UNIVERSITY COLLEGE LONDON

PHAS3441 GROUP PROJECT
GROUP 5: THE SAND·E GROUP

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The Development of a Sand Art–Drawing Robot: Sand·E

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Acknowledgements

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Write acknowledgements

Executive Summary

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Introduction

(*writer TBA*)

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Section 1

Introduction and Preliminary Research

1.1 Project brief

(*writer TBA*)

Introduction and Preliminary Research: project brief

1.2 Art review

(*A. Hyslop, A. Rutley*)

Land art (or Earth art) utilizes the landscape itself to produce the art. Structures are often made by placing natural materials, such as rocks or twigs, onto the land to form a pattern or picture. Another way they are produced is by sculpting the land to form patterns. The art is not simply placed onto the land, rather the land is the means of the creation. Pieces are often ephemeral in nature, being left to erode due to natural conditions over time, and so now only exist in photographic and video documentation. A significant inspiration for the creation of land art came from people's awareness of the negative impact they can have on the environment around them. By incorporating art into the natural landscape, artists hope that it will change peopleâĂŹs perspective of the environment around them.

Land art is a largely American movement which began in the late 1960s. The movement is an offshoot of conceptualism and minimalism and was a protest to the commercialization of American art, leading the artists to produce works which were removed from the art market.
It can be argued that land art was created by ancient cultures. Examples of land art occur around the world, such as the Nazca lines produced by the Nazca in southern Peru and The Great Serpent Mound in Ohio, US. It is believed that these pieces could have been created as a form of worship to the gods of the cultures which made these

(a) Sand-printing tractor. The roller on the front produces the imprints.

(b) Large-scale imprints produced using the tractor.

Figure 1.1: Gunilla Klingberg's 'sand machine' and the pattern it produces. (Retrieved from [1] on 2016–01–20)

pieces.
The modern movement began with the group exhibition "Earth works" in New York City in October 1968. In the following year, Willoughby Sharp curated the "Earth Art" exhibition at Cornell University which included many artists, such as Robert Smithson and Richard Long, who were big influences within the movement. Due to their monumental size the pieces were usually documented in photographs and maps which the artist could exhibit in a gallery. Land art was occasionally also produced within galleries; this was done by bringing in materials from the landscape and using them to create installations.

1.2.1 Sand art

There are various styles of sand art; the main two are large scale sculptures and 2-dimensional freehand drawings. Over recent years smaller scale sand storytelling has developed which is concerned with both the performance and the final images produced. Large-scale artists mostly use easily accessible equipment such as shovels, buckets and rakes for freehand drawing and trowels and spatulas for sculpting. However, Swedish artist Gunilla Klingberg has developed a sand-printing tractor(Figure 1.1a), which produces large imprints across beaches (Figure 1.1b). A low tide is needed for both printing and free hand drawing due to the wet sand.
Jim Denevan, a popular freehand sand artist, ranges the scale of his work from small beach compositions to land works the size of a city. He has done live performances for

exhibitions at Yerba Buena Centre for the Arts, 2005, and the Vancouver Sculpture Biennale, 2010. His work has also been featured in popular magazines such as the New York Times Magazine and National Geographic. Denevan does not use any sort of measuring tools and spends an average of 7 hours, walking about 30 miles, when producing his work. After all of this time his work is soon washed away by the incoming tide.

Though the transient nature of this art form seems defeatist, it is actually the motivation for many sand artists. Andres Amador says he prefers a temporary medium and is much more concerned with his "process and less about the result." He does not produce any form of permanent art work. Mr Amador's pieces, known as playa paintings, are produced using simply a rake and a rope as a guide (Figure 1.2).

(a) Andres Amador using a rake to produce his playa pictures.

(b) Large-scale imprints produced using the tractor.

Figure 1.2: (Retrieved from [2] on 2016–01–23)

Charlene Lanzel produces small-scale sand stories. Their creation can be observed as she creates images on a table top, projected onto a large screen sitting above her. Lanzel produces her images in darkness, the sand sitting on a glass table with lights underneath. Unlike other forms of sand art, her work is not washed away by the tide; instead she destroys the work herself in order to produce fluid images that play like an animation. Lanzel uses soundtracks alongside her performance to tell her stories and fully immerse her audience.

Sand sculpture may be the largest scale form of sand art. Competitions are popular on beaches around the world and sculptures with the stature and solidity of woodcarvings are often produced. Sculpture is also the most permanent style: many sculptures produced indoors last for more than a year.

1.3 History of robotics (*S. Wright, A. Kallaivannan*)

Autonomous robots have become common in many fields: factories make use of autonomous workers; space exploration vehicles include autonomous navigation systems and automated scientific instruments; military and commercial aircraft use autonomous systems to stay airborne; and large utilities providers (*e.g.* water treatment plants and power stations) have some automated control systems.
These technologies have been developing since the early 20th century. Some of those developments are of particular interest with regard to the development of a sand art–drawing robot.

One difficult challenge in autonomous robotics is that of navigation. Many of the most advanced navigating robots that have been designed have been entrants in a Micromouse competition.
The model of the Micromouse competition was introduced in 1977 by IEEE Spectrum magazine.[3] It involves robots competing to get to the centre of a maze in the fastest time. There have been many variations of the rules, but the main theme is that the robots are autonomous. The inaugural competition was held in 1979 and was won by a high-speed dumb wall follower. In 1980 an entrant became the first Micromouse robot to find the centre of the maze and know it had done so, although it travelled at only $0.2\,\mathrm{m\,s^{-1}}$.

