An Autonomous Toy-Rolling Robot

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Abstract

A mobile robot toy must be designed to be capable of facing the variety of situations that can be experienced in a household environment, while still be appealing to children and create interesting and meaningful interactions, all at a reasonable cost. In this paper we present Roball, a rolling robot. Children are used to play with ball-shaped objects, making Roball implicitly appealing. In addition, its spherical shape allows Roball to show robustness in facing all kind of obstacles, surfaces, and interplay situations. This paper describes the robot and observations made of children playing with Roball.

Keywords: Mobile robots, locomotion, entertainment.

1 Introduction

Designing an autonomous mobile robot to operate in unmodified environments, i.e., environments that have not been specifically engineered for the robot, is a very challenging problem. In a household environment for instance, dynamic, unpredictable and very diverse situations occur constantly. Research involving the design of software control architectures [2] to make mobile robots navigate, learn and plan their actions in the world put a lot of considerations on these issues. One primary concern then is to have the necessary processing power to implement the algorithms required for the robot. However, in doing so, other aspects of the robot are sometimes forgotten: its structure, its shape, its dimension, its weight, etc., will all have an influence on the situations the robot will experience. Also, the variety of objects (other toys, shoes, clothes, etc.), obstacles (walls, couch, table, chairs, stairs, etc.), operating surfaces (wooden floor, ceramic, shaggy carpets, etc.) and entities (dog, cat, people, etc.) that the robot can encounter in a household environment is very diversified. A robot on wheels may flip over or on the side; a tall walking robot may trip on something and accidently fall on somebody; or a heavy robot may cause a lot of damage falling down the stairs. While these situations may not always be avoidable, integrating physical, electrical and software considerations is very important in designing robots that are well prepared to handle situations that arise in a household environment.

These considerations are even more true for toy robots. Children are extremely hard on their toys: they grab them, throw them, kick them, put them in places they should not be in, etc. Electronic products are easily affected by these conditions. High tech toys would usually cost more because of the additional processing, electrical and mechanical components required to create sophisticated interactions with the child, and parents will think twice before paying more money for something that might get damaged more easily. Indicating the age range is one way of preventing misuse of a toy by younger children, assuming that older children will carefully use the toy. However, it is not a foolproof solution because once the toy is out of store, there are no guarantees that it will be properly used or that a child will respect the age restriction. For example, we have personally witnessed a one year old boy getting his hands on a Furby doll and rapidly damaging the doll. The damage would have been even worst (and costly) on an AIBO, Sony's robot-dog which originated from the MUTANT project [4].

Children like to play with a lot of things, and many different types of robotic toys can be imagined. The goal is to design a robot that is appealing to the child and capable of facing the variety of situations that can be experienced in a household environment, all at a reasonable cost. Toward achieving this goal, we have designed a rolling toy robot we named Roball. In this paper, we present how Roball is able to operate in real world environments and create interesting and meaningful interactions with children. The paper is organized as follows. Section 2 describes the general characteristics of Roball. Section 3 explains the software mechanisms used to control the robot, and

Section 4 presents observations made of children who played with Roball.

2 Roball, the Rolling Robot

As explained in the introduction, a toy robot must be appropriately designed to handle the variety of situations that arise in a household environment, and be extremely robust while still be appealing to children. The design we have come up with is to encapsulate the robot inside a sphere (or other rolling shapes), and use it to make the robot move around in the environment. This simple idea has the following advantages:

- The sphere protects the robot's circuitry against shocks, dirt and other things that high tech products are sensitive to. No assumptions on the child age or on the way the toy must be handled are then necessary.

- A spherical shape allows the robot to face all kind of obstacles, surfaces, and interplay situations. A rolling ball usually follow the path of less resistance. It has less chances of getting stuck on top of an object or in between the legs of a chair. In contrast, a wheeled robot may see its caster wheel work very poorly on a carpet, or the robot may get lift over when trying to move over a boot for example.

