Alph and Ralph:
Machine Intelligence and Herding Behavior

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Abstract

This paper explores the development of herding behavior in autonomous platforms. Alph and Ralph were designed to determine whether an agent with basic collision-avoidance behaviors could be directed by a larger, marginally more intelligent agent. The experiment was conducted as a design project in the Intelligent Machine Design Laboratory.

Introduction

Since the inception of robotics, one of the most popular avenues of research has been the simulation of the behaviors of living organisms. The challenge of developing agents capable of meaningful interaction is equally fundamental. This project is intended to further exploration into herding behavior in robots, using one small agent which wanders randomly and tries to avoid the other agent, and a herding agent, which will try to force the small agent toward a stationary beacon.

Platform

Alph, the herding robot, is constructed using the Mekatronix Talrik [1] platform, with the addition to the head of a mounting surface for the sonar receiver.

The Talrik platform (Figure 1) consists of a circular base, approximately 12 inches in diameter, and a bridge structure on which the head servo and switches are mounted. The platform itself is constructed of 1/8" birch plywood.

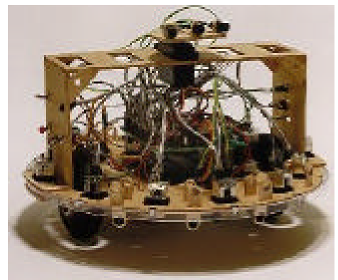


Figure 1

Alph's processing is accomplished using a Motorola MS68HC11 EVBU board and a Mekatronix ME11 expansion board, giving it 32k of SRAM and expanded input and output ports.

Actuation includes two 43 oz-in ball-bearing servos hacked into DC motors (as described in the Mekatronix Talrik assembly manual) and a 42 oz-in Futaba servo, unhacked, which actuates the head. 3.0-inch diameter Dubro model aircraft wheels are mounted on the hacked servos.

Alph is powered by eight rechargable NiCd AA batteries.

Ralph, the herded robot, is built on a Mekatronics TJ platform [2], with the addition of a head, on which are mounted the sonar emitter transducers, and a wire stand on which the microphone is mounted.

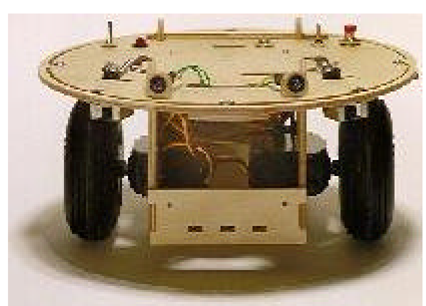


Figure 2

The TJ platform (Figure 2) consists of a circular head, approximately six inches in diameter, which mounts on a four inch-by-two inch box in which the battery pack and servos are mounted. The platform is constructed of 1/8" birch plywood.

The processing is accomplished via a Mekatronix MSCC11 single-chip board, incorporating a Motorola MS68HC11E2 microprocessor with 2k of on-chip EEPROM.

Ralph's actuation involves two 43 oz-in servos hacked into DC motors (using the hack described in the Mekatronix TJ assembly manual [2]) with 2.75-inch diameter Dubro model aircraft wheels.

Ralph is powered by six rechargable AA NiCd batteries.

Sensors

Alph's IR sensor suite includes four IR emitters evenly spaced across the front of the platform, and two Sharp GPIU58Y IR detectors, hacked (as described in the Mekatronix literature) for analog, at ninety degrees from each other. The emitters and detectors each cover approximately 180 degrees of arc in front of the platform.

Alph's emitters are powered off the ME11 board's 40 kHz output bus.

Alph's bump sensor suite consists of ten bump switches evenly spaced around its perimeter, connected by a rigid bumper. The sensors are wired such that the five in front act as a single sensor connected to the 68HC11 EVBU board, as do the five in back.

The bump sensors are active high: a "hit" has the value 255; otherwise the analog port reads a value of 0.

Ralph's bump sensor suite consists of four bump switches: three in front and one in back, connected by a rigid bumper. The front three switches are wired in parallel to the input port of the MSCC11.

Ralph's IR sensor suite consists of two IR emitters and two hacked Sharp GPIU58Y IR detectors in the front, and one emitter and two hacked detectors in the back. The detectors cover 180 degrees to the fore and rear; the emitters cover approximately 180 degrees to the fore and 60 degrees to the rear.

The emitters are powered off a 40 kHz output.

The audio suite consists of a microphone on Ralph and a 4.2 kHz piezo buzzer on Alph.

