Uncovering the strength and weaknesses of helical visualization

Soheil Kianzad, (skianzad@cs.ubc.ca)
Computer Science, University of British Columbia

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1 Introduction and Motivation

Among different representations of serial time data, spiral and radial layouts are considered to be effective for demonstrating periodic attributes of a dataset. However, for many phenomena, some irregularity in periodicity makes the radial approach less efficient. One approach to solve this problem is to use event-anchored model which suits periodic dataset with different duration [1]. One nontrivial challenge of this method is to detect the event where period starts. It is also possible to use different well known algorithms such as Discrete Wavelet Transform (DWT), Dynamic Time Warping (DTW), Symbolic Aggregate approXimation (SAX) and Machine learning (ML) to find and match periodic trends. However, many of the mentioned techniques are prone to error since anomalies in data can change the form of periodic attribute. These anomalies in many domains are the main point of interests for users.

There are many studies on the benefits and drawbacks of radial visualizations. Although they are useful for periodic displays and for some aesthetic reasons, there are some limitations to them such as: low rendering performance, interactivity and navigation problems and difficulties in attaching detail information[2][3] compared to Cartesian coordinates which impose a careful consideration in case of using them.

In this project, I will introduce Helix structure; a three dimensional curve which can preserves the continuity of the data by presenting it along the helical axis while periodic attributes are shown along radii axes. This visualization can provide more flexibility of tweaking the frequency while simultaneously displaying its effect on periodic attributes. Furthermore, I will investigate the benefits and drawbacks of using helical visualization in order to explore periodicity in serial data with respect to equivalent visualization in Cartesian coordinates and maybe eventually combining them into a hybrid multiple views visualization.

1. **Idiom** Helical/Vortex structure

2. **Data** The most important properties of the data is the serial continuity and periodicity with defined upper and lower frequency bounds. Although it is possible to use categorical attribute, my own interest lies in quantitative attribute.

3. **Task** Pure time-series periodic data have regular interval between each repeating cycles which can be expressed in frequency domain. Most of the current radial or spiral visualization are

limited to one frequency for example temperature changes in one month of year. It is not an easy task to visualize, *explore* and *compare* periodic attributes and harmonics in serial data with varying period duration. In this project I propose to exploit the users information about changes in frequency with respect to time to study rhythmic attributes in data. Users can import frequency information as an instantaneous speed for each time (see 2.3) or define it as a function of time (see 2.4) and finally do a fine tune by manually making the require adjustment.

2 Proposed Approach

2.1 Implementation Details

To express the data in helical structure, I use the following equations:

$$x_t = (R + d_t)\cos(\theta_t) \quad , y_t = (R + d_t)\sin(\theta_t), \quad z = \theta_t, \tag{1}$$

where $\theta(t)$ is defined by number of periodic cycles and R is a constant number representing the zooming in radial display.

$$\theta_t = index(data_t)/(2\pi * period), \tag{2}$$

to understand and test the visualization, I added two sinusoidal waves with 30 Hz frequency, 1.7 amplitude and 120 Hz frequency and 1 amplitude and corrupt the wave with white noise with zero mean and variance of 4 and 0.5 amplitude.

$$S(t) = 1.7\sin(2 * \pi * 30) + \sin(2 * \pi * 120) + .5 * w(t), \tag{3}$$

Fig 1: shows the visualization in helical structure 1.a) and 1.b) shows the plot of noisy signal and corresponding fast Fourier transform. By choosing the total period number to 10 and displaying the signal helical structure we have Figure 1.c). If we project the signal into x axis we will have figure 1.d) and correspondingly 1.e) can show the projection into z axis with superimposed method.Multiplying the number of peaks in 1.d) by 1.e) can give us the 30 Hz as one of the frequency components of the signal. 1.f) shows the behaviour of the signal for the last period.To compare the result with Cartesian coordinates we have 1.g) shows the superimposed signals divided by 10 period and 1.h is the rectilinear sector based visualization. As we can see it is possible to find the 30 Hz frequency clearly in 1.g and not as good in 1.h by doing the same multiplication of peaks by number of period.

