Tire Inflation Pressure Estimation Using Identification Techniques

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ABSTRACT

In this research study, one of the most crucial automotive engineering problems is intended to be solved. The necessity of tire pressure monitoring system is beyond doubt. Such systems are now provided relying on expensive sensors. In this study an indirect tire pressure monitoring system is proposed, utilizing identification techniques, which will reduce the cost of monitoring considerably in comparison to direct types, while keeping it just as reliable as the conventional types. A comprehensive study on system's parameters was undertaken by MATLAB-IDENTIFICATION toolbox, in order to find a proper method to estimate tire pressure indirectly. The best method was chosen among five well-known estimation methods, including Space State, AR, ARMA, NLARX and Wiener-Hammerstein. It was shown, the best method to estimate the pressure of a properly inflated tire is NLARX with a 94.51% precision while the best estimation for an under-inflated tire pressure is ARMA with a 92.3% accuracy.

Keywords

Vehicle Dynamics, Tire Pressure Monitoring System, IDENT, Estimation

1. Introduction

Tire air pressure is a crucial parameter in vehicle dynamics. An abnormality in its value could have drastic effects on vehicle's dynamic behavior and its fuel consumption rate. A study by Grugett et al. [1] proved that a five percent reduction in tire pressure from its nominal value (32 psi), will result in a three percent increase in fuel consumption [1, 2]. Tire Pressure Monitoring System (TPMS) is an electronic system that measures and indicates the tire pressure constantly. In this system the driver will be informed of any pressure changes by the means of a digital indicator, a low pressure warning light or an electronic alarm [3]. Such systems are also regarded as Tire Pressure Indication System (TPIS) which could be installed on any kind of vehicle that has got a tire.

In order to prevent unnecessary wiring and connections, most of the tire pressures monitoring systems gather data from sensors via radio frequency (RF) technology. The Electronic Computer Unit (ECU) receives these signals sent by each sensor and does the necessary processes and warns the driver if the calculations had shown a significant drop in tire pressure. Sensor is the element of these systems which challenges the broad use of TPMS. This is due to the fact that most of the sensors that are available in market have lithium batteries and work based on silicon pressure sensor and SAW or PLL radio frequency oscillators. These silicon sensors with lithium batteries are expensive and a pervasive use of these sensors in all of the production vehicles requires a vast and continuous resource of silicon and lithium. Until the last decade, using TPMS was confounded to heavy duty vehicles and vehicles equipped with run flat tires. TPMS became widely used when a law was set which compelled the car manufacturers to install TPMS on every lightweight motorized vehicle that is sold in USA after 1st, September, 2007 [4]. Tire pressure monitoring systems can be divided into two general categories, direct systems and indirect systems. Direct systems indicate the real time pressure of each tire by a gauge or pictogram display, while the vehicle is moving or even when it is stationary. In these systems a pressure and temperature sensor is installed in each tire and data retrieved from these sensors are transmitted to an indicator via RF communication [5]. On the other hand, if a tire is under-inflated, indirect systems will inform the driver of a possible defect, by closely monitoring each wheel's angular and linear speed and processing other signals. The theory behind most of indirect systems is based on the fact that an under-inflated tire has a slightly smaller radius than a properly inflated tire. . As a consequence, for the under-inflated tire to cover a same distance in a certain time in comparison to other tires it should spin faster; hence the system would detect pressure reduction in the regarded tire. Such systems are capable of detecting under-inflation of three tires simultaneously, but not all four. The reason for the regarded flaw is due to the fact that these systems are based on wheels angular speed difference, if all tires lose a same amount of air they will have a same radii and angular speed, therefore, pressure reduction would not be detected in such circumstances [6-8]. Recent progress in indirect TPMS made the detection of under-inflation feasible in all tires at a same time, by analyzing vibration of each wheel or the amount of force transmitted during acceleration or in a turn.

