Tractor Oil Pump Fault Diagnosis by Pseudo-spectrum Analysis of Vehicle Sound Records

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Abstract: A pseudo-spectrum analysis approach for fault diagnosis of tractor oil pump through sound records by mobile phones is presented. The sound of tractor engine is recorded in different conditions of an oil pump contamination to dust and being chocked. By analyzing the soundtracks the dust pollution level is determined and the oil pump chocked condition is efficiently detected.

Keywords—**Fault Diagnosis, Oil Pump, Pseudo Spectrum, Vibration Sound Track**

1. Introduction

Smart phones and internet technologies are increasingly in use towards the betterment of society. In complex and increasingly uncertain operating conditions, use of a smartphone with internet technologies could definitely be a novel innovation in monitoring and detection in the tractor, especially during the emergency conditions. Nowadays, a tractor while working in a field far away from the possible workshop, the farmer or driver can diagnose the problem by recording the undesirable known sound using the phone, namely, by putting it to sound generating area. This operation does not require knowledge of the mechanical technology of tractor operation to the users, due to an expert system, at the back end of the developed app for the mobile. Thus, it will offer a demanding tool as well a novel service to customers with respect to increasing processing power and portability of the phone as an important attribute.

2. Tractor Soundtrack Data Collection

First and the most important part of the research work over tractor parts defect detection is data collection and generation. To invent and introduce an efficient methodology, the collected data should be in ideal condition. Although providing multi-sensory data can be more useful in data processing, the fault diagnosis through single sensory data records of each part is a valuable task in increment of the user-friendly quality of the mobile phones application. In the other side, multi-sensory data not only brings the advantage of easing pre-processing of the data and removal of noise and signals

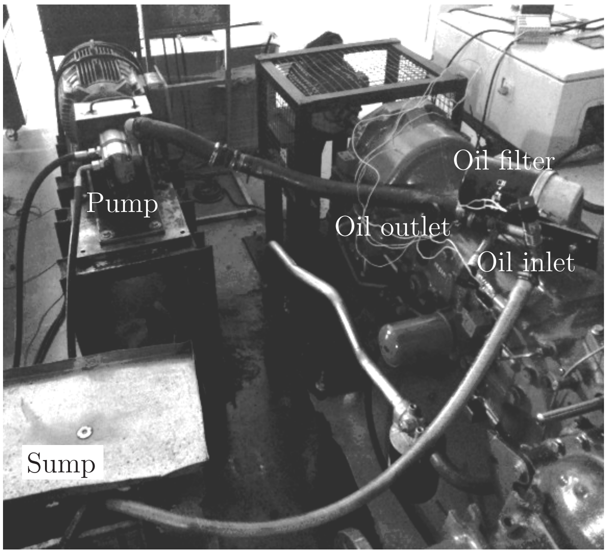

Figure 1. Laboratory setup for recording the sound of the oil pump.

interference, but also it provides more features and more accurate diagnosis. However, it requires more sophisticated microphones arrangements around the vehicle and therefore the complicated application for a user. To develop the study over processing of each sensor data in connection to its related part, availability of pure single sensory signal with minimum interference is a vital essence. Otherwise, the algorithm designed based on the signal features would include wrong features that can make the algorithm susceptible to false detection. Therefore, the single sensory data generation and collection is a crucial step in this research work. Considering that each defect has its individual generated vibration sound signal produced by the defected part, since one part can have different levels of fault, its associated defect vibration signal covers a broad class of defect indicating signals. Apart from a possible defect problem with its generated vibration sound, aging problem produces its corresponding vibration signal that can be categorized under a class of signals for different levels of aging. So, each assumed part A, can have two types of possi-

