MICROPHONE-BASED WIND VELOCITY SENSORS AND THEIR APPLICATION TO INTERACTIVE ANIMATION

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ABSTRACT

We are developing a simple low-cost wind velocity sensor based on small microphones. The sensor system consists of 4 microphones covered with specially shaped wind screens, 4 pre-amplifiers that respond to low frequency, and a commercial sound interface with multi channel inputs. In this paper, we first present the principle of the sensor, i.e., technique to successfully suppress the influence of external noise existing in the environment in order to determine the wind velocity and the wind direction from the output from a microphone. Then, we present an application for generating realistic motions of a virtual tree swaying in real wind.

Although the current sensor outputs significant leaps in a measured sequence of directions, the interactive animations demonstrate that it is usable for such applications, if we could reduce the leaps to some degree.

Keywords: wind sensor, wind velocity, microphone, interactive animation

1. Introduction

In constructing an MR system (mixed reality system) that is consistent with the real world, it is important to develop an animation system that operates according to natural phenomena in the real world, such as the wind.

In this research paper, we explore utilizing such an environment, and taking as our example the fluctuating movement of leaves of a tree in the wind, we develop an animated system of a virtual tree that will move according to real wind in the real world.

For the animation system, we use what we have proposed in references [1, 2], one which uses efficient technology for tree movement animations.

Not only wind speed sensors, but a variety of different sensors are necessary for the application system for the MR system. And we thought that, similar to the HMD, as one application for it might be to mount it on the human body, it would be better if it were small and light. Additionally, if we consider its potential use in widely used entertainment systems, then lower costs are also an important factor. The systems currently existing for measuring wind direction (aerovanes, anemometers) and wind velocity, are made to be highly accurate and precise, and because they are large they are also costly.

In this research, we are advancing the development of a simple wind sensor using a small microphone that will be suitable for its application as a portable MR system. When wind hits a microphone, it makes a lot of noise that is is mainly narrow-band frequency, and which I will refer to as wind noise in this paper.

Wind noise in any normal application is simply static, so there has been a lot of research done to try and isolate and remove this wind noise. However, there has been less research into positively analyzing wind noise, and there has been a limited amount of research into establishing methods for the measurement of wind velocity.

The research of H. Bass et al. [3] uses 3 microphones in array, and the cross-correlations between them, to measure wind speed, but in his setup each microphone needs to be placed at the corner of a triangle measuring just some tens of centimeters. In the research of Fujita et al. [4], they proposed a method to estimate wind velocity that uses highly correlated data accumulated in advance from just one microphone. For the wave frequency power spectrum of wind noise into the microphone, the literature [5] states that in when wind speed is less than 10m/s, wind speed is increased proportionately from a power of 2 to a power of 3, and the distribution is in the lower sound band. And when it is above that, middle to high frequency sounds also occur. This is what is described in this research, which concentrates on investigating the bandwidth of sounds above around 40Hz.

There are examples in portable games of products that use microphones as wind sensors. However, the way in which wind sensors are used in these games is this: rather than actual wind, they use expelled breath – a large instantaneous expulsion of breath - as the trigger to make changes in the characters' movements. Also there is the example of the electronic handicraft kit [6] of electronic wind chimes that respond to the wind. This example is less than 3-4Hz, and senses noise outside the audible range. When the noise exceeds the threshold, it triggers an oscillator and the chime sounds. But none of these examples sense or make use of changes in wind strength or weakness.

We can surmise from these examples that, for wind noise, by looking at the special characteristics of spectrum distribution including that composed of less than 20Hz (referred to subsequently as extremely low frequency or ELF), we can expect to measure wind speed.

In previous research [6], we developed a CG system that simulates trees moving in response to the movement of the wind in the real world.

In this research, we developed a sensor capable of sensing wind direction as well as wind speed by means of 4 microphones equipped with specially shaped wind screens.

2. Microphone based wind speed sensor

2.1 Finding the wind speed from wind noise

Using a sound interface that lets sounds through of less than 20Hz (hereafter called extremely low frequencies or ELF), we observe the wind noise arising when wind hits the microphone.