Ralph's microphone circuit (Figure 4) functions as a "clapper," such that a sound above the threshold determined by the comparator will instigate a certain behavior (in this case, Ralph's holding pattern).

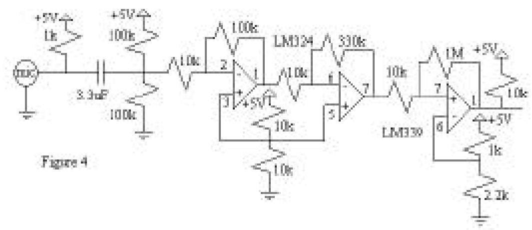


Figure 4

The condenser microphone used here yields a signal in the 10 mV range, which needs to be amplified in order to be used. A two-stage amplifier was constructed using a LM324 op-amp – two inverting amplifiers in series with a total gain of 330 – the output of which is then passed to a LM339 comparator, the output of which is then passed to PE1.

The circuit diagrams provided by Radio Shack in the microphone packaging call for a 1k resistor and 1 to 10 uF capacitor. However, experimentation initially indicated that both capacitor values are too high to yield a signal. Ed Carstens' robot "Ziggy" [6] included a microphone circuit which used a 2.2k resistor and 0.001uF capacitor, values which met with great success.

However, in order to improve the range from less than one centimeter, it was necessary to experiment with these values. The best range was achieved with a 1k resistor and a 3.3 uF capacitor. This setup allows the microphone to pick up a handclap from several feet away, provided that there is no other interference.

Alph's 4.2 kHz piezo buzzer needed no other circuitry and is operated off port A pin 4.

The sonar suite consists of a sonar receiver and filter on Alph, a sonar emitter on Ralph, and a stationary sonar beacon.
The sonar emitter is constructed using a sonar transducer, an audio transformer, and a 2N222A transistor (Figure 5).

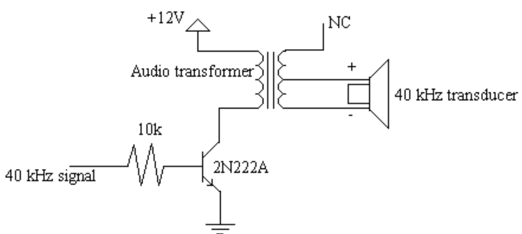


Figure 1: Sonar Transmitter

Figure 5

The original design was derived from Michael Apodaca's project Odin [5]; however, it was determined that his orientation of the audio transformer was backward, producing a gain of approximately two instead of eight. The corrected circuit, seen in Figure 5, produces the necessary gain. Ralph's emitter is run off PB0, the same pin used for the IR emitters; the standard collision avoidance program, written by Ivan Zapata of the MIL, includes a routine that produces a 3ms pulse every 20 ms at 40 kHz.

The stationary beacon (Figure 3) incorporates an emitter and a 40 kHz oscillator constructed with a CMOS 555. The resistor between pins 2 and 7 is actually a 10k potentiometer screwed down to approximately 5k, in series with a 10k carbon-film resistor. Originally, the circuit used only the potentiometer; however, that produced a frequency of 50 kHz instead of 40 kHz, which the receiver cannot detect. With the resistance increased to approximately 15k, the oscillator produces a 40 kHz signal. This 40 kHz signal is then passed to another oscillator, also constructed with a 555 timer, which produces a 1ms pulse every 15 ms.

The sonar receiver (Figure 6) was constructed using a 40 kHz transducer, LM339 comparator, and MAX 266 filter. It too was based on the design by Michael Apodaca; however, with the exception of substituting a 10k potentiometer for a 15k potentiometer at the positive input of the LM339 comparator, the circuit functioned properly as designed. The signal is received via the transducer, filtered by the MAX chip, and passed through the comparator, which renders a digital output. This output is then passed to PE3 on Alph's 68HC11 board.

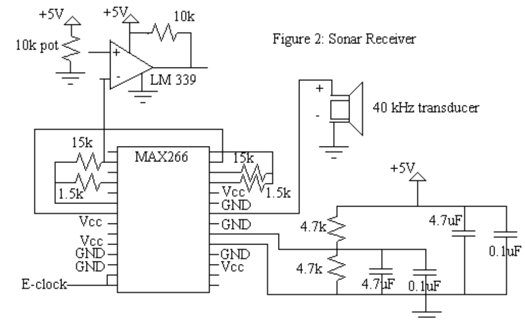


Figure 6

Alph's transducer is mounted on a servo, giving it a 180-degree range of motion. The head will rotate in ten-degree increments across the full range of its motion, allowing the receiver to scan for a sonar pulse. Once this pulse is located, the robot will orient itself toward that signal and pursue it.

