Construction of a National Scale ENF Map using Online Multimedia Data

Hyunsoo Kim, Youngbae Jeon, and Ji Won Yoon

Signal Processing and Advanced Intelligence (SPAI)

CIST, Korea University

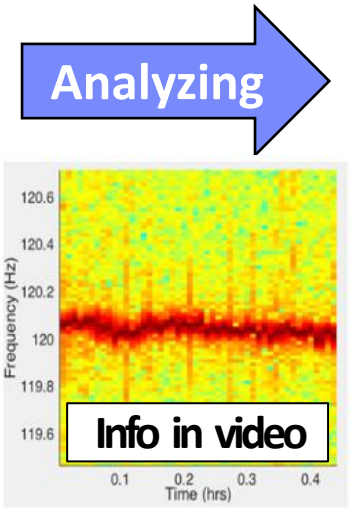
Homepage : https://sites.google.com/site/securesiplab/

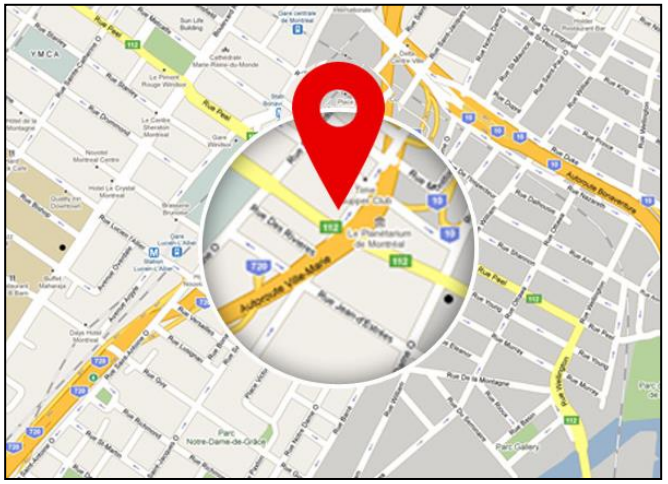
7 Nov. 2017

Index

Introduction - Background

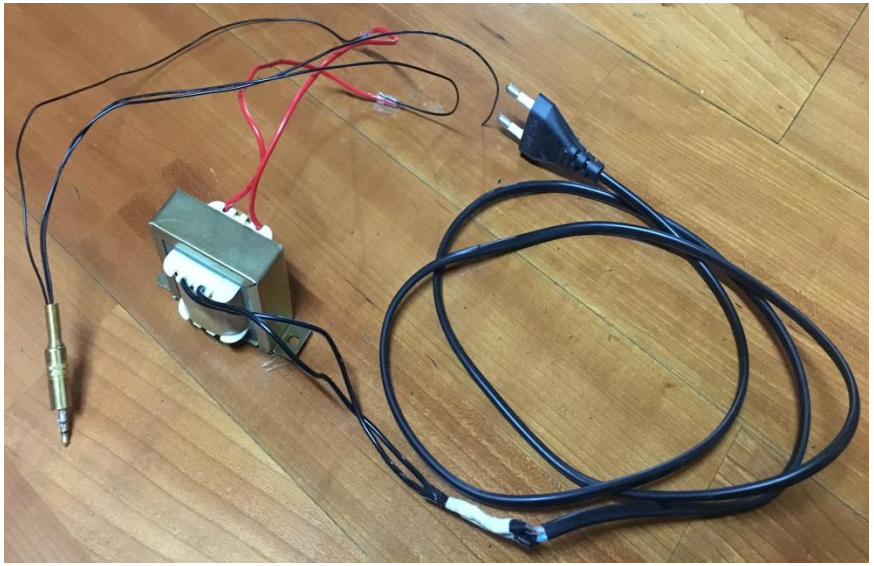
- "Time" and "Location", the key information in forensic analysis
  - When or where was the video actually been recording?
  - Wasn't video or audio artificially forged?
  - What could be the best information for this analysis?





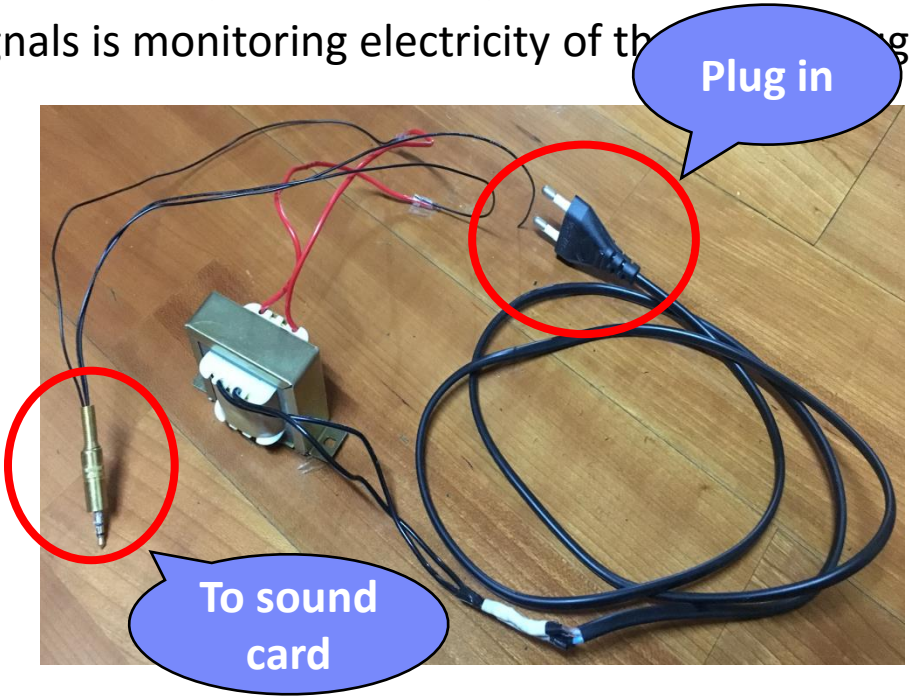
Introduction - Background

- What is Electrical Network Frequency (ENF)?
  - ENF is an unique pattern of electricity from power grid
  - Electrical energy has an unique pattern in accordance with time and location, by the influence of demand-supply
  - We can capture these patterns by measuring the electricity
  - A simple way to capture these signals is monitoring electricity of the power plug



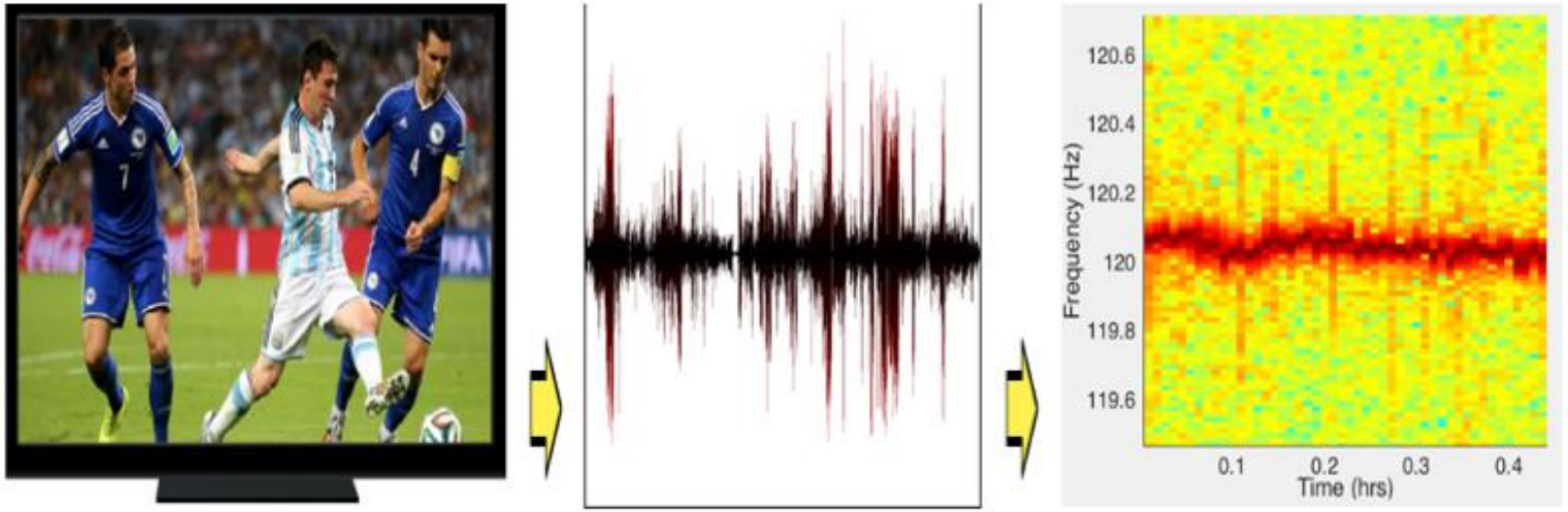
Introduction - Background

- What is Electrical Network Frequency (ENF)?
  - ENF is unique pattern of electricity from power grid
  - Electrical energy has a unique pattern in accordance with time and location, by the influence of demand-supply
  - We can capture these patterns by measuring the electricity
  - A simple way to capture these signals is monitoring electricity of th...g



Introduction - Background

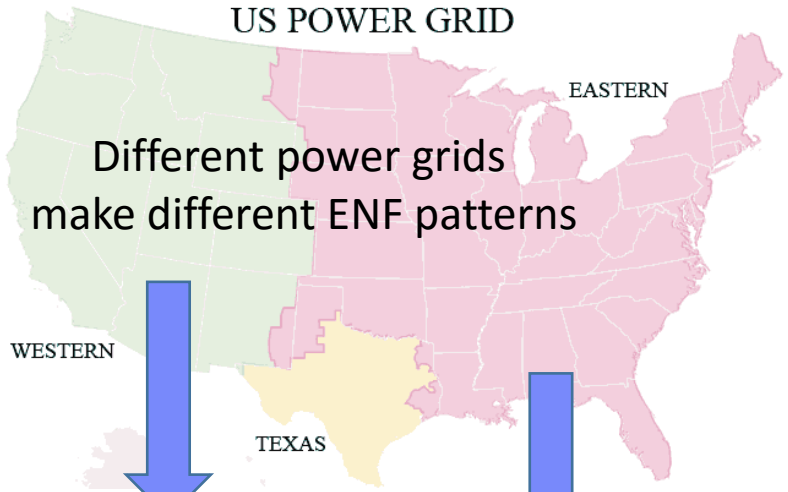
- ENF signals can be extracted from audio/video
  - When audio/video are being recorded, ENF signals are also being recorded together because of the electromagnetic influences from power line (wireless devices are not applicable)
  - ENF signals appear around 50Hz or 60Hz and its harmonics bands



