The first mobile robot?

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Abstract

Heron of Alexandria in around 60 A.D. described the construction of a self-moving cart. This wheeled base was moved by ropes wound round axles and attached to a counter-weight. By judicious winding of the rope the cart could be 'programmed' to move in any pattern. Other mechanisms described by Heron could have been used to make the cart reactive. This early example of an automaton influenced the development of a mechanistic view of behaviour, and is an interesting precursor to current mobile robots.

1. Introduction

One of the precursors of mobile robotics is the building of automata. Since ancient times people have attempted to build machines capable of moving and operating in an interesting fashion without being directly controlled. These machines were often inspired by animal behaviour, and the ability to construct them strongly influenced the development of mechanistic views of biology. For example, De Solla Price (1964) has argued that Greek automata demonstrate that the mechanistic view of nature has existed for far longer than is usually thought. Certainly automata would have provided a demonstration that mobility and apparent animacy - the main criteria specified by Aristotle for distinguishing animals from plants - were not exclusive properties of living things. Aristotle explicitly used automata as a metaphor in describing developmental processes in nature as an example of how something can be set in motion and continue to follow a complex sequence without further direct influences driving the results (cited in Murphy, 1995).

These early builders of automata, lacking electronics and clockwork let alone the modern microprocessor, were forced to develop great ingenuity in using mechanical means to produce complex behaviours. Indeed, it has been argued (e.g. in behaviour-based robotics) that we have now perhaps gone too far in the opposite direction and overlook potential mechanical solutions to problems of behaviour control because of our focus on the brain rather than the body of the robots we build. At least for low-level behaviours, like obstacle avoidance, mechanical solutions, like having an impact directly affect the steering mechanism to cause a turn, might be more efficient and effective - and arguably more like biological systems.

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The earliest detailed description of automata comes from the work ‘Peri automatopoietikes’ – ‘On automata-making’ written by Heron of Alexandria in around 60 A.D. (translated in Murphy, 1995; her translation is used in the extracts below). Rosheim (1994) describes these as “the first well documented, workable robots”. In this work Heron describes in detail several mechanisms for ‘toy stages’ that will perform a set of scenes without any direct control. However from the perspective of mobile robotics, the most fascinating part is that the first of his ‘stages’ is mounted on a wheeled cart, that autonomously moves forwards, stops while the scenes are performed and then moves back. Heron describes the cart in detail and includes means for ‘programming’ it to drive “as we determine” in any rectilinear figure or even “swerve like a snake”. The detail he includes in the description strongly suggests he had indeed constructed such a cart.

Other devices described elsewhere by Heron suggest ways such a cart could be made reactive to some simple stimuli, giving it a competence close to many recent microcontroller-based robots. Thus it is interesting to analyse this device from the point of view of robotics. Although it lacks some of the features required to be an 'autonomous vehicle', the ingenuity and flexibility inherent in its design make it a fascinating first link in the chain that leads to our current field of research.

2. Basic construction

The mobile base is a stage for an animated shrine to Dionysos. As Heron explains "when the automata is set down somewhere and we stand back, after a little while it will move to some prearranged spot. When it stops the altar in front of the Dionysos will blaze up; and either milk or water will squirt from Dionysos’ thyrsus, while wine is poured from his chalice…The Maenads will dance in a circle round the shrine and there will be a clamour of drums and symbols...and when they stop the shrine will return to the place from which it started".

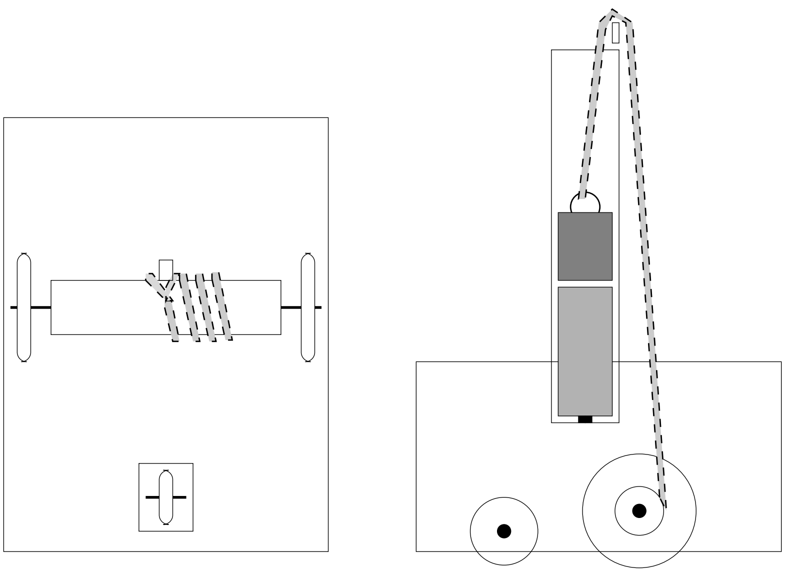

__Figure 1:__ Diagram of Heron’s autonomous vehicle, from below and side, based on his description. The base rests on three wheels, the two drive wheels are turned by a rope around the axle that connects to a descending counterweight. The descent of the weight is controlled by seeds dribbling from the bottom of the tube.

