

Smart Dog Bowl Using FFT Analysis of Dog's Bark

Brian Kubisiak
brian.kubisiak@gmail.com
MSC 606

1 Motivation

In designing a smart dog bowl to open only for a specific dog, it is important that method used for identifying the dog be very accurate; there should never be a case where a dog is unable to access his food. Obvious approaches to this problem would be to put some sort of identification tag on the dog's collar, such as RFID or a modulated IR beacon.

However, these approaches can easily break down under fairly common circumstances—IR must have a clear path to the sensor, and RFID depends on a specific orientation. In addition, these approaches require the dog to be wearing his collar, and—in the case of IR—the collar must be powered. I believe that the most important part of this bowl is that a dog must never approach his bowl, only to have it not open due to something blocking the identification on his collar.

2 Method of Approach

To solve the problems described above, I have elected to identify the dog using its bark. Just as humans each have a distinct-sounding voice, a dog's bark contains a unique spectrum of frequencies. By analyzing these frequencies, I believe that a system can be designed that will open for one dog's bark but not another's.

The dog can never really "lose" his bark, so it is ideal in that the dog will always be able to open the dish on his own. Additionally, in the case that an error causes the dog to be misidentified, the dog will likely try again, reducing the probability of error.

One disadvantage of this design is that the dog will have to be trained to bark in order to open his food dish. However, this seems fairly easy, as teaching a dog to "speak" is a fairly common trick. Another obvious disadvantage is that the analysis will not get a distance measurement to the dog. In order to overcome this, I will use ultrasonic ranging sensors to determine whether or not the dog is within a 1 ft radius.

3 Hardware Operation

My design comprises a microphone with an audio amplifier, triggering logic for generating interrupts, ultrasonic rangefinders for measuring proximity, an Arduino for performing the signal processing, and a servo motor for opening the dog bowl.

All of the signal processing for this design will be performed on an Arduino board. The processor will sample the dog's bark, then perform an FFT on the data and compare it to saved values. If the bark matches, the bowl will open.

There will be 4 ultrasonic proximity detectors to determine whether or not there is an object within 1 ft of the bowl. This will consist of an ultrasonic range finder and circuitry comparing it to a reference range. This detector will output a digital 1 if there is an object within a foot, and a 0 if there is not. Each range finder can detect in a 15° angle. By putting 4 of these in a circle around the bowl, they should be able to detect anything larger than a foot wide around the entire radius. More sensors can easily be used, at a slightly increased cost.

The microphone will output a simple analog signal into the Arduino. In addition, some analog circuitry will be used to generate an interrupt whenever the analog input reaches a certain threshold in order to allow the Arduino to idle at lower power when data is not being read.

A block diagram for this design is shown in figure (1).

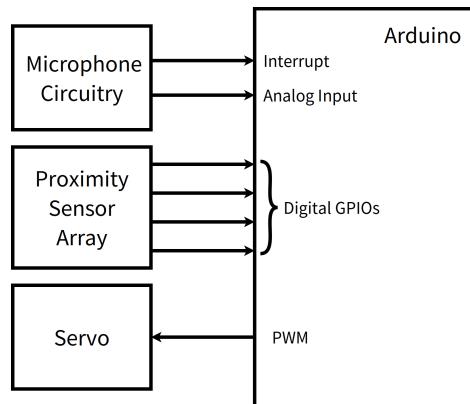


Figure 1: Top-level block diagram for the dog bowl.

3.1 Microphone Circuitry

All of the microphone circuitry is detailed in figure (2).

The microphone is powered from V_{cc} through a $2.2\text{ k}\Omega$ resistor, as recommended in the data sheet. The signal is then lowpass-filtered before being fed into the amplifier. The lowpass filter is designed with a corner frequency of 10 Hz using $R_2 = 100\text{ k}\Omega$ and $C_1 = 1\text{ }\mu\text{F}$. This will filter out the DC component without affecting the AC signal.

The audio amplifier uses an op-amp with a single-sided supply in order to amplify the input signal. The amplifier is arranged in a noninverting configuration, with a total amplification factor of 560 (27.5 dB). The resistor R_f can be adjusted as needed to change the amplification. Note that the AC input may go below ground, but this will be clipped by the amplifier.

