Evolving Noise Tolerant Antenna Configurations Using Shape Memory Alloys

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Abstract

The aims of this work are to investigate whether a genetic algorithm can be used to adapt the structure of an antenna with 16 degrees of freedom. Shape memory alloys were used as actuators within the antenna. The antenna was submerged into a very noisy environment where it attempted to maximize the signal being sent to it by a transmitter. The results show that evolution was able to achieve this goal by precise adaptation to its environment, thus minimising the effects of noise.

1. Introduction

Today's world is full of electromagnetic radiation. Mobile phones, entertainment broadcasts, electronic communications and noise generated by computer equipment fill our environment. With digital error-checking and large transmitters and receivers, this does not cause too many problems (except for the times when you need to get a signal on your phone). But in some applications (e.g. communication with spacecraft, or low-power transmitters) the background noise can prevent a useful signal from being received at all.

The aim of this work is to create an adaptive antenna that can morph its shape intelligently in order to maximise its reception of a transmitted string in a noisy environment. In an environment that is very noisy, small differences in shape and position of receivers can have a dramatic effect on the signal strength. This is because in many cases, we are not using the antenna to maximise the signal being transmitted from the transmitter (for it is already more than adequate in size and shape for good reception). Instead we are attempting to minimise the effect of the noise. An everyday example is the portable UHF antenna used for television reception. (Often designed similarly to those found on top of roofs, known as Yagi-Uda antennas). As anyone who has attempted to adjust such an antenna will testify, the precise orientation of the antenna is very important. Small changes can often make a dramatic difference to the reception. With this in mind, in this work a stationary antenna is created that can change its shape using shape memory alloys (as controlled by an evolutionary algorithm) to try to minimise the effects of noise in its environment.

2. Background

2.1 Shape Memory Alloys

NiTi, an alloy made of **Ni**ckel and **Ti**tanium, was developed by the Naval Ordinance Laboratory. When current runs through it, thus heating it to its activation temperature, it changes shape to the shape that it has been 'trained' to remember. The wires used in this project simply reduce in length, (conserving their volume and thus getting thicker), by about 5-8 %.

Shape Memory Alloys, when cooled from the stronger, high temperature form (Austenite), undergo a phase transformation in their crystal structure to the weaker, low temperature form (Martensite), figure 1. This phase transformation allows these alloys to be super elastic and have shape memory [1]. The phase transformation occurs over a narrow range of temperatures, although the beginning and end of the transformation actually spread over a much larger range of temperatures. Hysteresis occurs, as the temperature curves do not overlap during heating and cooling, see Fig. 1 [1]. The NiTi wires used in this experiment activated at a temperature of 70°C and were 0.127mm in diameter.

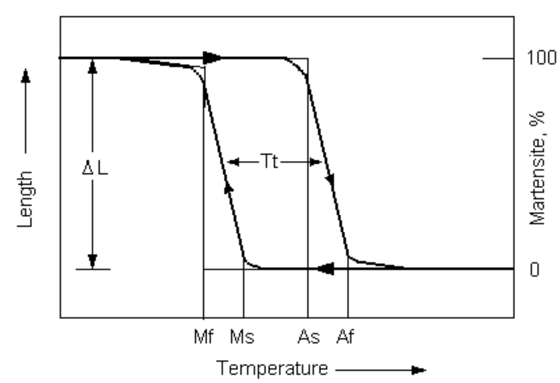

Figure 1 Change in length during heating and cooling. The hysteresis is represented by Tt.

2.2 What are antennas?

An antenna is a device that captures radio-frequency signals. It can be any conductive structure that can carry an electric current. Antennas can be transmitters or receivers. Transmitter antennas carry a time varying electrical current and radiate an electromagnetic wave. Receiver antennas do exactly the opposite. They pick electromagnetic waves and convert them into an electrical current. A passive antenna, that is one with no amplifiers attached, will have the same characteristics whether it is transmitting or receiving. [2]

The antenna being evolved in this work is a receiver antenna. Using up to 16 NiTi wires, it will attempt to maximize the signal strength being received by changing its shape.