As a result, with the microphones used in this research, the energy changed proportionaly to a power of 2.485 of the wind velocity. The frequency, including ELF was up to 4kHz. Thus, as we see in equation (1) below, we can find the wind speed S_{wind} from the wind noise output V_{out}. k is the microphone characteristics and the constant (in this research it is 2.485). V_0 exists to subtract the analogue part of the static, and is zero when there is no wind. g is to compensate for the gain in the analogue part. It is adjusted by measuring a known wind speed, and making the adjustment until the output matches the wind speed.

We know that many audio interface line inputs allow ELFs to pass through. By connecting a microphone to the line input using a pre-amp that allows these ELFs to pass through, we can easily configure the hardware.

$$S_{wind} = ((V_{out} - V_0) \times g)^{1/k} \qquad (1)$$

2.2 Smoothing

The wind noise ouput includes many short periodic fluctuations, and it was necessary to smooth it, applying method methods such as moving averages suited to the special characteristics of the CG system we were using.

In this research, in the tree simulation CG we had implemented, we set the wind speed of the CG system using a 50-step moving average. As we measured the wind speed every 100ms, we were able to take an average value every 5 seconds.

2.2 Separating out the ambient sound

With things as they were, ambient sounds would have been recognized as wind noise and included in the wind speed output. The ELF component doesn't occur in normal airspace. Even large volume sounds from sound sources right near the microphone .was no output in this band.

Accordingly, normally we observe only the ELF component and estimate the approximate wind speed from its strength, and change the cut off frequency of the low pass filter to isolate the necessary band width and thus find the wind speed. By doing this, we can largely separate ambient sound, and create a wind speed sensor that responds only to the wind.

3. Expanding it into a wind direction sensor

3.1 Wind screen

The small scale microphone unit senses wind speed alone regardless of wind direction. So we mounted a wind screen to it. With this wind screen, when wind comes from directly in front, it hits the microphone directly as it had been doing, but now when wind comes from directions other than directly in front the contruction of the wind screen protects against this (Figure 1).

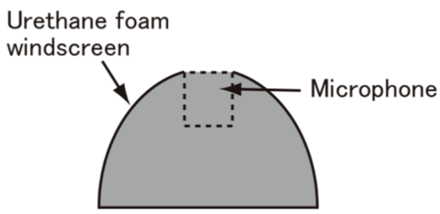

Figure 1. Constructing a windscreen

3.2 The positioning of the microphones

For example, if we placed microphones as described in the previous paragraph, at 30 degrees intervals, in twelve different places, even if we simply looked at the micropone that was picking up the greatest wind noise output, we would be able to find the wind direction for that 30 degree segment. However, this is not realistic from the point of view of costs or the scale of the hardware.

In this research, we used 4 microphones, and positioned them every 90 degrees (Figure 2). For ease of explanation, we have labeled the microphones from 0 to 3 counterclockwise from the front.

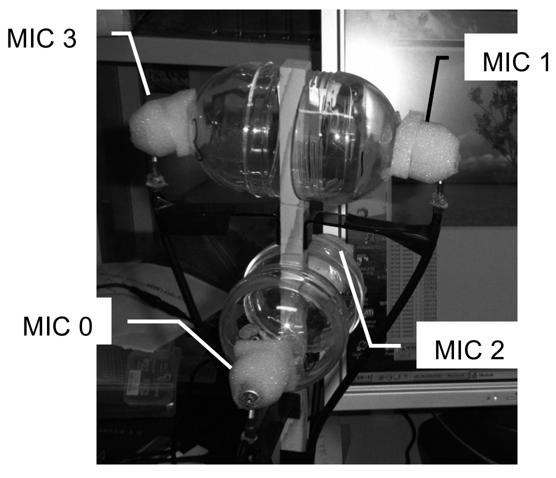

Figure 2. The position of the four microphones.

3.3 Audio interface

In order to use 4 microphones, an audio interface that can input more than 4 channels is necessary. There are few PCs that have the ability to input more than 2 channels as part of their internal hardware, but is also possible to use interfaces that can input a number of channels with multi-track recording (MTR) and that are commercially produced and sold.

The 4 microphones are set up connected to a modified pre-amp that passes the ELF through so as to improve the characteristics of the ELF (Figure 3).

