Dynamic modelling and experimental validation of an automotive windshield wiper system for hardware in the loop simulation

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In order to remain competitive, automotive companies use advanced simulation methods to assist in product development. Hardware in the loop (HIL) simulation is one such technique. To use HIL in the development of automotive electronic control units (ECU), accurate simulation models of the ECU’s sensors and actuators are needed. In this work, a full dynamic mathematical model of an automotive windshield wiper system is developed and validated. In the modelling phase, the wiper motor is analysed and a unique mathematical model is developed to capture the device’s two speed operation. A multi-body dynamic model of the linkages is implemented using the MathWorks’ SimMechanics software. The model is validated experimentally and its parameters are identified using genetic algorithms. The model is then simplified to allow it to be simulated in real time, making it suitable for HIL simulation. The HIL compatible model is used in the development of Automotive ECUs.

Keywords: windshield-wiper; hardware-in-the-loop; real-time simulation; genetic algorithm

1. Introduction

The Global Automotive Report 2013 compiled by Clearwater Corporate Finance LLP estimated the value of the automotive industry at $800bn (Clearwater Corporate Finance, 2013). In addition, worldwide passenger car sales in 2012 exceeded 60 million units and sales have tended to increase over the last decade (http://www.oica.net). The total number of passenger cars produced in 2012 was also greater than 60 million – representing an increase of 5.3% in production from 2011 (http://www.oica.net). New vehicles must meet stringent safety and environmental requirements, with industry standards such as ISO26262 being widely adhered to (Jeon, Cho, Jung, Park, & Han, 2011) whilst maintaining acceptable comfort and performance standards to make the product viable. It follows that automotive companies capable of producing quality and safe products in relatively short production times will benefit from the highly lucrative global automotive industry.

The development process for new products in the automotive industry follows the classic V model (Robert Bosch GmbH, 2007). Figure 1 shows an adapted version of this, highlighting the use of models in the production process. Modern product development processes use model-based design, development and testing tools to improve the tractability of requirements, the speed of development and the validity of early testing. A particularly important simulation-based testing procedure is hardware in the loop (HIL) simulation.

HIL is an advanced real-time simulation technique in which a purely simulated system has certain aspects replaced by hardware components (Hu & Azarnasab, 2013). In the automotive industry, HIL simulation is used extensively in the development and testing of electronic control units (ECU) (Ganesh, 2005; Schuette & Ploeger, 2007) because they allow extensive tests to be carried out before the final design and manufacture of components interfacing with the ECUs. Most of the innovations in modern luxury vehicles are in the electronic/software domains, with electronic systems replacing traditionally mechanical and pneumatic systems (Von Tils, 2006) and there are in excess of 100 ECUs in a modern luxury car (Waltermann, 2009). The purpose of the model developed here is to provide a simulation model of a windscreen wiper system to be used in the HIL testing of an ECU by Jaguar Land Rover.

The benefits of using a simulation model such as the one developed in this paper are as follows: (1) reduced need for a hardware prototype which takes up space and resources, (2) models can be quickly updated to incorporate design changes, whereas up to date prototypes are often unavailable, (3) tests done with simulation models have higher repeatability because all variables can be controlled and (4) testing for the development of ECUs

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can be carried out sooner than tests relying on hardware prototypes.

This paper first describes the wiper system to be modelled by showing its physical structure and operation principles. Then the modelling process of each element of the system is shown. Genetic algorithms (GA) are then used to identify the unknown parameters in the model. The model is then validated by comparing its performance against real data. Once this is complete, the model is simplified to allow it to be simulated in real time, making it suitable for HIL simulation.

More similar research to that presented here is given in Xiaoyu, Yanfeng, and Yengjie (2011) where physical modelling techniques are used to create a mechanical model of a wiper system to assist in the design of future components; however the model was not validated. Finally, previous publications of this work Wei, Mouzakitis, Wang, and Sun (2011) and Dooner, Wang, and Mouzakitis (2013) develop a model for HIL simulation which includes the motor and linkages.

3. Wiper system modelling

The model developed in the section simulates different behaviours from the models discussed in Section 2. The important elements of the wiper system that this model captures are (1) the dynamic torque load of the linkages driven by the motor and how this affects the motor current, (2) the switching transients on the motor current when switching between ON and OFF modes as well as FAST and SLOW, (3) such behaviour must be modelled across the systems entire operating speed. The model does not take into account effects such as vibration of the mechanical element.