2.3 Previous Work on Evolving Antennas

There has been much work on evolutionary design [3] and research has begun on using shape memory alloys with computers [4][5][6]. Most previous work related to antennas concentrates on the use of evolutionary algorithms in the design and optimisation of antenna structures. This is very different from the work proposed here that seeks to, given a general shape, vary the shape of the antenna intelligently to adapt to real world situations.

Linden was the first to use evolutionary algorithms to design antenna structures [7]. His work included the optimising of Yagi-Uda antenna structures, where the parallel wires of the Yagi-Udi structure were rotated about the central boom, as specified by a genetic algorithm. [7]. He went on to evolve designs of crooked-wire antenna (a single wire bent several times into a specific configuration), and treelike genetic antennas [8].

At NASA Ames Research Center, Lohn et al have used evolutionary algorithms to determine the size and spacing of the elements within a Yagi-Uda antenna [9]. More recently they have used a co-evolutionary algorithm to optimize the design parameters of a quadrifilar helical antenna [10]. Their plans include work to create antenna for space probes that will be designed to cope with the noise generated by other systems on the device.

Finally, the surprising work of Bird and Layzell [11] has also demonstrated the evolution of an antenna design, albeit by accident. In their experiment to evolve an electronic circuit that produced an oscillating signal as output, they discovered that instead, evolution had produced a primitive receiver that was receiving the background noise created by a nearby computer monitor and modifying it.

3. The Adaptive Antenna

The receiver antenna created in this work was designed to make best use of the 16 NiTi wires that were used to manipulate it. The antenna looks like an umbrella, see Fig. 2. The edges of the dish have 16 NiTi wires attached to them. These NiTi wires are attached to the base and then connected to the circuit board that can power them individually. As described, the NiTi wires used in this work simply contract by ~5-8%. This means that though the antenna would have 16 degrees of freedom (resulting in over 65000 different orientations), these would never drastically effect the overall shape of the antenna by much. This is useful for the genetic algorithm used to control the wires, as a change in one of the wires (and corresponding bit in the genome) would not result in a drastically different configuration – good for evolvability. The activation of the 16 NiTi wires has the result of bending and contorting the surface of the curved surface of the antenna.

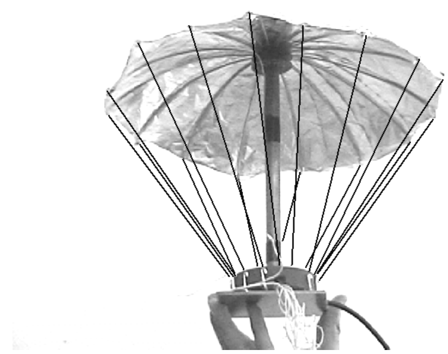

Figure 2 A photo of the adaptive antenna (NiTi wires highlighted in image).

The measurements and features of the antenna are illustrated in Fig. 3 below.

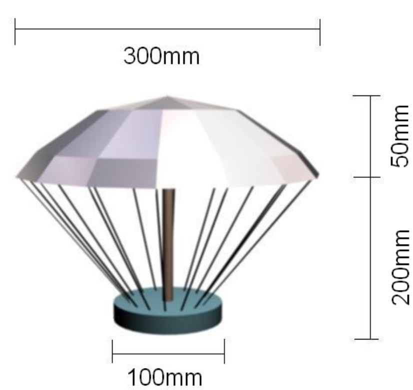

Figure 3 The dimensions of the adaptive antenna with 16 NiTi wires attached.

4. The Genetic Algorithm

4.1 The chromosome structure

There are a total of 16 NiTi wires that are available for activation by the genetic algorithm. Each individual in the population of solutions is described by a 16 bit string of ones and zeros. A one in the string would mean an active NiTi wire. In the example below, there are seven NiTi wires activated, see Fig. 4.

0	1	1	0	1	0	0	1	0	1	0	1	0	0	0	1

Figure 4 An individual is defined by a 16 bit string.

4.2 Genetic Operators

The crossover operator takes *n* bits from two chromosomes and swaps them. In the following example, two 16 bit strings are taken and 4 bits are selected from each of them, see Fig. 5.