(a) Multimedia data (b) Extracted audio signals (c) ENF patterns in spectrogram

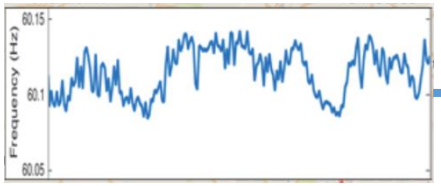
Introduction - Background

- This property would be helpful for investigation

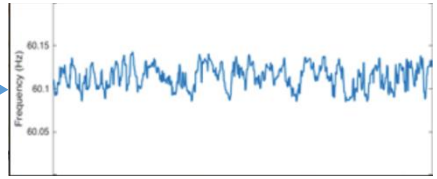


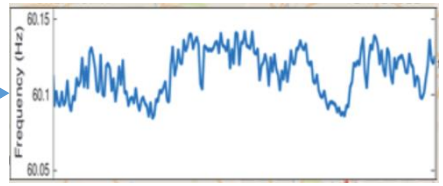
Different power grids
make different ENF patterns

Extract ENF
from the call



Comparing





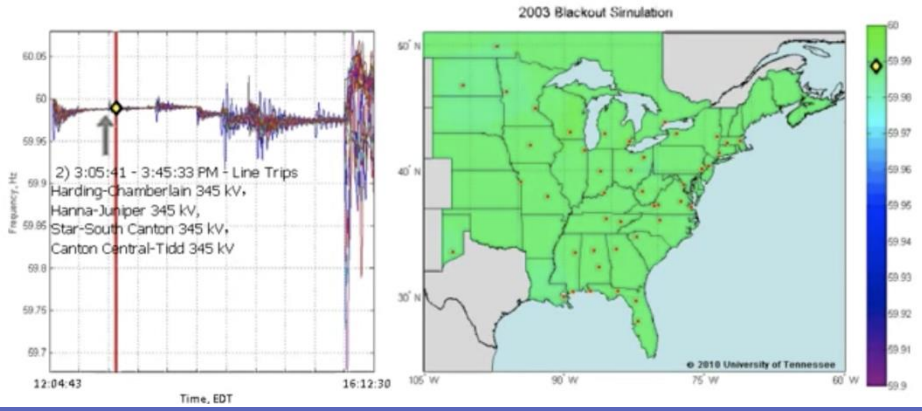
Guessing Location

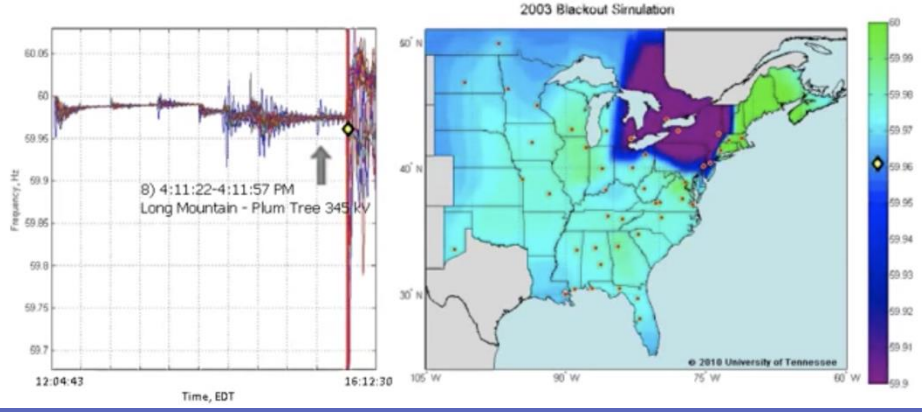
Introduction - Background

- ENF signals can be used not only for digital forensic, but also for many application domains
  - Prediction of grid instability and blackouts
  - Detection of system breakup
  - Societal events detection
  - etc..

Introduction - Background

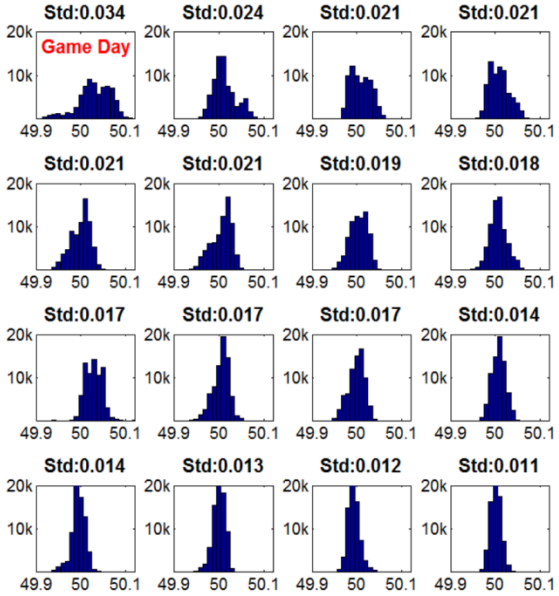
- Detailed descriptions of ENF applications (prediction of grid instability and blackouts):
  - Zhiyong Yuan et al. had researched on “Inter-area Oscillation Analysis Using Wide-Area Voltage Angle Measurements from FNET”
  - Jiahui Guo et al. also analyzed blackout detection in his research “Events Associated Power System Oscillations Observation Based on Distribution-level Phasor Measurements”
  - In their research, they analyzed inter-area oscillation of ENF and described the circumstance when blackout occurs
  - When the blackout occurs, the ENF signals greatly fluctuate

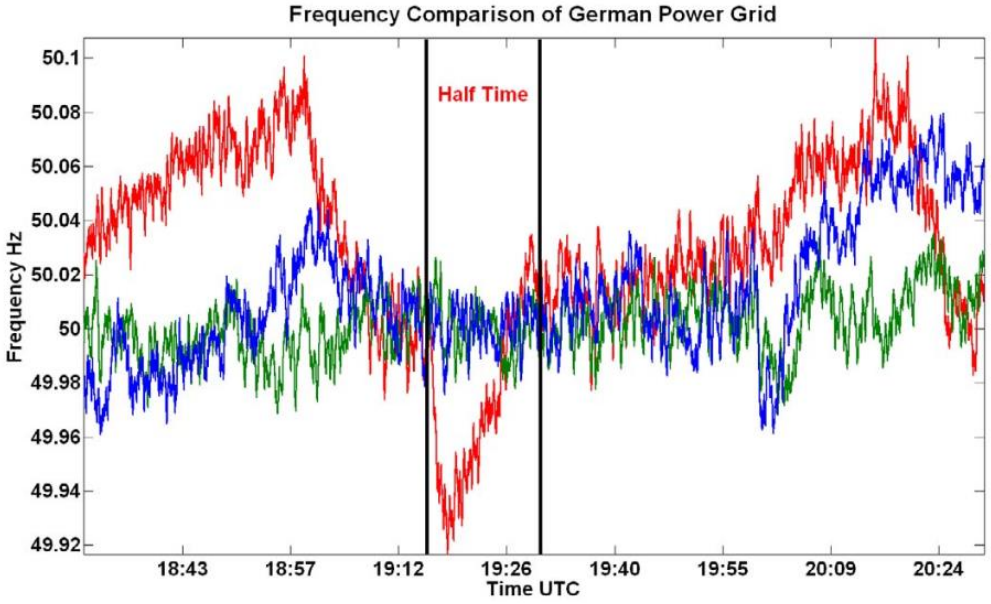




Introduction - Background

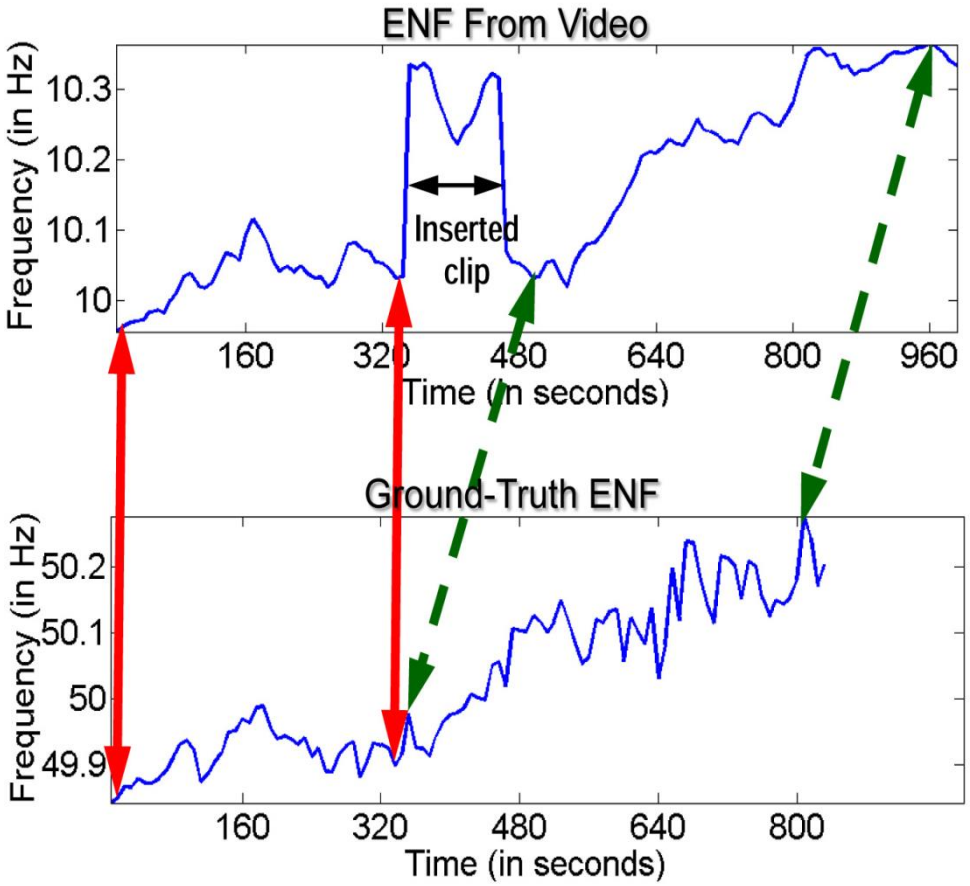
- Detailed descriptions of ENF applications (societal events detection):
  - Lang Chen et al. had researched the topic of societal events detection in “Analysis of Societal Event Impacts on the Power System Frequency using FNET Measurements”
  - How ENF signals fluctuate when Super Bowl games were being broadcasted was described
  - Frequency plot: game day (red), local max(blue), and min day(green)