In addition to capturing the system dynamics and coupling between the motor and linkages, the model must be capable of being simulated in real time (for use in HIL simulation) and be easy to update to incorporate design changes since the model will be used in the early stages of product development. To meet these goals a physical modelling approach has been employed using the MathWorks physical modelling tool, Simscape.

The system can be split into two elements for modelling: the wiper motor and the linkage system, as shown in
3.1. Linkage system modelling

The linkages used in a windshield wiper system are designed such that unidirectional rotational motion from a Permanent Magnet Direct Current (PMDC) motor can be translated into the oscillatory motion of the two wipers. The design and operation of the linkage system is demonstrated in Figure 3. The linkages have initially been modelled using the MathWorks tool SimMechanics. This was chosen because it simplifies the modelling and simulation process of Multi-body dynamic systems by using embedded equations and modular design (Wood & Kennedy, 2003). SimMechanics has also been successfully employed in similar projects (Xiaoyu et al., 2011).

The linkages are defined in the SimMechanics modelling environment as shown in Figure 4. Each individual linkage is represented by a ‘Solid’ block which defines the shape and material of the linkage. Two transformation blocks are used to define the length of the linkage and assign a co-ordinate system to either end. Each end is then attached to a revolute joint. The full five bar system is modelled using this method and is approximated as being in a plane. The complete model of the linkages is shown in Figure 5.

The measured parameters of the model are shown in Figure 3, adapted from Wei et al. (2011). The model is designed to allow any of the parameters to be easily changed so that the model can represent any physically viable design of the linkage system shown in Figure 3, allowing for design updates to be easily implemented. Also included in the parameters is the density of the material, 2.7 g/cm³, and the initial angle, \(\alpha\), of the crank, determining the park position of the wipers. The park position refers to the wipers rest position when not in operation, that is, at the bottom of the windscreen.

3.2. Wiper motor modelling

The brushed PMDC wiper motor is connected directly to the battery meaning that the speed of the motor, and thus
the wipers, cannot be controlled by changing the input voltage. In order to control the speed of the motor a third brush is added, offset from the magnetic neutral line, giving the motor two electrical inputs and one common ground output (Hameyer & Belmans, 1996). The structure can be seen in Figure 6.

The brush directly opposite to the common brush in the magnetic neutral line is connected to the slow speed input. Applying a voltage to this brush will cause the motor to operate as a standard two brush PMDC motor. Applying a voltage to the brush offset from the magnetic neutral line will cause the motor to operate in its fast mode. This increases the rotational velocity of the motor shaft and also the armature current, with a reduction in efficiency (Hillier, 1987).

No model of a wiper motor capturing the fast and slow speed operation, and the switching between them, could be found. Therefore a unique model of the wiper motor is developed here using classical electromagnetic theory.

To understand the two brush operation of the wiper motor the difference in the current paths around the armature windings in the two different states are considered. The current paths in the slow and fast operations are shown in Figures 7 and 8, respectively where the 12 armature slots are labelled ‘a’ to ‘l’ and contain two windings each. The 12 windings are labelled ‘1’ to ‘12’ with a tick representing the return path of the winding. The instantaneous direction of the current is represented using a cross for current into the page and a dot for current out of the page and the current paths are colour coded, with blue representing current path 1 and red representing current path 2. The arrows show the direction of the magnetic field caused by the permanent magnet. The magnetic field can be described in terms of the flux density vector, \( \vec{B} \), or the scalar denoting the magnitude of the magnetic flux density, \( B \), and the vector, \( \vec{r} \), which points radially away from the centre of the armature.

It can be seen that for the slow operation the current paths are symmetrical around the magnetic neutral line, as in a normal PMDC motor. However, in fast operation the current paths are not symmetrical, that is, they are unbalanced. The value of the current in each current path the same in slow mode, however it is different in fast mode due to the different physical lengths of the current paths.

An analysis is carried out based on Chapter 1 in Chasson (2005) on the torque developed in each armature slot.
The magnitude of the force in each slot is a function of the dimensions of the armature, the magnitude and direction of the \( \vec{B} \) field, and the magnitude and direction of the current. The unbalanced nature of the current paths in the wiper motor complicates the determination of the total torque (which is usually the torque in one armature slot multiplied by the number of slots). There are three cases to consider:

- The currents in the slot are equal and in the same direction.
- The currents in the slot are equal and in opposite directions.
- The currents in the slot are unequal and in the same direction.