Autonomous movement presents several other challenges. Many robots have been developed to move over different terrains. In particular these have been used to explore the surface of alien planets.
The history of successful Mars rover missions began in 1997 with NASA's pathfinder mission. The 'Pathfinder' lander contained a rover, 'Sojourner', capable of exploring the martian surface. Sojourner succeeded in traveling 330 feet from the lander before it stopped communicating.[4] Since then, NASA's Jet Propulsion Laboratory (JPL) has continued to develop robotic rovers for the unmanned exploration of Mars.
Mars rovers must operate over sandy and rocky terrain. To facilitate this movement, all four rovers which have remained in communication with Earth for more than a day were equipped with 6 wheels. This locomotion mechanism was developed by testing the movement of rover prototypes in a Mars analog environment here on Earth. Given its similar terrain, the Mojave desert was selected. By the very nature of their missions, Mars rovers must operate far from human physical intervention and between 4 and 24 minutes behind instructions from Earth.[5]
The motivation behind Mars rovers is two fold – to complete scientific objectives to

further improve our understanding of Mars and the solar system, and to complete mission objectives, improving the current state of space technology. Robotic rovers allow these objectives to be pursued (to varying degrees) without the risk of human life, and the far greater cost, of manned spaceflight.
The latest rover to be sent to Mars, The Mars Science Laboratory (MSL), or 'Curiosity', landed in August 2012.[6] It was deposited on the Martian surface by a vehicle called 'Skycrane'. The Skycrane propulsively slowed Curiosity's decent, before lowering it to the ground by cables. Aboard Curiosity are instruments including cameras, radiation detectors and X-ray diffraction and spectrometry equipment. With this technology Curiosity is able to explore Mars and conduct scientific investigation.

1.3.1 Sand-drawing robots *(S. Wright)*

Figure 1.3: ETH Z urich's BeachBot robot.(Retrieved from [7] on 2016–01–28)

The 'best-in-class', and indeed only notable, beach-scale drawing robot is Disney's BeachBot (Figure 1.3), produced by ETH Zurich.[7] The robot is capable of drawing images in the sand – this has particular application in marketing Disney's sea themed–franchises and providing entertainment at Disney's beach resorts.
The robot's drawing mechanism consists of fourteen rake teeth mounted in pairs on seven servo motors – this allows lines of varying width (or no lines) to be drawn. The BeachBot is driven by two rear wheels and steered by a front wheel – in a three-wheel configuration. It is fairly compact, measuring only sixty centimeters in length. BeachBot's chassis is enclosed in a sealed aluminum shell to protect its components from the sand. From this shell a laser scanner (part of BeachBot's guidance system) protrudes. The laser scanning guidance system directs BeachBot to draw its programmed image relative to reflecting posts installed by the user; this provides a 'canvas' on which BeachBot works.
BeachBot's shell is design to give it the appearance of a turtle from Disney's *Finding Nemo* property – not only does this incorporate Disney's brand image into the design, but it also provides a non-threatening look. The latter point will be important for our robot since it will need to operate on a beach, an environment in which people are not used to seeing machinery.
It has been suggested that with modification BeachBot could be used on snowy terrain

to promote Disney's winter themed–franchises.

Although not beach-scale, Google has produced tabletop-scale sand art machines called 'sketchbots' (Figure 1.4) (Operational at the science museum in London between 2012 and 2013).[8] The robot itself was integrated with the tabletop; it comprised an arm with a mounted stylus and a 'sweeping' implement, which moved in a circular motion, to clean the sand canvas. The robot took an input of the user's face from a camera, parsed the image and then drew it in the sand. Google created the installation as part of its 'Chrome Web Lab', showcasing modern web technologies such as HTML5.

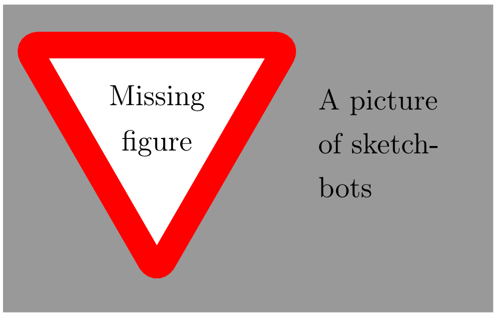


Figure 1.4

1.4 Robotics in education (*S. Searles-Bryant*)

The programming language Scratch was first released in 2005. It was designed by the Lifelong Kindergarten Group at the MIT Media Lab as a tool to introduce algorithmic thinking to 8–16 year-olds.[9] The group state on their website that

> "Scratch helps young people learn to think creatively, reason systematically, and work collaboratively – essential skills for life in the 21st century."

The inclusion of computational thinking in the primary science curriculum is gaining popularity. The ability to express the steps required to solve a given problem are important learning goals for children in a world where many rely on technology in the home, at work and in school.

Furthermore, tools which allow students to employ these skills in the real world have proved to be very popular. The first programmable Lego product was released in 1989; since then the concept has been developed by numerous groups. Now there are several robotics platforms for educational purposes. The Lego group have several such platforms: the Lego Mindstorms range includes commercial packages as well as packages designed for schools. These allow high-school students to build embedded systems using different sensors and effectors to interact which can be programmed. The Mindstorms range forms the basis for the First Lego League competitions, which operate all over the world. MIT's Zero Robotics competitions also allow high- and middle-school students to program spherical robots on the International Space Station

to solve challenges as part of an annual competition.[10]
More recently, systems have been developed for younger students. Lego WeDo and WeDo 2.0 are designed for children aged 7–10 years to build simple robots and program them to perform actions using a software package based on Scratch.[11] This approach to robotics and programming has been designed in accordance with the US National Research Council's 'Next Generation Science Standards'.