0	1	1	0	1	0	0	1	0	1	0	1	0	0	0	1

1	1	0	0	1	1	1	0	0	1	1	1	0	1	1	0

Figure 5 Four bits are selected from two 'parent' individuals.

These bits are then swapped and the resulting individuals are now ready for mutation, see Fig. 6.

0	1	0	0	1	1	0	1	0	1	1	1	0	0	0	1

1	1	1	0	1	0	1	0	0	1	0	1	0	1	1	0

Figure 6 The bits are swapped, resulting in two new 'child' individuals.

Mutation is also applied occasionally. This involves randomly choosing *m* bits from an individual and flipping them (ones becoming zeros and vice versa).

4.3 Selection and Initialisation

Elitism was used in the genetic algorithm, using roulette wheel selection. The initial population is created randomly. Each bit of each chromosome had a 0.3 chance of being a one (activated NiTi wire).

4.4 Fitness function

As will be described in the next section, the fitness of each individual was not the absolute number of strings received by the antenna during that individual's particular NiTi wire activations, but instead the *relative* number of received "PING" strings when compared to the neutral state at that time. The fitness function is as follows:

Fitness = *activated_reading* – *background_reading* + *C*

Where *activated_reading* is the number of strings successfully received while the antenna is reshaped according to the current individual design, *background_reading* is the number of strings successfully received when the antenna is in its relaxed, default shape (measured just before *activated_reading* is taken) and *C* is a constant that ensures that the fitness is always positive. Therefore if the value of *Fitness* is less than *C*, the NiTi activated individual has performed worse than if the wires were not activated in the first place. Likewise, if the value of *Fitness* is greater than *C*, the NiTi activated interval has performed better.

5. Experimental Setup

To assess the reception capabilities of the adaptive antenna in a noisy environment, a transmitter was constructed that transmitted the string "PING" twelve times a second at a frequency of 433MHz. The receiver antenna was connected to a PIC microcontroller board that attempted to receive the "PING" strings. If the whole string was received uncorrupted by noise, then that would be considered a successful transmission. Any corrupted string received (e.g. "PONG") would be rejected.

When the transmitter is placed within a metre of the antenna, every transmitted "PING" string is received. However as the transmitter is moved further away from the receiver antenna, the number of strings successfully transmitted reduces until eventually not even a single transmitted string is ever received by the antenna.

The experimentation was done within a lab at University College London with many unpredictable sources of noise. (These were caused by computers, the nearby BT telecommunication tower, mobile phones and other equipment in normal use.) The transmitter was placed just outside the room in order to reduce the signal strength and make the noise within the room more problematic, see Fig. 7.

These sources of noise, along with others that were not identifiable, did not have a constant and continuous effect on the receiver. This meant that the noise levels varied the whole time. The transmitter was set up in such a way so that the receiver could receive 70% or less of the strings sent. This was done to ensure that the noise present within the room had a significant enough impact on the receiver so as to corrupt some of the "PING" strings being transmitted.

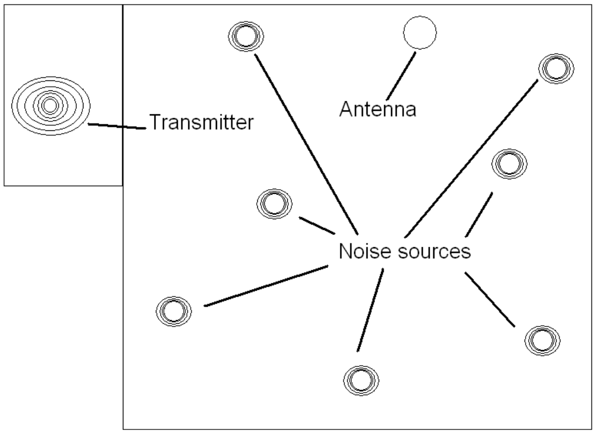

Figure 7 A plan of the room.

Figure 8 illustrates the noise during part of one run. In ideal conditions, the transmitted string can be received up to 27 times correctly in each test. The dark line shows (with the antenna in its default shape) just how noisy the environment is. The paler line shows the effect of activating the antenna into a specific shape, within a split second of each previous test. Clearly, activating the NiTi wires do affect reception. Experiments have shown that the wires themselves do not seem to be receiving or interfering with reception – only the change of antenna shape that they cause seems to affect reception. (Interestingly, earlier systems evolved to deactivate all wires, for the power drain caused by their activation reduced the power to the receiver electronics. The version described here now uses a separate power source for the wires.)

