Museum Robots: Multi-Robot Systems for Public Exhibition

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Abstract

Mobile robots provide a versatile platform for research, however they can also provide an interesting educational platform for public exhibition at museums. In general museums require exhibits that are both eye catching and exciting to the public whilst requiring a minimum of maintenance time from museum technicians. In many cases it is simply not possible to continuously change batteries and some method of supplying continous power is required. A powered flooring system is described that is capable of providing power continuously to a group of robots. Three different museum exhibit applications are described. All three robot exhibits are of a similar basic design although the exhibits are very different in appearance and behaviour. The durability and versatility of the robots also makes them extremely good candidates for long duration experiments such as those required by evolutionary robotics.

1. Introduction

Mobile robots are often used as a versatile platform for research, however they can also provide an interesting educational platform. In general museums need exhibits to be eye catching and interesting to the public whilst requiring a minimum of maintenance time from museum technicians.

One problem with exhibits involving real robots is the limited battery life of current robots – the exhibit must usually be able to run for twelve hours a day, seven days a week. This is far beyond the capacity of most current research robots and in many cases it is simply not practical to have staff available to change batteries or to swap robots for recharging every half hour or so. One obvious solution to this problem is to supply power to the robot from an external source. This could potentially be achieved by attaching a cable or tether that supplies power to the robot from an external power supply. However, such an approach can cause problems as tethers can easily become tangled even when only a single robot is being used in an environment. The problem is greatly exacerbated when multiple robots are employed in an environment.

A solution to this problem was developed in the summer of 1996 by Dave Keating and Iain Goodhew at the Department of Cybernetics, the University of Reading.

The solution to this problem devised by Keating and Goodhew was to supply power to the robot through a specially designed system of powered flooring. The robot was then able to receive power from the floor via a geometric arrangement of custom designed spring loaded brushes located on the underside of the robot. In addition to this the robot also had a backup battery that was constantly charged from power received from the floor, this battery could then be used in the event that connection with the floor was lost, forming an uninterruptible robot power supply.

2. Powered Floor and Brush Design

The powered floor design itself consists of several panels covered with a number of electrified stainless steel strips separated by a narrow insulating strip of epoxy resin. The floor is sanded after manufacture in order to form a smooth surface for robots to operate on. The purpose of the stainless steel strips is to conduct power to the brushes of the robot independent of the position and orientation of the robot within the arena. Each strip is alternately connected across the tile either to the supply voltage or to a current sink – see Figure 1. Similar floors have subsequently been constructed by other groups [Watson et al (1998)].

The robots receive power from the floor via a geometric arrangement of custom designed brushes mounted on the underside of each robot. The geometry of the brushes is such that the robots will receive power in any position or orientation on the powered flooring. The available power is used to both to supply all robot sub-systems in addition to trickle charging the backup battery.

Each robot possesses a set of five brushes, arranged in a cross hair configuration (see Figure 2a). The brush spacing, L_{gap}, is chosen so that at least two brushes are still in contact with the floor, even if three of the brushes are positioned over a strip of insulating epoxy resin. One or more brushes should therefore always make contact with a strip sourcing current from supply and one or more brushes should always make contact with a strip sinking current to ground. The current is then internally rectified within the robot by a network of diodes similar to that shown in Figure 2b.

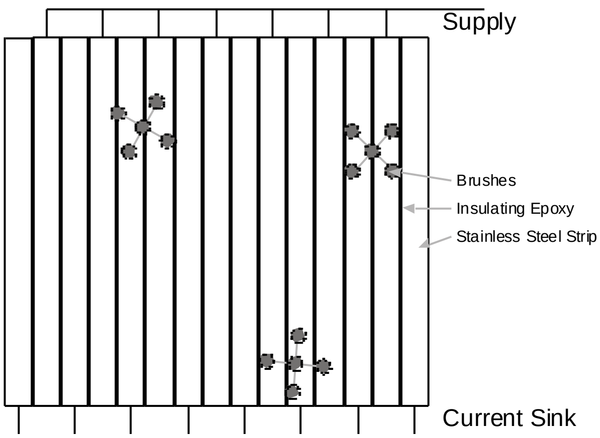

Figure 1: Schematic of powered floor, showing supply and brush positions.