2.1.1 Harmonics visualization

I was interested to see the effect of main period on visualizing the harmonics because it is intuitively hard to understand superposition of signals especially when we have noise in our signals. Although the Fourier transform can show us the frequency component of the signal but maybe we can get more information in helical display about what shape of signal is repeating with that frequency. Fig 2: shows the similar helical presentation while the number of periods is changed to 12. While it is not easy to find the 120 Hz frequency in Cartesian coordinates 1.b) and 1.c we can multiply the number of peaks in 2.d) by 1.c) to find the 120 Hz frequency. However 1.e) shows that we might not reach to the same results if we just display one period which might be a problem in radial sector visualization.

2.1.2 Chirp signal

Now lets assume that we do not have same duration in each period or to express that more mathematically, the phase is changing non-linearly rather than linearly with respect to time. so we have:

$$\theta = 2\pi t F(t) + 2\pi f_0 t + \phi, \tag{4}$$

where f_0 is the starting frequency and F_t is the frequency function that can change over time. For example in Linear chirp signal we have

$$F_t = \mu t, \quad \theta = 2\pi\mu t^2 + 2\pi f_0 t + \phi, \tag{5}$$

and the instantaneous frequency in Hz as:

$$F_i(t) = 2\mu t + f_0, \tag{6}$$

Now we can not use fast Fourier transform and we should present it in a spectrogram plot of the frequency over time. One of the main goal of this project is to get the frequency over time input from users as an attributes or defining a frequency function of time so we can better present the periodic patterns (e.g.increasing the speed of walking in 2.3 with constant acceleration).

2.2 Scenario of Use:Temperature

I first tried to visualize the temperature data due to the natural periodicity (months and year). I also found other groups also working on the same concept. While many of them used spiral or radial visualization for natural phenomena with periodicity two groups mentioned the use of helical structure to provide intuitive browsing through a large data set [4], or for ascetic reasons in Climate Lab Book [5]. My experiments with temperature data validates the claim of finding the oscillation frequency by means of number of pitches multiply by number of observable peaks. I also found visual cluttering in using superimposed method which means it is better to use sectors or spiral (vortex) view. I also realized that using mean of temperature for specific periods as the radius and showing the changes with respect can be confusing and require using filled graphs.

2.3 Scenario of Use: Gait Analysis and Rehabilitation

Physiotherapists use gate information to assess patients performance for rehabilitation purposes. In many cases they use visual observation to diagnose disorders or evaluate the prescribed treatment [6]. Growing number of patients and limitation of medical resources caused physiotherapists to play more supervisory role instead of having one by one meetings. Recently a few software have been developed to help both patients and physiotherapists with a focus of home rehabilitation to reduce hospital visits by providing real-time feedback to patients and aid them manage their chronic diseases [7][8]. Advances in wearable electronic and sensor technology facilitates real time joint angel data acquisition. Further studies are required to analyse, classify and visualize this data so patients can use them to correct their exercises [9]. Human gate signals are often periodic, however, since the sampling time is constant and users are changing their speed during the rehabilitation test or exercise, the frequency of these periods varies in time. In addition, there are cases that gate anomalies shows itself only in higher walking speeds and physiotherapists need to know them to determine the related disorders, for example in a rehabilitation test, one patient feel more pain in his hip towards the end of exercise likely because of loosing muscle strength which effect the gait periodic pattern [9].

Mar 13	More research (potential failures)
Mar 20	Simulating algorithm in MATLAB (Testing real datasets and implementing user functions)
Mar 27	D3 implementation (Helical and rectilinear graphs, sector and if needed superimpose)
April 3	D3 implementation (Adding interaction and hybrid display)
April 10	D3 implementation (user defined frequency function of time)
April 17	Debugging and testing and presentation
April 25	Discussion, report writing

Table 1: Timeline

2.4 Scenario of Use: Neural Oscillation

Scientists use oscillatory neural coupling to better understand functional brain networks and to study brain activities during communication, speech, hearing, language understanding and reading [10]. EEG signals show the changes in electric voltage when cluster of neurones are stimulated and fires synchronously. There are cases that these clusters fires quasi-periodically over time. In addition, These clusters might trigger another group of neurons in different part with some latency. This oscillation can be used to determined the network connection between different parts in the brain regions. For example using auditory evoked signals and observing the peaks in EEG signals and further analysis to encode disorders in children with listening problem [11]. The main properties of the recorded signals which are important for researchers include polarity, amplitude, latency and oscillatory period. It is also of a particular interest to study brain waves in different frequency ranges [12].