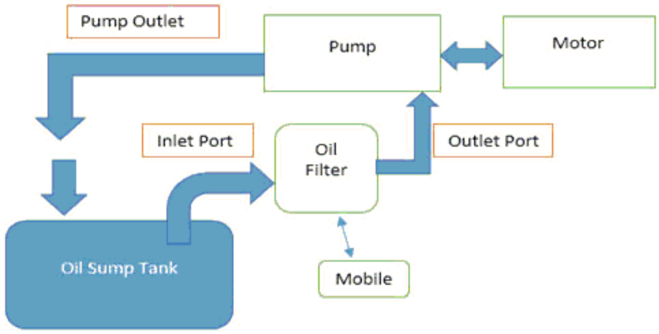

Figure 2. Schematics of the test setup for recording audio tracks out of tractor oil hydraulic system.

ble vibration signals; the vibration signal caused by aging and the vibration caused by defect or damage. The practical way of collecting ideal single sensory data is proposed and clarified as follows. First, lets consider the part A. We are going to record its aging vibration signals, after that, its defect signals. Since, we are going to have an ideal signal free of any interference, the part A (here the oil pump) with the age of T_A is mounted on a new tractor with a new and calm engine and parts. The sensors are mounted in proper place and the vibrations out of part A are recorded. For the part A with the age of T_A we record vibration signals related to different conditions of working such as soft, moderate and hard. In the case of oil pump here, we have considered different levels of dust pollution inside the oil pump. These levels are from zero which means clean oil pump, one level of dust, two levels of dust and so on till six levels of dust. After that, the pump is chocked that is the last condition of oil pump audio recording. This classification is done in consultation with tractor service technicians. Note that, the age of a part is not the matter of time but the efficacy of the part that can be categorized into three or five age groups as new, young, middle age, old and very old. This age classification is also considered in consultation with tractor service technicians. The above-mentioned methodology and classification for the collection of single sensory data are just a simplified explanation of what we have done in John Deere laboratories. In our research work, the research practice is done on tractor oil pump fault diagnosis through audio signal records by three different mobile phones, as in this paper they are mentioned as just first, second and third mobile phone. The test set up in the laboratory, and its schematics can be seen respectively in Figures 1 and 2. Figure 3 shows one second of audio tracks corresponding to three conditions: (i) just after starting the engine while the pump is a normal condition, (ii) polluted by dust at the middle of the way of being chocked, and (iii) the pump is chocked.

3. Data Analysis Methodology

After collection of single sensory vibration audio signal records by three different mobile phones, we process the audio tracks in connection with the level of dust inside the oil pump. The level of the dust inside the pump determines the age of the pump before being chocked. In order to detect the

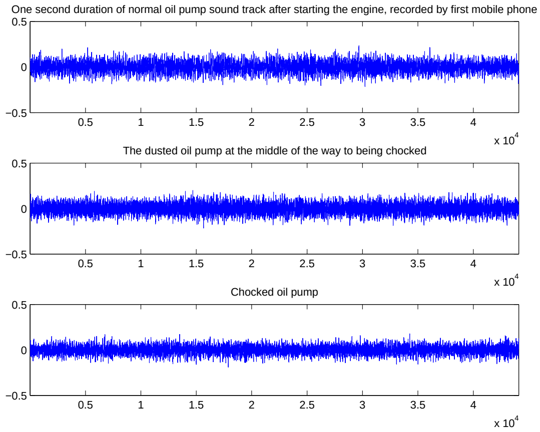

Figure 3. One second duration example of audio tracks recorded by one of the mobile phones. Top signal is the audio record after starting the engine while oil pump is in normal condition, the middle signal is related to the oil pump with almost half of the dust required to be chocked, and the bottom one is once the oil pump is chocked.

aging level before chocking and the chocking itself, a precise feature should be chosen. To aim this goal, here, the pseudo spectrum analysis of the audio tracks is proposed. Here, a brief review to pseudo-spectrum is given.