Consider, the three cases shown in Figure 3. Case A shows the condition when three central brushes are over an epoxy resin insulating strip, in this case the length, L_{gap}, should be less than, GAP_A, to ensure both the leftmost and rightmost brushes are in contact with their respective stainless steel strips.

Case B shows the condition where the three central brushes are on the centre of one strip and the other brushes are just past the insulating epoxy, in order to ensure contact in this condition the length, L_{gap}, should be greater than GAP_B. However, for values of L_{gap} close to GAP_B it would be possible to rotate the brushes so that they were no longer in contact. Therefore, we need to consider the rotated version as shown in case C, in this case L_{gap} should be set so that it is greater than $\sqrt{2}.GAP_C$. Intuitively, cases A and C form the limiting cases creating bounds on the value of L_{gap}, since rotating case A can only decrease horizontal spacing, whilst rotating case C can only increase horizontal spacing.

The values of GAP_A and GAP_C depend on the width of the stainless steel strips, W_{strip} and the width of the insulating epoxy resin, W_{epoxy}.

Therefore from Figure 3:

$$GAP_A = W_{strip}$$

and:

$$GAP_C=0.5\ W_{strip}+ W_{epoxy}$$

Consequently, the bounds of L_{gap} sufficient and necessary for full connectivity are:

$$W_{strip} \geq L_{gap} > \sqrt{2}.(\ 0.5\ W_{strip}+ W_{epoxy})$$

Obviously, this also sets a condition necessary for full connectivity on the width of each strip and the width of epoxy required, which is:

$$W_{strip}>[2/(\sqrt{2}-1)].W_{epoxy}$$

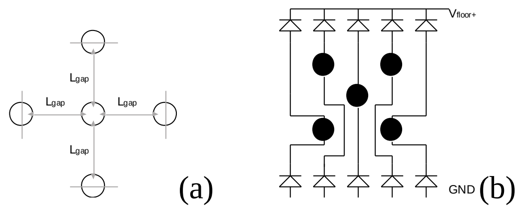

Figure 2: (a) Left: Brush Layout and Spacing. (b) Right: Brush Rectification Circuit.

There is also a more practical limitation on the width of the epoxy insulation; the width of insulation should be sufficiently large so that it is not possible for a brush to short circuit two strips together. Theoretically, of course a ball bearing will only have a point contact with the floor and the insulation could be made as thin as is practical. However, as the ball bearing wears during use, it is possible for the ball to develop flattened surfaces which could potentially short two sections together. In addition it would be sensible to use a sufficient gap to allow different brush designs that do not have a point contact to be tested. Also, the gap needs to be sufficiently large to allow for the manufacture of the floor. The insulation gap finally chosen was 4mm and the width of strip was chosen to be 38mm wide (this became the standard as the initial prototype floor made by Keating and Goodhew used conductive strips of tape that happened to be 38mm wide). With these measurements the range of values over which L_{gap} may range therefore becomes:

$$38mm \geq L_{gap} > 32.527mm$$

In order to allow for imperfections in the floor and brush layout it would be sensible to choose a value of L_{gap} somewhere close to the middle of these limiting values in order to leave the maximum tolerance. So long as the floor spacing meets the necessary condition the brush spacing, L_{gap}, can be chosen using:

$$L_{gap} \approx [(2+\sqrt{2})/4].\ W_{strip}+[\sqrt{2}/2].W_{epoxy}$$

This gives a value of $L_{gap}=35.26mm$ for the brush spacing when $W_{strip}=38mm$ and $W_{epoxy}=4mm$. With such a spacing electrical contact with the floor should theoretically be 100%, independent of both position and orientation.

3. Brush Contact Design

To ensure good contact with the floor, each brush is spring loaded with a weak spring pushing the ball bearing against the stainless steel strip, also forming an electrical connection between the ball bearing and the sheaf whilst still allowing the ball bearing to roll in its sheaf.