The output of the amplifier is then fed directly into the ADC on the Arduino board. This amplified signal is also fed into the comparator U2 in order to generate an interrupt to tell the Arduino to begin recording the audio. The trigger level is set with R_4 and R_5 . I have found that a level of around 1.7 V works well. This interrupt trigger is fed into a GPIO pin on the Arduino to generate an interrupt.

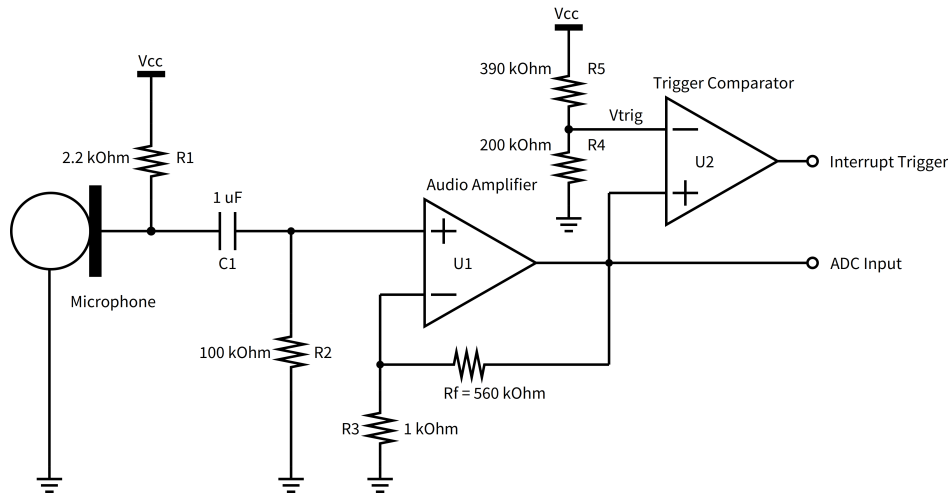


Figure 2: Microphone amplifier and trigger generator.

3.2 Proximity Sensor Array

The proximity sensor array is shown in figure (3).

The sensor array is fed by ultrasonic range finders. Each range finder outputs an analog voltage representing the distance to the nearest object (the exact relation is not important to this design). The output of these sensors will be fed into comparators, comparing them to a fixed voltage. This voltage will correspond to approximately 1 ft from the ultrasonic sensors. The voltage is created using a voltage divider with the resistors R6 and R7. I have found that a voltage level of 0.76 V works well for identifying objects approximately 1 ft away.

The outputs from all of these comparators will go into GPIO pins on the Arduino. When the microphone circuit triggers a recording, the Arduino will first check that at least one of the proximity sensors is triggered before computing the FFT of the recording.

Note that the comparators used in my design are open drain, so they do not drive the output to Vcc; rather, they put the output in a high-impedance state that requires a pull-up resistor. The Arduino GPIO pins have internal pull-up resistors, so these are not included in my analog circuitry.

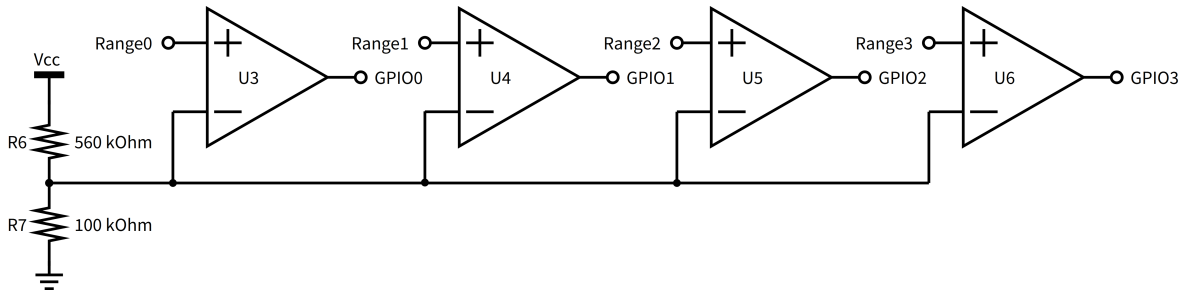


Figure 3: Circuit for the array of proximity sensors.