- Children are used to play with ball-shaped objects, making the robot implicitly appealing. But contrary to an usual ball, Roball would not necessarily stay in a corner once the child is done playing with it.

The prototype we have built in 1998 is shown in Figure 1. The mechanism differs from other round-shaped robots like Gyrover [9] in that it can rotate on all of its external surface, and not on a wheel. This prototype was built using a 68HC11 microcontroller board, a plastic sphere and components commonly available in robotic supplies. Roball is 6 inches in diameter and weighs about 4 pounds. The overall cost of material used was less than 100$US. Figure 2 illustrates the propulsion mechanism of the robot. Two motors attached to the extremities of the sphere are used to make the robot move. The battery is supported by a servo-motor and is used for steering. Tilt sensors are used to detect the horizontal and vertical inclinations of the internal plateau supporting the microcontroller.

After having built our first prototype of Roball, we found other designs of spherical robots. The Solar Ball Kit commercialized by Images Company Inc. is a

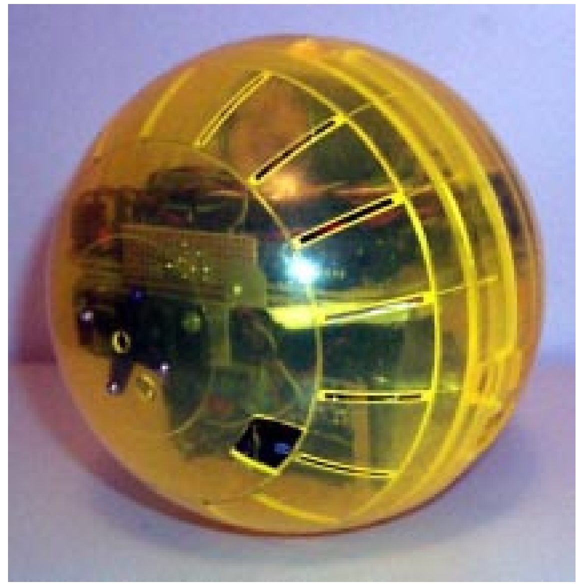

Figure 1: First prototype of Roball.

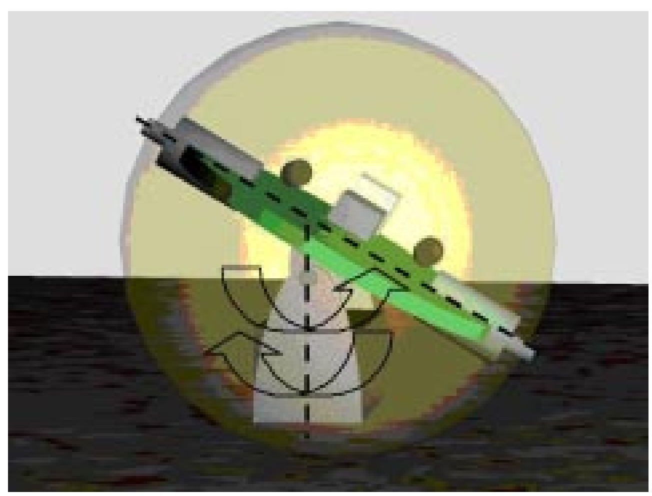

Figure 2: Roball's propulsion and steering mechanisms.

spherical robot that uses solar energy in its first version. In the second version, when light is detected a battery is activated and the robot moves. The Orbot rollerbot is a rolling sphere robot teleoperated using a TV remote control. Toy Biz Inc. [1] also has a patent on a self-propelled musical toy ball which plays musical tunes and generate sound effects. Once energized, the electronics of the ball operate to propel the ball and simultaneously activate an integrate circuit sound effects chip which plays a musical tune. When the ball bumps into something, the propulsion mechanism is disengaged and the circuit then plays a randomly selected pre-programmed sound effect. Thereafter, the propelling mechanism is again activated and the ball resumes playing the musical tune. Roball significantly differs from these products by using a microcontroller and sensors to make the toy navigate autonomously in the environment and interact in various ways with the child, as explained in the following section.