Figure 1.5: The Valiant Technology Classic Roamer, a robot designed to teach algorithmic thinking to primary-age children. It is based on the Logo programming language. (Retrieved from [12] on 2015–01–18)

However, none of the these technologies are new ideas: the programming language Logo was developed in 1967 as an educational tool. Among other features, Logo employed the idea of body-syntonic reasoning: processes are carried out relative to the current state, rather than relative to some reference state. One of Logo's creators, Seymour Papert, also invented a turtle robot (inspired by the tortoise robots developed by neurophysiologist William Grey Walter in the 1940s); this robot was programmed using Logo to move around a surface and draw patterns. It carried a pen and could be instructed to turn, move forwards and deploy or retract the pen. Using these simple commands, the turtle robot could be programmed to draw pictures and patterns on the surface over which it moved.
Seymour Papert's turtles continue to be popular in primary schools across the world; the modern iteration is Valiant Technology's Roamer (Figure 1.5).[12] Simple interfaces have been designed for the Roamer so it can be used without a programming language. Different models are available with different levels of complexity for different age ranges.

Section 2

Design Outline

2.1 Aims and motivations (*A. Goodsell*)

The invention of the difference engine in 1833, came with it an entire new process of thought and development. Since then, the field of computation and robotics has become one of the largest in the world. It is a field that requires developers to suspend their usual way of thinking and instead look at tasks and problems as a computer. These ways of thinking are not encountered in daily life. Other intellectual and physical fields have their foundations discovered through juvenile interactions. However, the ability to approach a task with an algorithmic method—a loop or conditional statements—is not naturally acquired. These skills must therefore be taught through non-conventional means. This could be as a teenager or adult, when first being confronted with programming; however, years of educational studies have shown that skills and understanding are much more easily acquired at an early age. This is the motivation of the Sand·E project: to develop a method, useable by schools and parents, to begin to nurture programming skills in children.

This section is identical to Section 4.1. Here should be some options for motivations and reasons for them, perhaps? (More in keeping with the rest of the chapter.)

The aim for this project is to develop a working prototype of a programmable, autonomous robot with the ability to draw large scale art in sand. The robot will be able to accept a set of repeatable instructions from a student. These instructions could include: navigation, for example an instruction to go from point A to B before turning and traveling to point C; the ability to control whether the robot should be drawing at any given time, and also the thickness of the line drawn. The student will create these instructions through a graphical user interface, before they are uploaded to the robot and their design is created in sand. The intention is that by passing a design to a robot, students will be forced to think about how a computer will tackle a task they would find simple. Hopefully, students will be able to understand that computers use a system of specific logic that can create wonderful things, which would take much longer by hand.

2.2 Movement (*S. Wright*)

In considering the robot's locomotion, the terrain over which it will travel (sand – potentially damp) and its purpose (drawing) are center-stage. The robot must have sufficient traction to travel over a beach. When considering the requirement that it draw, it must be able to turn as tightly as instructed to avoid incongruity between programmed and drawn images. It may also be possible to incorporate any turning limitations into the child's programming interface, such that an impossible turn cannot be instructed. It would also be far from ideal for the robot to obscure any lines it had already drawn when pathing back over them.

The main methods of robot locomotion that might be relevant are wheeled (or caterpillar tracked), walking, rolling, or slithering. Considering the scope of this project, and the budget available, the latter options are not viable. Companies such as Boston Dynamics have budgets of millions of dollars to work on the development of walking technology – achieving a robot capable of walking is a significant feat, even before considering drawing. While rolling or slithering may potentially be workable, they would contribute significant design complications to any kind of 'on/off' functionality. Flying private drones have increased in popularity dramatically; in considering a drone type robot as an option, the main challenges are the extreme comparative difficulty of achieving flight compared with traction and drawing a line in the sand. Creating a flying drone from scratch would pose many challenges, which it is unlikely we could surmount with this project's resources. The marker design also poses significant challenges – a marker fixed rigidly to a drone is likely to interfere with flight and a free-hanging marker runs the risk of not providing enough pressure to create a line. The most viable locomotion solutions are caterpillar tracks and wheels.

Caterpillar tracks combine very capable terrain handling with on-a-point turning, however they are very likely to disrupt the line left behind the robot, especially when on-a-point turning. With the right design and material, wheels might prove sufficiently able to handle the terrain and also cause limited harm to the robot's drawn lines. Such wheels would need to have a large surface area and be made of a reasonably soft material (*e.g.* soft touch plastic) – minimizing the robot's overall weight would also be important in making such a design choice viable. Although wheels open opportunities in terrain handling and line preservation, they come up short of caterpillar tracks on turning ability. A short wheelbase might go some way to improve this. There is also the potential of a three-wheel configuration, instead of four (or more) wheels – this was implemented in Disney's BeachBot (Section 1.3.1) to the benefit of the robotâĂŹs turning circle. It should be noted that a three-wheel design raises stability concerns. Ultimately the decision between caterpillar tracks and wheels comes to a question of whether, or to what extent, the child instructing the robot should be limited in their design.

2.3 Digging mechanism (*S. Wright*)

At its most basic level, a beach-scale sand drawing robot need only leave a line in the sand wherever it travels, in order to produce a picture – this poses a severe constraint on what can be drawn. In the case of our educational robot, the child would have the limitation of instructing the robot to draw a picture with only a single continuous movement. This 'always on' approach to the drawing mechanism can be improved upon.