2.5 Implementation tool

I had some progresses in implementing the system in MATLAB and I will finish the preliminary tests on it. Since I am interested in learning D3.js and I want this tool be available for everyone I will use use Javascript and the d3.js library which I think it suits the gait analysis and rehabilitation (2.3) as well where each patient can use it on its own electronic device and physiotherapists can check the data online.

3 Milestones

There are 6 working weeks left from March 6 to April 25. My plan for the following weeks is shown in table 1

4 Possible Addition: Evaluation Methodology

There is a possibility of collaboration with Dr. Dana Kulic, professor of electrical and computer engineering, university of Waterloo. At the moment, I am waiting for an approval of ethics proposal for secondary data analysis on human gate dataset. I hope that they can grant me access to both healthy and patient gate dataset to test the system for anomaly detection. Furthermore, we might evaluate the system with physiotherapists and modify the interface.

References

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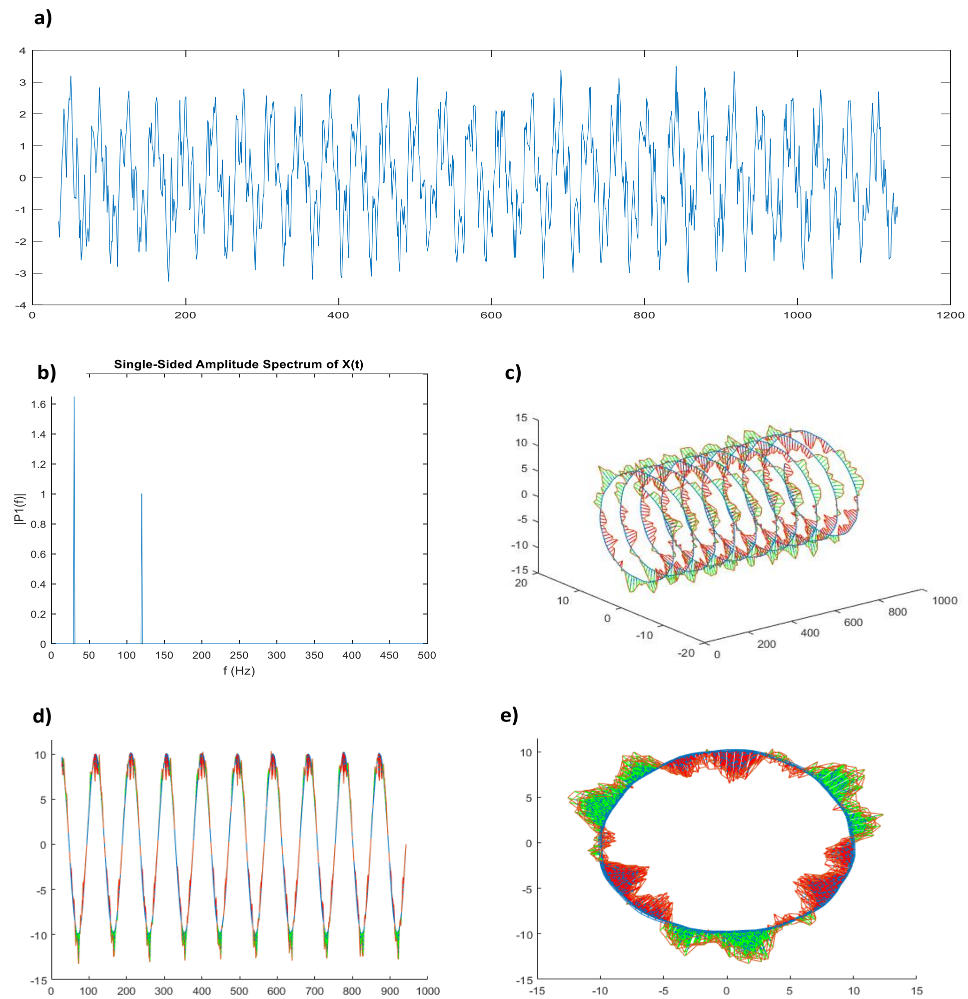
A Figures


a)
b)
Single-Sided Amplitude Spectrum of X(t)
|P1(f)|
f (Hz)
c)
d)
e)

