A low-cost and effective automobile engine fault diagnosis using instantaneous angular velocity evaluation

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Abstract: Automobile component malfunctions are typical causes of many on-road accidents. Proper fault diagnosis conducted on automobile engines helps to prevent accidents by providing early warnings. The instantaneous angular speed (IAS) method, which uses low-cost sensors, has proved useful in diagnosing combustion-related faults in engines. In this paper, we evaluated various types of faults that occur in engines using the IAS method. The method clearly reveals the differences between normal and anomalous temporal waveforms generated during the engine combustion process. The results show that the IAS method is capable of generating quality fault diagnostic results that are comparable with those obtained using expensive and conventional pressure sensors mounted on engines. This method could help prevent catastrophic accidents and minimise the improper consumption of expensive fuel.

Keywords: automobile inspection; engine fault diagnosis; instantaneous angular speed; IAS; combustion process health monitoring.


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1 Introduction

More than 3,000 traffic accidents occur around the world every day, and this number is expected to climb along with population growth. Casualties are mainly caused by automobile component malfunctions and human negligence. It is thus important to ensure the healthy status of each component. However, the inspection of an engine’s health status of and the corresponding internal combustion processes are usually time consuming and expensive because they must be carried out by experienced mechanics using expensive equipment. In the majority of cases, however, the mechanics recommend only that automobile owners purchase and replace components long before necessary to prevent accidents. Consequently, numerous components are thrown away and wasted. Hence, a low-cost, comprehensive, real-time fault diagnostic for running automobiles is required.

Remote diagnosis and maintenance comprising an embedded diagnostic algorithm and remote analysis centre aided by wireless communication have been proposed for many years. A number of articles (Qiu and Ren, 2002; You et al., 2005; Zeng et al., 2009) have addressed the different issues associated with this proposition. You et al. (2005) pointed out the emerging need for such a system, emphasising that it would only succeed with a reasonably low implementation cost. Therefore, only a system with both advanced diagnostic algorithms and a reasonably low cost would be suitable.

Cars include numerous components, the malfunctioning of which will surely affect the car’s performance. Engine malfunctioning, in particular, can have dire consequences. Many factors related to fuel injection systems and intake and exhaust valve systems can lead to engine failure. However, given the many mechanical and electrical components in an engine, monitoring its health can be very complicated. Condition monitoring of the engine combustion process has traditionally been achieved using pressure sensors. However, sensors that can bear high pressures and temperatures are expensive and must be installed in each cylinder to capture the operation status during combustion (Heywood, 1988).

Fault diagnosis in rotating machinery has always been a popular focus of researchers in terms of the application of sound and vibration signals instead of pressure signals. For instance, the use of a symmetrised dot pattern (SDP) has been proposed to visualise the sound signals collected from a motor bearing. A faulty SDP can be differentiable from a normal SDP if they are evaluated by well-trained personnel. Shibata et al. (2000) showed that an SDP can be used to achieve a higher signal-to-noise ratio. Wu and Chuang (2005) extended Shibata’s work by applying an SDP to both sound and vibration signals. They demonstrated the usefulness of this approach in detecting faults indifferent components such as combustion engines and cooling fans. However, the dot patterns are only interpretable by a trained person. The matching system Wu and Chuang proposed can only be accomplished with a huge number of history templates. On the other hand, Yadav et al. (2011) proposed a correlation approach to differentiate between healthy and faulty
engines. Their proposed method detects artificially induced defects with high accuracy after the collected sound signals are analysed. However, they did not include defects associated with the combustion process in their study, perhaps because sound signals cannot provide a satisfactory localisation source.

In addition to the aforementioned methods, the empirical mode decomposition (EMD) technique has been used to diagnose a four-stroke engine with a number of different engine faults (Fan et al., 2009; Li et al., 2010). Whereas Fan et al. (2009) used expensive sensors to capture the exhaust wave pressure for engine fault diagnosis, Li et al. (2010) used cheaper accelerometers and encoders to capture vibration signals and engine rotational crank angles, respectively. While both methods were proven effective, our method uses cheap encoders that can obtain the same diagnostic results.