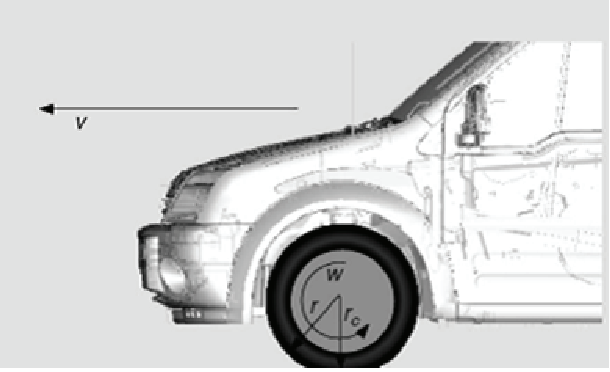


Figure 1.change in wheel angular speed due to the under inflation

$$\omega = \frac{v}{r - \delta_r}$$

(1)

$$\delta_r = r - r_c$$

(2)

$$\beta = \left| \frac{(\omega_{fL} + \omega_{rR}) - (\omega_{fR} + \omega_{rL})}{\omega_a} \right|$$

(3)

$$\omega_a = \frac{\omega_{fL} + \omega_{fR} + \omega_{rR} + \omega_{rL}}{4}$$

(4)

Table 1.Parameter of An under inflated tire

parameter	description
v	Longitudinal velocity of
r	Nominal tire radii
r_c	Effective tire radii
δ_r	distance

Equations 1 to 4 are used to calculate the tire pressure index. Deviation of this index from zero shows an abnormality in tire pressure. If this index gets greater than a certain value, the system will warn the driver of pressure reduction in a tire.

2. Identification Techniques

In this paper, it was intended to clarify the ability of IDENT toolbox methods on estimating tire pressure, which is the parameter that is sought after in this study. For this reason, five well-known methods were conducted to examine their capability in the regarded estimation. Figure 2 shows the IDENT panel in Matlab.

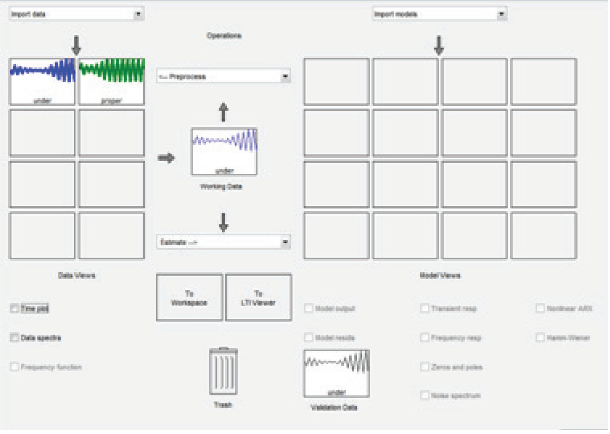


Figure 2.IDENT Panel

2.1.AR estimation

By the means of this response and other records, such as settling time, rise time and overshoot, we can tell if there is a deficiency in tire pressure or it is normal. Moreover, this analysis could be used as an estimation to predict the value of tire pressure.Figure 3 illustrates the step response of this estimation in a properly inflated and under-inflated tire.