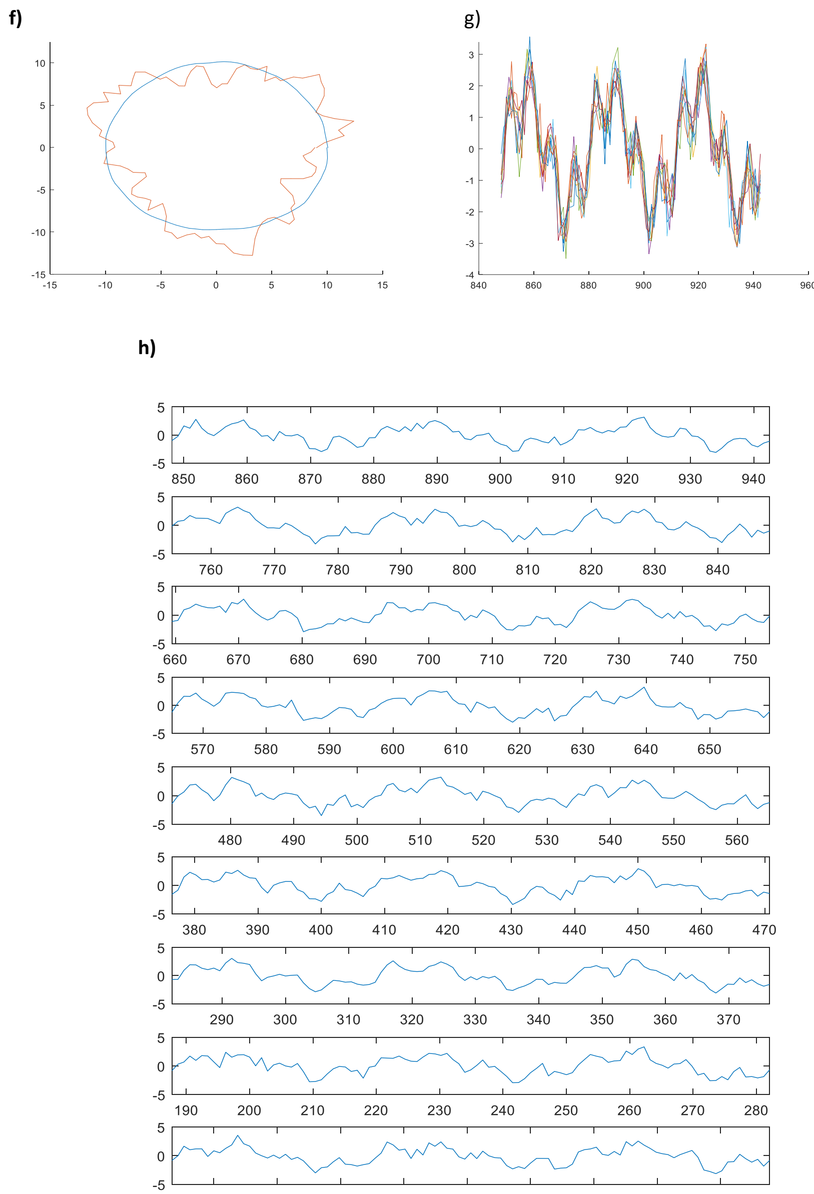
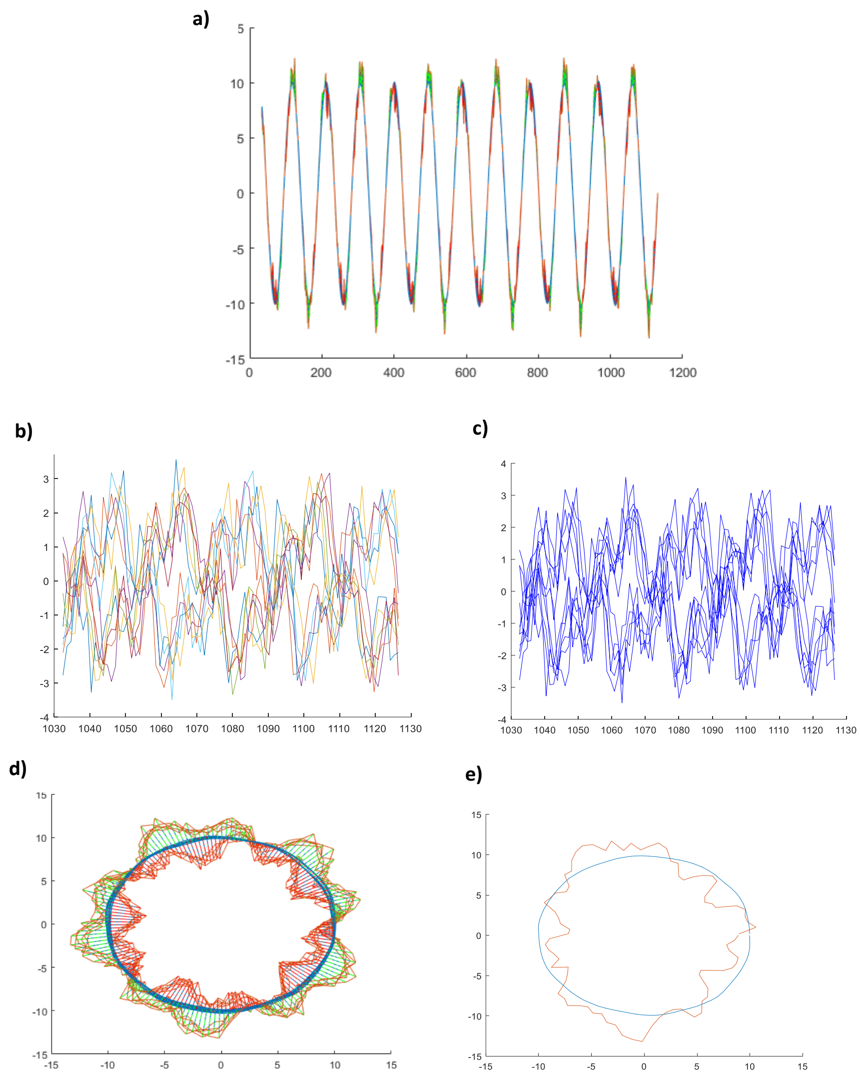


