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Real Time Prediction of Vehicle Mirror Vibration

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Abstract

The external and internal mirrors used particularly in high mass recreational and commercial vehicles are prone to vibrations. Under certain conditions, this leads to blurring of the reflected images above the tolerable levels for the human vision. While such vibrations are quite disturbing, they can compromise the driver's safety on the road. A hybrid adaptive predictive method is under development to dynamically compensate for the mirror vibrations under different driving conditions. The first stage of the work which consists of the development of an Auto-Regressive-Integrated-Moving-Average (ARIMA) model is reported. The progress made and the results obtained so far are provided. Copyright © 2004 Antoine Larchez

Keywords: Vibration, ARIMA, Active Compensation, Predictive Control, Vehicle

1. Introduction

The external and internal mirrors used in vehicles, particularly high mass recreational and commercial vehicles, are prone to vibration due to various factors such as large size of the mirror, wind and road surface roughness. The vibration can lead in certain conditions to blurring of the reflected images above tolerable levels for the human vision. Hence, it is quite disturbing for the driver, and in certain conditions becomes a safety hazard.

Although the rear-view mirrors' structural vibration characteristics have been optimised, and in particular their weight has been greatly diminished, the issue is still observed. Previous attempts using both passive damping and active vibration control have been unsuccessful at overcoming the resonant modes in particular. Therefore an intelligent vibration controller is required to maintain a sharp reflected image in the mirror under all driving conditions.

The study of such vibrations and development of effective methodologies to compensate for them is part of a research project supported by Co-operative Research Centre in Intelligent Manufacturing Systems and Technologies Ltd, Australia. It is carried out collaboratively by engineers and scientists from Schefenacker Visions Australia, manufacturer and initiator of the project, University of Wollongong, University of Adelaide, and University of South Australia.

This vibration motion observed in the mirror is transmitted from the car body and the bracket to the mirror itself. Vibrations directly reach the glass via its rotating mounting point on the bracket as well as via the two actuators used for adjustment. The latter allow changing the mirror’s angle along the vertical and horizontal axis.

The measured vibration on the mirror surface is the result of two major vibrations of the mirror assembly system. One is motion of the mirror surface around and relative to its axes. The other is the displacement of the entire mirror structure. Since the mirror itself when considered relative to its bracket, has its degrees of freedom only along the rotational dimensions, the active control of the vibration in the mirror is done along those dimensions.

The approach employed in this work is based on an adaptive control scheme, performed by dynamically tuning the controller’s parametric predictive model. A signal is generated to drive the actuators, which in turn rotate the surface of the mirror in such a way that vibrations are not perceptible.
The solution developed satisfies important criteria such as the expected low cost and exciting mechanical structure of mirror and its drives. In particular, the degree of electronic intelligence is increased to minimize the mechanical requirements.

In this paper, the conceptualisation and validation of the design of an intelligent vibration controller for vehicle mirrors is reported. Firstly a review of the previous work in this area has been carried out. The proposed concepts are then described and justified. The first stage of the work which consists of the development of an Auto-regressive-Integrated-Moving Average (ARIMA) model is herein reported. Finally the results obtained so far are presented and an analysis based on the previous methods and the future developments of the project are presented. The results of the study will be used to develop a hybrid predictive and adaptive controller to dynamically compensate for the vibration of a mirror in a moving vehicle.

2. Background

The focus of a significant number of previous works in this area has been on optimising the rear view mirrors mechanical structure based on Computer Aided Design tools (O'Grady, et al, 1996; Song and Ayorinde, 1999). Finite element analysis (FEA) techniques have been used thoroughly to optimise the shape and stiffness of mirrors to reduce vibration. Another approach employed has been Computer Aided Fluid Dynamics through which the flow patterns and pressure distribution around a mirror are studied (Homsi, et al, 1998). The results are combined with those of FEA to extract the mirror response frequency. The baseline designs of mirrors are consequently modified to minimise the dominant vibration modes.