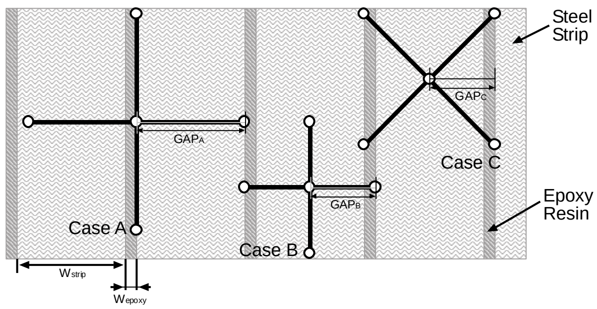

Figure 3: Brush spacing considerations to ensure 100% connectivity.

Each brush is also independently adjustable so as to allow the brush heights to be set and locked – see Figure 4. The ball bearing tends to rest on the spring when there is no motion and consequently there is only a high resistance connection between the ball and the sheaf itself, therefore the lowest resistance connection is formed between the ball bearing and the spring - *not* the ball bearing and the sheaf. Due to this, care has to be taken in order to ensure that the spring is sufficiently conductive. If the brush has too high a resistance and current demands from the robot are also high then the voltage drop from two brushes (two connections are required to the floor, one from supply and the other to ground) could be problematic if the voltage dropped below what is required to charge the robots backup battery or to run the robots systems. There are two obvious solutions to this problem either the floor voltage can be raised or the resistance of the brushes reduced. Due to safety considerations the floor voltage must not exceed 50V, in fact it is desirable to keep this as low as possible to avoid any electrical arcing on brushes and also to decrease the risk of accidental shock from the floor. Therefore, it is desirable to keep the brush resistance as low as possible and to use a floor voltage well below 50V.

4. Robots and Sensors

The robots used are all of a three wheel design, using two differentially driven rear wheels and a front castor wheel for balance, similar to the robots described in [Mitchell et al (1994)] and [Kelly (1997)].

The robots in all three different exhibits are equipped with a common suite of sensors. Each individual robot is equipped with a set of ultra-sonic range finding sensors that allow them to determine the range to hard objects in the environment. These sensors are used primarily for obstacle avoidance.

Each robot is also equipped with a digital scanning infra-red receiver and transmission beacon. This system is used by each robot in order to determine the approximate angle and range to other robots in the environment.

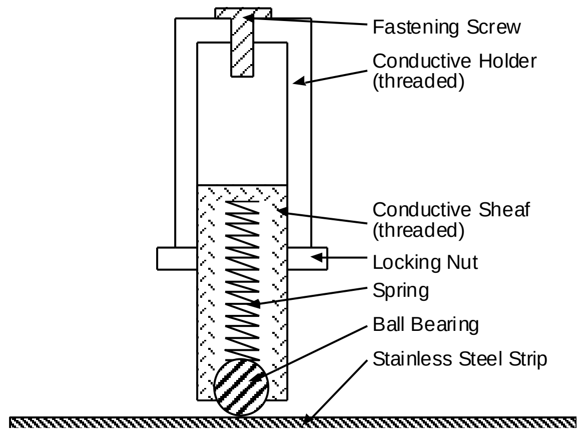

Figure 4: Spring Loaded Brush Schematic.

The receiver system consists of six infra red photodiodes, arranged in a circular configuration, spaced at 60 degrees.

First, the infra-red signal from each photodiode is amplified and then multiplexed this is then mixed and filtered using a standard FM radio IC, the received signal strength is then measured by an A/D converter. Also, since the received signal strength uses a logarithmic scale the range can be estimated using a simple linear approximation. The intensity information received at each transmission frequency can then be used in order to determine the approximate range and angle to each infra-red source within sensor range.

The robots are additionally equipped with a half duplex bi-directional radio communications system. This is used in order to co-ordinate exhibit behaviour via a base station, allowing robots to be removed and swapped, when a robot needs to be serviced.

5. Exhibit Descriptions

Three different exhibits have been built based on the same basic robot design and sensor suite.

