Low Power DSP with wireless monitoring for civil constructions

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ABSTRACT *Noise arising from the construction industry is a major source of noise pollution. Noise from construction sites affects not only the site itself, but also the surrounding area including neighbouring businesses and residents. The duration, complexity, schedule, location, method of construction and type of projects greatly affect the extent of noise impact. Although there are many noise regulation frameworks such as BS 5228, BS 7580 in the UK and 2002/49/EC across Europe to control and mitigate the impact of this construction noise, there is no standardized criteria for assessing construction noise impact. Hence there is a need to identify the extent and magnitude of the noise through using noise monitoring equipment. Such equipment should identify, quantify and differentiate various noise types such as piling demolition, hammering, reversing truck warning signals and their sources. The system should also provide a noise map of the locality and the surrounding area. This paper describes the development of a custom wireless sensor board for noise identification, monitoring and localisation using a low-power DSP and microcontroller. The system stores noise samples to a local SD memory card for future analysis and wirelessly transmits a summary of significant noise events in real time. This paper describes the result of an initial test of the system on a construction site in Cambridge. The noise event and their efficiency has been compared with high resolution, beamforming technology based SeeSV-S205 audio camera. Future work on the system will include further testing to develop better noise discrimination algorithms.*

1 INTRODUCTION

The construction and demolition noise although lasts only for few days and fixed hours, it is one of the major source of noise pollution throughout the world affecting the residential and commercial premises [1]. Several studies has been conducted in the past to show that residents, work offices get disturbed with many complaint logs as part of noise from these construction works affecting over a considerable amount of period. The adverse noise level creates harmful health effects such as concentration loss, mental, physiological and psychological dysfunction and has considerable socio-economic bearing. Some noise regulations across the UK (BS5228:2009, BS7580), Europe (2005/88/EC) are prevalent to decide the acceptable noise level. The acceptable noise level L_{Aeq} (Average equivalent of 'n' continuous sound sample for 15 minute) for industrial premises should be within 75 dB(A) while for offices, retail outlet it should be 70 dB(A). Similarly the residential properties has the acceptable noise level L_{Aeq} limit based on the timing of the day and these are 57.1 dB(A) between 0700 to 1900 hours Monday to Friday and 0700 to 1300 hours on Saturday, 53.1 dB(A) between 1900 to 2300 hours Monday to Friday while during night time between 2300 to 0700 hours Monday to Friday it should be within 48.2 dB(A) [2]. In such case it becomes important to predict, control and monitor the noise level to its acceptable limit without imposing unnecessary restrictions on contractors. CSIC has developed a low power based Digital Signal Processor (DSP) solution which can provide event based noise recognition and monitoring for certain types of noise such as demolition, piling, vibration machine, reversing truck warning signal, public address system, and airplane and background noise using Support Vector Machine (SVM) of Machine Learning approach and Frequency Selective method. Although SVM algorithm has been applied for face, handwriting recognition and other general pattern classification but little effort has been done for noise recognition and discrimination in a construction site [3].

2 APPROACH FOR NOISE DETECTION AND SEPARATION

Noise at a construction site can be detected using available sound level meter or microcontroller (MCU) based audio capturing system and the captured noise can be sent to any location for its processing and logging using various wireless methods such as Bluetooth, Bluetooth Low Energy (BLE), Zigbeee, WiFi or wired system with Ethernet. However the power consumption of the MCU based devices is typically higher due to the transmission of entire chunks of the data packet for its processing at far site. A portable battery to power up these devices contains only a limited amount of power. When the battery becomes exhausted, only option left is to change the battery or deploy other similar system. Due to the adverse location of the system in the construction site it becomes costly and difficult to replace the battery or even replace the system. The low power DSP developed system performs audio processing at the device level locally using various DSP functions before the transmission of important events to a central server location thus enhancing the battery life of the system.

2.1 Frequency selective approach

Here noise is recorded and stored into SD card in time domain using a block of fixed size arrays and it is transformed in frequency domain with Discrete Fourier Transform (DFT) using sliding window mechanism. After generating the frequency response of the captured noise, the signal spectrum can be passed through a range of parallel frequency windows with narrow filter bands to separate various types of noise. The total number of noise events can be identified if the amplitude of the signal within its duration is greater than a certain threshold. The extracted frequency response of the signal is again converted back into time domain using Inverse Discrete Fourier Transform (IDFT) for future use. The complete process has been shown in Fig. 1.