3.3 Servo Motor

The servo motor is a standard Parallax servo motor with 180° of motion. The position of the servo is controlled through PWM. One of the PWM outputs on the Arduino will switch the servo between the open position and the closed position when needed.

4 Software Operation

Note that the following code is still a work in progress.

4.1 FFT Function Declarations

```

1  /*
2  * fft.h
3  *
4  * Perform Fast Fourier Transforms on data.
5  *
6  * This code is used for computing a low-footprint, high-speed FFT on an array
7  * of data. Because of the limitations of the platform that I am working on,
8  * several optimizations have to be made in order for the code to work.
9  * Specifically, the limitations I have are:
10 *
11 *      8 kB of RAM
12 *      No floating-point unit
13 *      8 -> 16 bit multiplier
14 *      8 bit adder (for speed)
15 *
16 * Some limitations are self-imposed in order to produce faster code. Each data
17 * point is a complex number with 8 bits for the real part and 8 bits for the
18 * imaginary.
19 *
20 * Revision History:
21 *      16 Apr 2015      Brian Kubisiak      Initial revision.
22 */
23
24
25 #ifndef _FFT_H_
26 #define _FFT_H_
27
28
29 #include "data.h" /* Complex data type, size of array, etc. */
30
31
32 /*
33 * fft
34 *
35 * Description: Computes the fast Fourier transform (FFT) of an array of input
36 * data. This implementation is in-place, so it will take O(1)
37 * space. Additionally, optimizations are performed assuming that
38 * the data to transform is purely real. The implementation assumes
39 * 8-bit characters and 16-bit shorts. It attempts to avoid 16-bit
40 * additions/multiplications wherever possible in order to cut down
41 * on the number of clocks.
42 *
43 * Arguments:  data An array of complex numbers for performing the FFT. This
44 *               FFT assumes that the array contains 'SAMPLE_SIZE' values of
45 *               type 'complex'. Both of these are defined in 'data.h'.
46 */

```

```

47  * Limitations: Assumes that the input data is purely real. Because there is no
48  *              FPU and fixed-point arithmetic is used, the resulting FFT will
49  *              not be normalized to anything sensible.
50  */
51 void fft(complex *data);
52
53
54 #endif /* end of include guard: _FFT_H_ */

```

4.2 FFT Code

```

1  /*
2  * fft.c
3  *
4  * Perform Fast Fourier Transforms on data.
5  *
6  * This code is used for computing a low-footprint, high-speed FFT on an array
7  * of data. Because of the limitations of the platform that I am working on,
8  * several optimizations have to be made in order for the code to work.
9  * Specifically, the limitations I have are:
10 *
11 *      8 kB of RAM
12 *      No floating-point unit
13 *      8 -> 16 bit multiplier
14 *      8 bit adder (for speed)
15 *
16 * Some limitations are self-imposed in order to produce faster code. Each data
17 * point is a complex number with 8 bits for the real part and 8 bits for the
18 * imaginary.
19 *
20 * Revision History:
21 *      16 Apr 2015      Brian Kubisiak      Initial revision.
22 */
23
24 #include <stdio.h>
25 #include "fft.h"
26
27 extern complex root[SAMPLE_SIZE];
28
29
30 /*
31 * fft
32 *
33 * Description: Computes the fast Fourier transform (FFT) of an array of input
34 *              data. This implementation is in-place, so it will take O(1)
35 *              space. Additionally, optimizations are performed assuming that
36 *              the data to transform is purely real. The implementation assumes
37 *              8-bit characters and 16-bit shorts. It attempts to avoid 16-bit
38 *              additions/multiplications wherever possible in order to cut down
39 *              on the number of clocks.
40 *
41 * Arguments:   data An array of complex numbers for performing the FFT. This
42 *                FFT assumes that the array contains 'SAMPLE_SIZE' values of
43 *                type 'complex'. Both of these are defined in 'data.h'.
44 *
45 * Limitations: Assumes that the input data is purely real. Because there is no
46 *              FPU and fixed-point arithmetic is used, the resulting FFT will
47 *              not be normalized to anything sensible.
48 *
49 * Notes:      A lot of the notation below is made up. Basically, we do log2(N)
50 *              passes over the data, where each pass will iterate over a
51 *              cluster of butterflies (try googling 'FFT butterfly' if you