Expanding on the capture of sound and vibration signals, there is another non-invasive diagnostic method known as the instantaneous angular speed (IAS) method. The IAS method is based on crankshaft speed derivation, and captures the instantaneous angular rotating speed of the engine’s main crankshaft. The procedure of calculating IAS is relatively simple. It is the calculation of the time elapsed and the differences in crank angle when two successive sampling points were collected by the encoder. Given the time required to collect the two successive sampling points and their differences in crank angles are known, one can obtain the instantaneous angular velocity at each sampling point. In other words, the combustion pressure exerted on the piston which causes slow or fast piston movement at that particular moment can be obtained. The IAS waveform is to show such piston movement in terms of the variation of angular velocity.

The method has been applied in torsional vibration analysis (Remond, 1998) and fault diagnosis on diesel engines (Charles et al., 2009). The large tangential force generated from the piston movement is significantly altered if a potential defect is presented, and that also affects the angular velocity. Regardless of the severity of any fault occurring in the engine, the IAS signal shows pressure fluctuations (Charles et al., 2007; Johnson, 2006). Moreover, combustion inside an engine comprises various events, such as the opening and closing of valves and ignition, which occur at different angular positions that enable us to trace them one by one. This angle-range method has been adopted by many researchers in monitoring engine condition (Li et al., 2010; Lin and Tan, 2011; Yu et al., 2011). The results have proved to be applicable in detecting events that occur during a complete combustion cycle (720° angles). Therefore, by observing the shapes of the temporal combustion waveform and the corresponding firing angles of each cylinder, the IAS method could effectively determine which cylinders and accessories are working anomalously. This idea could benefit automobile owners and servicers because conventional checking systems require expensive pressure sensors, as shown in Figure 1. Six expensive pressure sensors are required to evaluate the health status of a six-cylinder engine. Our approach involves replacing these expensive sensors with affordable encoders. Figure 2 shows our method for diagnosing car engines. Although the IAS method uses accelerometers and laser sensors that are much cheaper than pressure sensors, the generated results are similar to those obtained using expensive pressure sensors.

Vibration-based signal analysis has long been used in reciprocating machinery fault detection, as destructive components produce a repetitive-impact type of vibration signal when the machine is operating. By simply converting the time domain signal to a frequency domain through a fast Fourier transform (FFT) application, one can observe the changes in the vibration signal at different frequency ranges. Hence, the abnormal
frequency generated by a particular defective component can be revealed. Due to the desire for instantaneous engine fault diagnosis, the techniques used for engine fault diagnosis cannot be too complicated or computationally time intensive. Hence, we use an FFT and the IAS method for instantaneous engine fault diagnosis. While the data collection occurred in real time, our program took a few seconds to complete the necessary data analysis.

Figure 1  An engine monitoring system using expensive pressure sensors (see online version for colours)

Figure 2  An engine monitoring system using low-cost sensors with the IAS algorithm (see online version for colours)

The remainder of this paper is organised as follows. Section 2 explains the methodologies used. Section 3 introduces the experimental setup. Section 4 describes the work performed on two tested cars and their corresponding results. Section 5 concludes the paper.

2 The estimation of IAS

The motion of a mechanical rotor system can be described in a generic form as (Li et al., 2005):

\[ J(t)\ddot{\theta} + D(t)\dot{\theta} + K(t)\theta = T_d(t) - T_i(t) \]  

(1)
where $\theta$ is the angular displacement, $J$ is the inertia of the rotor, $D$ is the damping coefficient associated with mechanical rotation of the machine, $K$ is the stiffness of the system, $T_d$ is the driving torque, $T_l$ is the torque due to mechanical load.

When the system parameters remain constant, the solution of this may be represented as shown in equation (2),

$$\theta = (\overline{\omega} \pm \omega) t,$$

that is the angular displacement, $\theta$, is dependent on two components, the constant average rotational speed $\overline{\omega}$ and the fluctuating component $\omega$, which represents the variations in speed.