Introduction - Background

- Detailed descriptions of ENF applications (digital forensics):
  - Every ENF signal has natural continuity
  - If an artificial clip is inserted, it breaks the naturalness of signals
  - Prof. Min Wu in MAST Lab, UMD described how they detected fabrication of video using ENF



Introduction - Our contribution

- Problem of previous collection method
  - Traditional method for collecting world-wide signals is difficult and expensive (for manufacture, installation, and maintenance)
  - Below device is FDR for collection of ENF (over $2,000 per device)
  - Fig ref: “Frequency Disturbance Recorder Design and Developments”

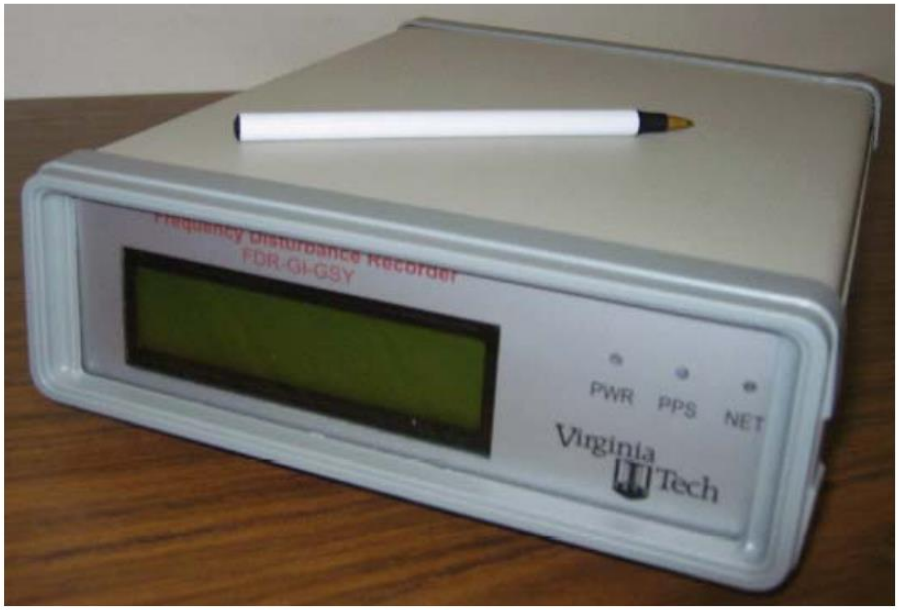
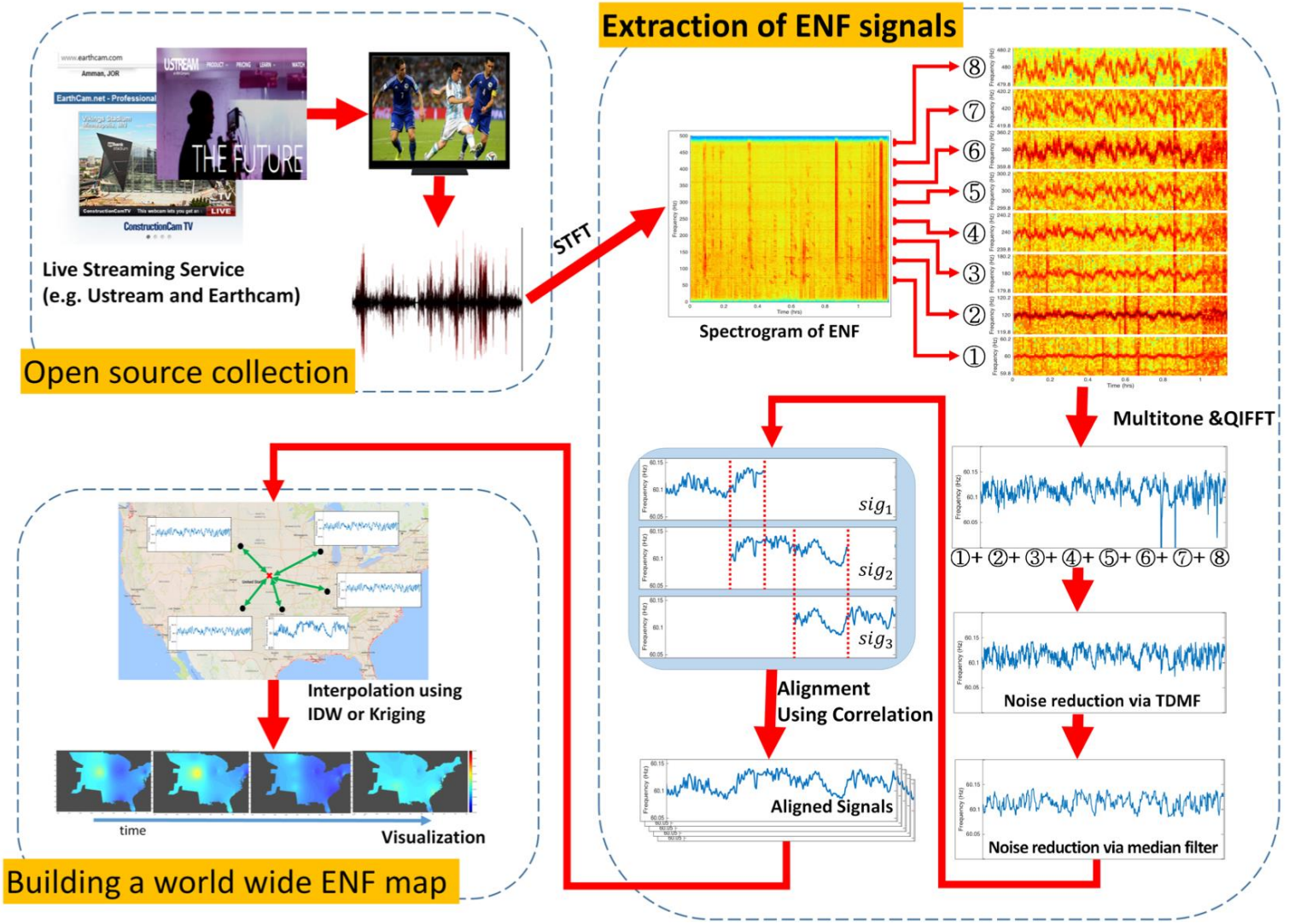


Fig. 5a. Second generation Frequency Disturbance Recorder

Introduction - Our contribution

- For that reason, we suggested a new approach for collection of ENF
  - Exploiting the property of ENF:
    - Multimedia data recorded by wired device include ENF signals
  - The concepts of our approach are as below:
    - Using online multimedia data
    - Recovering lockage of data using partial information
    - Interpolating the collected data for building ENF map for geometrical analysis
  - Our main contributions are as below:
    - Purely online/no need of physical devices – Manufacturing of devices is no longer needed
    - Simple management system – systems that monitor the status of sensors are no longer needed
    - Low budget – Because the proposed system obtains ENF signals from public online multimedia, it is free of charge

Proposed Approaches - Overview



Proposed Approaches - Open source collection

- Feasibility of collection ENF signals using open source media
  - As previous researches had proved, audio/video file contains unique-local ENF signals depending on when and where the file is recorded
  - To collect multimedia, we first crawl the metadata of video using “Scrapy” and download it with “FFmpeg” and “Livestreamer”
  - Online multimedia services that we used were as below:
    - EarthCam: World-wide Webcam Networks
    - Skyline webcams: Live Cams HD from the world!
    - Explore (Youtube): African Animals Camera - live video from Africa
    - Ustream: Streaming & Online Video Services

Proposed Approaches - Open source collection

- Multimedia data were obtained from the following number of services in each continent

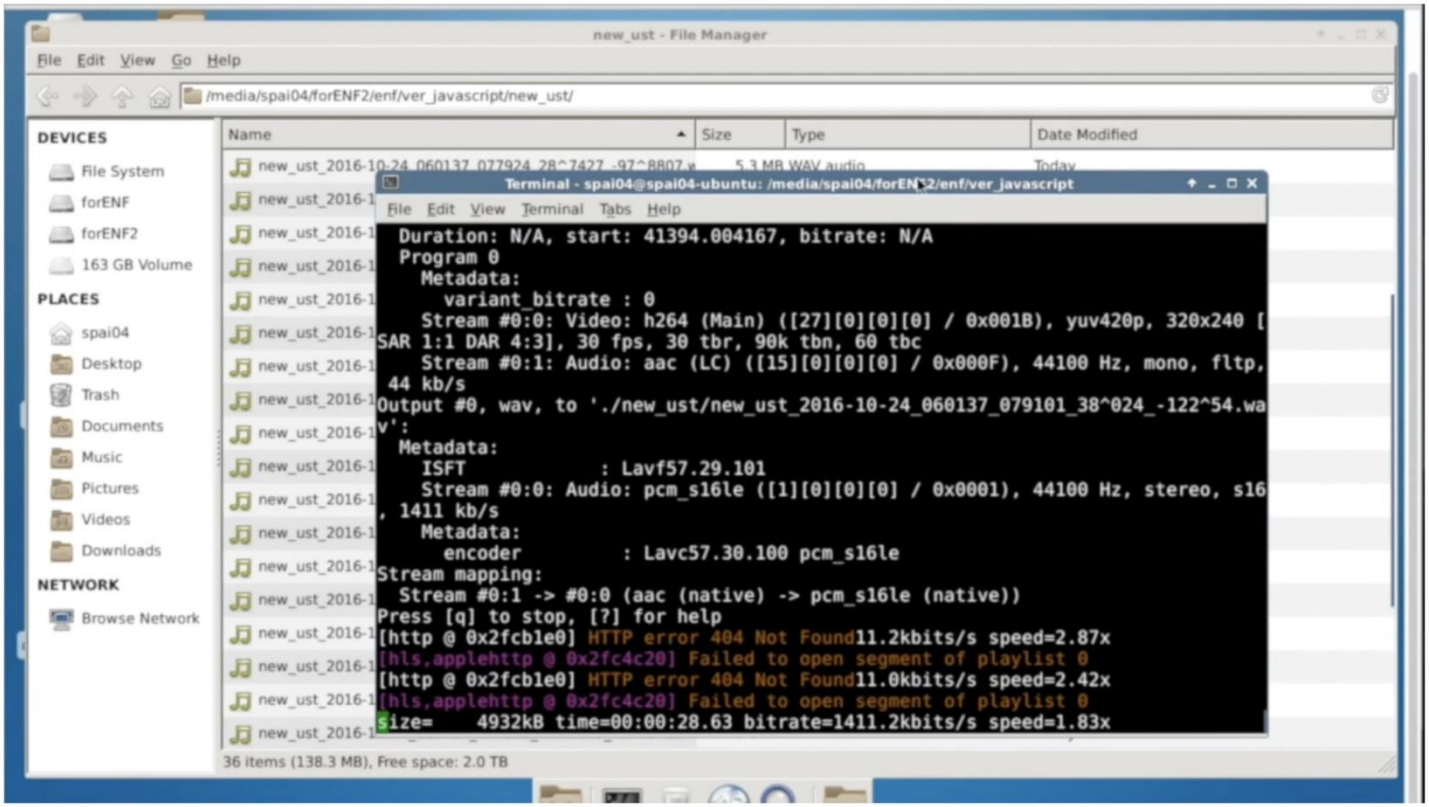
Europe	Asia	Africa	North America	South America	Oceania
71	22	3	165	3	4