Instead of fixing the robot's marking implement, it could be built to raise or lower, adding 'on/off' drawing functionality. The marking implement, or 'marker', could be fitted to an actuator to achieve this. The actuator could be linear or rotary; a linear actuator would lend itself to a marker below the robot chassis, while a rotary actuator would be more appropriate for a marker behind the chassis, like a rake tooth (as is being used in Figure 1.2a). A rear mounted, rake-like design might provide a more fluid, pulling movement through the sand. There are precedents for this positioning choice: Disney's BeachBot (Section 1.3.1) and plough attachments for tractors. While the addition of an actuator significantly improves the robot's drawing flexibility, it would be vulnerable to sand in its mechanism and would add cost, should one not be salvageable from spare parts. The use of an actuator would also place a small requirement on the robot's power supply.

The marker itself needs to exert sufficient force on the sand to leave a line behind the robot, without acting as a brake – this would inhibit the robot's movement. Inhibition of the robot's movement would lead to significant deviation in the drawn image compared to the programmed image. The key to avoiding this is to create a marker with appropriate depth; the marker should not penetrate so deep in the sand as to invite significant resistance to its motion, while reaching deep enough to leave a sufficient (*i.e.* visible) line.

Implementing software to vary the depth of the marker could serve to mitigate any issues arising from resistance, and also could ensure trouble does not arise on uneven beach area. The limitations here lie within the realm of software development, and potentially the requirement that the actuator provide feedback.

Within these parameters the marker itself could be varied – for instance having multiple markers would provide a different pattern to the line. These multiple markers could be fitted to more actuators (with the potential of substantially increased cost) to allow for a variable line width.

An alternative marker approach would be that of a cylindrical 'drum'. Such a cylinder could have a pattern embossed upon it that would leave a pattern as the robot's marking. Gunilla Klingberg's 'sand machine' (Section 1.2, Figure 1.1a) uses this approach. This approach could be implemented with 'on/off' functionality, but would allow for only a preset pattern in the line. The implementation of a patterned line of varying width (*e.g.* multiple drums with raising and lowering ability) could prove very problematic. Such an implementation of this method would be best achieved in a manner similar to NASA's RASSOR digging robot – a drum separate from the locomotion mechanism that can be lowered and raised.[13] In a similar way, the NASA's Curiosity rover leaves the pattern for "JPL" in Morse code in its tracks as it travels across the Martian surface.

2.4 Interface (*writer TBA*)

Design Outline: interface

2.5 Guidance (*C. Lau*)

In order to draw an image in a given area, the robot will need to be guided by some system. It has been decided that the robot will be autonomous. This section will focus on three different guidance systems: ultrasound, lasers, and GPS. There are many other guidance systems that have not been mentioned such as tethering, grid systems, infrared, and more. These other guidance systems have not been mentioned because they are either too complex, have too small of a range, or it is not possible to make an autonomous robot using the particular guidance system.

2.5.1 Ultrasound

An ultrasonic sensor is made up of two parts, a transmitter and a receiver. The transmitter emits a sound at a defined frequency (typically around 40 kHz) and the receiver collects the sound reflected back by the obstacles. The distance to the objects is calculated by measuring the time taken by the sound to return to the receiver. Ultrasound is normally used to measure distances because sensors because they are cheap and very simple to use. Ultrasound has a range of 1 cm to 250 cm and an effective working angle of approximately 30°.[14] The working angle of ultrasound can be pictured as a cone that has an angle of 30°, where measurements of distance will be more accurate within the centre of the cone and less accurate towards the sides.

Other things to be considered with ultrasound are the shape of the obstacle and the inability of ultrasound to make measurements of distance when the sensor is very close to an obstacle. This is due to the sensor needing a large enough return time for the wave that is reflected.

This is ambiguous; what do you mean? (CL)

2.5.2 Laser

Lasers can be used in different ways to guide the robot. One way is to have a guidance system for freely chosen courses, which uses a laser beam that hits strategically placed mirrors to reflect the beam. The on-board controller then analyses the angles that the beam is reflected at and uses triangulation to determine the position of the robot. Another method is to use a laser range finder that emits a beam and measures the time taken to reflect off the object and return to the sender. Both methods are accurate to within a few millimetres but the first method is the more accurate of the two. Laser guidance systems can be used in any environment and have a range of several metres. They have a range of several metres and out of the three guidance systems mentioned are the most accurate. The markers for the laser beams have to be set every 2.5 m to 4.5 m and should not be blocked. The robot must be able to see multiple markers (mirrors) at once so that it can determine its precise location. The only disadvantages of using a laser guidance system are that they are the most complicated and the most expensive of the three systems discussed.

2.5.3 GPS

Global Positioning System (GPS) receivers use a constellation of 31 satellites orbiting over 20,000 km, with a revolution period of 12 hours (as of February 1st 2016). Every satellite transmits data packs, which contains: the time, current position, other satellites positions and other information. The GPS receiver receives the information about position from the radio transmissions of the satellites it can track. 4 satellites are normally used to compute the position. Although it is possible to measure the position with fewer satellites, the margin of error is large.

GPS shields are inexpensive and as a guidance system, obviously have a very large range. However, the accuracy of GPS, which may be within few metres, may depend a number of things such as signal noise, satellite position, and obstruction from tall buildings. Therefore, if GPS is to be used as the guidance system for the robot, then its worth considering a location that is isolated from tall building when it comes to the testing of the robot because signal noise can cause errors up to 10 m and obstruction from tall buildings can cause errors three times more than the error from signal noise.[15] There are ways of getting the accuracy of the GPS down to a few centimetres by using correction methods such as a differential GPS, using a combination of GPS and some other local positioning systems such as electronic compasses or Inertial Navigation System (INS). However, these correction methods are complex and expensive and therefore they are not feasible solutions to increasing the accuracy of GPS.