In the first case, that is, the normal case as in slot ‘a’ Figure 6, the torque generated per slot can be shown to be,

\[
\vec{T}_a = l_1 l_2 B \hat{z} = K_i \hat{z},
\]

where \( \vec{T}_a \) is the torque in slot ‘a’, \( l_1 \) is the length of the armature, \( l_2 \) is the diameter of the armature, \( i \) is the current, \( B \) magnetic flux density and \( K_i \) is the torque constant of the motor. Unit vector \( \hat{z} \) points along the axis of rotation.

In the second case (as in slot ‘f’ in Figure 7), the torque produced by the two windings in the slot cancel each other out. In the case of slot ‘f’:

\[
\vec{T}_{1f} = l_1 \left( \frac{l_2}{2} \right) B \hat{z},
\]

\[
\vec{T}_{2f} = -l_1 \left( \frac{l_2}{2} \right) B \hat{z},
\]

\[
\vec{T}_{1f} + \vec{T}_{2f} = \vec{T}_f = 0.
\]

In the third case (as in slot ‘c’ of Figure 8), the torques produced by the two windings sum, but are of different magnitudes. In the case of slot ‘c’:

\[
\vec{T}_5 = l_1 \left( \frac{l_2}{2} \right) B i_1 \hat{z},
\]

\[
\vec{T}_6 = l_1 \left( \frac{l_2}{2} \right) B i_2 \hat{z},
\]

\[
\vec{T}_5 + \vec{T}_6 = \vec{T}_c = l_1 l_2 B (i_1 + i_2) \hat{z} = K_i (i_1 + i_2) \hat{z},
\]

where \( i_1 \) and \( i_2 \) are the currents through the separate current paths.

Expressions for the torque produced by the motor in slow and fast modes can now be derived by summing the torque produced in each individual slot, depending on current pattern,

\[
T_{\text{slow}} = T_a + T_b + \cdots + T_l = 10K_i i_{\text{slow}}, \quad \text{(1)}
\]

\[
T_{\text{fast}} = T_a + T_b + \cdots + T_l = 8K_i i_{\text{fast}} \quad \text{(2)}
\]

in scalar form where \( T_{\text{slow}} \) and \( T_{\text{fast}} \) are the torques produced in the motor’s slow and fast modes, respectively.

Likewise, \( i_{\text{slow}} \) and \( i_{\text{fast}} \) are the input currents in its slow and fast operations, respectively, with \( i_{\text{fast}} \) equalling \( i_1 + i_2 \).

When analysing the back electromotive force (EMF) produced by the motor, it is simpler to analyse armature winding loops, rather than armature slots. The following shows an analysis of the EMF produced by a single loop, which will then be applied to the wiper motor under investigation; the analysis is based on Chapter 1 in Chiasson (2005).

Figure 9 represents a single coil of wire in the armature. The transparent section represents the air gap and thus the flux surface of the magnetic field, \( S \), in the motor. Lengths \( l_1 \) and \( l_2 \) are the height and width of the armature, respectively, meaning that the flux surface is approximately a half cylinder of radius \( l_2/2 \) and length \( l_1 \). Figure 9 shows that the positive direction of travel around the coil is taken to be anti-clockwise, in accordance with the vector \( \vec{r} \) pointing radially away from the centre of the armature. The magnetic field in the air gap generated by the permanent magnet is known to be approximately radially directed with a constant magnitude of \( B \). Therefore an expression of the vector \( \vec{B} \) is given as:

\[
\vec{B} = \begin{cases} 
+ B \hat{r} & \text{for } 0 < \theta < \pi, \\
- B \hat{r} & \text{for } \pi < \theta < 2\pi.
\end{cases}
\]

A surface element, \( d\vec{S} \), of the flux surface defined in Figure 9 is shown in Figure 10; its direction is always outward of the cylinder. From Figure 10, an expression for \( d\vec{S} \) can be derived as:

\[
d\vec{S} = \left( \frac{l_2}{2} \right) d\theta \, d\vec{r}, \quad \text{(3)}
\]

where \( \theta \) is the position of the coil, with \( \theta = 0 \) on the magnetic neutral line between slots \( g \) and \( f \) in Figures 7 and 8.