- Then, table below indicates how many signals could be extracted properly

Source	Signal state (%)	
	Presence	Absence
Earth Cam	85.3	14.7
Skyline webcams	95.2	4.8
Explore	70.6	29.4
Ustream (gaming & wildlife)	42.1	67.9
Overall	72.1	27.9

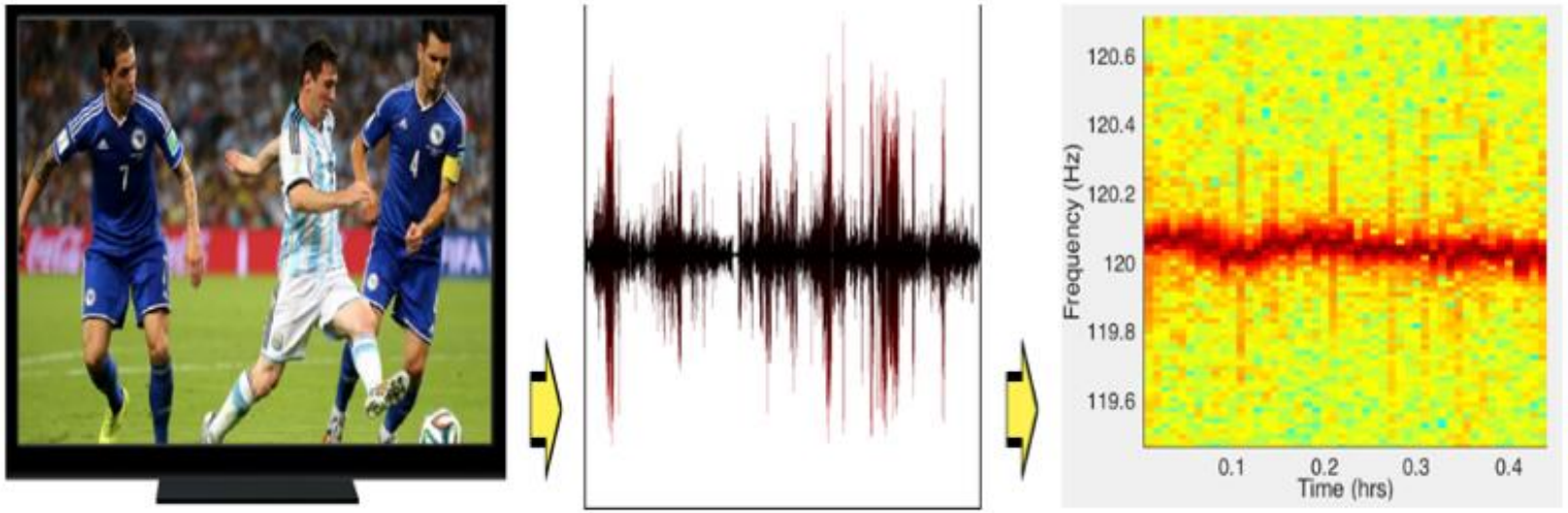
Proposed Approaches - Open source collection

- Figure below is a depiction of crawler module
  - The module is crawling and downloading multimedia data from online services



Proposed Approaches – Signal extraction

- How to check whether there is ENF signal in multimedia?
  - We can simply check it via spectrogram
  - As seen in the figures below, ENF signals appear around 50Hz or 60Hz and its harmonics bands



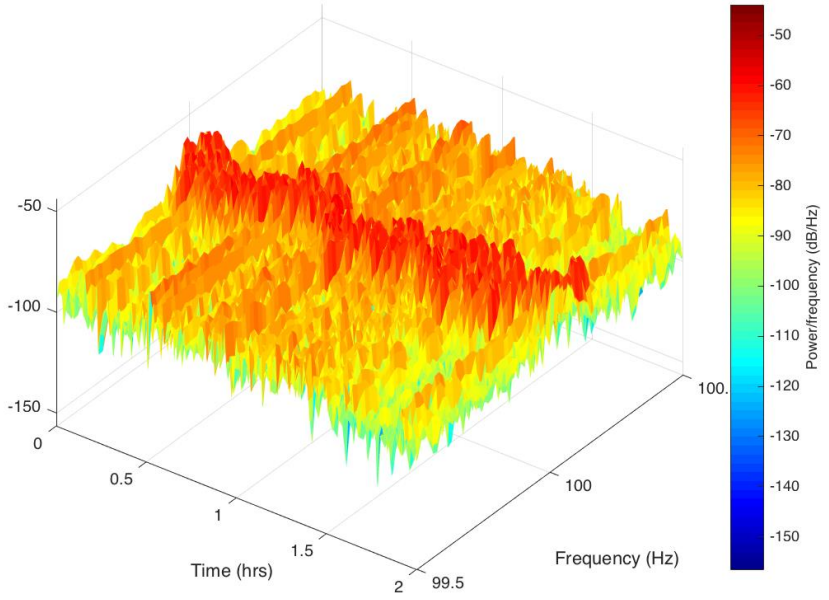
(a) Multimedia data

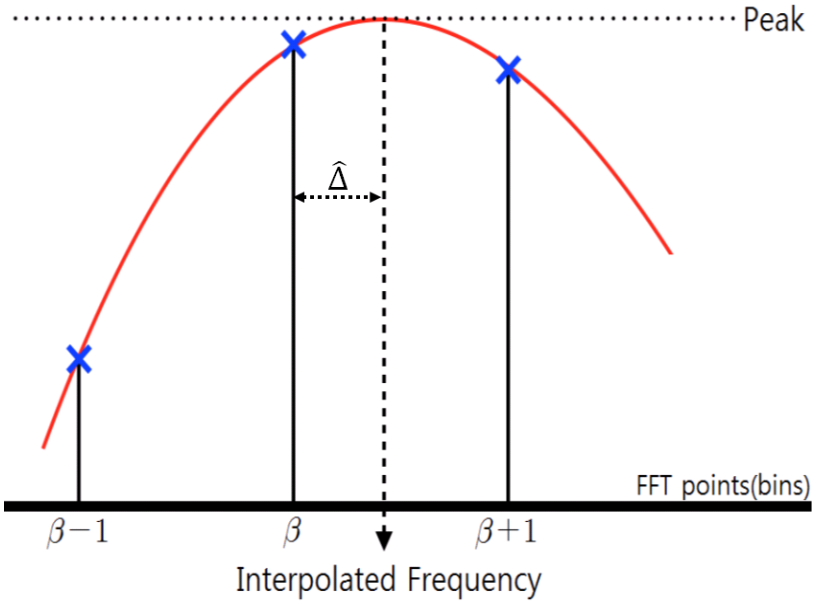
(b) Extracted audio signals

(c) ENF patterns in spectrogram

Proposed Approaches – Signal extraction

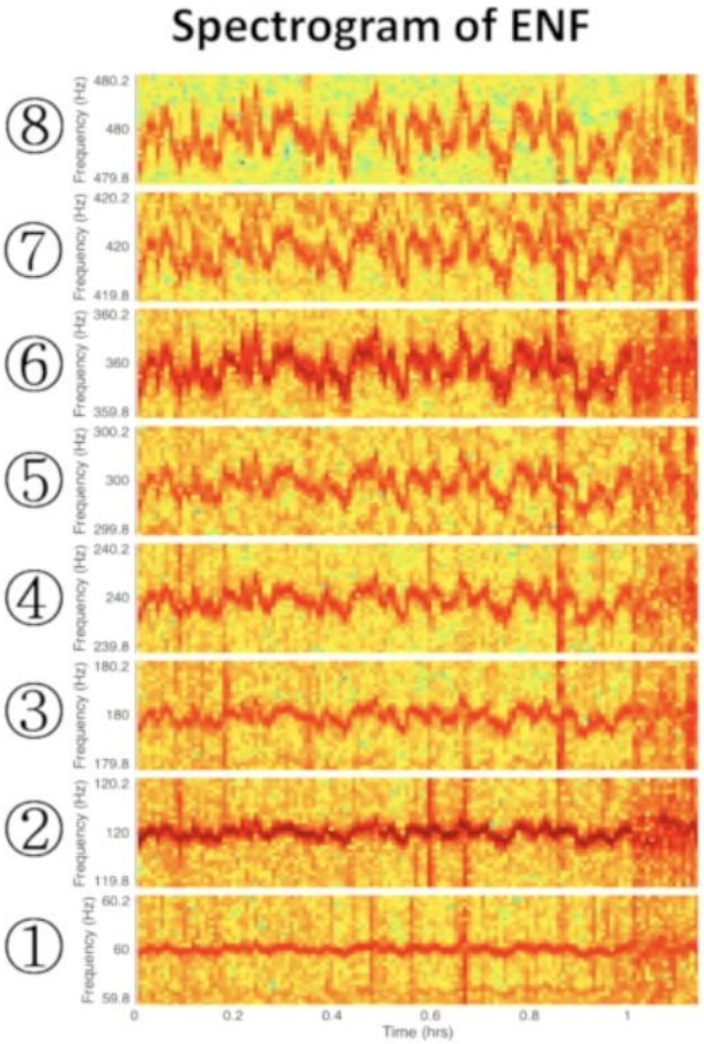
- Extraction of ENF signals from multimedia with QIFFT
  - QIFFT is one of the non-parametric methods for extracting signals from consecutive peaks of frequency domain data
  - Basic concept is similar to STFT, but it works more rapidly than STFT
  - It does not require large window size and overlap length for high resolution since it uses interpolated peak instead of calculation of accurate position of frequency peak





