1. Problem Description

The wah-wah effect is well known from its application product - the wah-wah pedal. The wah-wah pedal is consisted with the time varying audio filters that alter the tone of the signal to create a distinctive effect, imitating the human sound 'wah'. Each sound has its unique characteristics and resonant frequencies so does human voices, which can range from 60 to 7000Hz. While speaking of the wah-wah effect, the most important vowels for this effect are specifically the [u] vowel and the [a] vowel, which combine together forming the “wah” sound. For human, it is done by mouthing the [u] vowel initially and then expands the mouth for the [a] vowel by changing the mouth shape from a small O to a big O. These resonant sound frequencies of the small “o” to the big “O” are called “formants”. The wah-wah pedal works similarly in the way of its resonant formant frequency change. The variation in the peak response frequency of the filter resembles the change in formant frequency in the human vocal tract when producing the word "wah".

Each wah-wah pedal has its own sound characteristics such as different sweep ranges and frequency responses. Because of this, advanced guitarists would like to seek for a wah-wah pedal that has the sound they want. Therefore, the first problem for most of guitar players is how to enable users to customize their desired sound.

The other problem to deal with is to improve the quality of the sound. The wah-wah pedal is a device that converts the signal tone to imitate the human voice ‘wah’ as its sound effect. The quality of the sound can be improved so it is more like the human ‘wah’ voice. Most of wah-wah pedals on the market have a decent vowel quality but there are still rooms to improve.

2. Specification

The wah-wah effect normally has a bandpass filter with a peaking centre moving up and down the frequency spectrum, the same with rocking the pedal back and forth. From Lab Report 2, the important inputs that influence the effect can be listed below:
1. **Minimum point** - The lowest value of the peaking centre
2. **Maximum point** - The highest value of the peaking centre
3. **Damping factor** - Control the shape of the filter

By manipulating these inputs, the problem described previously can be solved and a better wah-wah effect application can be made.

**First problem: wah-wah pedal customization**

Since the change in formant frequency in the human vocal tract is resembled by the variation in the peak response frequency of the filter when the ‘wah’ sound is produced, the problem can be solved by designing an adjustable formant frequency. The maximum and minimum value for the effect application can be set according to the requirement of users. For example, by setting one of the formants to be static, the maximum and minimum values are close to each other so a better vocal like sound can be produced. Additionally, the formant can be set uncontrolled to move up and down continuously with pre-settings. This change of setting enables more variety of sound to be produced and hopefully the user can create their desired sound characteristics.

**Second problem: Sound quality improvement**

As illustrated from the figure below, the first formant frequency of the [ah] vowel spread between 700 Hz to 1200 Hz and its second formant frequency spread between 900Hz to 1700 Hz. Since the wah-wah pedal tries to imitate the human [wah] sound, its bandpass filter frequency range lies between 700Hz to 1200Hz as well in order to create this [ah] vowel. Currently, the bandpass filter is only able to deal with one frequency range at a time. In order to imitate this sound effect more close to the human sound voice, the larger sweep range, such as from 400Hz to 2200Hz, would be applied.
Fig. 1: Human voice sound regions.

The human speech vowel [wah] is formed by two formants, [u] and [ah] sound. Generally, the wah-wah pedals only have one peaking frequency centre, which acts as one of the formants in the frequency spectrum. To achieve an improved [wah] sound, a second filter in the frequency can be added as a second formant of the human speech vowel. This will improve the output sound, as if two wah-wah pedals are chained together next to each other and being used simultaneously.

3. Implementations

Inputs: damp = 0.05 minf=500; maxf=3000; fw = 2000;

Damping factor can change the size of the pass band. The lower the damping factor the smaller the pass band. Here it is set to damp = 0.05. Following by the minimum and maximum centre cutoff frequency of variable bandpass filter. They are set to 500 and 3000 respectively. Lastly the wah frequency decides how many Hz per second are cycled through and is set to 2000.

Process:

1. Create a triangle wave to modulate the centre frequency of the bandpass filter.

```matlab
% create triangle wave of centre frequency values
fc = minf:delta:maxf;
while(length(fc) < length(x) )
    fc = [ fc (maxf:-delta:minf) ];
    fc = [ fc (minf:delta:maxf) ];
```
2. Implementation of the state variable filter

```matlab
% trim tri wave to size of input
fc = fc(1:length(x));

% difference equation coefficients
% must be recalculated each time Fc changes
F1 = 2*sin((pi*fc(1))/fs);

% the Q value changes
deltaQ = qf/fs;

% create triangle wave of centre frequency values
Qc = dampmin:deltaQ:dampmax;

while (length(Qc) < length(x))
    Qc = [ Qc (dampmax:-deltaQ:dampmin) ];
    Qc = [ Qc (dampmin:deltaQ:dampmax) ];
end

% trim tri wave to size of input
Qc = Qc(1:length(x));
Qc = 2*Qc;

% create empty out vectors
yh=zeros(size(x));
yb=zeros(size(x));
yl=zeros(size(x));

% first sample, to avoid referencing of negative signals
yh(1) = x(1);
yb(1) = F1*yh(1);
yl(1) = F1*yb(1);
```

3. Repeated recalculation if centre frequency within the state variable filter loop

```matlab
% apply difference equation to the sample
for n=2:length(x),
    yh(n) = x(n) - yl(n-1) - Q1(n)*yb(n-1);
    yb(n) = F1*yh(n) + yb(n-1);
end
```
\[ y_l(n) = F_1 y_b(n) + y_l(n-1); \]
\[ F_1 = 2 \sin \left( \frac{\pi f_c(n)}{f_s} \right); \]

\textbf{4. Evaluation}

This improved customizable wah-wah effect device not only can deal with normal setting values (such as \( \text{damp} = 0.05 \), \( \text{minf} = 500 \), \( \text{maxf} = 3000 \), \( \text{fw} = 2000 \)), they can also handle the required value specified by users. Advanced users may also implement this application digitally in foot pedal to create the tone they want. With two formants, this wah-wah effect application is able to produce a better sound quality that is more like human vocal. By setting one of the formants is set to be static at a higher frequency domain and the foot controlled formant set at the lower area, the result will improve so much than an ordinary wah pedal in getting closer to a vowel sound. The users can test the setting with this wah-wah effect application to customize their own sound.