To obtain the angular displacement, an incremental optical encoder is commonly used. The pulse train created by the encoder is not uniform due to the variation of the rotor speed. The time interval between successive pulses is inversely proportional to the speed of the rotor. Therefore, finding the time interval permits the calculation of the angular speed and hence the angular displacement.

As there is a varying component of angular speed, the measured pulse train is actually a phase-modulated signal from signal analysis standpoint. Assuming this modulated signal is band-filtered so that only the content around the fundamental frequency or one of its harmonics is retained, the band-pass signal can thus be expressed as,

$$s(t) = A_c \cos \left( \omega_c t + \phi(t) \right)$$

where the subscript $c$ represents the carrier signal.

The relationship between the constant speed and the pulse-train carrier frequency is,

$$\overline{\omega} = \frac{\omega_c}{n}$$

where $n$ is the pulses per revolution and is defined by the geometry of the encoder. Similarly, the variation in angular speed can be represented as follows:

The elapsed time method was employed in this study (Remond, 1998). The IAS of reciprocating machine can be estimated by the angle difference between two successive slits and the time duration, as shown in equation (5),

$$\omega = \frac{d\phi(t)}{dt} \approx \frac{\phi_i - \phi_{i-1}}{\Delta t},$$

where $\phi_i - \phi_{i-1}$ is the angular displacement of the two consecutive slits of encoder and $\Delta t$ is the corresponding time duration. By using a laser encoder mounted at the end of crankshaft of the tested engine, the IAS temporal waveform in terms of crankshaft angles can be obtained.

3 The experimental setup

3.1 The apparatus used

Two automobiles were used in the testing process: a Toyota Prius and a Mitsubishi Lancer. LabVIEW was adopted as the programming language for developing the
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A laser-based encoder was installed on the Prius. The encoder was made by coupling a laser emission with a plastic disc, mounted on the output shaft of the engine as shown in Figure 3. The original output of the encoder’s signal is shown in Figure 4.

The laser disc came with two useful gratings. The inner grating was used for manipulating the IAS signal, while the outer grating was used to indicate whether a complete revolution of the engine had been made. The two laser-based encoders (Keyence LV-21A) used in this experiment gave a 0–5V output on the reflectivity of a plastic disc.

Figure 3  The laser-based encoders coupled with a plastic disc (see online version for colours)

Figure 4  The original output signal of the encoder (see online version for colours)

A variable reluctance proximity sensor (Sanjie SJ1095C) was used to replace one of the laser-based encoders in the Lancer, as there was no suitable or reachable place to mount the plastic disc. To synchronise the signal with the angular positions, the crankshaft was first turned artificially to its top-dead-centre (TDC) position. The corresponding gear tooth was then rubbed to produce a different signal so that the TDC position could be differentiated, just like the two different gratings on the plastic disc. Figure 5 shows the mounting positions of the accelerometers on the Prius engine. The geographical mounting locations of the accelerometers on the engine of the Lancer were similar to that of Prius engine. The specifications of the engines are given in Table 1. The terms BTDC, ABDC, BBDC and ATDC listed in Table 1 mean the ‘before top dead centre’, the ‘after bottom dead centre’, the ‘before bottom dead centre’ and the ‘after top dead centre’ respectively. They represent the positions at different crank angles when different valve operation
statuses are occurring. The ‘TDC’ is the position when the piston has been raised to the

top of cylinder compartment that covered by the piston head. This position is the farthest

from the crankshaft. The ‘bottom dead centre’ is the position of the piston dropped to the

bottom of the cylinder compartment. At this position, the piston is located nearest to the

crankshaft.

As mentioned earlier, a high-temperature tolerated pressure sensor is very expensive.

to verify and cross-check the effectiveness of an IAS method that uses only a low-cost

laser-based or mechanical encoder, a pressure sensor was installed in the tested Prius. A

pressure sensor can provide a very clear indication of a cylinder’s firing sequence and the

relative power output of that particular cylinder. An expensive pressure sensor is coupled

with a spark plug and can be installed in an engine as one of the four spark plugs. We

purchased the pressure sensor from Kistler at a cost of approximately US $6,500. Whilst,

the total price for the accelerometer and encoder adopted in our proposed method cost

only US $500, which is less than one tenth of the cost of the pressure sensor.