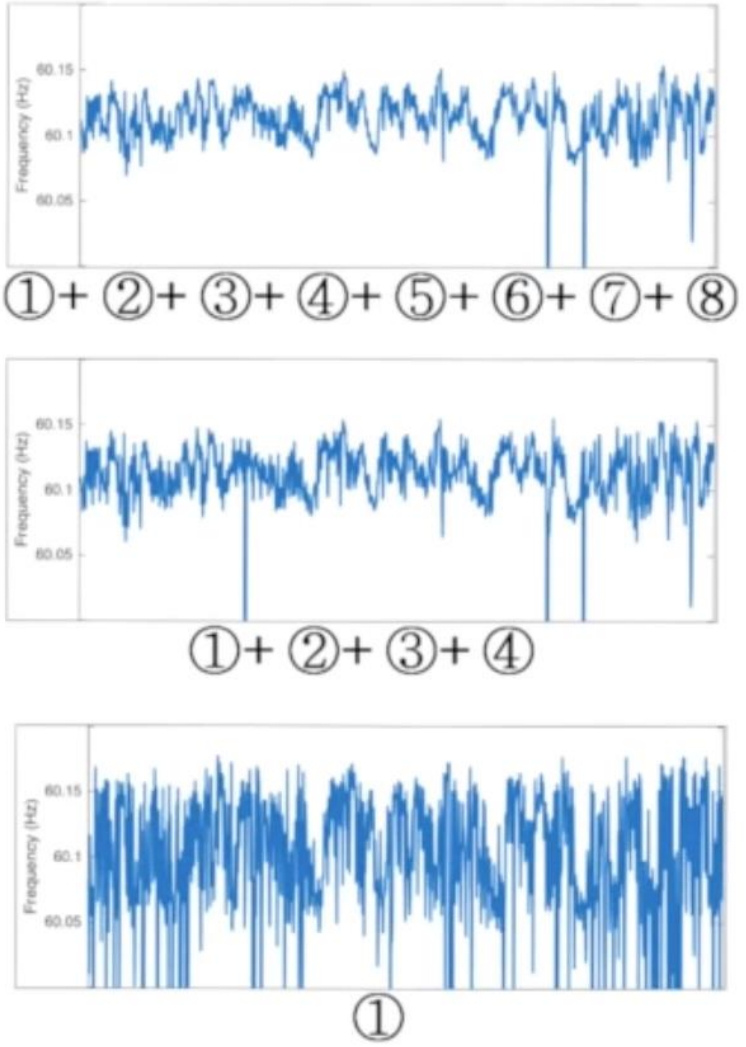
Proposed Approaches – Signal extraction

- Using harmonics information?
  - A harmonic is a signal or wave whose frequency is an integral (whole-number) multiple of the frequency of some reference signal or wave
  - For a signal whose fundamental frequency is f, the second harmonic has a frequency 2 f, the third harmonic has a frequency of 3 f, and so on
  - If the wave is not sinusoidal, it must include harmonics as shown in figure
  - We used these harmonics signals for noise removal and signal intensification



Proposed Approaches – Signal extraction

- Using harmonics information?
  - A harmonic is a signal or wave whose frequency is an integral (whole-number) multiple of the frequency of some reference signal or wave
  - For a signal whose fundamental frequency is f, the second harmonic has a frequency 2 f, the third harmonic has a frequency of 3 f, and so on
  - If the wave is not sinusoidal, it must include harmonics as shown in figure
  - We used these harmonics signals for noise removal and signal intensification

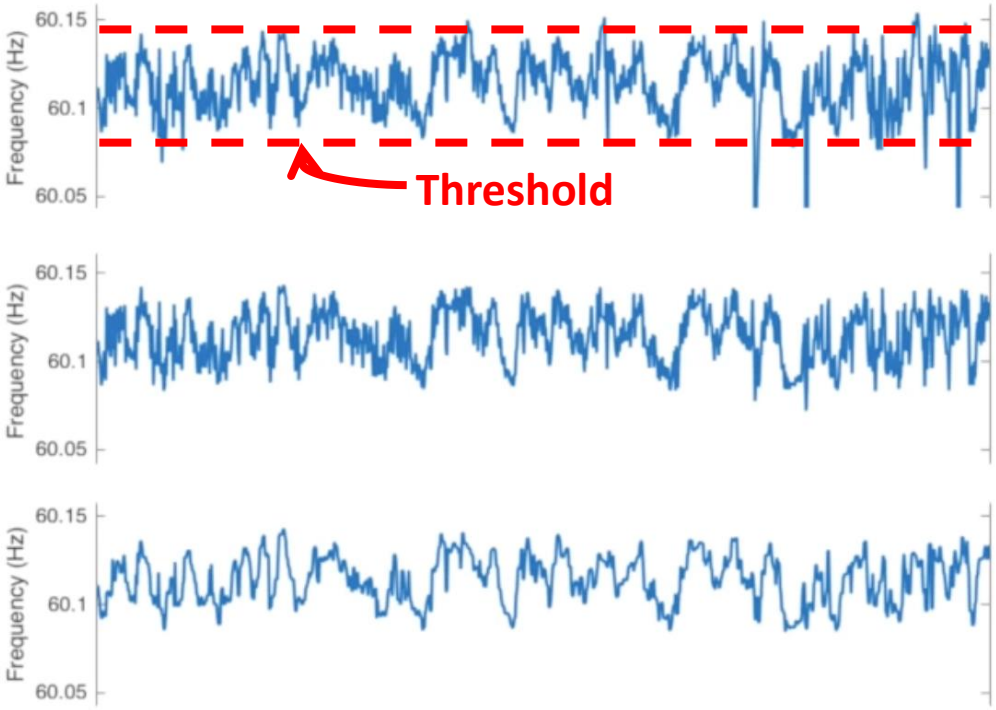


Proposed Approaches – Signal extraction

- Then, we applied TDMF (Threshold Dependent Median Filter) and Median filter
  - TDMF is a method for removing abnormal peak from ENF signals
  - As seen in the figures below, it removes abnormal peak using the specific criteria
  - ENF signals generally have a standard deviation (σ) of 0.01Hz
  - Therefore, we used $\pm$0.03Hz (3 σ) range from center frequency as a threshold

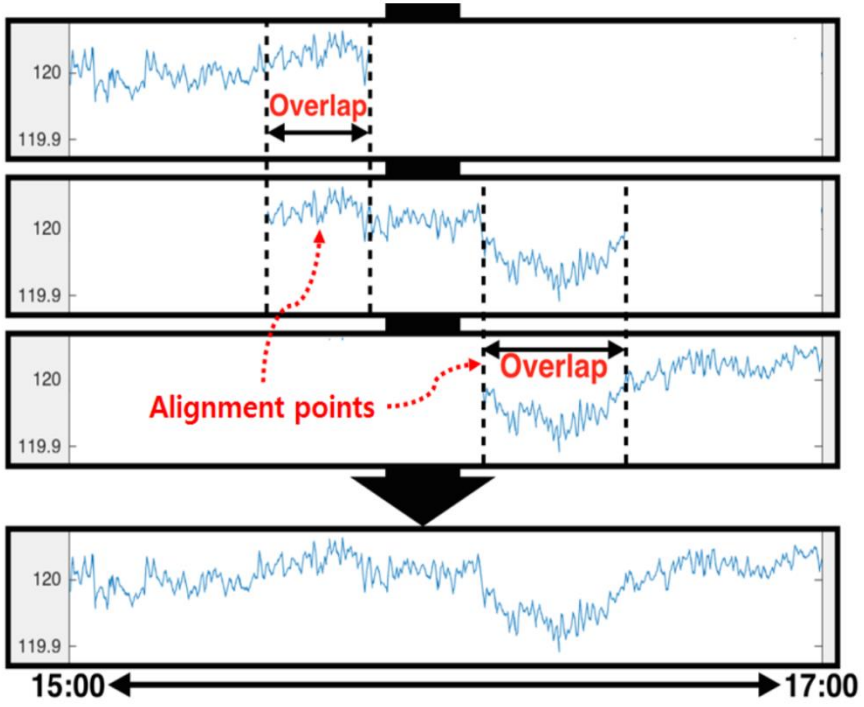
TDMF Filter

Median Filter



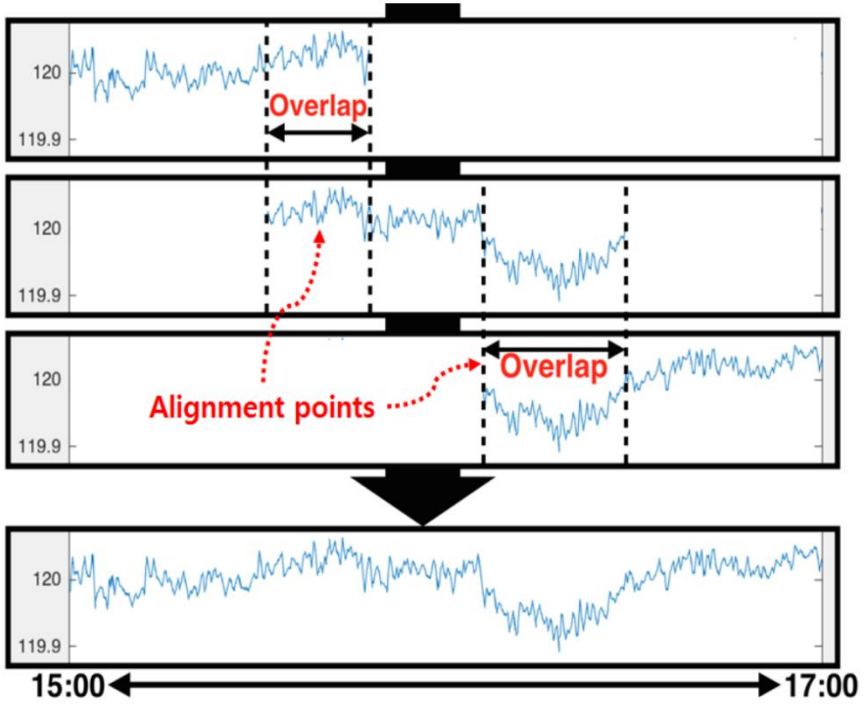
Proposed Approaches – Signal extraction

- Afterwards, we applied signal alignment technique (optional)
  - For restoring semi-complete signals from partial signals
  - Figure below depict signal alignment technique