3.1 Pseudo-spectrum

A well-behaved function, $f(x)$, in an interval, can be represented as expansion in a set of orthonormal functions, $P_n(x)$, as follows:

$$f(x) = \sum_{n=0}^{\infty} a_n P_n(x), \qquad x \in [a, b] \tag{1}$$

where $P_n(x)$'s are orthonormal polynomials as mathematically expressed:

$$\int_a^b w(x) P_n(x) P_m(x) dx = \delta_{nm}, \tag{2}$$

where $w(x)$ is an appropriate weight function for orthonormal condition. δ_{nm} is Kronecker delta that is defined as follows:

$$\delta_{nm} = \begin{cases} 1, & m = n \\ 0, & m \neq n. \end{cases} \tag{3}$$

Orthonormal polynomials as basis functions are classically well known as Bernard Shizgal has listed some of them in [1].

3.2 Eigenvalue Problem Approach to Pseudo-spectrum

An approach to pseudo-spectrum is eigenvector method. The pseudospectral method can be provided by eigenvalues as follows:

$$\int_a^b k(x, y) \psi_n(y) dy = \lambda_n \psi_n(x), \tag{4}$$

where $k(x, y)$ is the kernel with the assumption of being well behaved on both sides of the equation. By using the appropriate quadrature points, $\{x_i\}$, the integration is reduced to summation of a set of linear equations:

$$\sum_{i=1}^{N} W_i k(x_j, x_i)\psi_n(x_i) = \lambda_n \psi_n(x_j), \quad (5)$$

3.3 Multiple Signal Classification (MUSIC)

Similar to many other practical array signal processing, we are looking for an estimation of a set of reliable constant features/parameters to which the audio records are dependent. There have been some classical methods fulfilling the same goal, such as maximum likelihood (ML)[2] and maximum entropy (ME)[3]. However, the aforementioned classical methods suffer from parameters estimation sensitivity and bias of the parameters. These problems were overcome, by the deployment of the covariance matrix of the signal for estimation of complex sinusoids by Pisarenko[4]. Later, Schmidt by deriving a geometric solution developed multiple signal classification algorithm (MUSIC)[5]. MUSIC estimates pseudo-spectrum of the signal using the estimates of the eigenvectors of the correlation matrix of input data signal.

MUSIC estimation of the signal frequency content is by the deployment of eigenspace. Its assumption of the input signal is p complex exponentials together with background noise. The spanned subspace of signal is by the p eigenvectors corresponding to the p largest eigenvalues of $\mathbf{R_x}$, the $M \times M$ autocorrelation matrix of the input signal, while the sorting order of eigenvalues are is in decreasing direction.

3.4 Oil Pump Fault Diagnosis by MUSIC

Here by application of MUSIC algorithm on each signal record, its pseudo-spectrum is estimated. Thereafter, the pseudo-spectrum curves are compared and evaluated over the frequency range of the signals. Although MUSIC estimated pseudo spectrum is over normalized frequencies (in rad/sample), by having the sampling frequency of the records, we can perform the evaluation on frequencies in hertz.

4. Results and Discussion

The pseudo-spectrum of each mobile phone sound records corresponding to eight different conditions is analyzed. The oil pump sound is recorded in different conditions as follows:
1 The oil pump sound just after starting the engine while The oil pump is clean and without any dust.
2-7 The oil pump sound after adding one to six levels of dust.
8 The oil pump is chocked.
Figures 4, 5 and 6 show the MUSIC estimation of pseudo-spectrum of the oil pump sound records by first mobile phone, second and third mobile phones, respectively.

By observing the pseudo-spectrum curves of the first mobile phone and the third mobile, similarly, the following points are concluded:

- Pseudo-spectrum curves for normal condition of the working after starting the engine, one level and two level of dust addition, is very similar and almost the same.