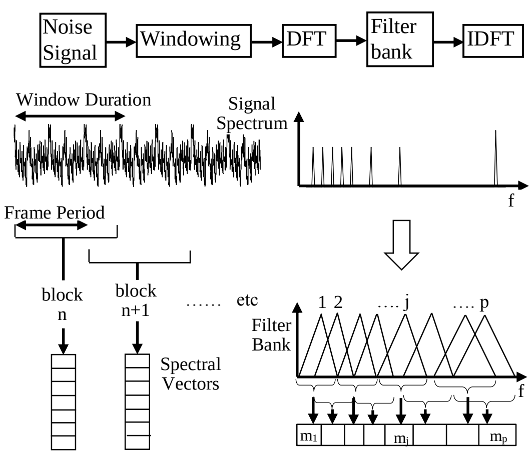


Fig. 1 – Frequency Selective mechanism for noise identification

2.2 SVM approach

The SVM is one type of supervised machine learning algorithm to classify the noise data in binary format using a kernel method where positive indicates data presence while negative indicates the absence of data. The SVM based noise recognition algorithm is dependent on signal detection, parameter identification and calculation, model training, classification and decision module. Once data is recorded using microphone and parameters are identified for classification, decision module and parameters are extracted from the signal. Parameters may be dependent on energy stored in certain sub-bands of the noise signal [4] as defined in (1) and sudden transient changes in the signal amplitude as defined in (2). Here P(n) defines the parameter for the power spectrum of the signal which expresses the signal's energy accumulation in this particular frequency band while n_{f1}, n_{f2}, n_{f1}' and n_{f2}' are the indices of the respective band limits. Although the parameter P(n) calculation is based on transient calculation changes, it requires complete noise data to be stored in number of frames and accessed before the actual calculation can be started.

$$p = \frac{\sum_{n_{f1}}^{n_{f2}} P(n)}{\sum_{n_{f1}'}^{n_{f2}'} P(n)} = \frac{energy\ in\ band\ 1}{energy\ in\ band\ 2} \quad - (1)$$

$$tr_{length} = n_{|P(n)|<P_{thr}} - n_{|P(n)|=\max(p)} \quad - (2)$$

There are many available techniques for noise data classification such as Hidden Markov Model (HMM), Gaussian Mixture Model (GMM), k-Nearest Neighbors (k-NN), Dynamic Time Warping (DTW), Artificial Neural Network (ANN) and SVM. The SVM [5] based noise classification methods use the parameters extracted from (1) and (2) where with sufficient examples of previous events database, classifiers are trained. These SVM based classifier techniques are primarily dependent on Linear and Nonlinear functions (Gaussian, Radial Basis Function, Sigmoidal Basis Function, Polynomial kernel function) for its kernel calculation [6]. In this scheme, the data vectors x_i with labels y_i is mapped to $Ø_n(x_i)$ in another dimensional space using an optimal hyperplane R^n so as to separate the data with positive and negative labels and sufficient margins while minimizing the data points falling in this margin. The hyperplane Y_i for linear SVM (or nonlinear SVM) can be defined using (3) where x_i (or $Ø_n(x_i)$ for nonlinear SVM) and w represents data vectors and m-dimensional weighting vector of the hyperplane respectively while b represents bias point [7]. An additional cost factor, C can be added to the equation to improve the margin of the hyperplane. The margin can be found out using (3) and defined as $2/\|w\|$.

$$Y_i = \begin{cases} f(w_i^T.x_i + b_i) > 1 & if\ y_i = 1 \\ f(w_i^T.x_i + b_i) < -1 & if\ y_i = -1 \end{cases} \quad - (3)$$

Here function f can be a linear or complex nonlinear function depending on the overlap of data points. If $Y_i = 1$, data is accepted otherwise data is discarded.

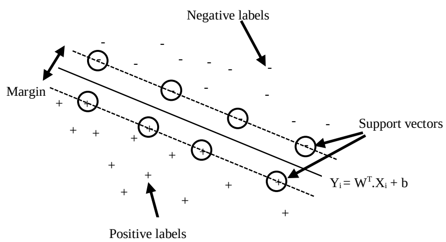


Fig. 2 – Linear SVM mechanism for noise identification

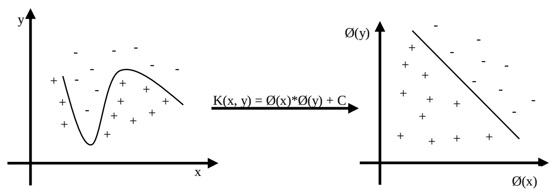


Fig. 3 – Non-linear SVM mechanism for noise identification

As shown in Fig. 2, the data can be easily separated using a linear equation while data being overlapped, a n^{th} order polynomial as shown in Fig. 3 can be defined to separate data points and using a suitable kernel function K(x, y) based on the previous training data sets with minimal training error, the polynomial space can be mapped to linearly separable data points.

2.3 Acoustic audio camera *SeeSV-S205*

The SeeSV-S205 as shown in Fig. 4 is a noise capturing acoustic camera which can produce a noise hot-spot representation of the area within its line-of-sight and records continuous audio stream in real-time for 180 second.