Proposed Approaches – Signal extraction

- Afterwards, we applied signal alignment technique (optional)
  - No every signal requires this procedure
  - This is only needed for the incomplete signals from “dynamic services” (will be explained in more details in the next slide)

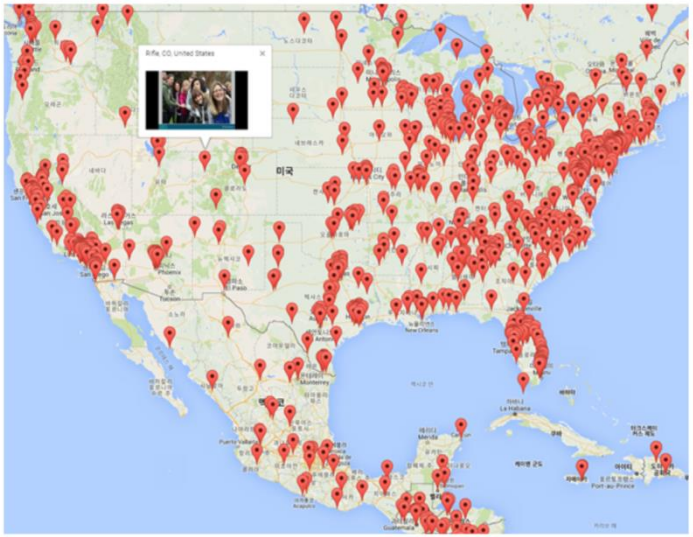


Proposed Approaches – Signal extraction

- Characteristic of each online service
  - Two types of online services; first is static service, second is dynamic service
    - Static services: Broadcasting location and time are static
      - Broadcasting their contents with cameras installed in static place
      - No worry about change of target location
      - EarthCam, Skyline webcams, and Explore are static services
    - Dynamic services: Broadcasting location and time are changeable
      - Personal broadcasting services are defined as “dynamic service”
      - The main agent of dynamic services is not an static installed camera but broadcaster
      - The broadcasting location and time are changeable depending on the situation of personal broadcaster
      - Ustream is a dynamic service

Proposed Approaches – Signal extraction

- Problem of the dynamic service
  - Ustream is one of the popular dynamic services (which provides various multimedia to more than 80 million users)
  - Pros: It is a potentially good service for ENF collection due to a huge number of users (the more number of users, the more diverse the contents are)
  - Cons: This service is not able to provide its contents on static location and time (only partial data could be obtained)

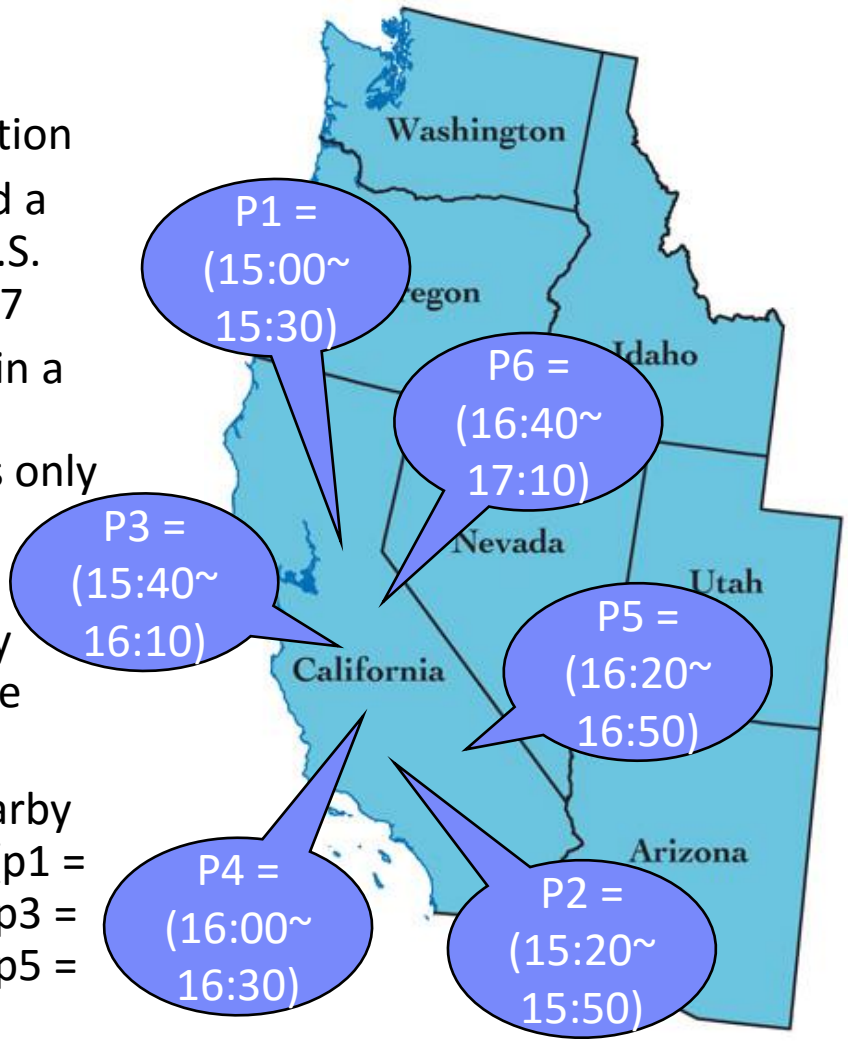


Proposed Approaches – Signal extraction

- Partial data?
  - Data that possesses incomplete information
  - For example, let us assume that we need a long ENF signal recorded in California, U.S. during 15:00 ~ 17:00 on March 12, 2017
  - Unfortunately, it was impossible to obtain a sufficient length of ENF signals because there was a broadcaster who broadcasts only during 15:00~15:30
  - However in this situation, by using the property of ENF, collected data in nearby places have a similar trend, so we restore ENF signals with sufficient length
  - We obtained other partial data from nearby places and collected the following data {p1 = (15 : 00, 15 : 30), p2 = (15 : 20, 15 : 50), p3 = (15 : 40, 16 : 10), p4 = (16 : 00, 16 : 30), p5 = (16 : 20, 16 : 50), p6 = (16 : 40, 17 : 10)}