Figure 5  The mounting positions of four accelerometers on the engine cover (see online version

for colours)

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The specification of the two engines</th>
</tr>
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<td>Engine model</td>
<td>Prius: 1NZ-FXE</td>
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<td>Compression ratio</td>
<td>13.0:1</td>
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<tr>
<td>Camshaft arrangement</td>
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<tr>
<td>Number of valves</td>
<td>Intake</td>
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<tr>
<td></td>
<td>Exhaust</td>
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<tr>
<td>Valve timing</td>
<td>Intake</td>
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<td></td>
<td>Closing</td>
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<td></td>
<td>Exhaust</td>
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<tr>
<td></td>
<td>Closing</td>
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<tr>
<td>Firing order</td>
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4 Tested faults and results for the Prius and Lancer

4.1 Types of faults tested on the Prius and the results

Several experiments were conducted on the Prius. Real-time vibration, angular speed and various other data that were embedded in the car computer logger were collected when the car was running at about 100 km/hour with no passenger except the driver was sitting in the car. The car was lifted by placing levers underneath it to allow the wheels to rotate freely above the laboratory floor.

4.1.1 Defective spark plugs

To show the faulty effect of misfiring in the engine, two defective spark plugs were made artificially. As shown in the upper figure in Table 2, the air gap between the fuse and the ground point of the spark plug was artificially elongated by 2 mm. Such an extended air gap caused difficulty in lighting the spark plug and affected the engine’s ignition starting time. The middle figure in Table 2 shows a more severely defective spark plug. Its cap was totally removed, and hence the lighting of the spark plug became very difficult or even impossible. It was assumed that these spark plugs would affect the pressure profile in that particular cylinder. The instantaneous rotating power generated by that cylinder was eventually affected and the IAS was reduced. The operating data collected from a normal spark plug (bottom figure in Table 2) were used as references.

Table 2 The different conditions of the tested spark plugs (see online version for colours)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately damaged spark plug with an air gap increased by 2 mm</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Severely damaged spark plug with its cap removed</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Normal spark plug</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
</tbody>
</table>

The IAS results generated by the normal spark plug and those of the moderately and severely damaged samples are presented in Figures 6, 7, and 8, respectively. As shown in Figure 6, the rotating speed of the crankshaft changed with the crank angle position. Regardless of whether the spark plug was normal or damaged, the shaft rotating speed exhibited an extent of fluctuation with its angular position. Four periods of fluctuation were observed in each working cycle (0–720° of the crankshaft). We believe these fluctuations were generated by the four cylinders in the engine. The detected peak-to-peak speed variation of cylinder 1 was 32.3, while the detected peak-to-peak
speed variation for cylinder 3 was 30.4. The difference between the two variations was about 5.88%.

As shown in Figure 7, the engine speed showed relatively stable peaks for a moderately damaged spark plug. A comparison of Figures 6 and 7 reveals that while the estimated speed variations were reduced when the spark plug was moderately damaged, the difference was not clearly observable. The peak-to-peak speed variation for cylinder 1 was 26, while the detected speed variation for cylinder 3 was 27.9. The difference between the two variations was about 7.31%.

The IAS waveforms generated by the severely damaged spark plug are presented in Figure 8. The damaged spark plug was installed in the first cylinder. The other cylinders were using normal spark plugs. According to the car’s engine service manual, the engine firing sequence is 1-3-4-2; in other words, the sequence of cycles is always the combustion cycle of cylinder 1 followed by those of 3, 4 and 2, with the sequence then repeating continuously. In Figure 8, fluctuations in engine speed and the small ripple of speed drop can be observed in the IAS temporal waveform. The detected peaks indicate that the variation between cylinders was much smaller during the operation of cylinders 1 and 4. The peak-to-peak speed variation for cylinder 1 was 29.7, while the peak-to-peak speed variation for cylinder 3 was 46.6. The difference between these two variations was about 56.9%, indicating a high distortion compared with the normal and moderately faulty spark plugs.