3 Software Mechanisms Used to Control Roball

Once the structure and the processing components of Roball assembled, the next step was to see what control mechanisms was required for autonomous navigation of the robot and for interaction with children. Two ways of interacting with the robot were implemented: by vocal messages and by the movements of the robot.

To generate vocal messages using a simple device, we used an ISD ChipCorder[1], a single chip device for voice recording and playback. Specific messages were memorized in ROM and were addressable by the microcontroller of Roball.

The approach used to control the robot must include efficient software mechanisms for sensing its environment, for low-level control of the robot's actuators, and also for managing the goals of the robot and create interesting interactions with the child. Following the guidelines of a software architectural methodology [6, 7, 8], the basic idea is to have behavior-producing modules (also called behaviors) control the actuators according to sensory data and the state of the robot, and dynamically change the selection of the behaviors over time. The selection of behaviors is done according to environmental states, the goals of the robot and reasoning done about the world.

As shown in Figure 3, four behaviors are used to control the velocity and the direction of Roball, using Subsumption [3] as the arbitration mechanism. These behaviors are, in order of priority: *Emergency*, used

[1] http://www.isd.com/.

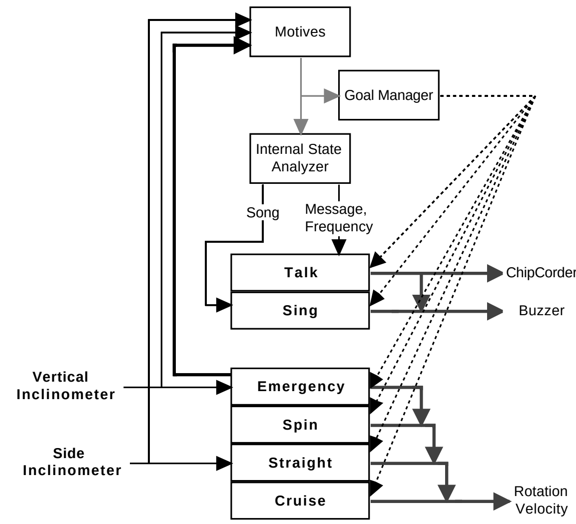

Figure 3: Representation of the software mechanisms.

when the robot comes in contact with an object; *Spin*, to make it turn in circle; *Straight* to make Roball go straight in one direction; and *Cruise* to make it move forward. In addition, a behavior named *Talk* is responsible for generating the proper message using the ChipCorder, and *Sing* plays songs using a simple buzzer.

Behaviors are implemented as individual processes that get activated or destroyed according to the goals of the robot. In a manner similar to [5], these goals are managed by internal variables called "motives" [7]. A motive is a variable that has an energy level and an activation level, both ranging from 0 to 100%. The energy level can be influenced by various factors: sensory conditions, the use of behaviors associated with the motive, activation of other motives and cycle time (for cyclic occurrences). The energy level is computed by the equation $E_m = \sum_{j=1}^{n} w_j \cdot f_j$, where f represents n influencing factors, weighted by w, affecting the motive. The activation level is used to determine the activation of behaviors, and is derived from the energy level using a mapping function. The general state of Roball is determined by three motives:

- *Hungry*. This motive verifies that the battery voltage level is greater than a preset threshold. If not, the *Cruise* behavior is deactivated to make the robot stop and ask to be recharged.

- *Distress*. This motive examines the frequent use of the *Emergency* behavior, which is a sign that Roball is having trouble moving freely. Every time the *Emergency* behavior is used because the robot encountered an objet, Roball apologizes for having hit the object. If *Emergency* is used frequently in a short period of time, Roball asks for help and the behavior *Spin* is activated to try to move the robot out of trouble.

- *Awake*. This motive is used to simulate sleeping periods during which Roball is not playing with the child. When *Awake* is not activated, all behaviors are deactivated. Otherwise, Roball is allowed to move and to interact with the child. Coming back from sleep, the robot says hello and play a short song. Roball stays awake longer when no distress situations are experienced or that the robot is not moving a lot.