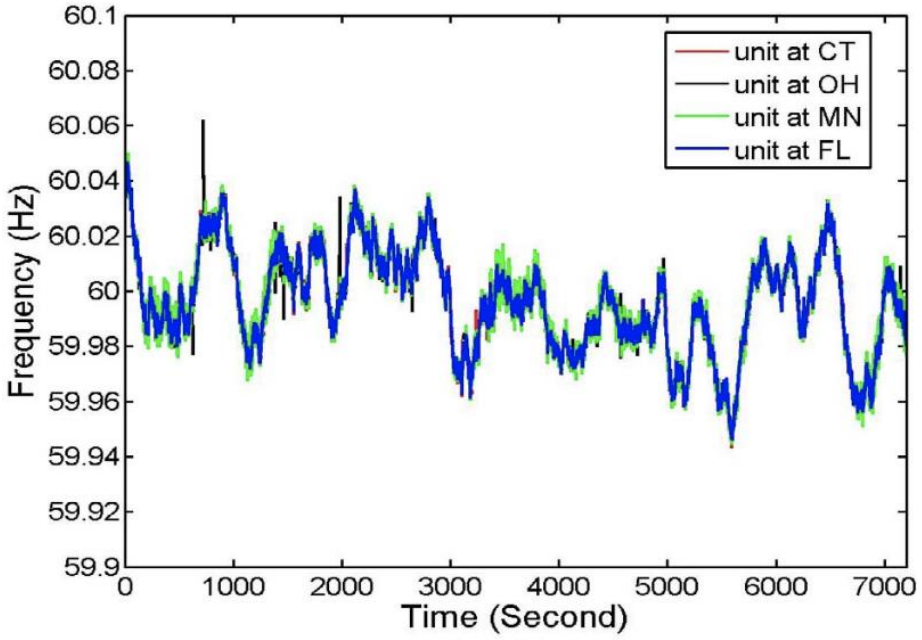
Proposed Approaches – Signal extraction

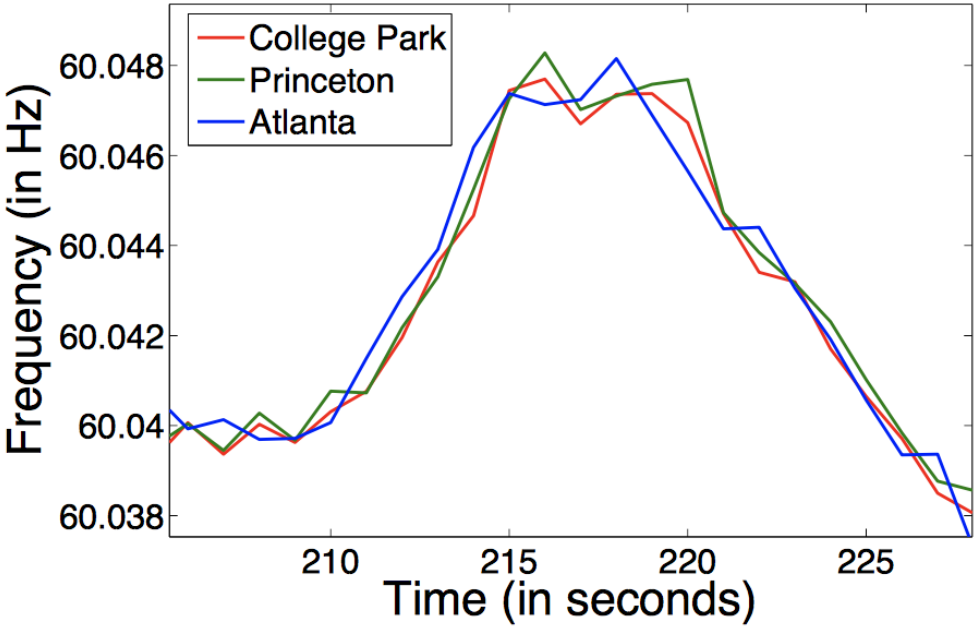
- Partial data?
  - Data that possesses incomplete information
  - For example, let us assume that we need a long ENF signal recorded in California, U.S. during 15:00 ~ 17:00 on March 12, 2017
  - Unfortunately, it was impossible to obtain a sufficient length of ENF signals because there was a broadcaster who broadcasts only during 15:00~15:30
  - However in this situation, by using the property of ENF, collected data in nearby places have a similar trend, so we restore ENF signals with sufficient length
  - We obtained other partial data from nearby places and collected the following data {p1 = (15 : 00, 15 : 30), p2 = (15 : 20, 15 : 50), p3 = (15 : 40, 16 : 10), p4 = (16 : 00, 16 : 30), p5 = (16 : 20, 16 : 50), p6 = (16 : 40, 17 : 10)}



Proposed Approaches – Signal extraction

- Possible?
  - ENF signals are unique
  - However, ENF signals have similarity in accordance with location and time (the closer locations, the similar signals)





Proposed Approaches – Signal extraction

- We used Normalized Cross Correlation for signal alignment
  - In this method, similarity (ρ) can be found using the following equation,

$$\rho = \frac{\sum_{L}^{n=1}(x[n]-\bar{x})(y[n]-\bar{y})}{(L-1)\sigma_x\sigma_y}$$

- The result below shows that the signals from far-away locations have low similarity

Miles	0~300	300~600	600~900	900~1200	1200~
ρ	0.81	0.55	0.53	0.45	0.32

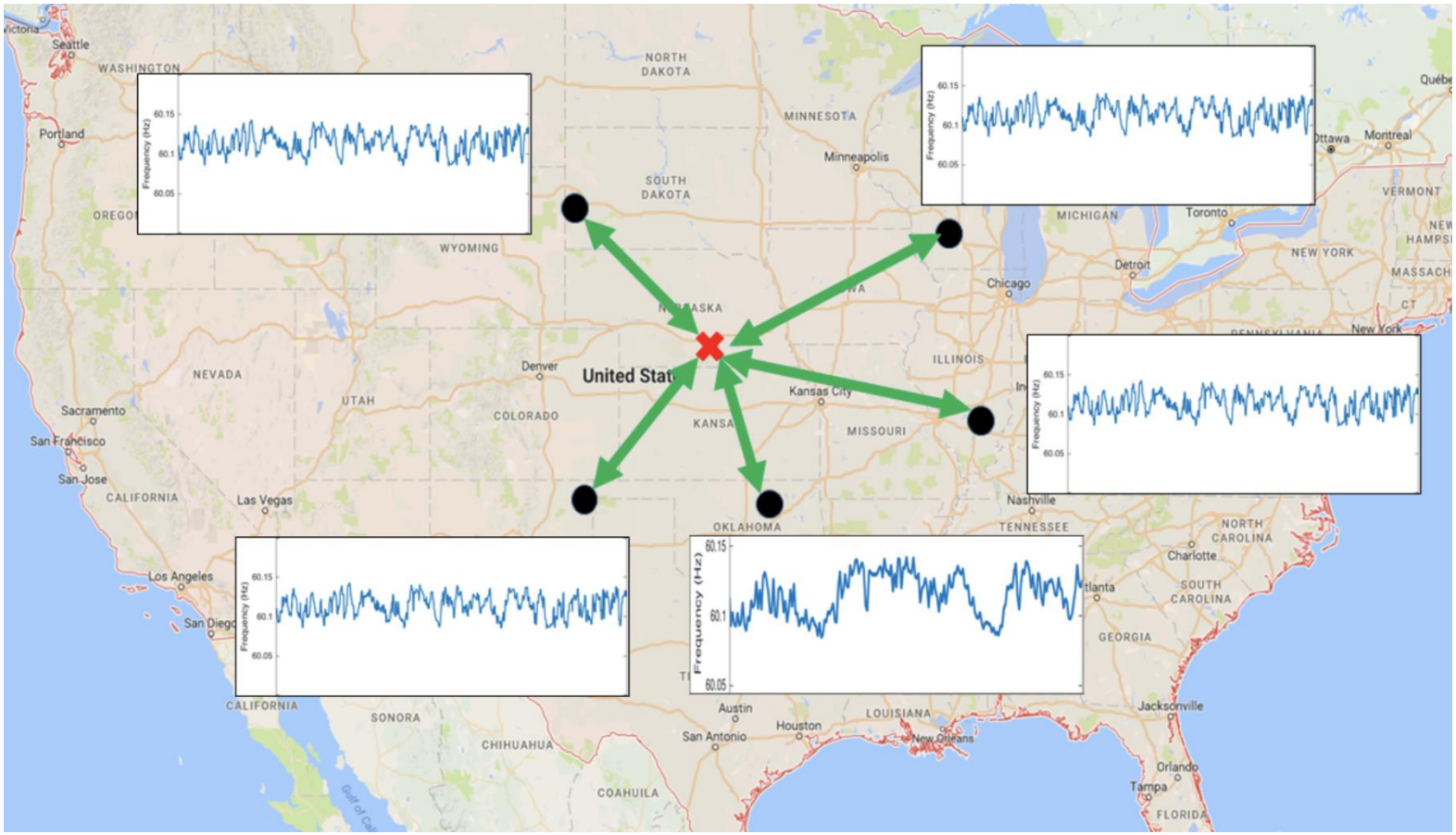
Proposed Approaches – Signal extraction

- Moreover, the error rates of signal alignment technique are as below
  - ρ in the first row indicates the signal similarities, and time ($t + \tau$) in the first column indicates overlap length
  - Through the result, we could check the actual criteria for signal alignment
  - To align the signals successfully, it is recommended that signal pairs, which have ρ similarity and overlap length more than 30 min, are used

$t + \tau$	ρ =0.33	ρ =0.44	ρ =0.56	ρ =0.70	ρ =0.82
20 min	23.69%	17.30%	17.17%	8.14%	1.42%
25 min	10.24%	5.99%	4.29%	4.48%	1.18%
30 min	3.08%	1.8%	1.91%	1.15%	0.00%

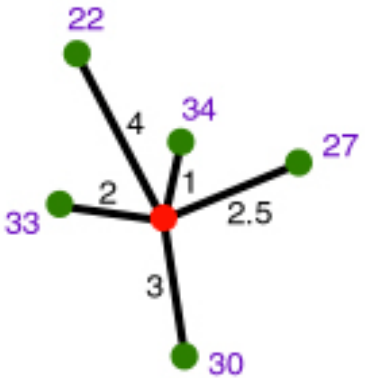
Proposed Approaches – Building ENF map…

- By calculating IDW for all ENF signals collected from same grid,

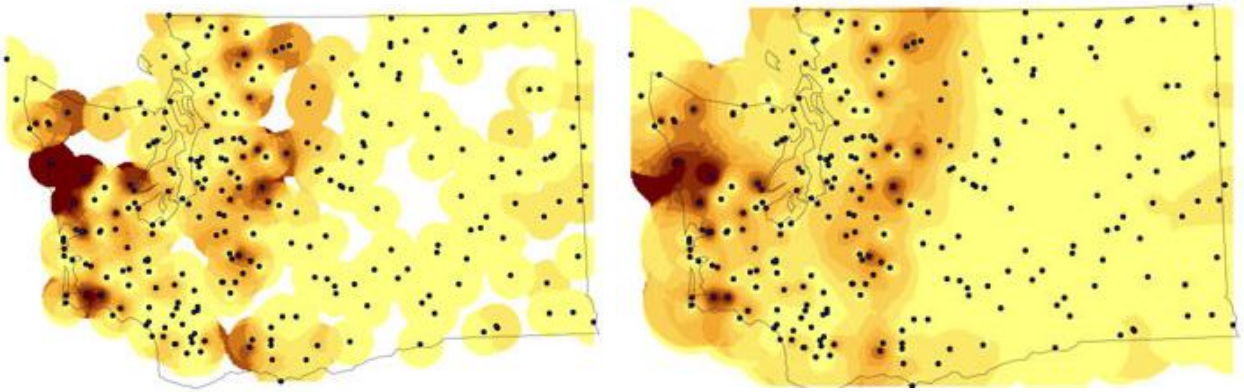


Proposed Approaches – Building ENF map…

- Then, we constructed large-scale ENF map using IDW interpolation
  - IDW (Inverse Distance Weighted) interpolation is a geometrical method
  - It is used for interpolation two-dimensional data to obtain signals from where we could not download multimedia