Figure 1: Visualization in helical structure


a)
5
10
5
0
-5
-10
-15
0 200 400 600 800 1000 1200
b)
3 2 1 0 -1 -2 -3 -4
1030 1040 1050 1060 1070 1080 1090 1100 1110 1120 1130
c)
4 3 2 1 0 -1 -2 -3 -4
1030 1040 1050 1060 1070 1080 1090 1100 1110 1120 1130
d)
15 10 5 0 -5 -10 -15
-15 -10 -5 0 5 10 15
e)
15 10 5 0 -5 -10 -15
-15 -10 -5 0 5 10 15

f)

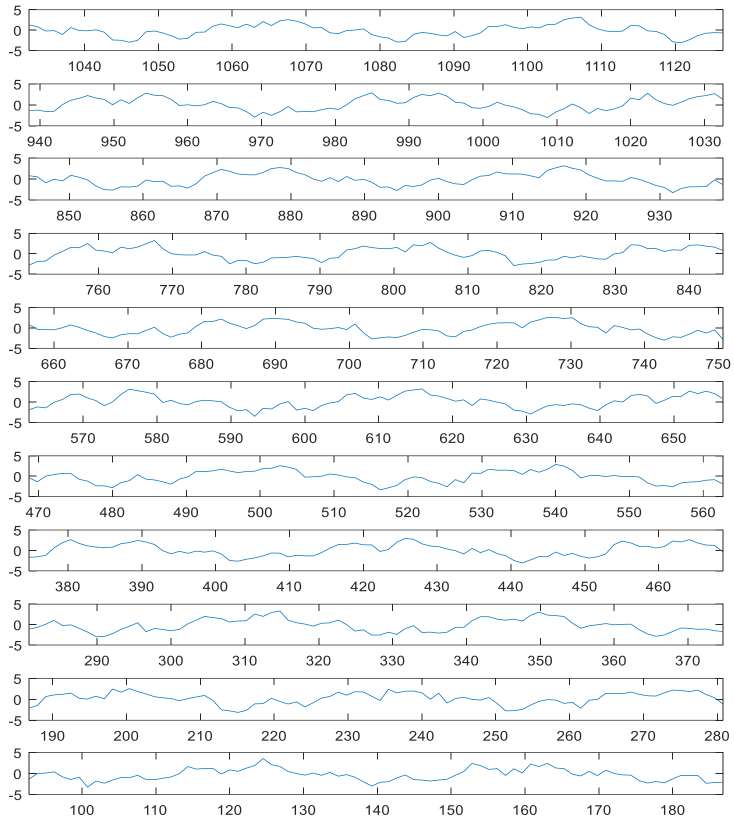


Figure 2: Visualization of forth harmonics