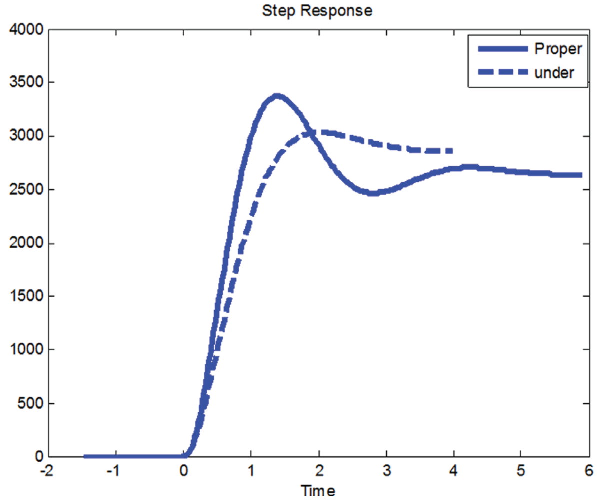
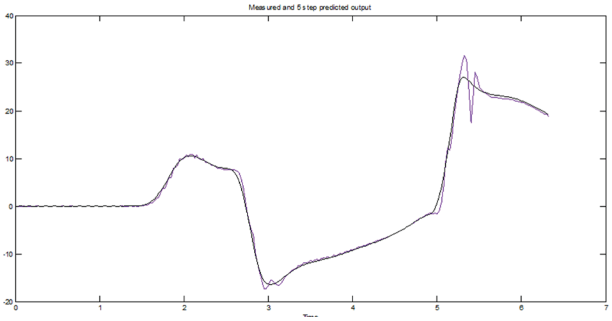


Figure 3.Step response in AR estimation

Figure 4, which indicates the results of the output estimation in AR model. It was shown at the normal tire pressure, this estimation shows a great accuracy of 91.82%.

Figure4.Model output estimation at the appropriate air pressure



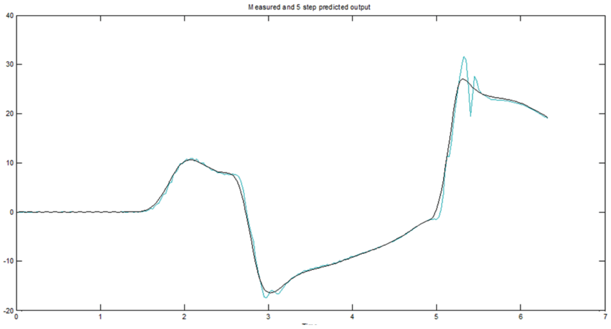


Figure5.Model output estimation in an under-inflated tire

We also have precise results of 92.26% precision in Figure 5 that demonstrates the estimation in an under-inflated tire. Figure 6 and Figure 7 illustrate the pole placement of the proposed estimation and its frequency analysis.

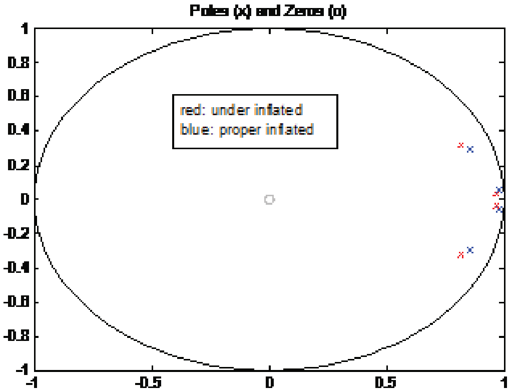


Figure 6.Poles and Zeros in AR

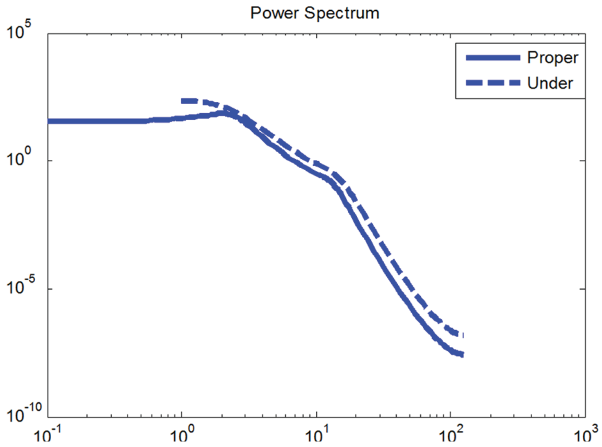


Figure 7.Frequency analysis in AR method

The result that the absolute reduction in the estimated coefficients indicates low tire pressure, is obtained from Table 2. As a proposal for future work, a series of data could be prepared for different pressures and the tire pressure reduction would be calculated based on their fluctuations.

