OPTIMIZATION OF THE DRIVING SIGNAL OF AN ULTRASONIC TRANSDUCER USING A GENETIC ALGORITHM

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ABSTRACT

A method of reducing the response time of an ultrasonic transducer by optimizing the driving signal is presented. The optimization is performed with all hardware in the optimization loop. The driving signal is divided into two parts, a part used to excite the transducer and a part for damping the vibration of the transducer. The latter part is optimized by using the Genetic Algorithm Toolbox of Matlab in combination with an arbitrary waveform generator and an oscilloscope, which are controlled by the Instrument Control Toolbox of Matlab. The results of the optimization show that this is an effective way of reducing the response time of the transducers. The results show an average response time reduction of approximately 25%.

1. INTRODUCTION

Ultrasonic sensors can be used for distance measuring, possibly in environments in which the sensor is exposed to dirt or moist. A well-known application of ultrasonic sensors are parking sensors where it is used as a proximity alert so that the driver knows when he is approaching an object. In other applications this is automated and used as a safety precaution. In the latter applications, further distance reductions should be prevented automatically when the measured distance to the nearest object falls inside a certain safety region. However the current response time of the transducers does not allow the measurements to take place at object distances which are less than 0.2 m, due to the undamped resonance of the transducer. The resulting voltage obscures the received signals from reflecting objects, especially if the object is very nearby. In the experiments described in this paper, the response time is decreased by driving the transducers with an optimized signal. This signal consists of two parts, namely a part which excites the transducer and a part which reduces the amplitude resulting in a shorter response time. The last part of the driving signal has been optimized by using the genetic algorithm in combination with an experimental setup. The experimental setup is used for driving the transducer and measuring the response time.

2. OPTIMIZATION

An experimental setup is used in combination with a genetic algorithm to optimize the driving signal. This section discusses the different parameters, variables and the equipment used during the optimization of the driving signal. The driving signal is used to drive an ultrasonic transducer (see Fig. 1). The transducers will be excited at the nominal driving frequency, which is 40 kHz.

Using Method	Nominal Freq. (kHz)	Operating Temp. Range (°C)	Detectable Range (m)
Dual use	40	-30 to 85	0.2 to 1.5

Figure 1. Ultrasonic transducer properties [1].

2.1. The driving signal

The driving signal sent to the arbitrary waveform generator consists of two parts, which are built up out of a number of points (see Fig. 2). The part exciting the transducer is unaltered during the optimization and consists of 4 pulses, which are low at the first half period of the pulse and high at the last half period. The transducer is only excited by the high part of the pulse. The part damping the excitation is optimized with the genetic algorithm. The number of variables during the optimization depends on the number of points used to build up one pulse and thus the driving signal. Both the excitation signal and the damping signal are defined as a number of pulses and a number of points per pulse. The pulse of the driving signal shown in Fig. 2 is built up out of 6 points. The damping signal consists of two pulse periods and therefore out of 12 variables. Because the final point of the driving signal determines the state of the signal sent to the transducer an additional point is added. This ensures the state at the end of the driving signal to be low (0).

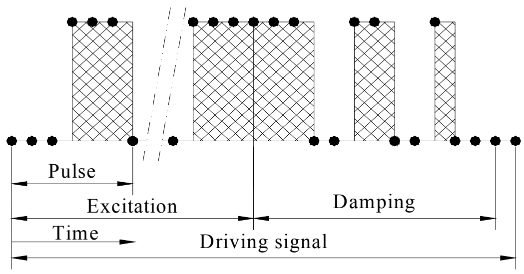

Figure 2. *Example of a driving signal*

The number of possible solutions will increase drastically with the number of variables used during the optimization. In case of 20 points per pulse and 4 pulses the number of different possibilities is equal to 2^{80}.

2.2. The Genetic algorithm

This section is primarily based on the user's guide [2] provided by MathWorks. The genetic algorithm is a method for solving optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm differs from a standard algorithm in two ways. The first difference between the genetic algorithm and a standard algorithm is that, at each iteration, the genetic algorithm generates, instead of a single point, a population of points that approach an optimal solution. This increases the chance of finding a global optimum. The second difference is the way in which the next point is selected. The genetic algorithm selects the next population by computations that involve random choices. Standard algorithms select the next point by a deterministic computation. During the optimization the genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects the fittest individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution.

