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Hardware-in-the-loop Simulation for Automatic Rack and Pinion Steering System

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Abstract. As new features for driver assistance and active safety system are going rapidly in vehicle, the interface between hardware and simulation model within a virtual and real environment has become ***necessity***. In this paper, a Hardware-in-the-loop Simulations (HILS) test rig has been develop using actual rack and pinion steering mechanism with controller in Matlab xPC Target environment, LVDT and rotary encoder sensors installed for data measurement at various steering angle. It can manipulate the steering mechanism with various control structure, decrease time with real experiment and trial risk as well as improve development efficiency. Results from HILS experimental model demonstrate a linear pattern occurred from maximum lock-to-lock steering wheel angle with acceptable error.

Introduction

Automatic steering system is merging into vehicle model more focuses on lateral control which concerned with lane keeping, lane changing and turning [1]. It involves the driver looking ahead at the intended path relative to the car and somehow processing the preview information and the current position data to yield the steering wheel or control inputs needed to make the car follow the desired path. Steering linkages play a very importance role in manoeuvring of a vehicle. Amongst the steering linkages, the rack and pinion steering linkage is the most popular and widely used in automotive passenger vehicle [2-4]. This linkage consists of two steering arms (wheel knuckle), two tie rods end as well as a rack and pinion. In future automatic steering system, the electric power steering is a vital component for control and improving vehicle handling and stability [5, 6]. A traditional method required long time and yet spend plenty of trial expenditure to test the new algorithm especially in steering system. Moreover the real test is extremely dangerous for test in vehicle under high speed condition. Therefore, it can be useful HILS as a development tool since it more repeatable and cost effective than a full in-vehicle test [7, 8].

Hardware-in-the-loop- Simulation (HILS) test setup

HIL Simulation is an effective technique to develop and test new control system and/or hardware. A real hardware interact with virtual system (simulation based on mathematical model) that replace part of actual system. A typical Hardware-in-the-loop simulation (HILS) system designed consist simulation and analysis platform (Host pc), man-machine interface (Target pc), controller and real time sensors. Fig. 1 a) shows the HILS structure developed for automatic steering system.

The relationship between rotation of pinion and rack displacement can be defined by perform an experimental on actual rack and pinion steering system through HILS. The front tire is set in normal position, and LVDT sensors used for calibration. The angular sensor collect the real time angle signal of steering wheel .As a driving device, the DC motor as an actuator to generate desired tire angle by rotating to the left or right accordingly.

The rotational motion of the pinion is converted into linear motion via steering rack. The linear motion of the steering rack is allowed to rotate the front tires at its steering axis. The actual steering system of Malaysian compact passenger car is used in HILS test rig shown in Fig. 1 b). In HILS testing, rotary encoder and potentiometer were used to measure the rotation angle of the steering wheel and DC motor pinion angle. Meanwhile, the LVDT was used to measure the linear displacement of the steering rack which than causes the tire turning into the desired angle. The outputs from both sensors (LVDT and encoder) are transferred into xPC Target in Matlab software for comparison and validation.