Table 2. AR Estimated Equations

Low $A(q)=1-3.564q^{-1}+4.856q^{-2}-3.008q^{-3}+0.7169q^{-4}$

Proper $A(q)=1-3.664q^{-1}+5.117q^{-2}-3.235q^{-3}+0.7828q^{-4}$

2.2. ARMA estimation

As it was made clear inFigure 8, step response on low tire pressures is distinctive from a properly inflated tire.

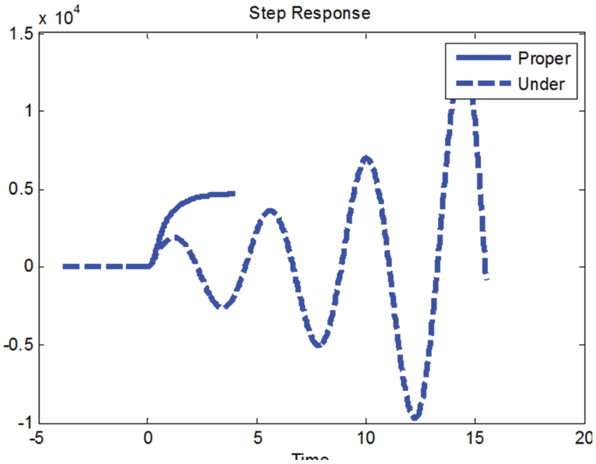


Figure 8.Step response of ARMA method

Moreover, it could be seen inFigure 9, that the ARMA model at the proper tire pressure provides a good estimation of the model output with an accuracy of 92.01%.

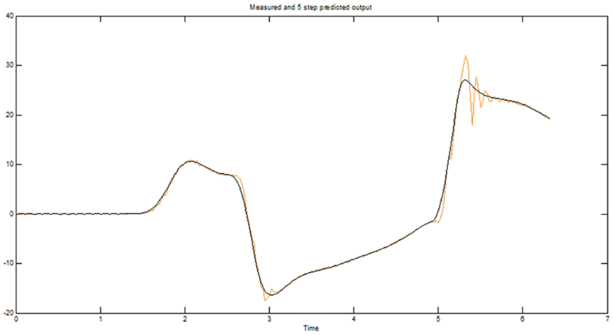


Figure 9.Model output estimation at the appropriate air pressure

Figure 10 illustrates the highest accuracy of 93.2%, which is the result of ARMA estimation method at low tire pressure.

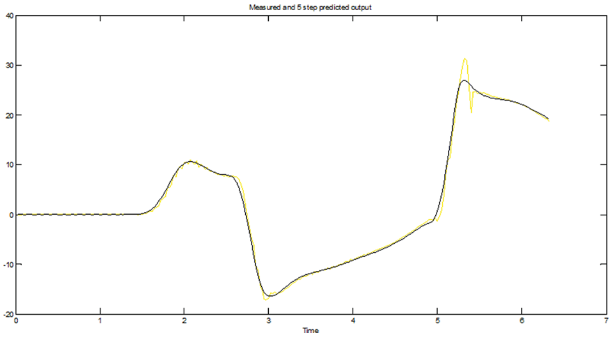


Figure 10.Model output estimation at the low air pressure

In this estimation there is no pole for low pressure tire. Tire pressure reduction could be realized by studying zeros and poles, as it can be seen inFigure 11.

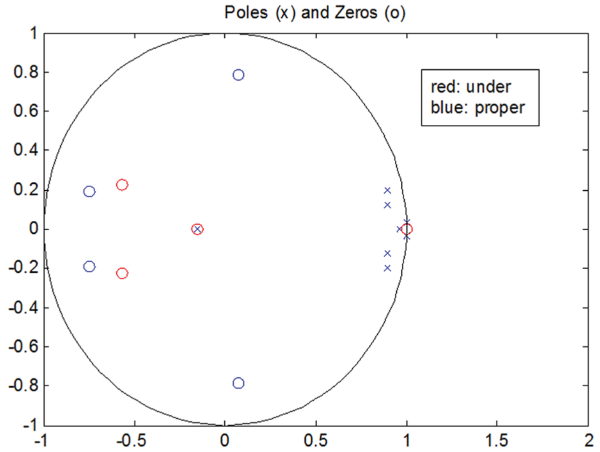


Figure 11.Poles and Zeros in ARMA method

As the frequency analysis given in Figure 12shows, the tire with the least pressure creates peak vibration at certain frequencies, which could also be used in advancing the goal of tire pressure reduction estimation.