He specifies that the floor should be smooth and hard, without bumps. The platform is to be as light as possible, "to prevent the mechanism being hindered by its own weight", and all moving parts made with as little friction as possible. Instructions are given for pre-stretching the cords that control the movement (see below). He also notes that the automaton is better made small so that sceptics will be convinced it is not being operated directly by a concealed human.

The base described is “one cubit long, four palms wide and three palms high” although the full height with the stage is 10 palms. An axle set into the sides of the base holds two wheels and a central cylinder with a protuding knob, and a third wheel revolves in a frame in the middle of the opposite side. See figure 1.

3. Motive force

A cord is looped onto the knob on the cylinder and then wound around the cylinder. A long tube is set on end in the center of the base, and the end of the cord is attached, via a pulley at the top of the tube, to a lead counterweight inside the tube. Thus, as the weight descends in the tube it pulls the cord which unwinds from the cylinder, turning the axle and the wheels, and so the base travels forwards.

This single counterweight provides the motor force for all the moving parts in the theatre, by a similar arrangement of ropes and axles. As Heron points out “although the cords are all drawn at an equal rate by the counterweight, the actual movements vary in speed because the cords are wound around objects of different diameter, some larger, some smaller”. To control the descent of the counterweight, the tube is filled with “something light, small and clinging ... such as millet grains or mustard seed” that dribbles out a hole in the bottom into a catchbasin. The hole is covered by a lid that can be opened and closed to stop and start the motion. Heron specifies that the weight of the counterweight must be adjusted so that it can overcome the inertia and friction in the base and wheels.

Such counterweights remain a common mechanism for the motive force in automata for many centuries. The only significant development is the invention of the escapement in the middle ages that enables an exact control on the rate of descent of the weight to be exerted. Thus Vaucanson’s famous autonomous duck, which “stretches out its neck to take corn out of your hand; it swallows it, digests it, and discharges it digested from the usual passage” (Vaucanson, 1738/1979), used a descending weight to drive the cams that controlled all the behaviour.

4. Stopping, pausing and reversing

The motion will be stopped if the cord unwinds fully and the loop falls off the knob; or if the motion of the counterweight is stopped either by closing the hole in the bottom of the tube, or having the weight come to rest on something (e.g. a 'switch' in the cylinder). However the full performance, or more complicated motions of the base, require some movements to pause while others continue. One method Heron describes is to have two counterweights in separate tubes, that can each control the opening and closing of the other. Thus after one has operated for a while, it has tightened a rope that opens the other, to set different items in motion - one of which might be the closing of the first tube.

More generally, pauses in motion by items attached to particular cords are caused by leaving a length of slack rope between the windings on the cylinder, corresponding to the length of the desired pause. Long slacks are formed into kinks and stuck with wax so that they slowly unfold as the counterweight pulls, until the rope is again tight and resumes exerting force on the axle.

To make the base move in one direction and then reverse, the cord is first wound one way around the axle, then looped around knob and wound in the opposite direction. As Heron explains “if we want the base to move back and forth often, we must make more frequent cross-windings with intervals between them of whatever size we choose”. Thus any variety of back and forward motions and pauses can be programmed by the selective winding of the cord onto the axle.

5. Curves and Cornering

Heron describes several methods by which the base can be made to move in directions other than a straight line. His first suggestion is to angle the single wheel, which will act as a castor or steering wheel to take the base in a circle. The subsequent discussion to this section describes the motion of rolling a cone, which will describe a circle. This seems to imply that he is also suggesting making the drive wheels of different sizes, although that it is not clearly stated. Of course different size wheels would mean only being able to go in circles - and would thus be rather less flexible than the castor solution. It would also raise problems such as whether the axle must be tilted to compensate for the different height of the wheels. It clearly does not seem a practical solution, so either Heron has been misinterpreted here, or he is suggesting this merely in theory rather than practice.

A rather more complicated way in which sharp (right angle) turns can be made is described next. This consists of constructing a second set of three wheels, oriented at right angles to the first, whose axles can be raised and lowered by a screw mechanism. When the second set of wheels are lowered, the first set are raised from the floor so that the base now runs in a different direction. The raising and lowering is itself programmed by the windings of a cord around the axle of the screw.