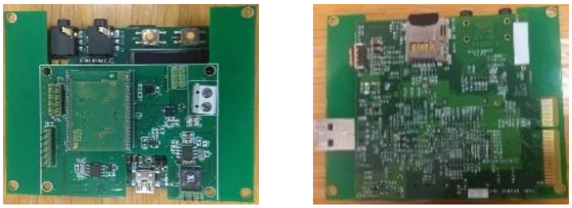
Fig. 4 – SeeSV-S205 Audio camera

The system has an in-built high resolution camera along with thirty numbers of highly sensitive digital MEMS microphones integrated with FPGA based high speed beamforming technology [8]. The system has also pre-built software with real time frequency adjustment, auto image ranging, and linear/exponential image averaging etc. for real time audio and video processing. Once the file is captured and stored in Technical Data Management Streaming (TDMS) format it can be converted in Audio Video Interface (AVI) and Waveform Audio (WAV) file format for easier processing. A fixed audio threshold level from the WAV file is used to identify and record the noise event. These all format conversion and processing can be achieved using Matlab script or Labview.

3 SYSTEM DESCRIPTION

The central part of the noise sensor contains low power TMS320C5515 DSP [9], 8 bit ATMega128RFA1 MCU [10] with integrated 2.4 GHz Wireless, SD card, 32 bit codec driven microphone. The MCU and DSP communicates through configurable Universal Asynchronous Receiver/Transmitter (UART) interface. During its normal operation including the noise capture, its processing and storage operation in SD card, various blocks (such as core supply, IO interface, LDOI, Memory interface, PLL, USB, Codec) of the DSP IC consumes about 14.03 mW/4.25 mA while various external interfaces (such as audio interface through codec, SD card, Clock and Memory) attached to DSP IC consumes about 264 mW/80 mA. Similarly MCU ATMega128RFA1 consumes 168 mW/51 mA. Hence the total power consumption of the DSP IC, the external interfaces and ATMega128RFA1 MCU is about 446.03 mW/135.25 mA. Since the source input for the Noise sensor board is 5 V, the power consumption at the source side is 446.03 mW/89.265 mA. The PCB as shown in Fig. 5 has been designed to be powered either through a solar panel or battery. Considering the construction site where the construction activities typically last for about three to four weeks, the system has been powered using a 12 V, 33 Amp-hour battery providing continuous operation up to 37 days. If the power down mode of the system is utilized through Software, the system can last for several months. As part of DSP applications development using Code Composer Studio (CCS) [11], various functions to initialize UART communication, baud rate configuration, time and date stamp using an on-board Real Time Clock (RTC), SD card initialization, SD card read and write, noise capture using a microphone attached to the system, noise event transmission using its wireless radio and events logging to local storage and remote server has been achieved. When the DSP receives an audio signal on its microphone, it performs Fast Fourier Transform (FFT) over a frame consisting of 1024 fixed data points by means of sliding window mechanism as mentioned in section 2.1 and 2.2, and as per the difference of the amplitude of the frequency spectrum with the noise threshold (65 dB in our case), the DSP algorithms identify the type and magnitude of noise. The processed result is then sent to the MCU over

UART for events generation as well as local storage in SD card and the inbuilt wireless radio within the MCU transmits the data to a gateway. The gateway then sends the data to a repository of a Raspberry PI based central server in real-time using 3G/4G modem card.



Top side of the PCB   Bottom side of the PCB

Fig. 5 Wireless based MCU system with DSP

4 DEPLOYMENT AND RESULTS

The DSP based noise monitoring systems along with the acoustic camera SeeSV-S205 has been deployed for its construction activity as shown in Fig. 5 at an upcoming James Dyson building in the Engineering department at University of Cambridge for the noise monitoring and logging. The Gateway was kept at a distance of about 30 m within the line of sight for its radio communication to the DSP system while the server was located within the department at a central location.

Fig. 5 – Noise sensor deployment at James Dyson Building

The acoustic camera can record sound events continuously only up to 180 second at a stretch. Since the result of the DSP based developed system has to be compared with the result of this acoustic camera, the window time of 180 second has been kept deliberately for the recording. In addition, the total number of the noise events within this 180 second time window has been manually counted for the efficiency calculation of the frequency selective and machine learning approach of the DSP based developed system and acoustic camera. Efficiency is defined as (the number of noise events recognized)/(total number of noise events counted manually). For the SVM approach, the developed SVM algorithm was trained with various construction noise video available at YouTube in order to enhance and optimize the algorithm for the real site deployment. The noise recording was obtained under two separate conditions, Real and Controlled construction events. In real construction activity, the noise generation event within the time window was unknown and it depended on the type of construction works and noise generation while in controlled construction the noise activity was certain to happen within the time period.