When Roball is awake, it is programmed to wander around in the environment until it decides to rest, based on the motive called *Resting*. This motive deactivates the *Cruise* behavior, stopping the robot for a certain period of time (determined randomly). During resting, the robot is allowed to interact with the child in one of three ways: Roball can ask to be spun, to be shaken or to receive a small push to start moving again. Three motives, *Spinning*, *Shaking* and *Pushing* respectively, are used to monitor these requests and the response from the child. For example, if the child shakes Roball when it asked to be spun, then the robot tells him to stop. When spinning is requested, Roball can indicate that it feels dizzy or that it wants to get another spin, depending on how it was spun. Spinning is detected by a particular state of the tilt sensors, which occur only when the robot is being spun. When spinning, a message expressing excitement is generated. If a response is given to a request for spinning, shaking or pushing in a reasonable amount of time, then Roball thanks the child. This action is monitored by a motive named *Happy*. If the child does not respond to the request, then the *Bored* motive gets activated and the robot tells the child that it is getting bored. When the energy level of *Resting* drops to zero, these interactions stop and Roball starts to move again. For the pushing request, the *Resting* motive becomes inactive right after the child give a small push to the robot, making it start to move.

Note that these interactions are different than those involving nurturing and petting gestures. The objective is not to create the illusion that Roball is an entity that needs caring. Instead, we want to create interactions that are more related to the dynamics and the structure of the toy. We also try to make these interactions more personalized by making Roball use the name of the child in some of the messages, like: "Simon, give me a little push please", or "See you later Simon". This helps create more meaningful interactions with the child.

4 Experiments with Roball

Since the first prototype of Roball was not designed robust enough to be used in very though interplay situations, tests were done in controlled environments and with a small number of children. Each child can have his or her own way of interacting with a toy: this may depend on age, interest, personality, etc. The goal of these first experiments was to see how children would react to Roball, and how it could create interesting and dynamic interplay interactions in various environments.

Roball was first tested with a 10 month old boy named Simon that had never played with a ball. The experiment was simply to see how the child would interact with Roball. At this age, the boy was not able to understand any verbal commands from the robot, so only the movement of Roball created some type of interactions with the child. In addition, Roball was not equipped with any obstacle detection sensors. The robot just moved around, coming into contact with obstacles and managing to move away from them using its spherical shape. During the first trial, as the robot started to move, Simon immediately started crawling to catch it. When he finally did, Simon tried to grab the robot and immobilize it but could not do so. Roball was always trying to move and every time Simon lost his grip, the robot started to move again in the released direction. Figure 4 illustrates Simon playing with Roball. This catch-and-grab cycle repeated itself a couple of times, as Roball got to move on wooden floor and ceramic, underneath a table and chairs, on the side of a couch, furnitures and walls. Simon did not seem to get tired of trying to catch it or of watching Roball move. Just having Roball wander around in the room made Simon want to follow it, also making him practice his crawling and moving skills. After about 30 minutes, the experiment ended when we stopped the robot, and necessarily making Simon very upset. To see how Simon would play with a ball, the next day we gave Simon a small size basketball, about the size of Roball. Simon went to grab the ball, played with it for about 30 seconds, and went away to play with other toys. We also gave Simon a small train that can move on the floor, and Simon usually grabbed the toy, threw it on the side and left it there. When the toy train is on the side or in front of an obstacle, it continues to move its wheels, just making a lot of noise until somebody decides to turn it off.

Figure 4: A 10 month old boy playing with Roball.

Four months later, we let Simon play again with Roball. He then knew how to play with a ball, so he was now trying to lift Roball and throw it on the floor (showing us that robustness of the sphere is very important). But again, since Roball was moving on its own, Simon continuously pursued Roball in the room. With the basketball, again Simon only threw it once or twice, then started to play with other toys.