All three exhibits are based on robots of a similar basic design although the exhibits are very different both in appearance and behaviour. In the first of the exhibits, the “Robochase” exhibit consists of a large 3x3m arena containing two robots, one visitor controlled and the other computer controlled. The visitor is able to select whether they wanted to play a game of “pursuit” or “evasion”. Then by means of a joystick interface the visitor can remotely control one of the robots and depending on the game selected the computer controlled robot will either run away from the visitor controlled robot or chase after it.

The second of the exhibits, the “Robot Pit” exhibit consists of a 4x1.4m arena containing up to six robots designed to demonstrate simple group behaviours. The visitor is able to select four different games “Herding”, “Flocking”, “Simon Says” and “Follow Me”.

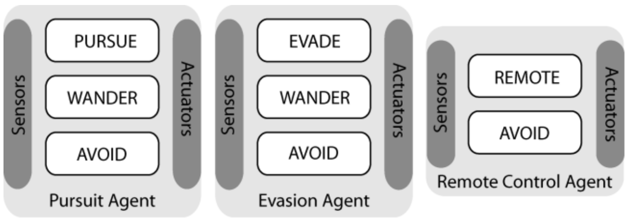

Figure 5: Robochase Control Architectures.

As in the first exhibit the visitor is allowed to remotely control one of the robots via a joystick interface, however the rest of the robots are under computer control. Depending on the mode the computer controlled robots react in a different manner to the actions of the visitor controlled robot. This produces different group behaviours that the visitor can influence.

The third of the exhibits, the “Learning Robot” exhibit is completely autonomous in that it automatically detects the presence of a visitor and attempts to attract their attention via means of a light display. The exhibit demonstrates a machine learning task with the robots gradually learning to follow one another in a line.

6 Control Architectures

In all three exhibits individual robot behaviour is generated by a subsumption style architecture [Brooks (1986)]. The subsumption architecture is a layered architecture where each behaviour is directly “wired in” from the sensors to the actuators. The subsumption architecture allows Low level reactive behaviours to be put in place first, such as halting if you get too near an object or initiating motion away from obstacles, higher level layers of behaviour are then built up on top of this first layer, in order to guide the robot in a particular direction, for instance. The second layer does not need to concern itself with obstacle avoidance as this is already dealt with by the first layer, neither does the first layer have to worry about what direction it should be heading in as this is dealt with by the second layer of behaviour. In this way it is possible to add behaviours to the system, piece by piece, with simple lower-level behaviours being suppressed or *subsumed* by higher-level behaviours.

6.1 Robochase Exhibit

In the Robochase exhibit three different subsumption controllers are used – these are shown in Figure 5. The exhibit operates in one of two modes a game of “evasion” or a game of “pursuit”. Two robots are present in the arena at any one time - one robot is under autonomous control whilst the other is remote controlled by the visitor via a simple joystick interface. Depending on the selected game mode the robot under autonomous control will either use the evasion controller or the pursuit controller.

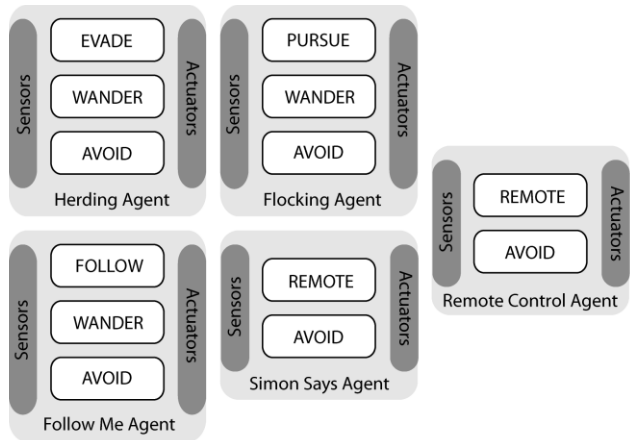

Figure 6: Robot Pit Control Architectures.

All three controllers utilise the same low-level avoidance behaviour, this uses the ultra-sonic range finding sensors in order to avoid collisions. This behaviour is also present on the remote controlled robot in order to prevent potential damage to the robot from a human user driving the robot into obstacles and walls.