2.2.1. The fitness function and the fitness value

The object function of the genetic algorithm is called the fitness function. In this case the input of a driving signal results in a certain response time of an ultrasonic transducer. The genetic algorithm tries to minimize the fitness value, in this case the response time. The data- and the signal flow during the optimizations are visualized in Fig. 3. The equipment as used in the experimental setup is controlled by the Matlab Instrument Control Toolbox. The driving signal is sent to an arbitrary waveform generator, which controls a driving circuit used for driving the transducers. For a more general use of the driving signal, the response of two transducers is measured. The response is measured by an oscilloscope; subsequently the data is readout by Matlab.

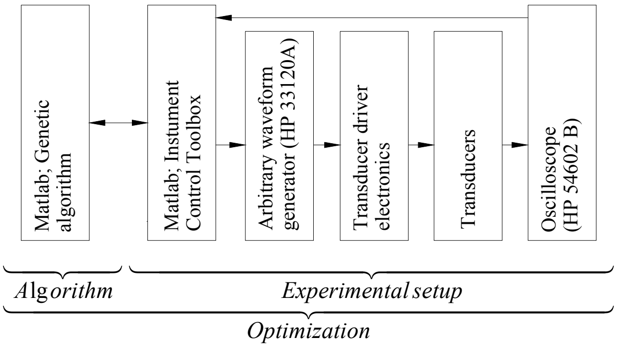

Figure 3. *Data- and signal path during the optimization*

From the measured data the average response time of the two transducers is determined. The response time is determined by the time after which the amplitude of the signal remains within a certain amplitude bandwidth. A bandwidth of at least twice the maximum amplitude of the noise on the signal is used to determine the response time (see Fig. 4).

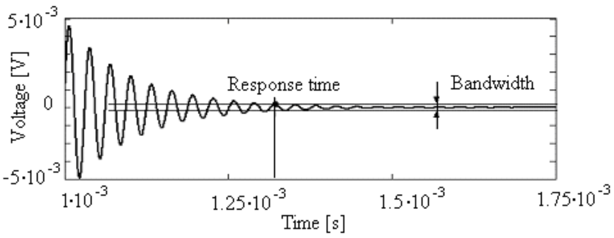

Figure 4. *Example of determining the response time of an ultrasonic transducer.*

The response times are determined for an entire population and are ranked, starting with the individual with the shortest response time.

2.2.2. The creation of a population

The initial population which is used when the genetic algorithm is initiated, can be randomly created by the genetic algorithm or it can be manually created. It is recommended that the size of the population is equal to the number of variables used during the optimization. It is also possible to resume an optimization from a previous optimization. In this case the final population of a previous optimization is used as the initial population of the current optimization. It will be clear that the number of variables in, and the size of that final population must equal the number of variables in, and the size of the initial population of the optimization. After the genetic algorithm has determined the fitness of the individuals in the initial population, the next generation is created. The genetic algorithm creates three type of children for the next generation:

- Elite child
- Crossover child
- Mutation child

The fittest individual of the current population, which is unaltered used in the next generation, is called an elite child. The number of elite children is set prior to the optimization. A crossover child is created from the combination of a pair of parents. The two options used during this research are: the crossover at a single point and scattering. The first combines the first half of the first parent with the second half of the second parent. The latter combines random points of two parents to create a child. A mutation child is a child that is created by making changes to a single parent. Two ways of mutation are used during this research, namely, uniform mutation and custom mutation. In case of the uniform mutation, the algorithm first selects a fraction of the vector entries of an individual for mutation, where each entry has a probability rate of being mutated. Next, the algorithm replaces each selected entry by a random number selected uniformly from the range for that entry. In case of the custom mutation the algorithm selects a cluster of high points (see Fig. 2) to be mutated. The mutation can take place at both the beginning and at the end, at just the beginning or at just the end of the cluster. The combination of the mutations at these positions can shift the cluster to either side and shorten or lengthen the cluster.

2.3. Optimization time

The main problem of this method is the duration of the optimization. At each iteration, the driving signal is sent to the arbitrary function generator, and the data is read out from the oscilloscope and processed. Time is saved by sending the driving signal to the volatile memory without copying the signal into the permanent memory, by reading the oscilloscope without averaging the signal and by measuring identical driving signals once. As the genetic algorithm advances it is most likely that identical driving signals occur in the population. The identical driving signals are measured once and the fitness value is assigned to the other identical driving signals. By applying these time saving measures an optimization with 4 damping pulses and 24 points per pulse only takes approximately 18 hours (otherwise approximately 30 hours). These long optimization times can be accepted because of the few times the driving signal is optimized.

2.4. Optimal solution

The optimal solution is found by combining the previous discussed ways of creating a population. Different ways of resuming from a solution of a successful optimization are assessed. Mesh refinement is applied by starting the optimization with 4 points per pulse and by scaling the solution to a population with 8 or more points per pulse. Different crossover functions and different mutation functions have been used to create the next generation. The best parameters for the optimization routine were determined by trial and error.