Figure 6 The IAS results generated by the normal spark plug (see online version for colours)

Figure 7 The IAS results generated by the 2mm moderately faulty spark plug (see online version for colours)
In addition, the overall firing angles in the normal and cap-removed cases showed significant differences from the aforementioned experiment. Whereas Figure 9 shows that the standard deviation (STD) of the first four firing angle intervals in the normal case was 1.73, Figure 10 shows that the STD for the cap-removed condition was 6.40. The defective spark plug significantly interfered with the corresponding ignition time inside the cylinder.

**Figure 8** The IAS results generated from the spark plug without a cap (see online version for colours)

**Figure 9** The IAS results generated by the normal spark plug with a small variation between the firing angle intervals (see online version for colours)

**Figure 10** The IAS results generated by the cap-removed spark plug with a larger variation between the firing angle intervals (see online version for colours)
FFT spectra were obtained from these three conditions and are shown in Figure 11. The vibration zone appeared around 1.7–2 kHz. The vibration results did not provide a sharp result compared with the IAS results. Hence, the IAS method is more effective than the conventional FFT method in engine spark plug fault diagnosis.

Figure 11  The FFT results of the normal and defective spark plugs (see online version for colours)

4.1.2 Oil leakage

The second test conducted on the Prius considered oil leakage. An improper oil injection leads to oil leakage and wastage of expensive fuel. Extensive leakage may also lead to explosion. The oil injector at cylinder 1 was made to malfunction to demonstrate the faulty effect of oil leakage. Figures 12 and 13 show the artificially created oil leakage fault and an electronic-controlled oil injector in the tested car, respectively. As shown in Figure 12, a small-size screw was inserted into the oil entrance of cylinder 1. The screw was used to reduce the amount of oil injected into the cylinder. It was assumed that a small amount of fuel would leak upon injection.

A pressure sensor coupled with a normal spark plug was installed in cylinder 1 of the tested car. This cylinder was used to imitate the oil leakage fault. The IAS results of the normal and oil leakage cylinders are shown in Figures 14 and 15, respectively. The top diagrams of Figures 14 and 15 show the temporal waveforms corresponding to the angular positions of the rotating engine’s main crankshaft that were collected using the IAS method. The bottom diagrams show the temporal pressure waveforms of cylinder 1, which were collected using the expensive pressure sensor.
Regardless of the leakage condition, the shaft rotating speed changed with its angular position. As shown in Figure 15, when the injection of oil was reduced at cylinder 1 while other cylinders were kept in a normal injection process, the recorded pressure peak dropped significantly during the combustion cycle of cylinder 1. Comparing the pressure plots (bottom diagrams of Figures 14 and 15), one can observe that oil leakage in the engine led to a significant decrease in the maximum pressure generated in cylinder 1. A substantial drop of 14.4 bar to 6.25 bar (a difference of 57%) was observed.
Figure 14  The IAS waveform (top) and pressure plot (bottom) captured in normal oil injection (see online version for colours)

Figure 15  The IAS (top) and pressure (bottom) plots when cylinder1 suffered from oil leakage (see online version for colours)
According to the top diagram of Figure 14, the detected local peaks for all four cylinders ranged from 775 to 779.5, with cylinder 1 peaking at 778 in normal condition. As shown in Figure 15, in the oil leakage condition, the peak speeds of all of the cylinders dropped from 725.5 to 737, with cylinder 1 peaking at 725.5. The reduced angular speed produced by the oil leakage was substantial. Note that cylinder 4 again showed a drop similar to cylinder 1, as they worked as a pair. As shown in Figure 14, the detected peak-to-peak speed variation for cylinder 1 was 75, and the detected peak-to-peak speed variation for cylinder 3 was 60.5. The difference between these two variations was about 19.33%. However, as shown in Figure 15, the detected peak-to-peak speed variation for cylinder 1 was 60.5, and the detected peak-to-peak speed variation for cylinder 3 was 80. The difference between these two variations was about 32.23%. The larger variation obtained using the IAS method suggests that the much cheaper encoder-based IAS suffered a similar effect caused by oil leakage compared with the pressure difference obtained from the expensive pressure sensor.