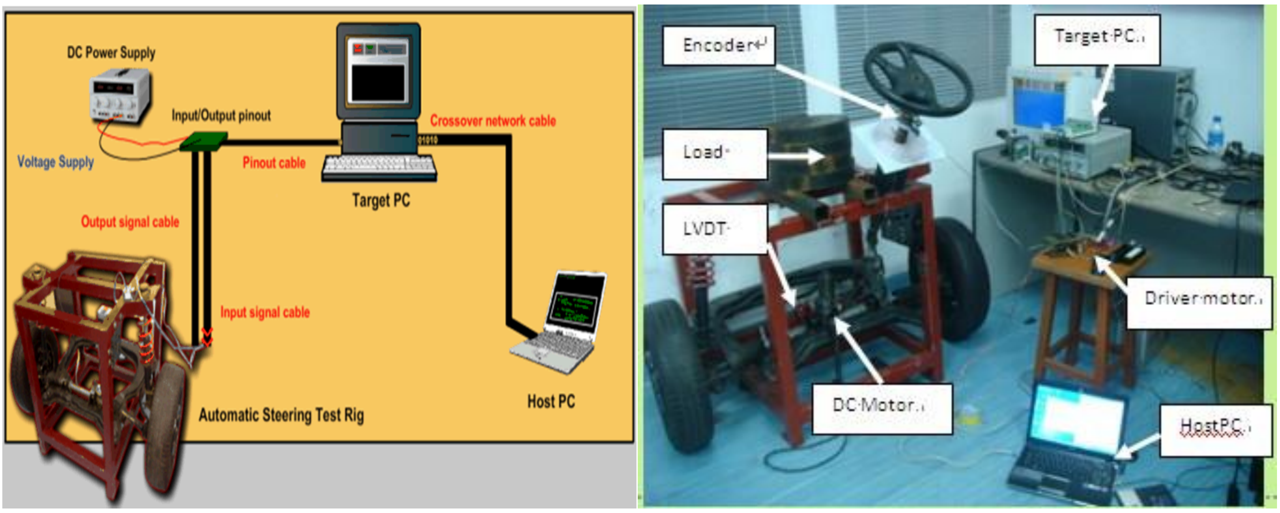


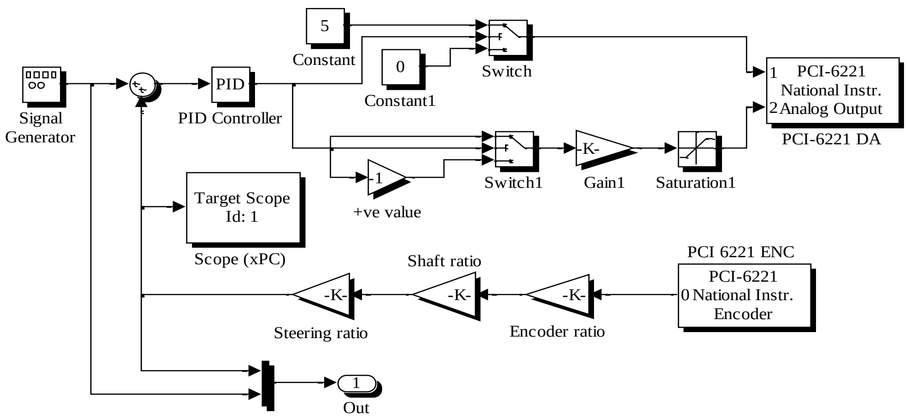
Figure 1. a) HILS diagram. b) Experimental set up of HILS for rack and pinion steering linkage

Position Tracking of DC motor

Position tracking of DC motor is required to perform to ensure the control system design for motor is good enough to follow the desired steering input. Fig. 2 show the controller of brushed DC motor is developed for position tracking in HILS testing. This test is performed on actual rack and pinion steering linkage with both tire contact on ground and carry 150 kg load for engine weight representation.

xPC Target was used to perform model identification for DC motor which must have capabilities to run under various degree of steering input. Signal generator used to represent steering input such as sine 30° means rotating the steering wheel 30° clockwise and anticlockwise. The desired steering position from the signal input given is compared with the actual angle position of the motor rotating shaft measured by rotary encoder, which results in position deviation error denoted by *e(t)*. The input signal of DC motor is voltage, *U(t)*, which is represented as the required rotational DC motor speed that is commanded to a pulse generator's block. The error is weighted PID controller value via try and error approaches which resulting in current voltage.

$$U(t) = K_p(t)\,e(t) + K_i(t)\int e(t)dt + K_d(t)\frac{d}{dt}e(t) \tag{1}$$



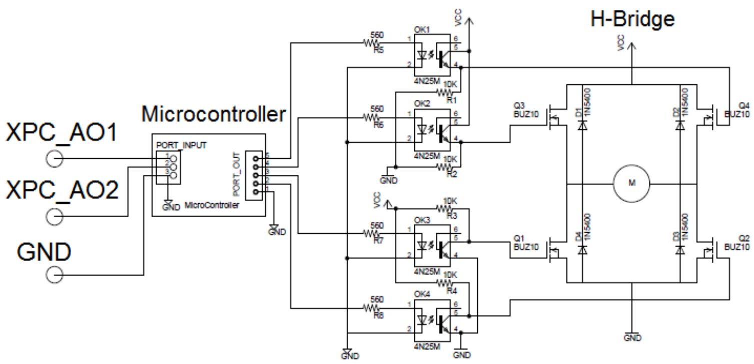
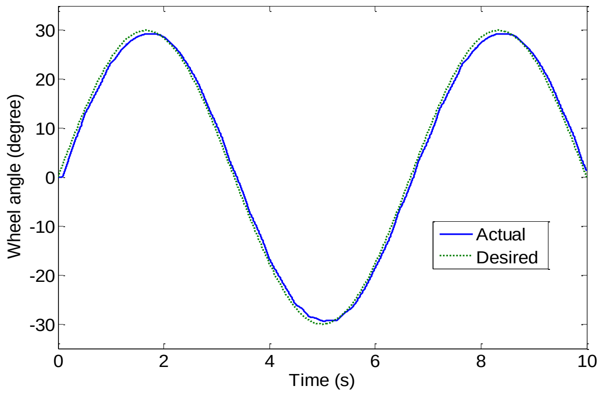


Figure 2 a) Position control develop for HIL via xPC Target. b) DC motor circuit

The output from xPC Target will be analog output voltage that used as input current driver motor circuit. The current driver consists of MOSFET H bridge circuit for DC motor and ATMEGA 32 microcontroller. The Microcontroller will receive 2 inputs from xPC Target. The first (AO1) is for reverse forward switch in H bridge and the second (AO2) is used for motor speed & torque analog signal that will be converted by microcontroller to generate PWM signal for DC motor.