```

```

52 *          don't know what this is). Each cluster of butterflies is
53 *          separated by a certain stride value, so we can just continue to
54 *          increment by this stride until the data is covered. Then, start
55 *          the next pass.
56 *
57 *          If you don't understand how this works, try staring at FFT
58 *          butterflies a bit longer and it will hopefully make sense. If
59 *          that doesn't work, try eating ice cream because yum ice cream.
60 */
61
62 void fft(complex *data)
63 {
64     /*
65     * The stride of each pass over the data is a measure of the distance
66     * between the two data points combined together in a butterfly. It is
67     * always a power of two.
68     */
69     unsigned int stride;
70     unsigned int i, j, k;      /* Loop indices. */
71
72
73     /* We start off with two separate clusters of butterfly nodes filling the
74     * entire data set. */
75     stride = SAMPLE_SIZE / 2;
76
77     /* We need to perform log2(N) iterations over the data in order to fully
78     * transform it. */
79     for (i = 0; i < LOG2_SAMPLE_SIZE; i++)
80     {
81         /*
82         * Keep striding through the data until we cover all of it. Note that we
83         * only go to 'SAMPLE_SIZE / 2', since each butterfly covers 2 data
84         * points.
85         */
86         for (j = 0; j < SAMPLE_SIZE; j += 2*stride)
87         {
88             /*
89             * Iterate over every butterfly in the cluster. This will use one
90             * data point in the cluster, and one in the next cluster. We then
91             * stride over the next butterfly cluster to avoid redoing this
92             * computation.
93             */
94             for (k = j; k < j + stride; k++)
95             {
96                 /* Get the two data points that we are transforming. */
97                 complex a = data[k];
98                 complex b = data[k+stride];
99
100                /* Since the roots are stored in bit-reversed order, we can just
101                * index into the array with the butterfly index. */
102                complex w = root[j];
103
104                /* The negative of the root is just 180 degrees around the unit
105                * circle. */
106                complex neg_w = root[j + SAMPLE_SIZE / 2];
107
108                /* Now transform them using a butterfly. */
109                data[k] = add(a, mul(b, w));
110                data[k+stride] = add(a, mul(b, neg_w));
111            }
112        }
113
114        /* Reduce the stride for the next pass over the data. */
115        stride /= 2;
116    }

```

117 | }

4.3 Complex Number Data Type

```

1  /*
2  * data.h
3  *
4  * Data types and constants for analyzing a frequency spectrum.
5  *
6  * This file describes the complex number data type, as well as functions for
7  * adding and multiplying complex numbers. Constants for determining the number
8  * of samples to use are also defined here.
9  *
10 * Revision History:
11 *      16 Apr 2015      Brian Kubisiak      Initial revision.
12 *      04 Jun 2015      Brian Kubisiak      Changes to SAMPLE_SIZE macro.
13 */
14
15 #ifndef _DATA_H_
16 #define _DATA_H_
17
18
19
20 #ifndef SAMPLE_SIZE
21 #define SAMPLE_SIZE      256      /* Number of samples in the buffer. */
22 #define LOG2_SAMPLE_SIZE      8
23 #endif
24
25
26 /*
27 * complex
28 *
29 * Description: Data type for holding a complex number. This data type uses
30 * Cartesian coordinates for holding the number, so it is optimized
31 * for addition rather than multiplication.
32 *
33 * Members:      real  The real part of the complex number.
34 *               imag  The imaginary part of the complex number.
35 */
36 typedef struct _complex {
37     char real;
38     char imag;
39 } complex;
40
41
42 /*
43 * add
44 *
45 * Description: Adds together two complex numbers in the Cartesian plane.
46 *
47 * Arguments:      a  The first number to add.
48 *                 b  The second number to add.
49 *
50 * Returns:      Returns the complex number that is the sum of the two inputs.
51 */
52 complex add(complex a, complex b);
53
54
55 /*
56 * mul
57 *
58 * Description: Computes the product of two complex numbers in the Cartesian