2.6 Construction materials *(A. Kallaivannan)*

An important consideration when deciding on a material for the body and base of the robot is the penetration into the sand. A denser material will cause the robot to sink more, but lighter materials will mean a compromise in strength, stability, or price. However, if the wheels or tracks of the robot are wise enough, there may be some freedom when deciding what materials the components of the robot should be made of.

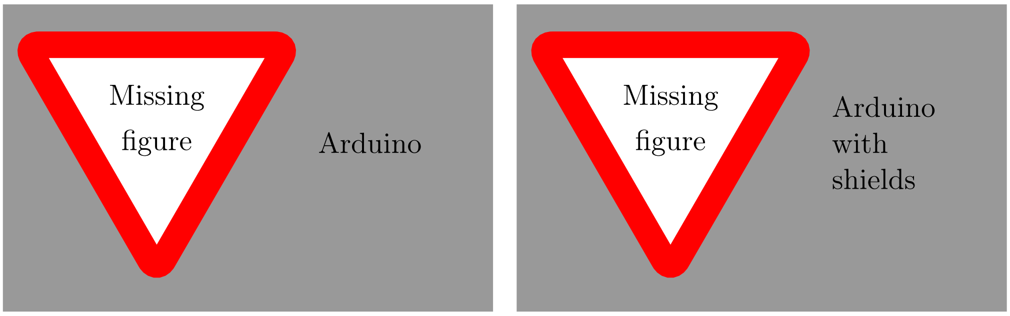
Researchers at the Georgia Institute of Technology have been able to vary the strength of the supporting ground by using varying air flow from beneath.[16] This has allowed them to vary the stiffness of the sand and observe the performance of a robot on these surfaces.

The robot should be made to be water resistant; contact with water at some point is inevitable and water coming into contact with the electrics would reduce the lifespan and reliability of the machine. Damage caused by sand should also be a consideration: the machine is likely to come into contact with a substantial amount of sand. Sand is silica, which is very abrasive; if this abrasion occurs around the more sensitive areas of the machine it could cause extensive damage. Sandusa is a range of beach products that are water- and sand-proof.[17] This is due to a smooth nylon material that allows sand to slide off easily combined with an inner waterproof lining. This material could be used to protect the robot.

2.7 Electronics platform *(S. Searles-Bryant)*

The robot will need a control system to plan and control its movement, and to control the drawing tool. This system could be developed from proprietary systems or built by the group for this specific application.

Arduino (Figure 2.1a) is an open-source micro-controller system designed for embedded systems control. It can be expanded by the use of *shields* (Figure 2.1b), circuit boards designed to attach to header pins on the primary micro-controller board to created stacks of circuits with different functions. This would allow us to build a control system for the robot using pre-designed circuits. Shields, which can be sourced from many electronics suppliers, are available to add bluetooth, GPS, motor control, and



(a) The Arduino controller circuit board (b) An Arduino with shields attached

Figure 2.1: (Retrieved from on 2016–01–25)

many other functions to the primary circuit.
There is a large online community supporting the Arduino project, which could be leveraged to solve programming difficulties if they arise. The Arduino project provides an integrated development environment (IDE); the Arduino is programmed using a language based on the C and C++ languages.

Netduino is a variant of the Arduino which runs on Microsoft's .NET framework. The online support community for this system is smaller, although some group members (A. Goodsell, L. Yeo) have a pre-existing familiarity with the .NET framework.

Electronics: rework the following paragraphs

Paspberry Pi is a small single-board computer developed in the UK to promote access to computer science education in schools. Because on this, the platform is already widely used in an educational setting and thus would allow this project to be more easily integrated into the teaching of computer science. The computer itself is low-cost (<£50).

check the price of Raspberry Pi

The Raspberry Pi Foundation also produce smaller versions of the Raspberry Pi computer which are designed for use in embedded systems. These boards are less customizable than the Arduino system. However, it is compatible with the Python language, which has an extensive support community online and is familiar to all the group, as well as C, C++, Java, and others.

A micro-controller integrated circuit could be used in a purpouse-built circuit to control the robot. This would require the design of all the supporting electronics. The microprocessor would need to be programmed in a low-level assembly language or a

language designed specifically for the micro-controller product we use.
These components would be cheaper than commercially available systems, but would require much more electronics design work and fabrication.

2.8 Summary and decisions

Design Outline: summary and decisions

Aims and motivations (*writer TBA*)

Drawing tool (*writer TBA*)

Electronics platform and guidance system (*writer TBA*)

2.8.1 Outline specification (Whole Group)

The project

1. We shall design and build a prototype robot to draw 2d line drawings in sand.
2. The robot shall take input from a user which it shall translate into instructions to draw the picture;
3. the drawings should be ??? in size;
   how big will the drawings be?
4. the robot should be for educational uses.

Control systems

5. The robot shall be controlled with an Arduino;
6. the robot shall use GPS for guidance;
7. the robot should detect objects in front of it. The robot should not collide with objects;
8. the robot should circumvent obstacles.

The robot hardware

9. The robot shall move across the sand using ???;
   how will it move?
10. the robot shall use ??? to draw the images;
    how will it draw?
11. the robot shall be built from ??? ;
    what will it be built from?

12. the robot shall have dimensions equal to or less than $(56 \times 45 \times 25)$ cm.