Further statistical methods have been applied to increase the robustness of the mirror optimization process (Hwang, et al, 2001). Within constraints of cost and manufacturing, the state of the art in design and manufacturing of car mirrors seems to have reached a relatively high level. Consequently the weight of the rear-view mirror has been greatly diminished and its structural characteristics have been optimised. The issue of vibration of the mirror, however, is still outstanding and requires further work.
There are two patents which specifically address vibration damping in side-view mirrors, and internal rear-view mirror featuring day/night position (Nyhof and O'Farrell, 1996; Wellington, et al., 1991). The method proposes a passive vibration compensator. The vibration dampers or stabilizers are mounted on the pivotally adjustable reflective mirror subassembly.

The concept of using active compensation to remove vibration in mirror systems has also been addressed to some extent in the literature (Moo and Huynh, 2002). Experimentation was first undertaken to quantify the vibration threshold of human perception. In parallel, tests were conducted to reveal the actual vibration of the mirror on the truck. The comparison of those two frequency responses has shown that perception was the most affected by frequencies in the range of \([0,40\,\text{Hz}]\).

Furthermore, three control algorithms, namely PID control, optimal control and adaptive feedback were applied to the model of the mirror through computer simulation. The adaptive method was based on filtered-X-least mean square (FXLMS) algorithm. All the models used in the feedback controllers were developed offline. Yet, the limits of robustness of such models have been observed. The methods have shown poor tolerance not only to plant variations but also to the external dynamic variations affecting the mirror system.

3. Vibration Characteristics

The measured vibration of the mirror surface is the result of two major vibrations of the mirror assembly systems. One is the rotation and translation of the mirror surface around and relative to its axes and the other is the displacement of the mirror itself including the mirror housing, the mirror arm and the mirror bracket relative.

The vibration of the mirror itself consists of four components (Figure 3);

- rotation around the axis perpendicular to the mirror surface
- displacements parallel to its surface
- the transition displacement
- the rotation around the vertical and horizontal axes

The motions (a) and (b) do not affect the location of the image as seen by the driver. However in the other two cases the image moves forward and backward parallel to the perpendicular of its axis and will cause noticeable shifting of the reflected image. The active control of the vibration in the mirror primarily can remove the rotational movement.

According to the studies conducted by Watkins and Oswald (1999) the aerodynamics of the vehicle are the main cause of vibration for frequencies above 20Hz. Frequencies below this value are mainly attributed to the car body vibration. The compensator should, however, respond to all frequencies in the range \([0-200\,\text{Hz}]\) with special emphasis on the resonant modes.
4. Hybrid Predictive Approach

In order to suppress the vibrations occurring in a moving vehicle’s mirrors, a hybrid predictive Active Vibration Control (AVC) system is presented.

The method is hybrid in that it combines both passive and active ways to compensate for the different sources and types of vibration. Besides the optimisation of the mechanical structure and use of frictional dampers between the glass and the bracket, the effort is put on the electronic part to suppress the most significant part of the vibrations at minimal cost.

The controller generates a signal utilised to cancel out the oscillation using superposition technique. The model used by the controller is based on the structural response of the mirror assembly structure to the vibrations.

Furthermore, the method is predictive as there is always a delay between the measurement of the vibration signal and the generated control signal. Therefore it is essential to predict the future amplitude value of the vibration. The minimum prediction horizon necessary correspond to the overall loop delay required for signal processing - i.e analog-to-digital conversion, digital processing, digital-to-analog conversion of the signal and actuator response time.

The predictive controller calculates the most likely value of the vibration signal for the next future interval and generates a control signal for the actuators accordingly. Although a 100% match for a stochastic signal cannot be met by any predictive method, some residual vibration due to prediction errors is acceptable when kept under a certain level. Passive damping plays the role of minimising those attenuated vibrations further more.

Mathematically, the vibration waveforms are a combination of various frequencies and magnitude of vibration which depend on the external conditions. These factors include wind velocity and direction, engine regime, road surface roughness and hence are neither predictable nor practically measurable. Therefore it is necessary to dynamically tune the controller in order to obtain the necessary compensation efficiency.