Behaviors

The basic behaviors for Ralph include collision avoidance; wandering; and responding to an audio signal. The integration of these behaviors should result in Ralph trying to avoid Alph as the latter tries to herd it.

The behaviors for Alph include collision avoidance; scanning for sonar; time-of-flight measurement and response; and behavior arbitration in response to sensor input.

Collision avoidance for both platforms is achieved primarily with the IR systems, using the bump switches as backup.

Alph's IR emitters are turned on at the beginning of the main routine and remain functional throughout the operation of the robot. The LEDs are positioned to provide a 180-degree arc of illumination in front of the robot. The detectors each cover one forward quadrant, such that, should either detect an IR value above a set threshold, the platform will turn in the other direction.

Alph's behavior arbitration is based on a positive signal from the back bumper. When the back bumper pin (PE5) goes high in response to a hit, Alph will switch from collision avoidance and wandering to scanning for sonar.

In the scanning routine, Alph's sonar receiver sweeps out a 180 degree arc in 10-degree increments, covering the area in front of the platform. When a signal is detected, Alph turns toward it and continues scanning. The collision avoidance and sonar scanning are integrated, such that Alph will avoid an obstacle even if that means turning away from a sonar signal.

Alph's time-of-flight interpolation routine is triggered as soon as it detects a signal. Since the receiver circuit is designed to provide an active low signal in which the low pulse is proportional to the distance between the receiver and emitter, Alph can determine its approximate distance from the signal by counting the length of the low pulse. If this low pulse indicates a separation distance of less than two feet, Alph will emit a half-second pulse on the 4.2 kHz buzzer (theoretically, in order to signal Ralph to stop) before pausing for one second, backing up and turning away from the signal, and continuing its search in a different area.

Ralph's collision avoidance is based on both the bumper and the fore and aft IR detectors. The rear IR detectors were mounted specifically to detect the large IR signature of Alph's array of emitters, and to turn away from Alph depending on its position.

Ralph's holding pattern is triggered by a high pulse on PE1 via the microphone, which has a range of several feet for a handclap or other similarly loud noise. Upon recognition of this signal, Ralph will begin spinning in place. This behavior has the added benefit of providing a 360-degree sweep of sonar, guaranteeing that Alph will be able to "see" it.

Experimental Results

The following experiments were conducted on Alph.

Infrared Array

In order to determine the range and sensitivity of the IR arrays, a series of obstacles was set up, and readings taken from the analog ports at varying distances.

Further tests with a sheet of white paper yielded a maximum of 125 at two inches and a minimum of 87 beyond twelve inches.

Graphed, the data shows a decaying exponential relationship between the distance to an obstacle and the analog value returned by the IR detector. Therefore, once a reflective object (i.e. one that does not absorb IR) is within two inches, the detectors saturate. Accordingly, the threshold was set at 98, at which point the obstacle is approximately nine inches away, giving Ralph sufficient clearance to turn and avoid it.

A simple test program for collision avoidance functioned admirably.

Bump Sensors

To test the bump sensors, data was collected from the analog ports PE6 and PE7 before, during, and after the switches were activated. It was thus confirmed that the switches are active high, and to establish that the values do not register above 120 unless a switch has been closed. (Note: the rear bumper was later switched to PE5.)

A test program, by which the platform would move forward until a hit was registered, at which point it would pause, confirmed that the sensors were functioning properly and that the platform would be able to respond appropriately.

Sonar Array

Experiment 1: In order to determine the correlation between the length of the low pulse and the distance between the sonar emitter and receiver, a simple IC program was written which activates a counter as soon as the sonar input goes low. The number of counts is therefore related to the separation distance.

From a graph of the data, the linear relation between the distance and low pulse length is apparent. While not precisely one-to-one, the relation is nonetheless sufficiently linear that, particularly in ranges of less than two feet, this counter program can be used to allow Alph to determine whether it is close enough to the beacon to signal Ralph to stop.

The experiment was set up as follows: the beacon was set in a small vise clamp, such that the emitter emitted horizontally. The receiver was clamped in a "third hand" such that it was on the same level as the emitter, and facing the emitter as directly as possible. The beacon was then moved along the table in increments of six inches to take data points.