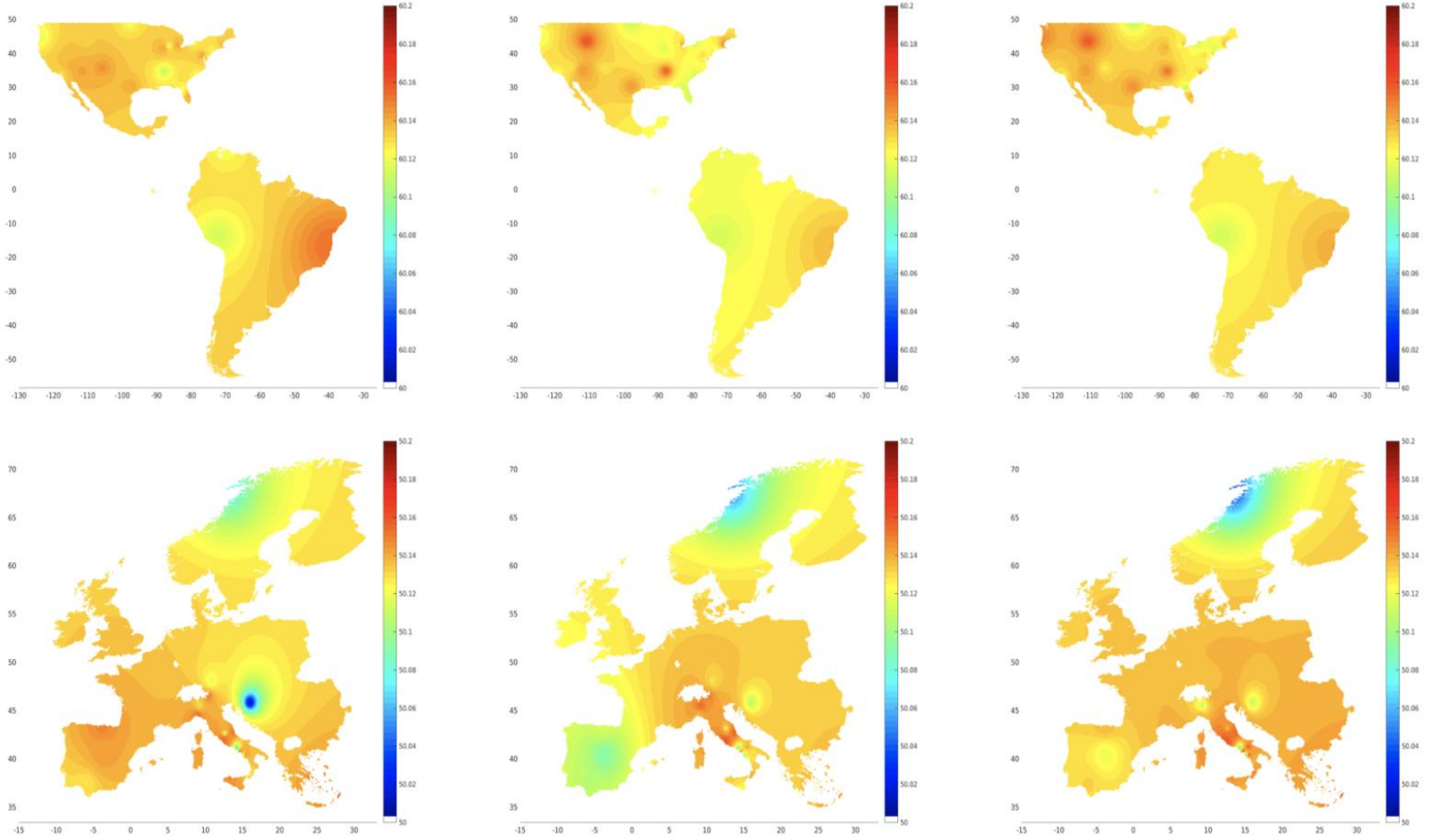


$$Z(x) = \frac{\sum w_i z_i}{\sum w_i} = \frac{\frac{34}{1^2} + \frac{33}{2^2} + \frac{27}{2.5^2} + \frac{30}{3^2} + \frac{22}{4^2}}{\frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{2.5^2} + \frac{1}{3^2} + \frac{1}{4^2}} = 32.38$$



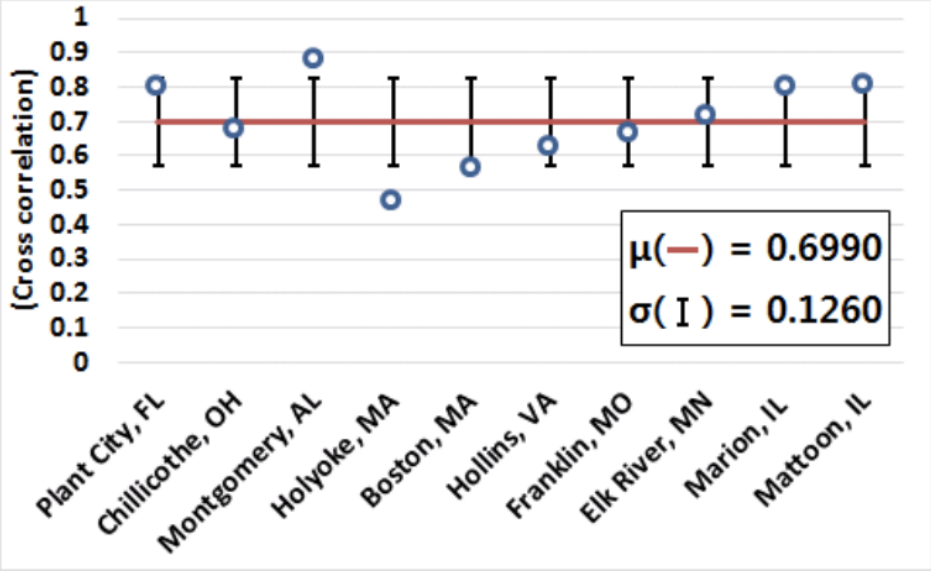
Proposed Approaches – Building ENF map…

- We, finally, could obtain these world ENF map for geometry analysis

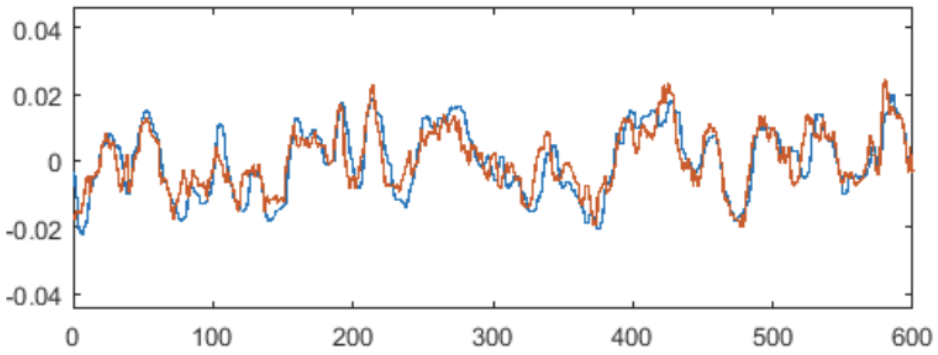


Proposed Approaches – Building ENF map…

- To check the result values from IDW interpolation, we compared interpolated signals with ground truth data from FNET/Grideye



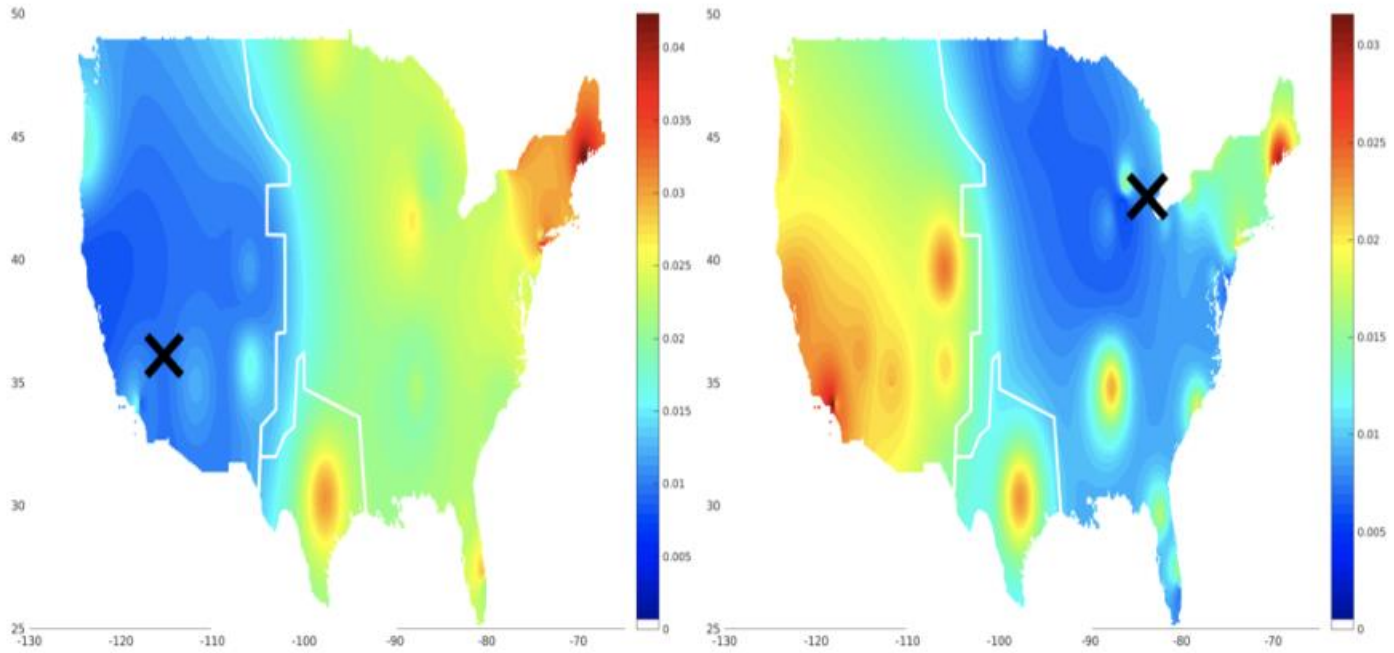
(a) Similarity between ground truth signal and constructed signal via IDW for 10 positions



(b) The ground-truth signal with a red line and, constructed signal with a blue line

Applications

- With the collected data, we checked whether several applications are properly working
  - First application is estimating the time and the location using ENF signals
  - Through this examination, we could confirm that discovering the source location of multimedia is possible



Discussion and Conclusion

- Future works
  - Through this research, we could cover U.S and Europe, and some other countries, however, it is yet incomplete and the number of data is also insufficient
  - To improve the performance of our work, we will try to discover other online services

- Conclusion
  - We proposed a new alternative approach to collecting ENF signals from online multimedia data and reconstructing a worldwide ENF map
  - We claim that our approach is much more efficient and stable than previous methods using hardware
  - Although the quality of the signals from such hardware would be better, our approach is more economical and practical than the previous method
    - because we have eliminated tasks associated with devices, such as design, installation, and maintenance


Q&A