An adaptive algorithm is incorporated to enhance the accuracy of the prediction model dynamically. It uses the measured error between the actual vibration signal and predicted signal. The predictive model is optimized for performance and computational requirements.

The Pl31 model mirrors driven by DC servo motor actuators are used to conduct the experiments. The structural response of the mirror to the vibration is measured using accelerometer sensors. The overall efficiency of the system is assessed according to the human perception threshold of mirror vibration. However, both the approach and the algorithms developed are kept generic. It is envisaged that the developed controller can be applied to other mirror systems with minimum effort.

5. Real Time Prediction with ARIMA Model

Auto Regressive Integrated Moving Average (ARIMA) has been chosen as the first approach to model the vibration data produced by the mirror. The method was selected because of its accuracy and the well-defined development methodology for the identification, estimation and validation of a model. The ARIMA model provides an estimate value of the future values of a parameter based on the past measured values and past prediction errors.

In developing the ARIMA model, a series of test data produced by the Royal Melbourne Institute of Technology (Lee, et al., 2003) is used. The data was acquired from a mirror mounted on a car driven on a stretch of highway. The data was recorded for segments of about 90 seconds with vehicle speeds ranging from 80 to 110 kph. The data was sampled at a rate of 500Hz, giving an available frequency range of 0-250Hz, slightly above what is required.

5.1. ARIMA Model Construction

Several random segments of 200 samples (400ms) of data were used to develop the model. The first half of each segment was used to identify and estimate the model parameters, while the second half was kept for its
validation by comparison to the predicted data. Plots are shown for one segment of the horizontal component of the rotational acceleration in Figure 4.

The signal does not show any clear pattern but only two significantly apart cyclic components, which are not stable enough to apply seasonal modelling in a proper manner. The data can be made stationary by applying a first order difference, as shown in Figure 5.

Figure 4  Raw signal for horizontal rotational vibration

Figure 5  Signal after the first order difference

Figure 6  ACF for 1st order difference with confidence band in red
Figure 7 PACF for 1st order difference

The normalised Auto Correlation function (ACF) and Partial ACF (PACF) confirm that the first order regular differentiating has significantly and sufficiently removed trend in the data (Figures 6 and 7). Hence the samples can be used as such for further modelling. ACF and PACF indicate a second and a third order moving average (MA) parameter in particular. There are no particular patterns of seasonality that can be inferred from the ACF/PACF.

ARIMA models of order (p,1,q) were estimated for all the combined values of p and q from 0 to 5. The selection of the most adequate model was achieved by calculating both the Akaike Information Criterion (AIC) and Akaike Final Prediction Error (FPE) for each model. Results are reported in Table 1.

Both estimators are consistent and show that ARIMA(2,1,2) has the lowest prediction error for this sample of data.

Table 1 AIC and FPE values for different ARIMA model orders

<table>
<thead>
<tr>
<th>ARIMA order *</th>
<th>AIC (*1e8)</th>
<th>FPE (*1e7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0 1 1]</td>
<td>1.6865</td>
<td>2.1114</td>
</tr>
<tr>
<td>[1 1 0]</td>
<td>1.6866</td>
<td>2.1115</td>
</tr>
<tr>
<td>[1 1 1]</td>
<td>1.6775</td>
<td>1.9297</td>
</tr>
<tr>
<td>[2 1 0]</td>
<td>1.6820</td>
<td>2.0173</td>
</tr>
<tr>
<td>[2 1 1]</td>
<td>1.6689</td>
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</tr>
<tr>
<td>[2 1 2]</td>
<td><strong>1.6673</strong></td>
<td><strong>1.7425</strong></td>
</tr>
<tr>
<td>[3 1 0]</td>
<td>1.6682</td>
<td>1.7574</td>
</tr>
<tr>
<td>[3 1 1]</td>
<td>1.6683</td>
<td>1.7588</td>
</tr>
<tr>
<td>[3 1 2]</td>
<td>1.6695</td>
<td>1.7806</td>
</tr>
<tr>
<td>[3 1 3]</td>
<td>1.6713</td>
<td>1.8131</td>
</tr>
<tr>
<td>[4 1 0]</td>
<td>1.6711</td>
<td>1.8087</td>
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</table>