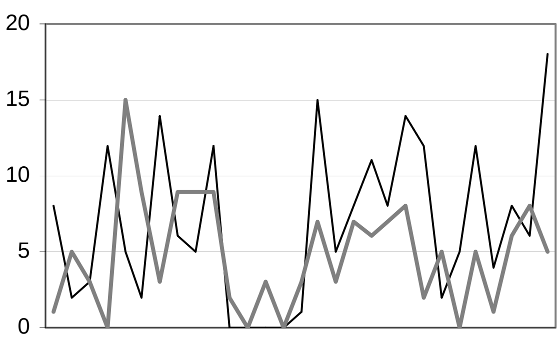

Figure 8 Typical equilibrium (dark line) and activated (light line) reception levels over time.

As described in the previous section, the fitness of an individual is measured relative to the performance of the relaxed antenna. Both are measured immediately one after the other in an attempt to ensure they are receiving in the same noise conditions. So the actual fitness of any individual is actually the difference between the two measurements.

Because of the noise, if one evolving individual outperforms another on a particular test, it doesn't mean that it is better, it could mean that at that particular time, the noise levels were less. This is another reason why a genetic algorithm is good to use, as a solution can be found that is good over most noise conditions. Simply running through all 65536 possible antenna configurations would not do this. Figure 9 illustrates the fitness of the individual shown in figure 8 under different noise conditions. The value of *C* is 27, meaning that if the fitness is below the dashed line, the individual performs worse than the neutral antenna. If above the dashed line, it performs better.

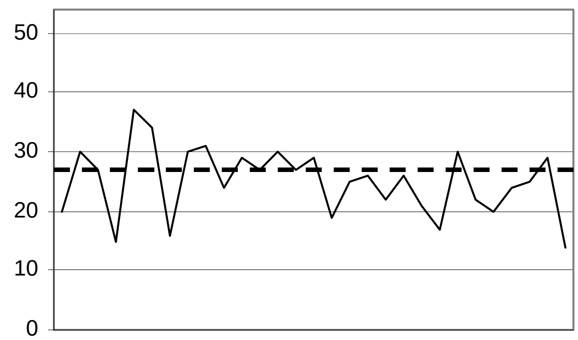

Figure 9 Signal reception quality relative to the background noise.

The experiment was run several times. The longest run recorded lasted approximately 12 hours, and the results for this run are reported here (although other runs showed similar results). Each individual was given 2 seconds to receive as many of the "PING" strings as possible in both the neutral and configured states. The genetic algorithm parameters are as follows:

- Population size: 20 individuals
- Crossover: 4/16 bits crossed, each time.
- Mutation rate: Every fifth generation, there is a 1/16 chance of one bit mutating.
- Generations: 300.
- The value of *C* = 27.

6. Results

Figure 10 shows the results of the experiment. Although subtle, because of the extensive noise, it is clear that the population average increases above the value of *C* as evolution progresses. It also shows that the maximum fitness remains at around the same level, but significantly the amplitude of the noise seems to be lower. Finally, the chart shows clearly how the minimum fitness increases – demonstrating evolution of antenna configurations that minimise the harmful effects of the noise.

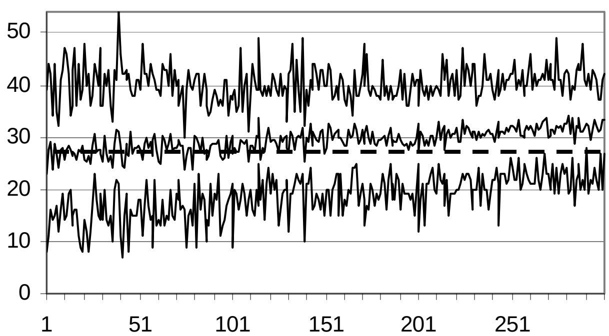

Figure 10 Fitnesses of evolving antenna designs per generation. Top line shows population best, middle line shows population average, bottom line shows population worst. The dashed line at a value of 27 is where the activated configuration receives the same number of strings as in the neutral state.