The flux can be derived by integrating the flux density over the air gap shown in Figure 9, making use of the expression
for the surface element area in Equation (3). Thus, using Equation (3), an expression for the flux, \( \phi \), can be derived:

\[
\phi(\theta_R) = \int_S \vec{B} \cdot d\vec{S},
\]

\[
\phi(\theta_R) = \int_0^{\theta_R} \int_{\theta=\theta_R}^{\theta=\pi} (B\hat{r}) \cdot \left( \frac{l_2}{2} d\theta d\hat{r} \right)
\]

\[
+ \int_0^{\theta_R} \int_{\theta=\theta_R}^{\theta=\pi} (-B\hat{r}) \cdot \left( \frac{l_2}{2} d\theta d\hat{r} \right),
\]

\[
\phi(\theta_R) = -l_1 l_2 B \left( \theta_R - \frac{\pi}{2} \right) \quad \text{for} \quad 0 < \theta_R < \pi.
\]

Similarly, it can be shown that the flux for \( \pi < \theta_R < 2\pi \) is:

\[
\phi(\theta_R) = -l_1 l_2 B \left( \theta_R - \frac{\pi}{2} - \pi \right).
\]

The induced EMF in the rotor loop can therefore be calculated as:

\[
\xi = -\frac{d\phi}{dt} = (l_1 l_2 B) \frac{d\theta_R}{dt} = K_e \omega_R,
\]

where \( \xi \) is the EMF, \( K_e \) is the back EMF constant and equals \( l_1 l_2 B \) and \( \omega_R \) is the rotor’s angular velocity.

Using the above expression, an expression for the EMF produced by each coil can be derived for both the slow and fast modes of operation. These are then summed to get an expression for the total EMF produced by the motor in each mode. Referring to Figure 7, it can be seen that the forward and return paths of coil 1 both lie in the positive direction of \( \vec{B} \) when the motor is operating in its slow mode. Likewise, coil 12’s forward and return paths both lie in the negative direction of \( \vec{B} \). This means that these two coils will produce no back EMF. This is also true for the fast mode. Figure 8 shows that the current in coil 4 in the fast mode is in the reverse direction to the so called positive direction defined in Figure 9. This means that the EMF produced by the will be negative. Therefore, the total EMF in the motors slow and fast modes are:

\[
\xi_{\text{slow}} = 10K_e \omega_R, \quad (4)
\]

\[
\xi_{\text{fast}} = 8K_e \omega_R. \quad (5)
\]

When a voltage is applied to either of the inputs, the current will see two paths to ground. In the slow operation the resistance of the paths is virtually equal. However in the fast operation, one path is physically shorter than the other and thus its resistance is lower. Considering the two current paths as two resistors in parallel, the overall armature resistance of the motor in its fast mode is smaller than in its slow mode. A similar analysis can be done for the inductance, with the same conclusion.

The eight parameter dynamic simulation model of the wiper motor is implemented as shown in Figure 11. Each separate DC motor represents a separate speed and implements the model with the following equations (Chiasson, 2005):

\[
V - R_a I_a - L \frac{dI_a}{dt} - K_e \frac{d\theta}{dt} = 0,
\]

\[
K_t I_a - J \frac{d^2\theta}{dt^2} - b \frac{d\theta}{dt} - T_L = 0,
\]

where \( V \) is input voltage, \( R_a \) is armature resistance, \( I_a \) is armature current, \( L \) is armature inductance, \( K_e \) is the EMF constant, \( \theta \) is the rotor position, \( K_t \) is the torque constant, \( J \) is the motor inertia, \( b \) is the damping and \( T_L \) is the torque load.

The using Equations (1)–(5), along with the analysis of the resistance and inductance of the motor, it is concluded that to represent the fast mode, the resistance, inductance and \( K \) parameters will be lower than the slow mode. The mechanical parameters remain the same for both modes.

The model also includes a gear box to model the worm and wheel gears built into the motor. The park switch is
generated by measuring the position of the crank shaft and outputting a pulse when the wipers are in their park position.

4. Modelling for real-time simulation

The model presented in Section 3 is not optimized for real-time simulation. A powerful enough machine could simulate the model in real time; however there are steps that can be taken to make its simulation less computationally intensive.

The off-line model was simulated on a Desk-top PC with 4 GB of RAM and a 3.4 GHz processor. The solver used was a fixed step (ode14x) solver with a step size of 1 ms. Simulating 60 s of data took 86 s, giving a time per simulation step of 1.43 ms, that is, one simulation step of 1 ms takes 1.43 ms to simulate. This means that to simulate the model in real time for HIL, significant increases in code efficiency would be required.

To move from off-line to online real-time simulation there are four areas in which changes can be made (Miller & Wendlandt 2013):

- Increase the step size of the simulation; however the step size is fixed at 0.001 s in this case.
- Utilize the local solvers supplied by SimScape. The local solvers greatly increase the simulation speed but cannot be used when a SimMechanics model is connected to the physical network.
- Reduce the number of iterations the solver makes, reducing accuracy but increasing speed.
- Decrease the overall model fidelity by removing insignificant or irrelevant elements.