```

```
59 *           plane.
60 *
61 * Arguments:  a  First number to multiply.
62 *           b  Second number to multiply.
63 *
64 * Returns:    Returns the complex number that is the product of the two
65 *           inputs.
66 *
67 * Notes:      The number is stored in rectangular coordinates, so taking the
68 *           product will be a bit slow.
69 */
70 complex mul(complex a, complex b);
71
72
73
74 #endif /* end of include guard: _DATA_H_ */
```

4.4 Complex Number Operations

```
1  /*
2  * data.c
3  *
4  * Data types and constants for analyzing a frequency spectrum.
5  *
6  * This file describes the complex number data type, as well as functions for
7  * adding and multiplying complex numbers. Constants for determining the number
8  * of samples to use are also defined here.
9  *
10 * Revision History:
11 *   16 Apr 2015    Brian Kubisiak    Initial revision.
12 */
13
14 #include "data.h"
15
16
17
18 /*
19 * add
20 *
21 * Description: Adds together two complex numbers in the Cartesian plane.
22 *
23 * Arguments:  a  The first number to add.
24 *           b  The second number to add.
25 *
26 * Returns:    Returns the complex number that is the sum of the two inputs.
27 */
28 complex add(complex a, complex b)
29 {
30     complex res;
31
32     /* Real part of result is sum of real parts of inputs. */
33     res.real = a.real + b.real;
34     /* Imaginary part of result is sum of imaginary parts of inputs. */
35     res.imag = a.imag + b.imag;
36
37     return res;
38 }
39
40
41 /*
42 * mul
43 *
```



```

44 * Description: Computes the product of two complex numbers in the Cartesian
45 *             plane.
46 *
47 * Arguments:  a  First number to multiply.
48 *             b  Second number to multiply.
49 *
50 * Returns:    Returns the complex number that is the product of the two
51 *             inputs.
52 *
53 * Notes:      The number is stored in rectangular coordinates, so taking the
54 *             product will be a bit slow.
55 */
56 complex mul(complex a, complex b)
57 {
58     complex res;
59
60     /* (a + jb)(c + jd) = ac + jad + jbc + j^2 cd = (ac - cd) + j(ad + bc) */
61
62     /* Real part of result comes from product of real parts minus product of
63      * imaginary parts. */
64     res.real = (a.real * b.real) - (a.imag * b.imag);
65     /* Imaginary part is sum of cross products of inputs. */
66     res.imag = (a.real * b.imag) + (a.imag * b.real);
67
68     return res;
69 }

```

4.5 Proximity Sensor Function Declarations

```

1  /*
2  * proximity.h
3  *
4  * Code for detecting proximity of the dog using the GPIO pins.
5  *
6  * This file contains an interface for detecting whether or not there is an
7  * object detected by the ultrasonic rangefinders. The rangefinders feed into
8  * comparators, which are connected to GPIO pins on the microcontroller; the
9  * functions in this file will read the status off the GPIO pins to determine
10 * whether or not anything is detected by the ultrasonic rangefinders.
11 *
12 * Peripherals Used:
13 *     GPIO
14 *
15 * Pins Used:
16 *     PA[0..7]
17 *
18 * Revision History:
19 *     05 Jun 2015    Brian Kubisiak    Initial revision.
20 */
21
22 #ifndef _PROXIMITY_H_
23 #define _PROXIMITY_H_
24
25
26 /*
27 * init_prox_gpio
28 *
29 * Description: This function initializes the GPIO pins so that they are ready
30 *             to read data from the proximity sensors. This process involves:
31 *             - Writing a 0 to DDA to set GPIO as input.
32 *             - Writing a 1 to PORTA to enable the pull-up resistor.
33 *             - Writing a 0 to the PUD bit in MCUCR