We also gave Roball to a 3 years old boy named Remi. Remi is a very active boy, always trying on new things. When he saw Roball the first time, he immediately went to play with it. Remi understood that Roball had to stay on the floor (a carpet in this experiment) to move, so he started to follow the robot around, going where Roball was going (like under tables, between furnitures, etc.). He also played with Roball by throwing the basketball at the back of the robot, again showing the need for robustness. Remi was able to understand Roball, and his first reflex was to talk back to the robot, giving it commands and asking it why it was behaving in particular way. When Remi did not get an answer from Roball, he started to shout his requests to the robot: he knew the robot was able to talk, and expected it to understand what he was saying. Speech interaction seems to be important to create even more interesting interplay situations, and the next prototype of Roball will incorporate this ability.

Another experiment was done with Alexis, a boy the same age as Remi. Alexis is calm and shy, so the first contact with Roball was very different than for Remi. The experiment was done on a concrete floor in a small garage, with a small slope toward the drain located in the center of the garage. Roball did not experienced any problem in moving all around in the garage on this surface, even sometimes going outside on the pavement. Initially, Alexis stood outside the garage, looking at Roball and analyzing it from a distance. Alexis was not scared: he was looking at the robot, smiling. He was very intrigued by the fact that Roball was moving on its own. He was used to play with a remote controlled car, and he did not understand how Roball was moving on its own. The fact that Roball talked was also something new to him, and Alexis sometime repeated to his father what Roball was saying, explaining what the robot was doing. After a couple of minutes and a bit of reassurance from his father (who went to play with Roball), Alexis also went to play with Roball. He let the robot pass under his legs, and responded to Roball's requests for spinning, shaking or pushing. Contrary to Remi, Alexis was always very gentle with the robot. For instance, the first spin he gave Roball, the robot only made one turn. For children like Alexis, experiments should be done on longer periods (by letting him go home with the robot for a couple of days) to see what types of interactions they will have pass the familiarization stage. Our second prototype of Roball will allow us to do such tests.

Figure 5: A 3 years old boy playing with Roball.

For older children, interactions must be more complex and diversified to create interesting interplay situations. More sophisticated programs and capabilities would need to be incorporated to the robot. Children may also have new use for the robot like using it to play soccer or throwing it high in the air. While physical robustness is even more essential, these situations may be detected by the robot and messages can be issued by the robot to ask children to stop using it this way. Roball's abilities for autonomous navigation and to adapt its behavior according to the situations make it more than just a simple toy. Also, all children eventually get bored with their toys, but high tech toys have the advantage that changes can be made to their programming to create new interplay situations. These changes can be done by designing new programs to control the robot, or by giving the toy the ability to learn and evolve over time. The architectural methodology followed for the design of the software mechanisms for Roball will facilitate the addition of this abilities in future developments. Artificial intelligence and autonomous robots research can benefit greatly from the field of entertainment, using it as an experimental setup for developing innovative ways of making physical machines interact intelligently in real life situations.

5 Summary and Conclusion

This paper first describes the requirements for designing a mobile toy robot. The conditions a mobile robot must face in a household environment are very diversified, and being also a toy for children is even more demanding. The robot must be very robust while still being able to create appealing and meaningful interplay situations with the child. This presents important challenges for the research community, with great marketing opportunities. The paper argues and demonstrates how a spherical rolling robot is a simple approach that meet these specifications, at a reasonable cost.

Another interesting aspect of this project is that we are able to integrate the physical structure of the robot, its dynamics and its programming to create interactions particular to Roball. The spinning interactions with the robot is a good example of this property, which help establish the believability in that the robot is actually playing and not simply executing a program.

We are presently working on a new pre-commercial prototype of Roball. This will allow us to conduct more experiments with children of different ages and for long-time usage of the robot, and acquire more quantitative results to evaluate how Roball makes an interesting autonomous toy robot. Different categories of Roball are also in preparation, starting with a small version that can simply move, to more complex designs of various shapes and sizes and that can make Roball perceive various things in the world, creating more elaborate interactions with children of all ages.

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