After considering the available options, the decision was made to remove the SimMechanics element from the model and replace it with a mathematical model so that local solvers could be used. Therefore the linkage model needed to be replaced, without a significant loss of accuracy.

4.1. Position of the wipers

To simulate the position of the wipers, a simple look-up table was used. This method was chosen because there is a direct relationship between the position of the crank and the position of the wipers. Two look-up tables were used per wiper to represent the forward and backward sweeps. This approximation introduced virtually no error into the simulation.

4.2. Torque load

Using a look-up table to represent the torque load applied to the motor by the linkages would have been unwieldy because, not only is the instantaneous torque value dependent of the position of the rotor, it is also dependent on the motor’s angular velocity.

The fundamental shape of the torque produced by the linkages is the same for each revolution, or ‘wipe’. The shape of the torque produced by a forward and backward sweep of the wipers has been modelled separately with two polynomials, \( f(x) \) and \( g(x) \), respectively, where \( x \) is the angle of the motor’s rotor and is between 0 and \( 2\pi \). The polynomials are:

\[
\begin{align*}
 f(x) & = -0.19224x^4 + 0.021796x^3 - 0.15435x^2 \\
 & \quad - 0.077812x + 0.68626, \\
 g(x) & = 0.4184x^7 - 0.30315x^6 - 0.42441x^5 + 0.12634x^4 \\
 & \quad + 0.21484x^3 - 0.10093x^2 - 0.29859x + 0.63276.
\end{align*}
\]

Both the average and peak-to-peak values of the torque increase with velocity. This was modelled using Simulink to represent the following equation:

\[
\tau = \begin{cases} 
(C_2 \ast v) \ast (f(x) + (C_1 \ast v)) & \text{if } \cos x \text{ is } + \\
(C_2 \ast v) \ast (g(x) + (C_1 \ast v)) & \text{if } \cos x \text{ is } -
\end{cases},
\]

where \( \tau \) is the torque, \( v \) is the velocity of the motor and \( C_1 \) and \( C_2 \) are unknown unit-less constants to be identified. \( C_1 \) determines the average value of the torque and \( C_2 \) determines the peak-to-peak value of the fundamental shape.

To estimate \( C_1 \) and \( C_2 \) a GA was used. A GA is an advanced optimization tool based on the principles of biological evolution and natural selection. Typically, a GA will attempt to minimize a cost function by changing the values of its population using the following operators: selection, mating and mutation. In this case the population consists of the two constants to be identified, \( C_1 \) and \( C_2 \). For more information on GAs refer to Goldberg (1989) and Haupt and Haupt (2004).

The cost function used in the GA is defined below.

\[
\sigma_i = \sum_{i=1}^{N} |\tau - \tau'|,
\]

\[
\text{cost} = \frac{1}{N} \sum_{i=1}^{5} \sigma_i,
\]

where \( \sigma_i \) is the result of the absolute error between the torque, \( \tau \), calculated from the off-line SimMechanics model and the torque, \( \tau' \), calculated by the simplified approximated model described in Equation (6) at a specific speed. \( N \) is the number of sampled points, in this case \( N = 1001 \). The value of cost is the sum of \( \sigma_i \) for \( i = (1, 2, \ldots, 5) \), that is, the torque load at five different speeds, representing a range of speeds of the wiper system. The result of cost is the value to be minimized by the GA.
The GA identified the constants as $C_1 = 0.0035$ and $C_2 = 0.2738$. The performance of the torque approximation at the slowest and fastest speeds is shown in Figure 12. It can be seen that the approximated model accurately matches the original torque.

The look-up tables and torque approximation model replace the SimMechanics linkages in the model.

4.3. Performance

With the SimMechanics linkages removed and replaced with a simplified model, local solvers can be used. The modified model was simulated under the same conditions as the off-line model and was measured as being able to simulate 60 s of simulation time in 4 s of real time, meaning each simulation step of 1 ms can be simulated in 0.067 ms. The model is now suitable for simulation in real time and ready for implementation in an HIL test facility.