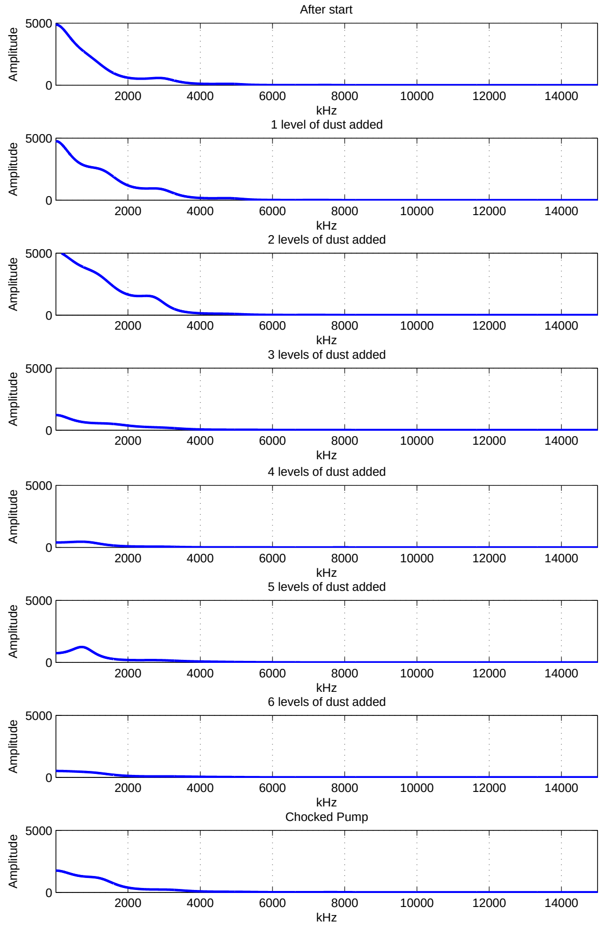

Figure 4. Pseudo-spectrum of the audio tracks recorded by the **first** mobile phone. Up: just after starting while the oil pump is clean. Second row: one level of dust addition to the pump. Third row: two levels of dust addition to the pump. Fourth row: three levels of dust addition to the pump. Fifth row: four levels of dust addition to the pump. Sixth row: five levels of dust addition to the pump. Seventh row: six levels of dust addition to the pump, and the bottom row: the pump is chocked.

- By the addition of the third level of dust, the power of pseudo-spectrum considerably decreases.
- The addition of levels of dust after the third level does not bring any considerable change to Pseudo-spectrum content.
- By being chocked, pseudo-spectrum shows a bit increase in lower frequency content.

By observing the pseudo-spectrum curves of the second mobile phone records, the similar points can be found. Moreover, another point strongly shows off. A pseudo-spectrum peak around 13 kHz exists in a normal condition of working just after starting the engine, and it is around one-third the maximum point of the spectrum. By adding more dust, the peak mentioned earlier starts to grow up while the low-frequency contents of pseudo-spectrum decline. The amplitude of the 13 kHz peak reaches to three times the highest frequency content of pseudo-spectrum at the third level of dust. But, by adding dust more than the third level, the peak disappears. The 13