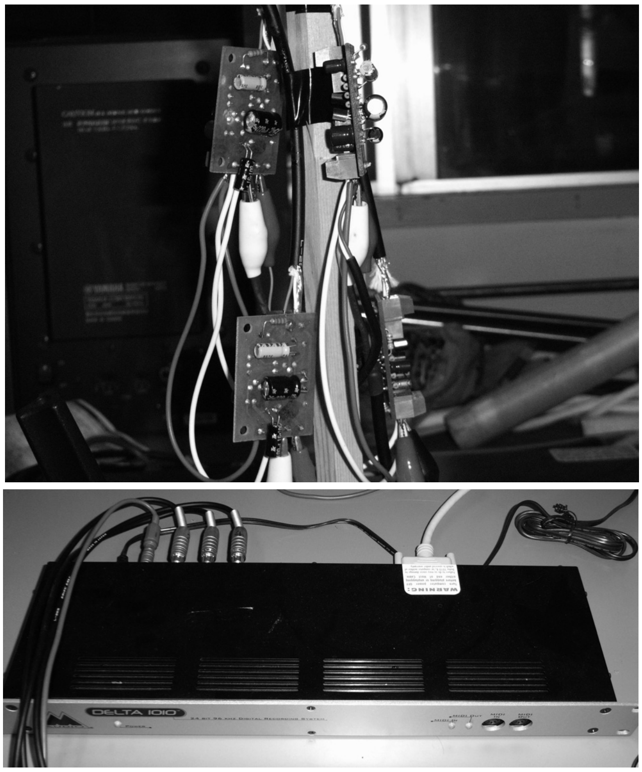

Figure 3. An audio interface and pre-amps.

3.4 Calibrating the microphones

The sensitivity for each microphone has a dispersion of around 3dB. We measure the difference beforehand and compensate by means of software. When wind hits each microphone from the front, we look for the mean value of the noise level over around one minute, and we then decided the calibration factor to put them in line with the microphone with the lowest sensitivity (table 1, Figure 4).

Table1. The output difference for each microphone and the calibration factor.

	Avg. Output	Rel. Sensitivity rathio	Compensation coefficient
MIC 0	3968.375	0.902842	0.805317
MIC 1	4395.425	1.000000	0.727074
MIC 2	3195.800	0.727074	1.000000
MIC 3	4085.786	0.929554	0.782175

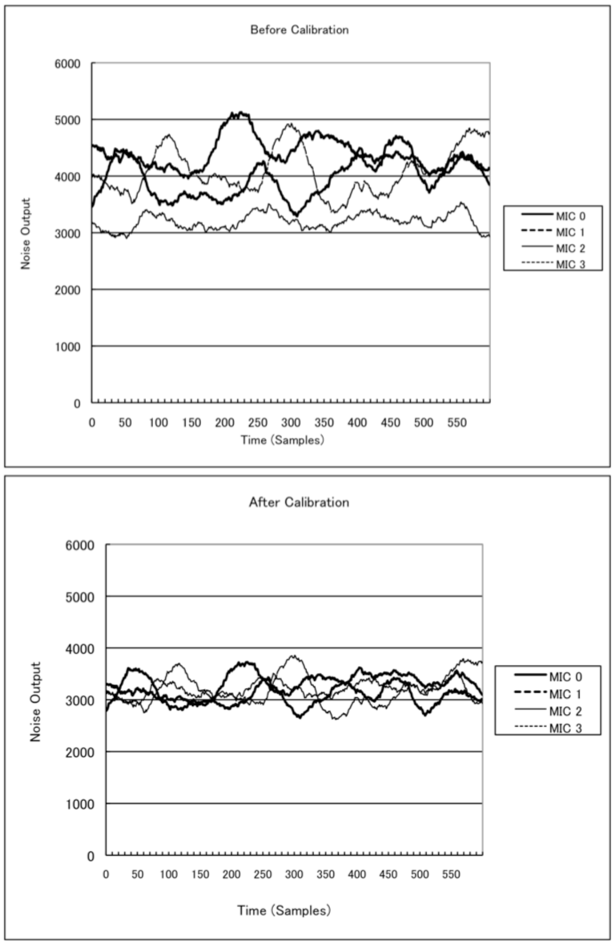

Figure 4. The wind noise output: before calibratio (above), and after calibration (below)

3.5 Variations in noise output according to wind direction

If the wind direction is not head on to the microphone, the noise output becomes smaller. Because we use 4 microphones, we make use of the variations in noise output from a 90 degree range from the direct front. The CG system that aims at a simulation of nature doesn't require high precision, so we look for noise output from two points – when wind hits the microphone from directly in front, and when it comes from 90 degrees off the direct front, and we call the middle the linear interpolation. For the noise output, in the same way as for the microphone calibration, we use the measured value of one minute intervals.