The values do not extend past seven and a half feet because the beacon was, at the time, powered off the EVBU board's five volt supply instead of a separate power supply, and the extension cord was only seven and a half feet long. However, values up to approximately sixteen feet were obtained by bouncing the signal off the wall. This data was not plotted and analyzed because it was erratic – focusing the emitter and receiver on the same spot was an inaccurate science at best – and because the sonar was not used for wall-following or mapping, but for tracking and rough time-of-flight approximations.

Experiment 2: With the use of a simple routine in which Alph moves forward upon receiving a sonar pulse and stops when the signal is terminated, it was possible to determine the approximate arc of detection and emission for the sonar transducers. Using the stationary beacon (Figure 3), the receiver has a range of vision covering approximately 60 degrees. The results are most consistent within a cone of about 45 degrees.

The following experiments were performed on Ralph.

Sonar Distribution

As previously noted, the sonar emitters have a range of approximately sixty degrees. In order to spread the signal in all directions such that Alph's receiver would be able to detect it even when not facing the emitter, experimentation with an inverse parabolic reflector, as suggested by Scott Jantz of the MIL, was implemented.

A rough approximation of the reflector was constructed from tinfoil, selected because of its reflective properties, malleability, and availability. It was determined that such a reflector would indeed provide the desired response; namely, the sonar receiver could pick up a signal even when perpendicular to the plane of emission.

The experiment was performed by holding the cone over the emitter and moving the receiver until it detected a signal, which was then displayed on an oscilloscope. No hard data was collected because this was merely an experiment to determine whether the theory was sound.

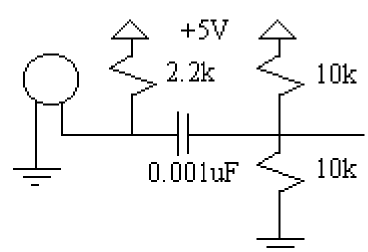
This reflector design was not implemented due to time constraints as well as the difficulty inherent in minimizing flaws in the surface of the reflector that might negatively affect the propagation of the signal. It should be noted that the time-of-flight measurements taken when using the reflector were erratic, probably due in part to the extremely crude design.

Microphone Range

The microphone circuitry went through several iterations before its final realization in the circuitry seen on Ralph (see Figure 4). Initially, the intention was to incorporate audio sensors on both platforms; however, due to time constraints and the problem of interference from the servos in the form of noise, only Ralph has a microphone.

The primary concern in implementing the audio circuitry was providing sufficient range that it would be feasible. The initial circuitry used a 2.2 k resistor and a 0.001 uF capacitor; however, this resulted in a range of less than one centimeter for the 4.2 kHz piezo buzzer.

original microphone circuit



By replacing the 0.001 uF capacitor with a 0.1 uF capacitor, the range was increased to approximately two inches. However, increasing the capacitor value to 1 uF and 10 uF had no further effect on the range.

Changing the resistors in the voltage divider to 100k from 10k increased the range slightly further, to approximately three inches, but also decreased the amplitude.

By then increasing the capacitor value to 3.3 uF, the range was increased to approximately six inches (for the piezo buzzer); changing the pullup resistor value to 1k instead of 2.2k further increased the range and sensitivity.

The handclap or other loud noise caused a consistent reading even at a maximum distance of nine feet. The response to the piezo buzzer, however, displayed an approximation of a decaying exponential curve.

The addition of a lowpass filter with a center frequency of 5 kHz and a highpass filter with a center frequency of 3.5 kHz did not improve the range, nor did the filters remove the noise from the servos, which, according to oscilloscope readings, has a large component around 4 kHz. Further experimentation involved the interaction between Alph and Ralph and the myriad software iterations necessary to accomplish this.

Conclusions and Future Work

In summary, Alph's collision avoidance, sonar tracking, and time-of-flight interpolation routines were successfully integrated. Alph was capable of finding and following Ralph or finding and approaching the beacon; most of the time, Alph would also stop and turn away before colliding with either. Ralph's evasion of pursuit was almost too successful, as was its response to audio signals.

Observation in different environments – specifically, the hallway outside Benton 312, the IMDL lab, and the demonstration arena – indicates that this particular system functions best in a small, well-defined area with few irregular corners and narrow (i.e. invisible to IR) obstacles.

There are several areas in which improvement is possible. The microphone circuitry never worked as well as was hoped; when transferred from the prototype board to a breadboard, the range of the microphone was inevitably halved, at least, despite intensive efforts to correct this. Further, it was discovered that Ralph's servos squeak at almost exactly 4 kHz, thereby making attempts to filter out the servo noise almost entirely futile.