Both the pursuit and evasion agents have a basic wander behaviour built in which causes the robot to wander randomly around the arena when it is above a specified range from the remote controlled robot. When it is within a specified range either the pursuit or evasion behaviour becomes dominant. In a game of pursuit the robot turns towards the remote controlled robot and heads towards it at full speed whilst in a game of evasion the robot will turn away from the remote controlled robot and head towards clear space.

In addition to the game playing behaviours a further power-seek behaviour was also added this behaviour ensured the robots are always in good contact with the powered floor when the exhibit is idle thereby preventing the possibility of the back-up batteries running flat.

6.2 Robot Pit Exhibit

The robot pit exhibit operates in a similar fashion to the Robochase exhibit except that up to six robots are present in the arena at any one time. The exhibit operates in one of four user selectable modes “Herding”, “Flocking”, “Simon Says” and “Follow Me”. A different subsumption architecture is used for each different behaviour – these are shown in Figure 6. During testing of the exhibit prototype it was noted that visitors found it difficult to determine which of the six robots they were controlling. In order to make this more obvious an animated light display was added to the top of the robot under remote control in order to draw attention to that robot.

The architectures that implement the “Herding” and “Flocking” behaviours are very similar to the behaviours that implement the “Evasion” and “Pursuit” behaviours in the Robochase exhibit with the thresholds for activating the evade and pursue behaviours set to different levels. The effect of the “Herding” behaviour is that the autonomously controlled robots will attempt to get as far away as possible from the remote controlled robot. The effect of the “Flocking” behaviour is that the autonomously controlled robots will attempt to get as close as possible to the remote controlled robot.

The “Simon Says” behaviour is merely a copy of the remote control behaviour. With a basic avoid behaviour in place to help prevent damage from collisions with walls and other robots in the arena. The effect of this behaviour is that all robots emulate the behaviour of the remote controlled robot.

The most complex behaviour used in the Robot Pit exhibit is the “Follow Me” behaviour. This behaviour is based on the pursue behaviour except that each robot is allocated another robot to follow i.e. robot C follows robot B, which in turn follows robot A which is under remote control. The effect of this behaviour is that as the lead robot is driven the robots form into a chain behind the lead robot in an orderly queue.

A picture of the actual Robot Pit exhibit is shown in Figure 7. The powered floor brush pick-ups can clearly be seen below the robots and the “crowns” visible on top of the robots are part of the infra-red location system.

As in the Robochase exhibit a power-seek behaviour was also implemented in addition to the game playing behaviours. This was designed to ensure that the robots are always on power and to ensure that they are in good contact with the floor when the exhibit is turned off. This ensures that when power is restored the robots are able to power up correctly.

6.3 Learning Robot Exhibit

The “Learning Robot” exhibit is by far the most complex of the three exhibits. The exhibit is completely autonomous, with the robots quickly learning to follow one another in a line using a simple reinforcement learning algorithm [Sutton and Barto (1998)]. The exhibit consists of 6 small robots operating on a powered floor. When a visitor approaches a PIR detector triggers the beginning of the learning sequence. As the sequence begins, the robots light up in order to attract the visitors attention and begin the reinforcement learning demonstration. Initially, the robots take random actions and gradually learn by a process of trial and error the correct actions to perform in order to achieve the task. The robots take approximately two minutes to learn the follow-in-a-line behaviour.

Figure 7: Robot Pit Exhibit in the Science Museum, London.

At the end of the learning period the robots are stopped and the exhibit is reset until another visitor is detected by the PIR detector.

7. Conclusion

Whilst the robots described were initially developed for museum exhibits the durability and versatility of these robots also makes them suitable for other areas of research that potentially require long duration experiments such as machine learning or evolutionary robotics experiments. The powered floor system allows for multiple robots to run in the same area for extended periods of time without tethers or having to recharge batteries. The existing sensor suite also allows for the robots to be controlled remotely and to determine range and angle from fixed beacons thereby allowing the position and orientation of each robot to be known within an arena.

8. References

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