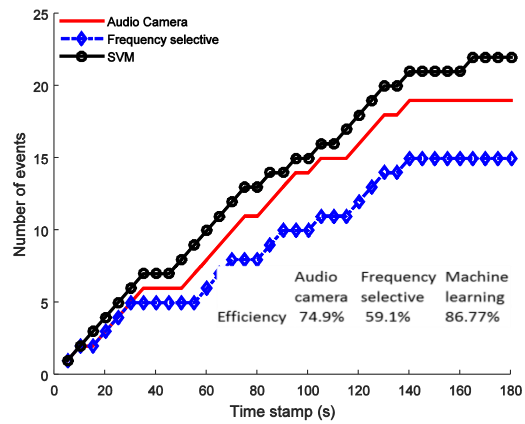


Fig. 6 - Real construction events at James Dyson Building

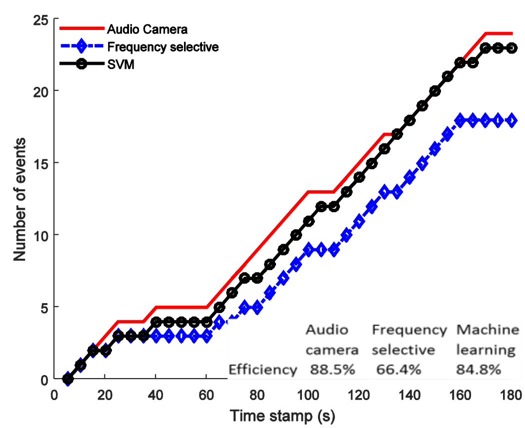


Fig.7 - Controlled construction events at James Dyson Building

5 DISCUSSION AND CONCLUSION

Here a low power DSP based and MCU integrated with Wireless radio solution has been designed to capture the noise, store the raw data into SD card and send the noise event to a remote location using a Raspberry PI server. The processing of noise has been obtained using frequency selective approach and Support Vector Machine. As shown in Fig. 6 and 7, the number of noise events for a real and controlled construction activity using the Frequency Selective and SVM method has been compared with an accurate audio camera SeeSV-S205. The SVM based machine learning algorithm shows a higher efficiency of 86.77% and 84.8% for real and controlled demolition events with identification of the total number of noise events while the frequency selective approach shows a poor efficiency of 59.1% and 66.4%. Thus noise capture from the developed SVM method in DSP card compares reasonably well with the audio camera SeeSV-S205. Future works include the refinement of these noise recognition algorithms for identifying and discriminating various types of noise such as Piling, demolition, truck reversal, vibration machine and public address system and deployment of the system at other upcoming construction sites.

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REFERENCES

[1] Shen L.-Y., Lu W.-S., Yao H. and Wu D.-H. 2005. A computer-based scoring method for measuring the environmental performance of construction activities. Automation in Construction, 14:297-309.

[2] Fahy, F. and Walker, J. 2004. Advanced applications in Acoustics, Noise & Vibration, London: Spon. Press, 187.

[3] Byun, H. and Lee, S. W. 2003. A survey on pattern recognition applications of support vector machines. International Journal of Pattern Recognition and Artificial Intelligence, 17(3), 459–486.

[4] Zwan, P. and Czyzewski, A. 2008. Automatic sound recognition for security purposes. In: Proc. 124th Audio Engineering Society Convention Amsterdam.

[5] Cortes, C. and Vapnik, V. 1995. Support-vector network. Machine Learning Journal, 20, 273-297.

[6] Keerthi, S. and Lin, C.-J. 2003. Asymptotic behaviors of support vector machines with Gaussian kernel, Neural Comput. 15(7), 1667-1689.

[7] Hearst, M. A., Dumais, S. T., Osman, E., Platt, J. and Scholkopf, B., 1998. Support vector machines, in *Intelligent Systems and their Applications, IEEE*, 13(4), 18-28.

[8] Christensen, J. J. and Hold, J. 2004. "Beamforming," Bruel & Kjaer Technical Review No. 1-2004, 3-35.

[9] Spectrum Digital, TMS320C5515 eZDSP USB Stick Technical Reference, 512845-0001 Rev A II 2010 http://support.spectrumdigital.com/boards/usbstk5515/reva/files/usbstk5515_TechRef_RevA.pdf

[10] Atmel, "Atmega128rfa1: 8-bit AVR microcontroller with low power 2.4 GHz transceiver for Zigbee and IEEE 802.15.4," datasheet, 2001. [Online].
Available: http://www.atmel.com/Images/doc8266.pdf

[11] Code Composer Studio (CCS), Texas Instrument, 2014