```

```

34  *
35  * Notes:      This function assumes that no other peripherals are going to use
36  *             PA[0..7] pins; the configuration might not work if this is the
37  *             case.
38  */
39 void init_prox_gpio(void);
40
41
42 /*
43  * is_obj_nearby
44  *
45  * Description: Determine whether or not there is an object nearby using the
46  *             ultrasonic proximity sensors. This function returns 0 if no
47  *             objects are detected by the proximity sensors, and returns
48  *             nonzero if objects are detected.
49  *
50  * Return:      If no objects are in range of the ultrasonic sensors, returns 0.
51  *             If one or more objects are in range, returns nonzero.
52  *
53  * Notes:      The return value uses the low 4 bits to represent the
54  *             rangefinders in each direction, so the number of triggered
55  *             rangefinders can also be found from the return value.
56  */
57 unsigned char is_obj_nearby(void);
58
59
60 #endif /* end of include guard: _PROXIMITY_H_ */

```

4.6 Proximity Sensor Functions

```

1  /*
2  * proximity.c
3  *
4  * Code for detecting proximity of the dog using the GPIO pins.
5  *
6  * This file contains an interface for detecting whether or not there is an
7  * object detected by the ultrasonic rangefinders. The rangefinders feed into
8  * comparators, which are connected to GPIO pins on the microcontroller; the
9  * functions in this file will read the status off the GPIO pins to determine
10 * whether or not anything is detected by the ultrasonic rangefinders.
11 *
12 * Peripherals Used:
13 *     GPIO
14 *
15 * Pins Used:
16 *     PA[0..7]
17 *
18 * Revision History:
19 *     05 Jun 2015    Brian Kubisiak    Initial revision.
20 */
21
22 #include "proximity.h"
23
24 /* Define the addresses for controlling GPIO port A. */
25 #define PINA_ADDR  0x20    /* Address for reading values off pins. */
26 #define DDRA_ADDR  0x21    /* Address for configuring direction of pins. */
27 #define PORTA_ADDR 0x22    /* Address for enabling pull-up resistors. */
28
29 /* Constants for setting the values of the control registers. */
30 #define DDR_INPUT  0x00    /* Configure all pins as inputs. */
31 #define PORT_PULLUP 0xFF    /* Activate all pull-up resistors. */
32

```

```
33  /* Constant for masking out the unused pins. */
34  #define ACTIVE_PINS 0x0F
35
36  /*
37   * init_prox_gpio
38   *
39   * Description: This function initializes the GPIO pins so that they are ready
40   *              to read data from the proximity sensors. This process involves:
41   *              - Writing a 0 to DDA to set GPIO as input.
42   *              - Writing a 1 to PORTA to enable the pull-up resistor.
43   *
44   * Notes:      This function assumes that no other peripherals are going to use
45   *              PA[0..7] pins; the configuration might not work if this is the
46   *              case.
47   */
48  void init_prox_gpio(void)
49  {
50      /* Get the addresses of the memory-mapped control registers. */
51      volatile unsigned char *dircfg = (volatile unsigned char *)DDRA_ADDR;
52      volatile unsigned char *pullupcfg = (volatile unsigned char *)PORTA_ADDR;
53
54      /* Set the configurations. */
55      *dircfg = DDR_INPUT;
56      *pullupcfg = PORT_PULLUP;
57  }
58
59
60  /*
61   * is_obj_nearby
62   *
63   * Description: Determine whether or not there is an object nearby using the
64   *              ultrasonic proximity sensors. This function returns 0 if no
65   *              objects are detected by the proximity sensors, and returns
66   *              nonzero if objects are detected.
67   *
68   * Return:     If no objects are in range of the ultrasonic sensors, returns 0.
69   *             If one or more objects are in range, returns nonzero.
70   *
71   * Notes:      The return value uses the low 4 bits to represent the
72   *              rangefinders in each direction, so the number of triggered
73   *              rangefinders can also be found from the return value.
74   */
75  unsigned char is_obj_nearby(void)
76  {
77      /* Get the address for the memory-mapped input register. */
78      volatile unsigned char *pins = (volatile unsigned char *)PINA_ADDR;
79
80      /* Returns 0 if all pins are inactive, otherwise returns nonzero. */
81      return ACTIVE_PINS & (*pins);
82  }
```