Safety

13. The robot shall have an emergency shut-down switch;
14. the robot should indicate operating faults to the user;
15. the robot should have documentation and instructions for end users.
16. The robot should comply with Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys.[18]

Section 3

Design Specification

3.1 Robot design and hardware *(writer TBA)*

Design Specification: hardware

3.2 Electronics and control systems *(writer TBA)*

Design Specification: electronics

3.3 Software and user interface *(writer TBA)*

Design Specification: software

3.4 Other considerations *(writer TBA)*

Design Specification: other considerations

Section 4

Summary

4.1 Background and objectives (*A. Goodsell*)

The invention of the difference engine in 1833, came with it an entire new process of thought and development. Since then, the field of computation and robotics has become one of the largest in the world. It is a field that requires developers to suspend their usual way of thinking and instead look at tasks and problems as a computer. These ways of thinking are not encountered in daily life. Other intellectual and physical fields have their foundations discovered through juvenile interactions. However, the ability to approach a task with an algorithmic method—a loop or conditional statements—is not naturally acquired. These skills must therefore be taught through non-conventional means. This could be as a teenager or adult, when first being confronted with programming; however, years of educational studies have shown that skills and understanding are much more easily acquired at an early age. This is the motivation of the Sand·E project: to develop a method, useable by schools and parents, to begin to nurture programming skills in children.

title of this section needs thought

Currently this is identical to Section 2.1. SSB thinks it fits really nicely here so perhaps something should be put in the design outline that describes more possibilities?

The aim for the Sand·E project is to develop a working prototype of a programmable, autonomous robot with the ability to draw large scale art in sand. The robot will be able to accept a set of repeatable instructions from a student. These instructions could include: navigation, for example an instruction to go from point A to B before turning and traveling to point C; the ability to control whether the robot should be drawing at any given time, and also the thickness of the line drawn. The student will create these instructions through a graphical user interface, before they are uploaded to the robot and their design is created in sand. The intention is that by passing a design to a robot, students will be forced to think about how a computer will tackle a task they would find simple. Hopefully, students will be able to understand that computers use a system of specific logic that can create wonderful things, which would take much longer by hand.

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Glossary

Global Positioning System (GPS)

is a satellite-based navigation system that provides location and time information. 13, 16

Inertial Navigation System (INS)

Summary: definition of Inertial Navigation System

. 13

Annex A

Board Meeting Minutes

(*Minutes kept and compiled by S. Searles-Bryant*)

Group board meeting: The Sand·E Group

Minutes for 2016–01–13

Present: A. Goodsell (Chair), M. Fry (Board member), L. Foglianti Spadini, A. Hyslop, A. Kallaivannan, R. Kent, C. Lau, A. Rutley, S. Searles-Bryant, S. Wright, L. Yeo

Announcements

1. The assessment criteria for the peer-assessment component of the module have been chosen:

   Communication "Exchanging ideas and updating others on progress/feedback."

   Productivity "Maximising your contribution within a given time frame."

   Participation "Willingness to engage in, and contribute to, the project."

   Quality "Clear work which significantly furthers the progress of the project."

   Cooperation "Prioritising effectively towards a common goal."

   Reliability "Do what you say you're going to do; be trustworthy."

   Scores should be between 1 and 3 (less than expected; expected; exceeds expectations). These must be sent weekly to MF before 17.00 each Monday, starting Monday, January 25.

Allocation of roles

1. AG will chair meeting and act as the team leader.
2. SSB will take minutes and act as the contact person for MF and the course coordinator.
3. RK will collate the peer-assessment scores and send to SSB to forward to MF each week.
4. CL will act as the group treasurer.

Project brief (MF)

> "The challenge is to develop a robot which can draw artwork on sandy beaches."

1. The final product should be small enough to fit in a rucksack/suitcase. It should be manageable on public transport.
2. Examples of sand art at `https://www.flickr.com/photos/martinartman`.
3. The product can draw large-scale on a beach, or small-scale in a table-top sandpit.
4. The robot should be named
5. The specifics of what sorts of images the robot should draw are left for us to decide; the purpose and motivations for the project have not been specified.

Resources

1. The project budget is £200.
2. A case can be made to the course coordinator to obtain extra funding (MF advises probably only up to £50).
3. The robot designed for this course a few years ago is available for parts. MF advises that the motors (value c. £100) are particularly useful.

Next Meeting: Tuesday, January 19, at 11:15 in MPEB 3.14a

Actions

> Discuss skills and divide responsibilities among team members ***(all)***

> Decide upon purpose and motivations for the product ***(all)***

Group board meeting: The Sand·E Group

Minutes for 2016–01–19

Present: A. Goodsell (Chair), M. Fry (Board member), L. Foglianti Spadini, A. Hyslop, A. Kallaivannan, R. Kent, C. Lau, A. Rutley, S. Searles-Bryant, S. Wright, L. Yeo

Old business

1. The minutes of the previous meeting were approved.

Announcements & progress

1. We now have bench space in Lab 3. No access 1300–1400 every day and 1400–1630 on Wednesdays. A 3d printer is available; a sketch must be made and shown to the technician. (RK)
2. Final report has been started on Overleaf. Team can edit at `www.overleaf.com/4075528rppsqb`.

Aims and motivations

3. Motivation is to build a robot for education. The robot should be programable by children; they set start/end points and waypoints and whether or not to draw in between. This teaches algorithmic thinking (*e.g.* age 6–9).