To make the base “swerve like a snake”, Heron adopts a rather more elegant solution that could potentially be used for sharp turns also. The two drive wheels are given separate axles, so that one can be stopped (by kinked slack in its rope) while the other turns, to move in a curve. He suggests this will work better if the single wheel is also connected to the counterweight, i.e. provides a constant drive force also. Although not suggested, presumably the two main wheels could also be turned in opposite directions to make a turn on the spot - but the success of this would depend on the sideways friction in the third wheel.

Heron also suggests a sensible way to 'program' the required behaviour. It might seem rather daunting to figure out the exact windings and lengths of slack needed to have the base follow a particular course. However, by starting the base at the desired finish position and moving it backwards by hand over the path, the cords can be wound on and the slack gathered appropriately. This is reminiscent of the industrial robot that memorizes a trajectory indicated by manual movement - the automata stores the 'training' path in the windings of the cords and plays it back. It is notable how this differs from most subsequent ‘clockwork’ automata in that it can potentially be programmed to act in many different ways, rather than always playing out the same behaviour.

6. Reacting and Adapting?

Although the vehicle described by Heron can perform various complex sequences of actions under its own control, it cannot react to anything - like obstacles in its path - or find its way to a target other than by a preset trajectory. As Grey Walter (1953) expresses it, such devices “are not automata in the sense of being endued with any spontaneous motion, and in no sense of the word have they any claim to autonomy or self-regulation”.

However other devices that Heron describes elsewhere, particularly in his ‘Pneumatika’ (Kranzberg & Pursell, 1967) do indeed have primitive ‘sensory’ capabilities enabling them to alter their behaviour depending on external events. Most commonly this is in the form of a lever that when depressed starts or stops a mechanism. For example his bird automata, which sing via an organ pipe mechanism, fall silent when an owl is turned towards them. He also describes the first ‘coin-in-the-slot’ machine, a dispenser of holy water that produces a flow only when money is placed in it, which trips a lever. Another device for use in temples corresponds to a kind of 'heat' sensor – when a burnt offering is made in a certain place, it heats a hidden water tank and the resulting steam powers the temple doors to open and a statue of the god to emerge.

Although such mechanisms are not described for the mobile theatre it is reasonably easy to imagine how the lever devices might be deployed to make the behaviour of the vehicle more reactive. A lever operating as a bumper could produce a change in direction by turning the castor wheel or lowering the second set of wheels to make a sharp turn when obstacles are encountered. Similar mechanisms could be adopted for wall-following – having a slightly curved default path taking it towards a wall but impact with the wall turning the castor away for a short time.

Moreover the notion of a feedback device was possibly known at this time. Heron describes the use of 'conical valves' that can be used to regulate the flow of water. In an Arabic treatise that draws closely on the pneumatic mechanisms of Heron, a more precise description makes evident that a conical valve is being used as a feedback device as follows. A downpipe that ends in a hollow cone shape feeds into a container in which floats an upturned cone. The requirement is that the height of water in this container is kept constant so that an outflow from the bottom of it is at a constant rate. If the water flows in too fast, the cone rises and cuts off the flow, if too slow the cone drops and the flow increases. It is reported by Hill (1993) that this device can produce a very finely graded control.

7. Conclusion

Despite the highly constrained technology, Heron's autonomous vehicle could produce an interesting range of behaviours. His devices show the number of effects that can be achieved by converting one motive force – the descent of a counter-weight – into a variety of others simply through appropriate physical construction. Similar physical devices for controlling behaviour through sensing and even feedback existed at this time.

Could this 'automaton' be considered 'autonomous'? Autonomy is used in the mobile robotics community to cover a variety of properties. Sometimes an 'autonomous vehicle' is distinguished only by the fact that it is mobile and not teleoperated. Pfeiffer (1996) defines autonomous as "able to function without human intervention, supervision or instruction". The first two properties seem too weak, in that they apply equally to 'automatic' machines. Operating without 'instruction' is a stronger condition than is satisfied by none of today's mobile robots (or even most humans!) as it implies that an instruction like 'collect fuel' imposed by the designer makes a robot not autonomous. Smithers (1997) has argued that such a meaning – consistent with the origins of the word 'self-governed' and its use in other fields – should nevertheless be adopted, and the truly autonomous be distinguished from the merely automatic and the intermediate self-controlling devices.

If there is a continuum between the self-moving and the truly self-governing, most of today's robots fall rather closer to the automatic than the autonomous end of the spectrum. We have progressed since Heron's time but it is interesting to note that the impression made by these devices suggests that the tendency to attribute animacy, and to be fascinated by such behaviour, was as common to the Greeks as to the modern mobile robot audience. The modern mobile robot constructor might be heartened by the approval of the ancients – as Heron states "the study of automaton making has been considered by our predecessors worthy of acceptance, both because of the complexity of the craftmanship involved, and because of the striking nature of the spectacle…"

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