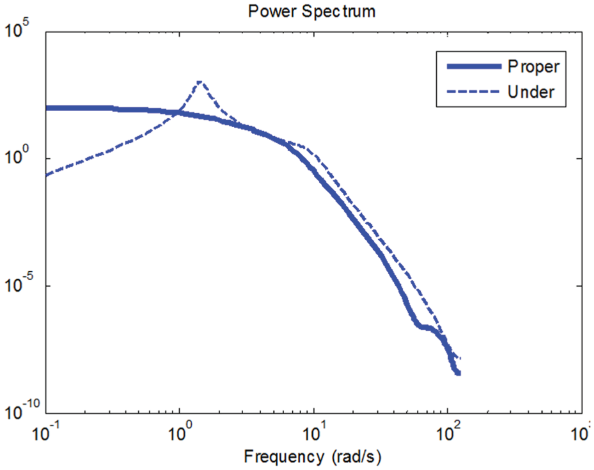


Figure 12.Frequency analysis in ARMA method

Table 3 indicates that the absolute increase in the estimated coefficients is the sign of low tire pressure. As a proposal for the future, a series of data could be prepared for different pressures and the tire pressure reduction would be calculated based on their fluctuations.

Table 3. Equations obtained in ARMA method

Low	$A(q)=1-3.794q^{-1}+5.432q^{-2}-3.486q^{-3}+0.8457q^{-4}$ $C(q)=1+0.2845q^{-1}+0.739q^{-2}+0.4881q^{-3}+0.05733q^{-4}$
Proper	$A(q)=1-2.613q^{-1}+2.145q^{-2}-0.4115q^{-3}-0.1186q^{-4}$ $C(q)=1+1.347q^{-1}+0.9933q^{-2}+0.8456q^{-3}+0.3749q^{-4}$

2.3. NLARX estimation

The same methodology as the previous methods was used to examine the NLARX estimation performance. Therefore, the description of this part was neglected. Nevertheless, Figure 13 and Figure 14 which indicate the results of the output estimation in AR model for proper and underinflated tire, respectively

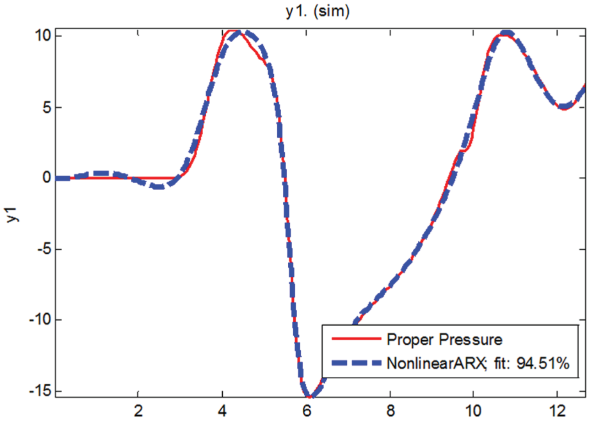


Figure 13. Non-linear ARX Estimation of Model Output at the appropriate air pressure