5. Identifying the model parameters

Motor parameterization could be achieved in a number of ways, for example: Measuring the parameters directly, datasheets or by using optimization algorithms. A GA was chosen for the following reasons: (1) Although some parameters can be measured directly, many cannot because the motor and linkages are a single unit and thus no load or constant load tests (including step inputs) are difficult to do. Also, data used in a GA may be available where a physical prototype is not, (2) Because the motor model is unique, datasheets do not contain the relevant information and (3) For off-line parameterization GA is ideal because it is superior at finding a global maximum solution over local optimizers but takes more time, which is not a problem for off-line parameterization.

The eight parameters to identify are: $K_{\text{fast}}$, $K_{\text{slow}}$, $L_{\text{fast}}$, $L_{\text{slow}}$, $R_{\text{fast}}$, $R_{\text{slow}}$, $J$ and $bm$. The cost function for this GA is more complicated than Equation (7) because it is attempting to minimize the error in both the angle of the wipers and the motor current, hence the cost function is a multi-objective function. The cost function used is:

$$
\text{Cost}_\text{cur} = W_{\text{cur}} \sum_{j=1}^{N} \sum_{i=1}^{4} (\mu(j, i) - \mu'(j, i))^2, \quad (9)
$$

$$
\text{Cost}_\text{pos} = W_{\text{pos}} \sum_{j=1}^{N} \sum_{i=1}^{4} (\theta(j, i) - \theta'(j, i))^2, \quad (10)
$$

$$
\text{Cost}_\text{total} = \frac{1}{N} (\text{Cost}_\text{cur} + \text{Cost}_\text{pos}). \quad (11)
$$

Equations (9) and (10) compare the simulated current, $\mu'$, and simulated wiper angle, $\theta'$, with measured current, $\mu$, and position, $\theta$, data, respectively. $W_{\text{cur}}$ and $W_{\text{pos}}$ are the weights applied to Equations (9) and (10), respectively, to bring the errors of each equation into a similar range. $W_{\text{cur}} = 8$ and $W_{\text{pos}}$ is 1, which were chosen to bring the errors in the current and position to with a similar absolute value so one cost function does not dominate in Equation (11). In this case $N$, which is the number of data points sampled, is 501. Equation (11) sums the value of Equations (9) and (10) and divides it by $N$ to calculate the accumulated cost of the current and angle. In around 50 generations the algorithm found an optimal set of parameters. Table 1 shows the values of the parameters identified by the GA. The parameters were identified using four data sets, representing the full operating range of the system. The results were then validated against a fifth data set which was not used for parameter identification.

The performance of the model in representing the motor current and wiper angle of the real system is shown in Figures 13 and 14 at the slowest and fastest speeds,

Table 1. Wiper motor equivalent parameters.

| Parameter  | Value   | Unit     |
|------------|---------|----------|
| $K_{\text{fast}}$ | 0.0423  | V/rpm    |
| $K_{\text{slow}}$ | 0.065   | V/rpm    |
| $L_{\text{fast}}$ | $9.41 \times 10^{-10}$ | H        |
| $L_{\text{slow}}$ | $9.6 \times 10^{-10}$  | H        |
| $R_{\text{fast}}$ | 0.58    | $\Omega$ |
| $R_{\text{slow}}$ | 0.6     | $\Omega$ |
| $J$          | 0.004   | kgm$^2$  |
| $bm$         | 0.0185  | Nm/((rad)/s) |
respectively. It can be seen that the model accurately recreates the output of the real system, particularly in the fast mode of operation. The largest error, and thus the worst-case performance of this model, is the steady state current error in the slow operation. This error is likely to be due to the simplified friction model implemented in the motor and linkages. The accuracy model could be improved by increasing the complexity and fidelity of the friction model, however this will add extra parameters to be identified by the GA.

6. Implementing the model in an HIL facility

A diagram of the HIL facility in which the wiper model is implemented is shown in Figure 15.

The model is integrated into an existing control system for the wipers and real-time executable code is generated using the MathWorks real-time workshop tool. This code is transferred to the DS1006 processor board and can be simulated in real time whilst interacting with hardware. The results of the simulation can now be used to test the ECU’s control system.

7. Conclusion

In the automotive industry ECUs are developed with the aid of HIL simulation. Accurate, real-time capable simulation models of the loads and actuators connected to the ECUs are required in order to carry out this testing. An off-line physical model of a windscreen wiper motor and linkage system has been developed whose parameters can be updated to capture design changes in the development process. The physical model has then been simplified
using system identification methods to decrease its simulation time, making it suitable for HIL simulation. GAs were used to identify the unknown parameters of the model. The model has been implemented in an HIL rig used for the testing of ECUs.

Further work on this project will be to add the wiper blades and windscreen elements to the model.

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