Also in need of improvement is the sonar tracking routine. Provided that the target is stationary or moves slowly, Alph can find and track it without excessive difficulty. However, there was a distressing tendency to lose Ralph before (and, in fact, even after) Ralph's velocity was slowed (due to the servos not being balanced, Ralph's current programming causes it to move in a circle).

Finally, the actual herding behavior needs to be implemented. Experimentation with this behavior was unsuccessful to date and so could not be demonstrated. This is due in large part to the failure of the pulse differentiation routine, the implementation of which was most likely inherently flawed.

The principle areas in which further work should be concentrated are the audio system and herding behavior. Greater range and better sensitivity are required for the microphone to actually pick up the "stop" signal from Alph without constantly being set off by the noise from the servos.

The herding behavior is feasible; however, rather than having Alph look for two different sonar signals and try to arbitrate between the two, a better alternative would be to keep the sonar for tracking the beacon and use CDS cells to look for a light to be placed on Ralph. In this way, the time-of-flight precision would be available with respect to the beacon while simplifying the algorithm considerably. The biggest problem involved in this project was the attempt to discern between the 1ms pulse from the beacon and the 3ms pulse from Ralph. If two different systems were assigned to the two tasks of finding the beacon and finding Ralph, the problem of interference would be nonexistent.

Bibliography

[1] Mekatronix Talrik Manual, 1995.

[2] Mekatronix TJ Manual, 1995.

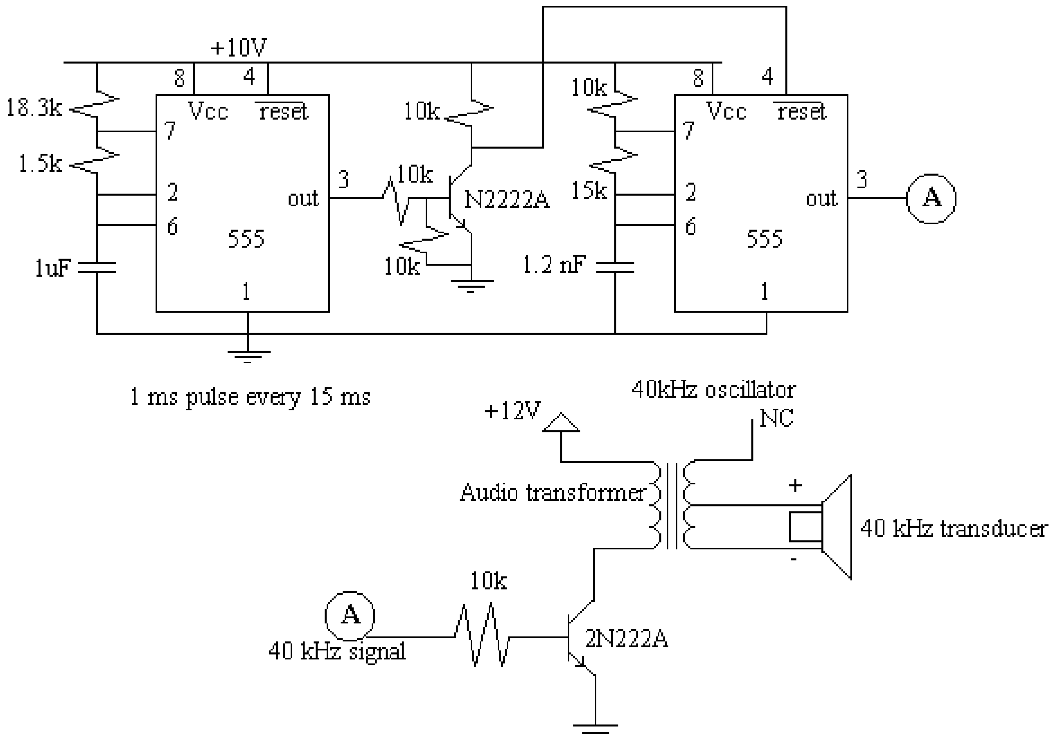
[3] Mekatronix ME11 Manual, 1995.

[4] Martin, Fred, The 6.270 Robot Builder's Guide. MIT, 1992.

[5] Apodaca, Michael, "Odin." IMDL, Spring 1998

[6] Carstens, Ed, "Ziggy." IMDL, Fall 1994

Figure 3



Stationary Sonar Beacon