3. RESULTS

During the research the response times associating with the optimal driving signal of 7 transducers were assessed. The results of one transducer are presented in some detail in this section; other results are only mentioned. The response of a transducer driven by only the basic excitation part of the driving signal is visualized in Fig. 5. The time is displayed on the horizontal axes and the voltage on the vertical axes. The response time of this transducer is approximately 1.1 ms.

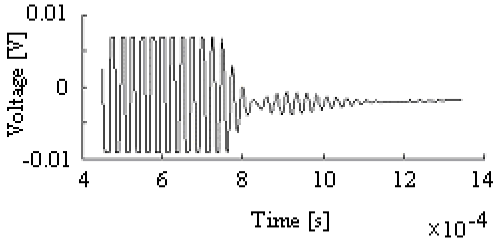

Figure 5. Response of a transducer which is driven by the standard sequence of excitation pulses.

The amplitude of a signal reflected from a hard surface (no absorption of acoustic energy) is approximately 5 mV. This will reduce when the surface absorbs acoustic energy or when de surface scatters the acoustic energy. Because of these uncertainties, it is not recommended that the distance measurement take place while the transducer is still vibrating. This means that when the transducer is excited by 4 pulses, the measurement can start after 1.2 ms (*f* in Eq. (1) is 40 kHz).

$$T = \frac{1}{f} \tag{1}$$

in which T is the period and f is the frequency. This is equal to a minimum measurable distance of 0.21 m which is determined by

$$d_m = \frac{c_0\left(e_t + r_t\right)}{2} \tag{2}$$

in which d_m is the minimum measurable distance, c_0 is the speed of sound (343 m/s at 20°C [3]), e_t is the excitation time and r_t is the response time. The measurable distance must be 0.15 m or less which is equal to a response time of 775 μs or less. The damping part of the driving signal resulting from the optimization discussed in this Section consists of 4 pulses with 24 points per pulse. The result of the optimization is shown in Fig. 6. The dashed lines represent the half period positions of the pulses. The first four cluster of points at which the transducer is driven by the damping signal all lie inside the 180 decrease phase shift area, compared to the signal used to excite the transducer (see Fig. 2). The last two clusters are in-phase, as compared with the excitation signal. The exact cause of this phase-shift remains unknown.

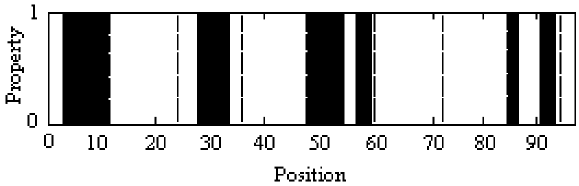

Figure 6. *Optimal damping part of the driving signal.*

The resulting response of a transducer driven by 4 exciting pulses followed by the damping signal of Fig. 6, is presented in Fig. 7. The response time is approximately 700 μs which satisfies the requirements. Comparing the results of Fig. 7 with Fig. 5 leads to the conclusion that the response time is reduced by 36 percent.

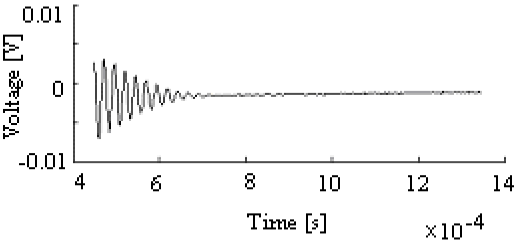

Figure 7. *Response of a transducer driven by the optimal driving signal.*

There are two transducers that did not satisfy the requirements when driven by the driving signal presented in Fig. 6. In these cases, the response times (850 μs and 950 μs) can be decreased by approximately 20 percent but this is not enough. This means that 28 percent of the transducers cannot be used for measuring a distance of 0.15m.

4. CONCLUSIONS

In this paper, the input driving signal and the resulting response time of a transducer were successfully modified with a genetic optimization procedure. The optimization process was performed with all hardware in the optimization loop. Besides the transducer and driving circuitry, the hardware consisted of an arbitrary waveform generator and an oscilloscope, which were controlled by the Matlab Instrument Control Toolbox. It has been shown that it is possible to reduce the response time of the transducers by using a driving signal optimized by the genetic algorithm. It has been found that the genetic algorithm is a suitable optimization method to find an optimum represented as a bit-string. The response time of the optimal solution satisfies the requirements by 75 μs. An average of 62 percent of the transducers satisfies the requirements of a desired response time of 775 μs.

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6. REFERENCES

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