Group structure and roles

4. Roles which have been allocated.
   - (AR, AH) Art review: Looking into history of sand art; choose type of thing to draw.
   - (SW, AK) Robotics review: Look at movement/digging mech, materials, and history.
   - (SSB) Education review: Case for teaching children algorithmic thinking; existing ways in which this is achieved.

(AG, AH) Website: Project website.

5. Design outline: Areas of design which should be decided upon this week.
   - Movement (SW, AK)
   - Interface
   - Guidance (LFS, CL)
   - Construction materials (SW, AK)
   - Digging mechanism (SW, AK)
   - Electronics platform (CL, SSB)

Preliminary research

6. Art review. (AR, AH)
   Began as protest of commercialization of art in US. Motivations behind recent works are to bring attention to the environment.
   There are many large scale sculptures using rakes, trowels. Smaller sand patterns use ropes; precise measurement is not emphasized. New movement of small-scale 'sand-stories' involving light projection.
7. History of robotics review (incl. preliminary survey of methods of movement and digging mechanisms). (SW, AK)
   (a) Drawing mechanics: most viable options are rakes/teeth and rollers.
   (b) Locomotion: problems include purchase on sand and not ruining the drawing. Tracks ruin previous drawing; best option looks like SandBot: three wheels.
   (c) Brief summary of history of robotics
   (d) Materials: waterproof/sandproof towels exist, could be used to protect sensitive components.
8. Education review. (SSB)
   Turtles have been used for education since 1960s. Drawing robots exist based on the Logo language; ink-and-paper equivalents of what we aim to build are very popular in primary schools.
   The idea of teaching computation in primary schools has received enormous interest recently.

9. Electronics and guidance mechanisms (LFS, CL)

    (a) GPS and compass: compass necessary to determine direction of robot. Cost would be c. £50. Not sure if precision is adequate for our needs.
    (b) Laser grids: prebuilt modules are too expensive; should look into building our own. Ultrasound equivalent is too short-range.
    (c) Tethering: requires child to follow the robot.
    (d) Remote control (bluetooth): can use a mobile phone; range of 30 feet. Software exists for Arduino.

10. Electronics platform (SSB)

    (a) Arduino: best option for embedded systems; large community online for support. Cost $<$ £50.
    (b) NETduino: similar to Arduino but uses .NET framework. Possibly easier to program (several team members know .NET languages).
    (c) Raspberry Pi: more a computer than for embedded systems. Used a lot for education.
    (d) Micro-controller: Requires all supporting circuitry to be built by us; more difficult to program. Possible but would require a lot of time.
    (e) A systems engineer role should be appointed to ensure compatibility of all components (software and hardware). LFS points out that power supplies will be an issue that needs some attention.

New Business

1. Resources and examples (MF)

    (a) Rake: adjustable tines. Too large for our project but mechanism may be of interest
    (b) “Ed-bot”: small line-following robot built by MF’s son.

   (c) USB shield for Arduino: includes dongle for cordless Playstation controller
   (d) Assorted servo motors.

2. Time management plan and Gantt chart. (AG)
   (a) SSB thinks more troubleshooting/testing time should be added. AG says build phases include time for testing.
   (b) First software task needs to be a tool to allow hardware to be tested manually.
   (c) A second Gantt chart should be produced once the design has been completed and detailed development processes are known.
3. Discussion of material to be posted on the website. (AG)
   (a) Demonstration of website.
   (b) Mirrors report in sections with summaries of each part.
   (c) In future will have photos and a video of the robot.
4. Peer-assessment scores need to be collected

Next Meeting: Tuesday, January 26, at 11:15 in MPEB 3.14a

Actions

> Add research to the report on Overleaf ***(all)***

> Investivate building our own LiDAR system for guidance. ***(SSB)***

> Collect peer assessment scores ***(RK)***

Group board meeting: The Sand·E Group

Minutes for 2016–01–26

Present: A. Goodsell (Chair), M. Fry (Board member), L. Foglianti Spadini, A. Hyslop, A. Kallaivannan, R. Kent, C. Lau, A. Rutley, S. Searles-Bryant, S. Wright, L. Yeo

Old business

1. The minutes of the previous meeting were approved.
2. The report is now available to view in Dropbox at `https://goo.gl/1CujQq` or to view and edit in Overleaf at `www.overleaf.com/4075528rppsqb`. These will be updated and kept synced with SSB's local copy roughly daily.
3. Peer assessment form has been filled out for this week

Announcements & progress

1. We do not have access to our space in Lab 3 on Tuesdays unless we make special arrangements. We also only have half a bench.
2. Servos: We have 7 in the lab, MF may have more. Plan is to use 3 for the rakes.
3. Motors: 148:1 gear ratio. We have 4 in the lab from the stair-climbing project.
4. The code for the Physics study room (top floor of Physics Bldg) is 0921.

Electronics platform (SSB, SW, AH)

5. The electronics platform outline. Discussion of exact requirements.
   (a) We believe that we need the following for the project (from Adafruit in the US):
      - Arduino board: Arduino Uno ($24.95) `https://www.adafruit.com/products/50`

- Motor control shield ($19.95)
  `https://www.adafruit.com/products/1438`
- GPS shield ($49.95)
  `https://www.adafruit.com/products/1272`
- Servo control shield ($17.50)
  `https://www.adafruit.com/products/1411`
- Compass breakout board ($19.95)
  `https://www.adafruit.com/products/1746`

(b) The GPS could be a breakout (`https://www.adafruit.com/products/746`) instead of a shield at a saving of $15.

(c) The servo control board is unnecessary if only 2 servos are used since the motor shield board can handle these.

(d) The motors and servos should be powered separately from the control board. 2 PP3 (9V) batteries should be sufficient.