7. Analysis

The final population contained mostly similar genomes. Figure 12 shows the "average genome" (formed by choosing the most commonly appearing 1s and 0s at each genome position in the population). Figure 13 shows how this genome translates into an antenna design.

1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	1

Figure 12 "Average genome" in the final population.

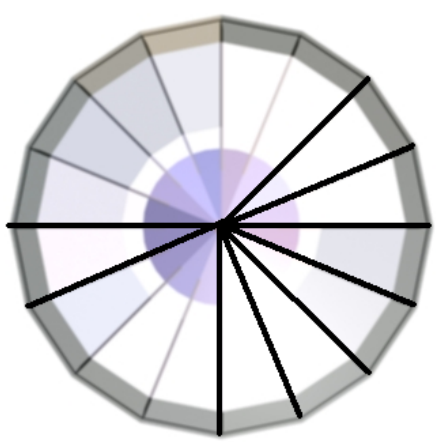

Figure 13 The top view of the antenna with the activated NiTi wires indicated. The transmitter is located directly to the left of this.

To obtain some further measure of the quality of this final, evolved solution, the configured antenna was compared to the antenna in its relaxed state in 20 tests (during which the background noise varied as always). Figure 14 shows how the evolved antenna maintains a high reception rate, compared to the neutral configuration, which shows highly variable reception caused by noise. Figure 15 shows the normalised results or fitness during this time.

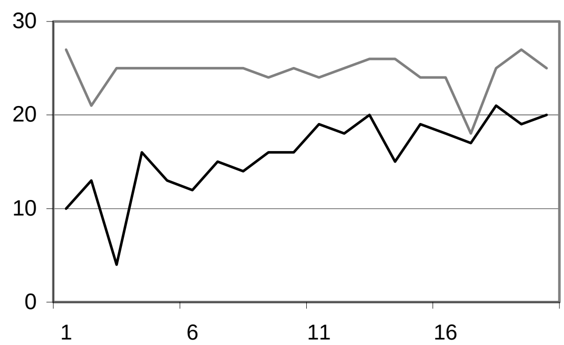

Figure 14 The activated antenna (light line) compared to the neutral state reception (dark line).

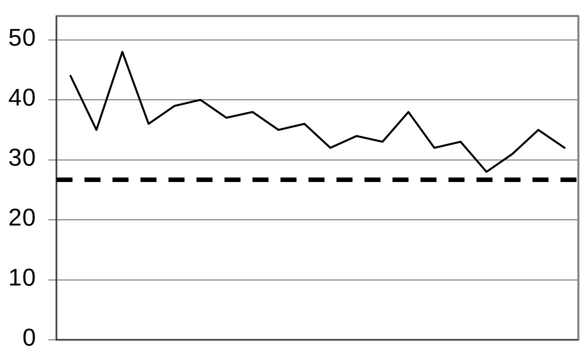

Figure 15 The normalised graph of the activated antenna's reception.

Significantly, the evolutionary run that created this design was performed overnight. It was hypothesised that the noise conditions at night would greatly differ from those present during the day. Therefore the same genome was again compared to reception of the neutral state during the daytime. The results are plotted in Fig. 16 and 17.

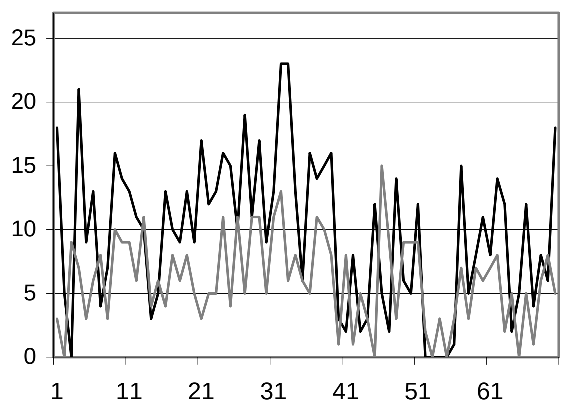

Figure 16 The neutral state reception (dark line) and the reception of the activated antenna (light line).