Experimental results

The position tracking test for DC motor is performed to ensure the motor could follow the desired steering input. When steering wheel is rotate by giving input signal, the DC motor tend to follow the desired signal via rotating the pinion angle which than pull or push the tie rod end turn the tires to the desired angle.



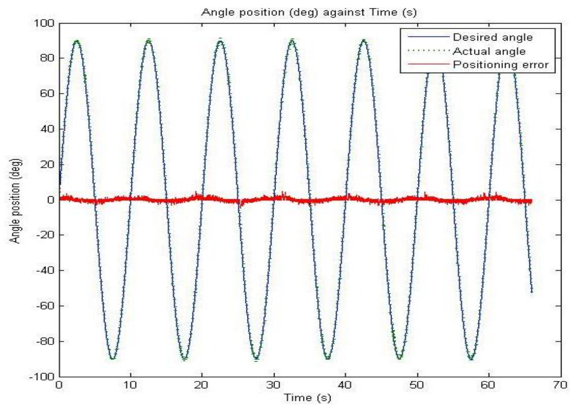


Figure 3. Positioning tracking for DC motor
Figure 4. HILS result of sine input for automatic steering system

The position tracking test for sine wave input for 30° is shown in Fig. 3. It demonstrates the actual rack and pinion measured through LVDT sensor and pinion angle closely follow the desired angle of steering input with small error.

Figure 4 shows the Hardware-in-the-Simulations (HILS) test result. The sine steer input parameter at 90° clockwise and anticlockwise at high frequency was used to represent steering wheel rotation angle. It is demonstrates the results gathered from HILS testing where the steering system follow the desired trajectory angle very well with acceptable position error. The motor and controller is capable to follow the desired trajectory at extreme condition where tire full contact with ground plus body weight to simulate real situation. It is evident that the HILS has been developed can simulate better for real drive system.

Figure 5 shows simulation and experimental results for rack and pinion steering linkage system. Y-axis represents the steering rack displacement and X-axis represents the steering wheel angle. The linear trend occurred when the steering wheel is rotate maximum lock-to-lock (610° clockwise and 610° anticlockwise). The dash line in the plotted graph shows a nonlinear behaviour from HILS experimental data at 200° anticlockwise. This is due to backlash in the gearbox of the steering linkage mechanism. Gear pairs like rack and pinion have clearance between gear teeth matching called backlash. When pinion are rotated, slack occurred at a point where it has clearance between pinion and rack. This happen at the range of 22 mm to 25 mm as referred to Fig. 5.

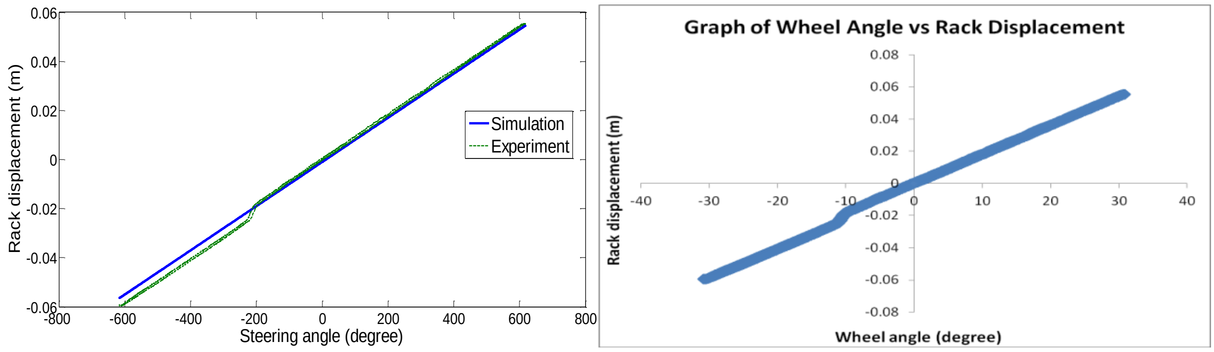


Figure 5 a) Relationship of rack displacement and pinion angle in MATLAB and HILS system. b) Relationship of rack displacement and tire angle in HILS steering system

To simplify the relationship between the rack and pinion steering mechanisms, the rack displacement is assumed directly proportional to the pinion rotational angle with relationship Y= 0.00005X - 0.001. From automatic steering system model, the correlation between displacement of rack and wheel angle can be defined as shown in Fig. 5 b. The maximum length of 60.5 mm will provide 30.5° tire angle from longitudinal axis.

Conclusion

The Hardware-in-the-loop Simulation (HILS) for automatic steering system have developed in this paper where provide a better tool to study the steering control system. The relationship of steering rack displacement and pinion angle is achieved by perform experimental measurement for actual rack and pinion steering linkage system. A result from sine input simulation demonstrates a good performance where it's closely follows the trend occurred through HILS experiment with acceptable error. The maximum rack displacement of Malaysia passenger compact car from normal position is 60.5 mm that provide maximum tire angle 30.5°.

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