As we can see in the figure, angles larger than 90 degrees, that is to say, if wind hits the microphone from the rear, there is not much variation in sound output, or there is slightly more variation in the sound coming in from the 180 degree direction. We can say then that if the angle increases beyond 90 degrees, the noise output doesn't deteriorate accordingly.

Because in this research the wind screen was hand-made, there is some dispersion of data because of the shape of the screen. Because of this, the proportion of the noise output coming from the front, and coming from the 90 degrees direction, is different for each microphone. The noise output is different for sound coming from the +90 degree direction and that from the -90 degree direction. We provisionally make the ratio of one microphone the representative value (Figure 5, table 2). If we were to mass-produce this system, we would be able to use a more stable form of screen and so improve the precision. With this observed data as the base, we find the wind direction, as described below.

Table 2. Directional characteristics

direction (°)	-90	0	90
Level	1082.605	3156.998	556.041
Rathio	0.343	1.000	0.176

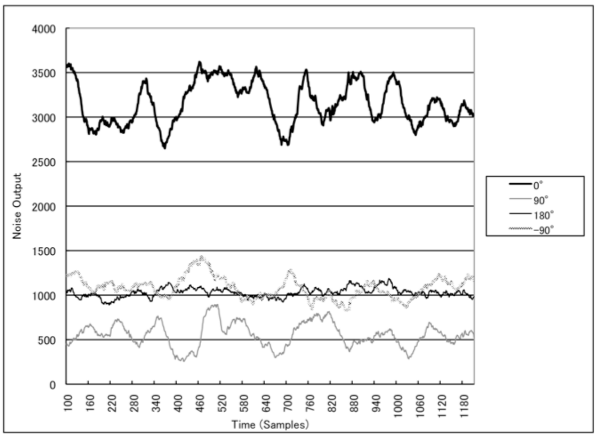

Figure 5. Directional characteristics

When the wind is coming directly from the front, between the front microphones and the adjacent microphones there is noise output along the lines of the ratio of the observed data. As the wind veers away from the direct front, the ratio becomes correspondingly smaller, and at 45 degrees the output becomes equal to that of the adjacent microphones. We can do linear interpolation on this variation as in equation (2), and find an offset value for when the wind is off coming directly from the front.

$$Offset = (N_s / N_f - R)/(1 - R) \times 45 \qquad (2)$$

N_f is the noise output of the microphone with the largest ouput f (f=0-3), N_s is the sound output of the microphone adjacent to microphone f that has the largest noise output: s(s=mod (f+1,4), and s = mod (f+3,4). R is what we found from tbe observed data of the 90 degree/direct front ratio, and for this research we used 0.34. According to the wind screen shape problem, there is a possibility it could amount to $Ns/N_f<R$, but in that case, if we set R=0, we make the offset = 0.

3.6 Significant leap in the wind direction data

We installed software to find the wind direction into the CG system, and observed the CG images produced. Because the CG system is one to simulate trees, although the precision of wind direction is low, the CG system didn’t recognize it as a problem in the animation displayed. However, according to the fluctuation of the noise from each microphone, sometimes there is a very large fluctuation in the wind direction variable over an exceedingly short time. This appears on the screen as an unnatural image much like a video that has been abruptly cut together.

In order to remove this unnatural quality, for each sample, we took a value constituting the upper limit of the absolute value of each increment and called it *th*, and in the case that an observed data for the wind speed was over this upper limit, we took the value for one time period before and added *th* to it (or detracted from it), and so proposed a method for replacing these leaps. In our system, we experimented with *th* = 3.0. We sought to establish the wind direction every tenth of a second, so because of this we were limited to finding the wind direction variation 30 times per second (Figure 6, 7). With this value the unnatural phenomena stopped showing on the screen. It is possible to adjust the th value according to the special characteristics of the CG system being used.