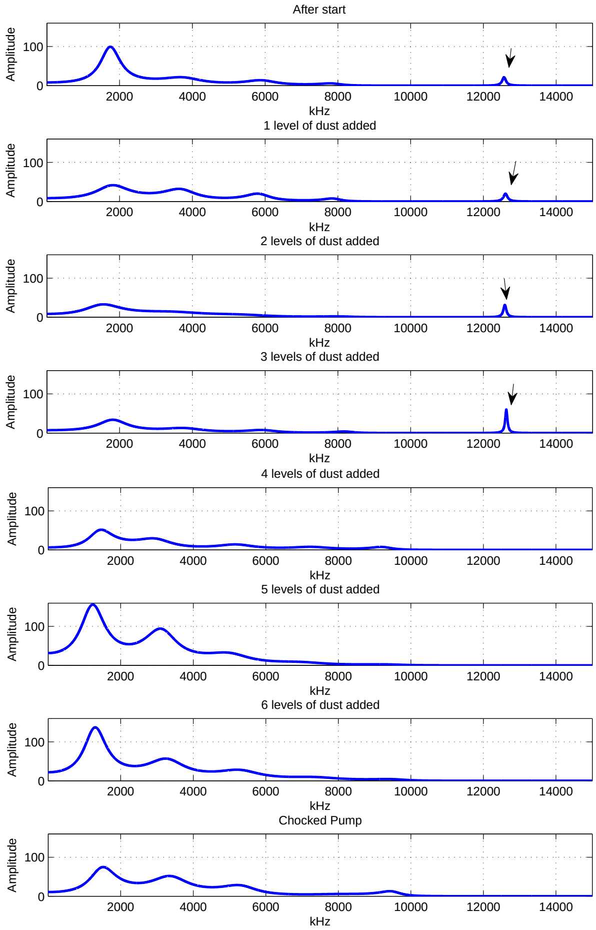

Figure 5. Pseudo-spectrum of the audio tracks recorded by the **second** mobile phone. For the explanation of the top to bottom rows, refer to the caption of the figure 4.

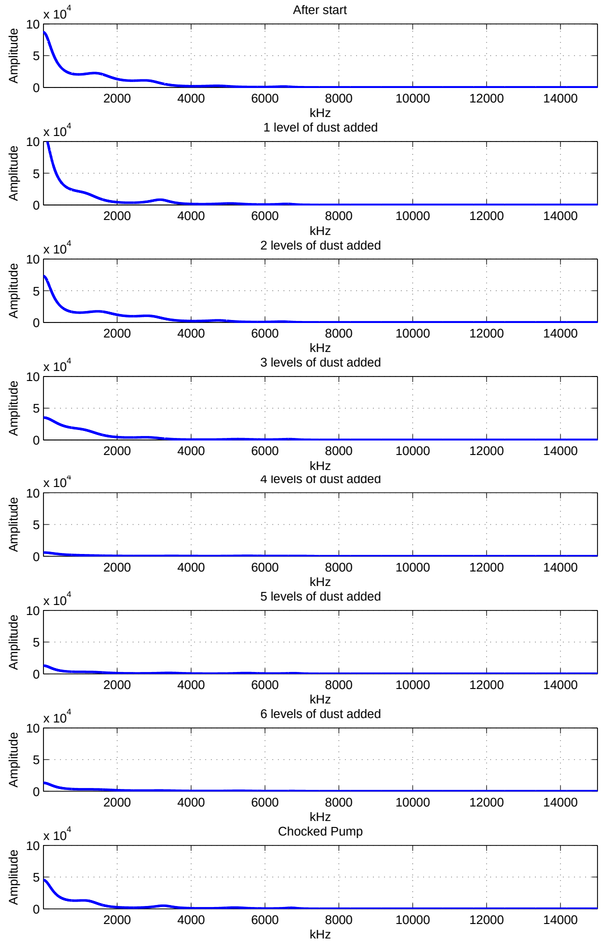

Figure 6. Pseudo-spectrum of the audio tracks recorded by the **third** mobile phone. For the explanation of the top to bottom rows, refer to the caption of the figure 4.

kHz peak can be used as a concrete detector for the condition of oil pump being chocked. However, this peak just has been observed in the records by the second phone that it might be in result of higher bandwidth of its microphone.

5. Conclusion

The fault diagnosis of Tractor oil pump by a user-friendly mobile application is a useful, crucial and economic approach. Here, the oil pump sound records by three different brands of mobile phones are analyzed for the same purpose, while the oil pump is working in eight various conditions of standard, one to six levels of being dusty and being chocked. The pseudo-spectrum estimation by MUSIC algorithm is deployed for analyzing the soundtracks of tractor oil pump. The pseudo spectrum of the normal condition and low levels of dust is almost the same. At the middle of the way to being chocked the power of the pseudo-spectrum considerably reduces, and by being chocked it increases. In pseudo-spectrum of the records by the second phone, a peak around 13kHz exists. Its height grows upper and upper by going from normal into the third level of dust. At the third level of dust addition, its amplitude becomes almost three times the highest frequency content of the engine while at first this ratio is one-third. By increasing the dust level more than the third level, it completely disappears. Pseudo-spectrum power besides the proportion of 13kHZ peak to the maximum low-frequency peak is proposed as an index for fault diagnosis and dust level detection in tractor oil pump hydraulic system.

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