ARIMA order (*| AIC (*1e8) | FPE (*1e7) |
<table>
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<th></th>
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<th></th>
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<tbody>
<tr>
<td>[4 1 1]</td>
<td>1.6712</td>
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<td>[4 1 2]</td>
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<td>[4 1 4]</td>
<td>1.6724</td>
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</tr>
<tr>
<td>[5 1 0]</td>
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</tr>
<tr>
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<tr>
<td>[5 1 5]</td>
<td>1.6821</td>
<td>2.0213</td>
</tr>
</tbody>
</table>

Other tests were run taking a total of 40, 100 and 400 samples for the modelling. Orders of the best model found are show in table 2.

Models of orders [5 1 5] and [4 1 4] were found when identification was made with 400 samples total. These higher order models have smaller AIC, but only by 4.8% from lower orders such as [2 1 2]. Hence the latter model is still preferred for real-time computations and is chosen as the most adequate amongst all the others.
Table 2: Best ARIMA model order for varying sample length

<table>
<thead>
<tr>
<th>Number of samples</th>
<th>ARIMA order</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>[2 1 2]</td>
</tr>
<tr>
<td>100</td>
<td>[2 1 2]</td>
</tr>
<tr>
<td>200</td>
<td>[2 1 2]</td>
</tr>
<tr>
<td>400</td>
<td>[5 1 5] - [4 1 4] ... [2 1 2]</td>
</tr>
</tbody>
</table>

This result is close to what was expected from the previous analysis of the ACF/PACF functions. In this more precise analysis however, the 3rd order MA parameter does not actually appear significant enough to be integrated in the model. Hence the MA order is kept at 2.

The following [2,1,2] ARIMA model was obtained:

\[
y(t+1) = 1.028 * y(t) - 0.626 * y(t-1) - 1.282 * e(t) - 0.518 * e(t-1) \tag{1}
\]

Where:
- \( y \) is the time series representing the vibration signal
- \( e \) is the time series constructed by measuring the error between the past measured value of the vibration and the past prediction, for each past sample.

We are interested in knowing the prediction capability of the selected model. In practice a prediction horizon of only one step ahead is sufficient as the data for the immediate last sample vibration value is always guaranteed to be in the controller’s memory. However in here the model is tested for several prediction steps ahead, in order to improve the analysis. Figure 8 illustrates a prediction up to 20 samples ahead, made on a random segment of data different from the one used for estimating the parameters. It can be seen that the one-step-ahead prediction has a satisfactory error of 4.2%.

![Figure 8: Error graph](image)

Although we are not concerned in practice with the predictions made at steps above 1, for which uncertainties accumulate, the curve still generates similar variations as that of the real data showing good fitting of the model.

5.2. Real-time prediction

The method developed above was tested in a real time environment to predict vibrations. For the experiment the mirror was mounted on a shaker. Accelerometers placed appropriately on the surface of the glass were used to obtain the new vibrations patterns. A first sample of vibration data was recorded and used to calculate the ARIMA model. The resulting parameters of the predictor were loaded into the real-time controller. Figure 9 shows the vibration successfully predicted 1 step ahead in real time with only a small error.
6. Conclusion

The initial development of a predictive method to compensate vibrations of a mirror in a moving vehicle has been reported. The conceptualisation of the new approach has been exposed and the online performance of the prediction algorithm has been shown. The mean and time-varying characteristics of the vibration signal can be accounted for by an ARIMA model with computational simplicity and accuracy which allow for further promising developments. In particular it is planned to recursively re-estimate the model parameters to adapt the controller model in real time according to the disturbances. The algorithms will be tested on-road on a P131 mirror in the future.

References

[11] Acknowledgement: The support of CRC in Intelligent Manufacturing and Systems Ltd for this project is acknowledged.