as arose in Hong Kong in the 80s, ie a technically advanced engineering profession conversent with up to date technologies. Micromouse and robot ping pong provide low cost, and exciting, ways of getting students interested in mechatronics.

7. Conclusions

During the five years that micromouse has been used for final year project work at City Polytechnic of Hong Kong thirty two mice have been built by forty three students. About twenty of these have successfully reached the centre of the maze. In 1991 World Championships, CPHK students came Ilth and 12th. In the 1993 World Finals in London the Hong Kong Champion came 2nd in the Student Class. Clearly great strides have been made.

The integration of electronics, mechanics and software, allied with the time and cost constraints, has made each micromouse project one of the best simulations of a real life design problem.

The added bonus of working as part of a team, and also the competitive nature of the contests, has also given the students a foretaste of the commercial environment. This is not usually possible with most final year projects, and would certainly not be true if only one or two mice were built each year.

The close working relationships expected with teams of students from ME courses gives the EE students experience in working with people from other, related, disciplines.

Finally, the rapid expansion of micromouse projects amongst the secondary schools, colleges and universities of Hong Kong is providing a means for students to meet 'real' engineering challenges. As Hong Kong loses its production base to southern China, this ability to solve problems in a close simulation of an industrial environment may be the only experience of project planning and management that our students meet in the local context.

8. References

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