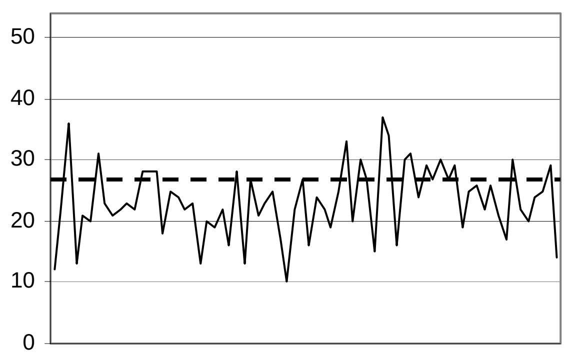

Figure 17 Normalised reception of activated antenna.

The activated antenna now shows a completely different result – it consistently underperforms. This means that although it has adapted well to the main sources of noise during the night, during the day, when different noise sources were present, this configuration is now a maladaptation that harms performance. Of course, while this might be a problem for traditional, fixed antennas, in this system the configuration can simply be re-evolved for daytime noise (or for noise during the day and night).

8. Conclusion

The aim of this work was to investigate whether an antenna, whose configuration was controlled by the activation of NiTi wires, could adapt its shape in order to maximise its reception of a transmitted signal. This was done through evolution by a genetic algorithm.

The GA discovered a noise tolerant antenna that minimised the effect of noise on the system. A more intensive investigation was then carried out, which reconfirmed this solution's tolerance to noise. The same system was then tested under very different noise characteristics. It was observed that adaptation to the previous conditions was so precise that in the vastly different noise environment, the solution was no longer ideal and in fact performed consistently worse then the neutral state orientation.

This is the first work to demonstrate an antenna capable of adapting to specific noise conditions. The results confirm the utility of the approach. It seems likely that these ideas will be highly beneficial in numerous applications.

Acknowledgements

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References

[1] Hodgson, Darel E. (2002), *Shape Memory Applications, Inc.*, Ming H. Wu, *Memory Technologies*, and Robert J. Biermann, *Harrison Alloys, Inc.* www.sma.com/Shape Memory Alloys.htm

[2] Robert S. Elliott (2002) Antenna Theory & Design (IEEE Press Series on Electromagnetic Wave Theory) John Wiley and Sons Inc.

[3] Bentley, P. J. (Ed.) (1999) *Evolutionary Design by Computers*. Morgan Kaufmann Pub.

[4] Haroun Mahdavi, S. (2002) Evolving Motion. Master's Dissertation, MSc IS, University College London, Dept. Computer Science.

[5] Haroun Mahdavi, S. and Bentley, P. J.(2003) Evolving Motion of Robots with Muscles. In Proc. of EvoROB2003, the 2nd European Workshop on Evolutionary Robotics, EuroGP 2003. pp. 655-664.

[6] Haroun Mahdavi, S. and Bentley, P. J. (2003) An Evolutionary Approach to Damage Recovery of Robot Motion with Muscles. To appear in Proc. of the European Conference on Artificial Life (ECAL 2003).

[7] Linden, D. S. (1997). *Automated Design and Optimisation of Wire Antennas Using Genetic Algorithms*. Ph.D. dissertation, MIT.

[8] Bentley, P. J. and Corne, D. W. (Ed.) (2002) *Creative Evolutionary Systems*. Morgan Kaufmann Pub.

[9] J.D. Lohn, W.F. Kraus, S.P. Colombano. Evolutionary Optimization of Yagi-Uda Antennas, Proc. of the Fourth International Conference on Evolvable Systems, Tokyo, October 3-5, 2001, pp. 236-243.

[10] J.D. Lohn, W.F. Kraus, D.S. Linden. Evolutionary Optimization of a Quadrifilar Helical Antenna, Proc. of the IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting , June, 2002, to appear.

[11] Jon Bird and Paul Layzell (2002) The Evolved Radio and its Implications for Modelling the Evolution of Novel Sensors. In Proc. of Congress on Evolutionary Computation (CEC2002).pp1836-1841.