(e) The total cost for all of the components is a little over $128, or £90, plus shipping.

(f) We would also need a few other components (bypass capacitors; cables; battery connectors) which could be sourced in the UK (*e.g.* Maplin).

(g) The Arduino (Genuino) 101 has built in accelerometer. This would be very useful for navigation and making the positioning more precise.

Decisions Procure Genuino 101 from Arduino in Italy. All shields and the compass breakout from Adafruit. RK will order through Lab 3. SSB will forward details to RK and CL.

Robot design (AR, RK)

6. CAD design made.
7. Use acrylic to manufacture (easy to work with; won't rust)
8. Could have an acrylic box over top for protection
9. Dimensions TBC
10. Discussion of whether two driven wheels should be at the front or the back

11. AG has a friend who will design a pretty box for us to be 3d-rpinted.
12. Suggestion from MF: consider using only 1 rake up/down to keep simple
13. Consider how much we can achieve this year; don't be over ambitious and perhaps leave some development for a further project.
14. We could recycle wheels from previous project (cable spools).
15. Safety regulations are extensive.

Software (AG, LFS, LY)

16. Started looking at Arduino boards but handed that off to electronics subgroup because it made more sense for them to do it.
17. LY has investigated generating images (fractal-type diagrams) without using GPS. It is feasible to draw images without a positioning system even with possible turning and moving errors accounted for (computer simulations). This would be a good avenue to pursue if GPS and current plans fail. (MF: minimum goal should be to have a spiral-drawing robot tethered to a centre-point.)
18. LY has found a website for simulating Arduino output for some code (`https://123d.circuits.io/`). We can also connect simulated circuits, readings *etc.* for simulation of the whole system. We should start a project on this website to simulate our code.

New Business

1. Jobs to be assigned in group general meeting tomorrow.

Next Meeting: Tuesday, February 2, at 11:15 in MPEB 3.14a

Actions

> Written work to be sent to SSB for compilation ***(all)***

> Aims and Motivations sections to be written up ***(AG)***

$>$ Investigate procurements options for shields ***(SSB, AH, SW)***

$>$ Buy Arduino controller board ***(RK, SSB)***

$>$ Buy other electronics ***(RK, SSB)***

Group board meeting: The Sand·E Group

Minutes for 2016–02–02

Present: A. Goodsell (Chair), M. Fry (Board member), L. Foglianti Spadini, A. Hyslop, R. Kent, C. Lau, A. Rutley, S. Searles-Bryant, S. Wright, L. Yeo

Absent: A. Kallaivannan *(apologies)*

Old business & announcements

1. The minutes of the previous meeting were approved.
2. The robot has been officially named Sand·E (Sand Education, or Sand Art 'n' Design Experiment).
3. The components discussed last week have been ordered from RS.

Progress

Modelling and robot chassis

1. Cardboard models of the robot and the electronics have been built. (discussion)
   (a) motors are on underside of chassis
   (b) on this model the large, driven wheels are at the front.
   (c) a more robust, moving prototype will be built this week.
   (d) the electronics box can be bought (see below)

Decisions The two driven wheels should be on the front; the drawing mechanism on the back with the single caster wheel. This will avoid "trolley syndrome", where the leading caster wheel will lead the rear wheels astray.

2. SSB has found a suitable box and on/off switch. Would require:
   - "Hammond Project Box Light Grey 125x100x90mm" £6.29 from Maplin (N26HG)
   - "Miniature 6A AC 230V Rocker Switch DPDT" £2.09 (YX65V)
   - 2× "Maplin Cable Exit Gland 15mm with Sleeve" £3.89 (JZ43W)

Software

3. AG, LFS, LY have got motors running in the online simulator.

Website

4. There is some content on the website, but it is not yet live.

New Business

1. LFS, RK, and LY have not yet contributed to the report. Now we have finished a lot of the initial design SSB would like to get those sections finished.

Feedback from MF

2. There seems to be an imbalance in the contributions from different members of the team (4 people seem to be contributing more than others). AG confirms that our team meetings on Wednesdays are very different, and everybody is contributing fairly.

Next Meeting: Tuesday, February 9, at 11:15 in MPEB 3.14a

Actions

> Contribute research to report ***(LFS, RK, LY)***

> Write up design work ***(all)***

> Build a second prototype ***(RK, CL, AK, AR)***

> Calculate how long a PP3 will last driving the motors and investigate other battery options ***(SSB)***

> Find out how to recoup expenses for components ***(SSB, AG)***

> Download some of Martin Artman's photos for the website & report ***(SSB)***

Annex B

The Sand·E Group

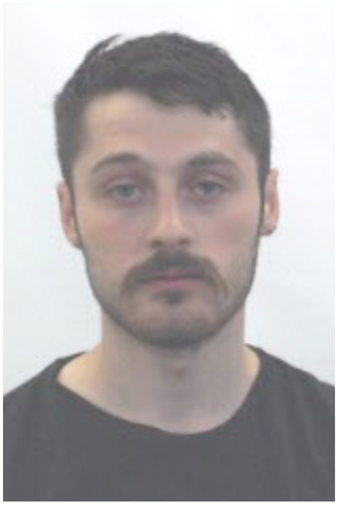
Check you all approve of these photos. If not, please supply SSB with a 2:3 photo.

Alexander Goodsell

Lorenzo Foglianti Spadini

Ashleigh Hyslop

Arunyan Kallaivannan



Robert Kent

Calvin Lau

Alan Rutley

Samuel Searles-Bryant

Samuel Wright

Luke Yeo

Martin Fry