By setting up this arrangement, we observed the data of wind hitting the sensors from every direction, and recorded the data in Figure 8. We set a ventilator in place, and rotated the sensor 45 degrees every minute and observed the results. To rotate it 45 degrees every minute, we changed the angle slightly every ten seconds or so. In this system, we were able to obtain values for the wind direction data from 0 degrees to 360 degrees, but in order to make the graph simpler to understand, when the values were greater than 270 degrees as the time for measuring drew near, we subtracted 360 and expressed the wind direction as a negative value.

In the system we set up, we cannot say that the precision was adequate. Especially MIC 3 showed some peculiar characteristics, and when it was shifted +90 degrees towards (MIC 0) to, it didn’t show variation in noise output, and from 270 degrees to 360 degrees (=0 degrees) there was a large error in the measured value. We expect that this problem would be solved by the use of a wind screen with a more stable form.

$$
\begin{aligned}
&\mathit{if}\ (|\Delta d| > th) \\
&\qquad d_t = d_{t-1} + th \times (\Delta d / |\Delta d|); \\
&\mathit{else} \\
&\qquad d_t = m;
\end{aligned}
$$

m: wind direction calculated from the sound output
d_t: current wind direction
Δd: = m - d_{t-1}
th: the upper limit of the variation range

Figure 6. Removing the leaps

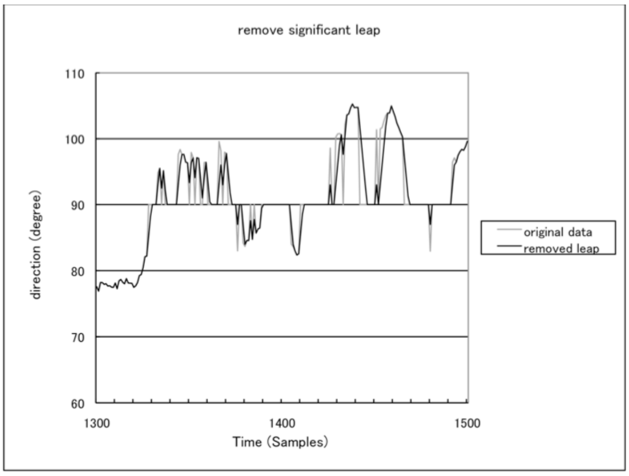

Figure 7. Removing the significant leaps

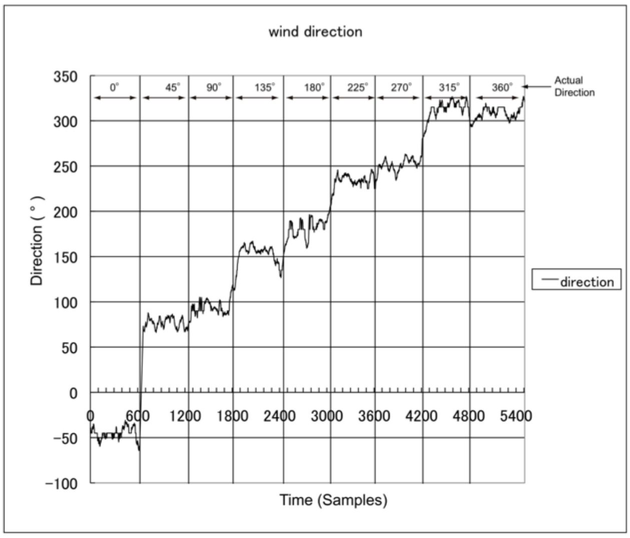

Figure 8.

4. Conclusion

We developed sensors using 4 microphones to develop a sensor that can easily detect wind direction and speed, and by mouting it to a CG system that simulates trees moving in the wind, were able to validate the compatibility with a nature-simulating CG system. The multi-channel audio interface that we used for this research is produced for recording use, and so it is easily obtainable, though because of the limitations of the input and output connector standards, the unit size is large. If one designs hardware limited to 4 channel input, and integrates it with pre-amps, a down-sized version becomes possible.

The windscreen was urethane foam, and it is difficult to manufacture it uniformly in a trial, but if it were to be made commercially, it would be possible to make it in a uniform form. Because we attached a windscreen, and used a number of microphones, the size of the sensors was bigger than would have been the case had they been only sensors for wind speed alone, but by coming up with the idea of separating out the sensors and attaching them to the surroundings of the sensor unit, it is possible to minimize awareness of their existence for the users.

5. REFERENCES

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