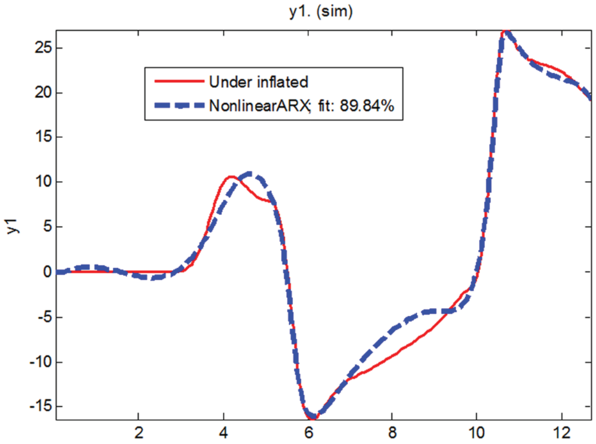


Figure 14. Non-linear ARX Estimation of Model Output at the low air pressure

2.4. Hammerstein-Wiener estimation

Hammerstein-Wiener estimation was employed to recognize the proper tire and underinflated tire as shown in Figure 15 and Figure 16, respectively.

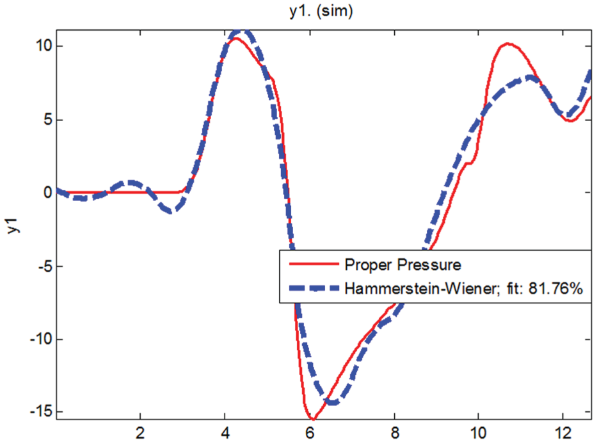


Figure 15. Non-linear Hammerstein-Wiener Estimation of Model Output at the appropriate air pressure

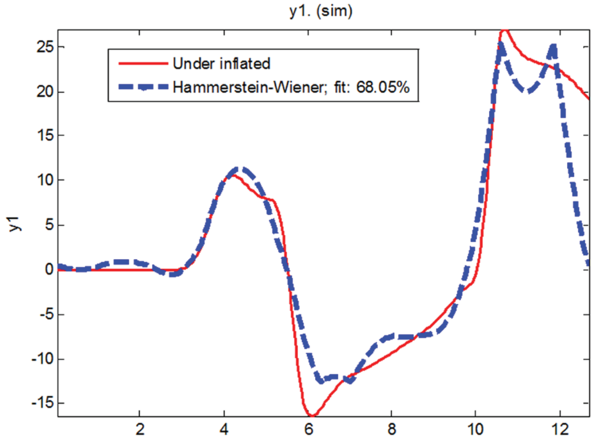


Figure 16. Non-linear Hammerstein-Wiener Estimation of Model Output at the low air pressure

3. Discussion and Analysis

The results of the analysis of these five methods are all given in Table 4. According to Table 4, the NLARX provides the best estimation for the properly-inflated tire while ARMA method results in a precise estimation for an under-inflated tire.

Table 4. Comparison of Different Estimations

Estimation Type	Appropriate Air pressure	Low Air Pressure
State Space	91.97	92.22
AR	91.82	92.26
ARMA	92.01	93.2
NLARX	94.51	89.8
Hammerstein-Wiener	81.76	68.05

4. Conclusion

In this paper, a novel indirect method for monitoring tire pressure is introduced by some existent IDENT toolbox methods in MATLAB software. Among, NLARX could be highlighted to predict the low tire inflation. This method can be used instead of direct expensive methods. The only signal necessary for this analysis is the yaw rate which is easy to monitor. It was clarified, that the best method to estimate the pressure of a properly inflated tire is NLARX with a 94.51% precision while the most accurate estimation for an under-inflated tire is ARMA estimation method with a 92.3% accuracy. It should be mentioned that these two methods were chosen amongst five well-known estimation methods, including Space State, AR, ARMA, NLARX and Wiener-Hammerstein.

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