The FFT spectra for the normal and oil leakage conditions are shown in Figure 16. Because oil leakage leads to an incomplete burning of fuel inside a cylinder as the air-fuel ratio is altered, the expected power output should be lowered. The incomplete fuel burning process causes vibration in the engine. As shown in Figure 16, the magnitude of the peak vibration in normal condition (around 1.5–2 kHz) doubled in the oil leakage condition. Note that the frequency zone, which shows the change in vibration, matches the zone exhibiting a defective spark plug in Figure 11.

4.2 Types of faults tested on the Lancer

The Lancer was also seeded with faults. Similar to the previous case, the data were collected while running the Lancer at the same speed, without any extra load carried by the car except the driver.
4.2.1 Defective valves

Prolonged services of the camshaft can result in wear due to extensive mechanical motion. Once the camshaft wears out, the control of the opening and closing valves loses accuracy. The residual gases cannot easily be ejected due to the malfunctioning of the valves. Consequently, the efficiency of the engine combustion is affected significantly and results in a waste of expensive fuel. In our experimental studies, we chose to seed cylinder 2 with different valve defect conditions.

To verify the exhaust and intake valves’ influence on engine performance, several combinations of valve defects were introduced to the car engine. As listed in Table 1, each cylinder had one intake valve and two exhaust valves. The IAS waveforms generated from the normal condition, the condition of disabling one intake valve and one exhaust valve and the condition of disabling all of the valves in cylinder 2 are presented in Figures 17, 18 and 19, respectively.

Although the intake valve was disabled, four successive peaks are still observable in Figure 18. Improper closure of the intake valve should affect the air-fuel mixture of the fuel flowing into the combustion chamber. For cylinder 2, the variation of the IAS dropped to 6.6 compared with 21.5 at normal operation for an observed difference of over 69%. In contrast, during the operation time of the exhaust valve opening, which usually occurred after the maximum corresponding cylinders’ peak, the speed variation of cylinder 2 dropped to a much lower point compared with those of the other three cylinders. It can be concluded that disabling the exhaust valve significantly alters the speed variation.

With all of the valves in cylinder 2 disabled, the IAS waveform of cylinder 2 as plotted in Figure 19 showed no peak at all, suggesting a significant loss of power due to defective valves. In addition, the valve timing defects significantly changed the combustion profile and consequently affected the performance of the power output generated by cylinder 2. The estimated speed showed a large fluctuation. One can imagine this is how the presence and content of fuel and residual gases affect engine performance.

Figure 17 The IAS graph obtained in normal valve operating condition (see online version for colours)
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Figure 18  The IAS graph obtained after disabling one intake valve and one exhaust valve in cylinder 2 (see online version for colours)

Figure 19  The IAS graph obtained after disabling all of the valves in cylinder 2 (see online version for colours)

The FFT spectra for the valve timing defects are shown in Figure 20. Because valve timing defects pose a significant hindrance to the operation inside each cylinder, the instability caused by the missing ignition leads to severe vibration. It can be observed at the middle FFT spectrum in Figure 20 that when the intake and exhaust valves malfunctioned, the overall spectrum energy and local maximum magnitude at frequencies around 2.85 kHz were all higher than that of the normal condition. The bottom FFT graph in Figure 20 shows that when all of the valves malfunctioned, the overall spectrum energy and the local maximum magnitude amplitude at frequencies around 1.2 kHz increased significantly. For instance, the increase from normal when one intake and one exhaust valve were disabled was around 324%, and the increase from normal when all of the valves in cylinder 2 were disabled was around 1,800%. Although these high frequency components are not easily identified, the significant increase can be used to crosscheck the results obtained from the IAS method as shown previously. Both IAS and FFT can be used to detect the defective valves. Nevertheless, the distortions are easier to be revealed from the IAS graph rather than that from the FFT frequency spectra. Note here, the generated IAS profile shows a significant reduction of speed variation due to defective valve conditions, whilst, the FFT shows an overall increase in the frequency components’ magnitudes which may also cause by the existence of high noise level and/or other irrelevant vibrations. The IAS waveforms can clearly show a reduction of speed variation caused by defective valves.
4.2.2 The test for engine cylinder wear

Because piston rings and internal cylinder blocks constantly suffer from extensive rubbing due to the vigorous motion within each cylinder, they are subject to wear. Wear can be a serious problem for a car, as it ultimately causes a significant loss of pressure and hence a reduction of power output, affecting the angular speed. Moreover, due to wear, motor oil may leak through the cylinder and burn to blue smoke that causes serious contamination. Such problems may result in abnormal engine vibration, engine speed instability, loud engine sound, loss of power and burning of engine oil. To demonstrate such effects, the internal surface of the engine cylinder block in our experiment was worn artificially by scratching the surface slightly. Figure 21 shows the worn surface inside the engine cylinder.

The IAS waveforms generated from cylinder 2 in normal and worn conditions are presented in Figure 22. When cylinder 2 was operating in normal condition, its local maximum peak was roughly the same as those of the other cylinders. In both conditions, the variation of the IAS did not really show a sharp variation, as they only show 13% and 15.8% differences respectively. However, while it was operating in worn condition, its local maximum peak dropped. Whereas the STD of the detected peak speeds in the normal condition was found to be about 3.42, it increased to 8.10 or much higher in the worn condition across the peak variations. Hence, the IAS method can detect cylinder wear condition.

The FFT spectra for the normal and worn conditions are shown in Figure 23. It is worth noting that the difference between the normal and worn cases is not obvious.
compared with the results obtained using the IAS method. Hence, the IAS method is more effective at detecting engine cylinder wear.

Figure 21  The wear of the cylinder inside the engine (see online version for colours)

Figure 22  The IAS waveforms obtained from the normal and worn conditions of cylinder 2 (see online version for colours)

Figure 23  The FFT results of the normal and cylinder wear conditions (see online version for colours)
5 Conclusions

With the aim of minimising the casualties caused by traffic accidents due to automobile component malfunction and to reduce the wastage of expensive fuel, we adopted an IAS method to monitor the health conditions of automobile engines. Expensive pressure sensors can be replaced with affordable encoders so that a low-cost, effective IAS method can be used for automobiles. The results obtained from our experiments conducted on two passenger cars show that the IAS method is capable of detecting abnormal engine conditions. Nonetheless, the diagnostic results obtained from a vibration analysis could also be used to cross-check the results obtained from the IAS method. With the help of both methods, the accuracy and reliability of engine fault diagnosis could be substantially enhanced.

To achieve real-time fault diagnosis capability, the methods cannot be too computationally intensive, given that they may eventually be used to provide fast diagnosis when an automobile is running on the road. Hence, a simple vibration analysis and simplified IAS method are implemented and reported on in this study. More engine faults must be investigated to provide quantitative analysis for the further verification of the IAS method’s effectiveness. As mentioned previously, in addition to investigating the possibility of using the IAS method to diagnose car engines, we also developed remote diagnostic and just-in-time maintenance for running automobiles using GPS and mobile phone communication. We prepared separate reports on the design and implementation of a platform for remote diagnostic and fleet management. However, due to page limitations, we only report on engine fault diagnosis using the IAS method in this paper. Another journal paper will be prepared to report on the operation, function and results of a remote car engine monitoring and on-road advisory system that uses GPS and mobile phones for data communication and to deliver maintenance advice to automobile drivers.

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References


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Notes

1 The paper presented in this conference focused mainly on the development of a remote control centre with the mobile connection; while this paper concerned on the development of intelligent diagnostic method and emphasised the use of instantaneous angular speed (IAS) in detecting different faults occurred in car engine. The first author declares here that these two papers showed significant differences in the content objectives and aims.