

Engine Stop Position Estimation

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ABSTRACT

This paper describes a method to estimate the engine stop position using any production style crank position sensor, while accounting for possible engine rock-back. The approach is based on modeling the engine speed state, achieving robustness and ease of calibration by adapting the rubbing friction model component during the first part of engine coast-down, followed by open-loop modeling when the engine speed has dropped below the sensor signal validity threshold.

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INTRODUCTION

Accurate knowledge of the engine stop position has become increasingly important for Engine Management Systems (EMS) as it is required for quicker engine starts by knowing the position of the engine for the subsequent start. It allows for the elimination of the rotation normally required for cylinder identification before fuel can be injected. This is important on engines that require sequential prime pulses due to low emission requirements, or hybrid engines that have many start/stop events that must occur without perceived power interruption of the driver.

Engine stop estimation is challenging because the crank position sensors can not be assumed to measure at the very low engine speeds associated with the last part of the engine rotation prior to coming to a stop. Also, due to the pumping torque, the engine rotation might reverse prior to coming to a complete rest [1], and typical production sensors only measure speed and not direction of rotation.

Two different crank sensors are used in current day EMS. Variable reluctance (VR) sensors are most common, but their signal strength is proportional to engine speed which means they provide no information at zero speed. Hall-effect sensors are somewhat more expensive, and they can measure to lower engine speeds, but still not zero. The predominant type of hall-effect sensors used can not detect rotational direction, and even more costly dual-hall sensors are required for directional detection and therefore uncommon.

Existing inventions utilize either a modified hall-effect sensor, or a unique characteristic of the VR sensor as rotation changes. However, modified hall-effect sensors are more expensive, and utilizing the VR sensor characteristic at rotation change requires measurement down to very low speed which is an area where the signal will be very weak,

and therefore very vulnerable to noise in a real-world application. [1] describes such a method. Other relevant papers on the subject are [2, 3, 4, 5].

The goal of the work reported here was to develop an algorithm that is robust to engine directional changes and work for any normal production style sensor.

METHOD

The method reported here is based on a model of the engine speed state governed by models of the pumping and friction torques that govern the fluctuating RPM trace as a reciprocating engine comes to a stop, and potentially reverses direction (rock-back). The pumping torque profile is phase dependent for a given engine, and also varies between engines depending on number of cylinders and cam profiles. This pumping torque sub-model can be calibrated based on post-processing of engine speed measurements of an engine during its shutdown process using a relatively cheap instrument grade directional speed sensor.

The frictional torque is found to be reasonably well approximated as a constant at the low engine speeds associated with a stopping engine. This makes it feasible to learn the frictional torque on every engine shutdown during the portion when a reliable engine speed signal is still available. It is learnt by adapting the value required to make the model match the measurements taken with the normal production style sensor. The adapted value of friction torque is not updated at engine speeds below where the sensor signal is no longer considered reliable. Instead, the model operates in open-loop and provides an estimate of the engine final stop position, including potential rock-back.

The method is therefore partially self-calibratable, and importantly so for the friction torque term which varies significantly with operating conditions such as e.g. coolant

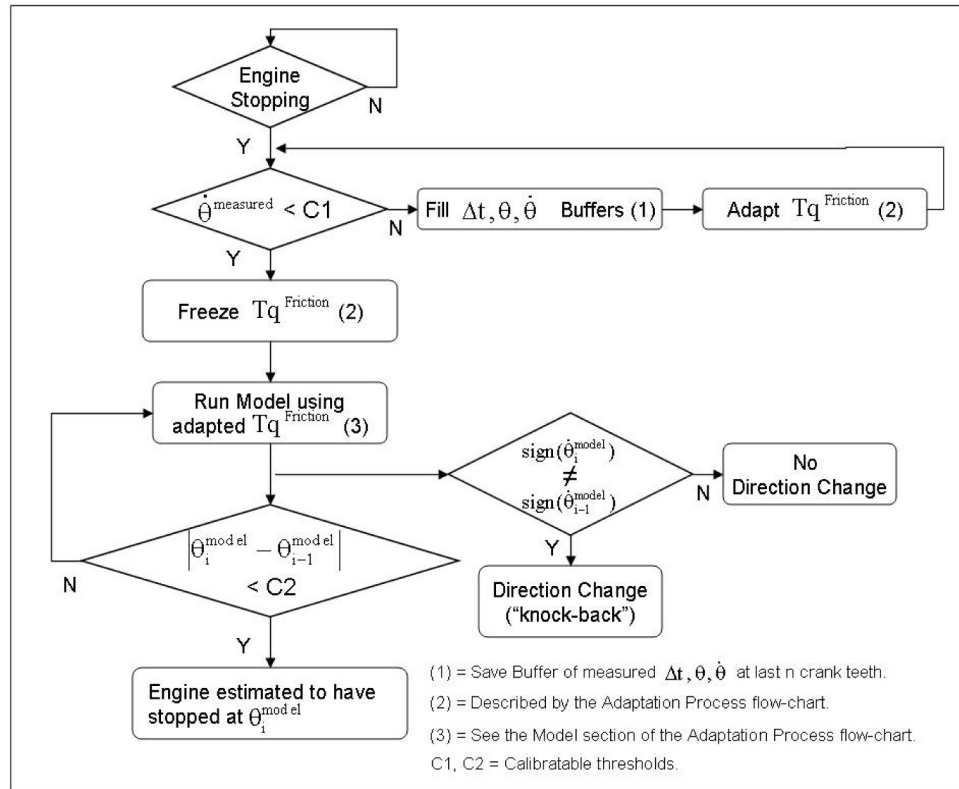


Figure 1. High-level Engine Stop Estimation process

temperature. This therefore significantly reduces the required calibration effort.

Figure 1 illustrates the Engine Stop Estimation process at a high level.

MODEL

The Engine Speed State Equation is well known as:

$$\ddot{\theta} = \frac{\sum \text{Torque}}{\text{Inertia}} = \frac{T_q^{\text{Total}}}{\text{Inertia}} \quad (1)$$

During engine coast down combustion is no longer present, and it is thought sufficient to only consider the two main friction terms when modeling total engine torque:

$$T_q^{\text{Total}} = T_q^{\text{Pumping}} + k T_q^{\text{Friction}} \quad (2)$$

where

$$T_q^{\text{Pumping}} = f(\theta) \quad (3)$$

$$T_q^{\text{Friction}} \approx \text{const} \tan t \quad (4)$$

$$k = \begin{cases} 1 & , \quad \dot{\theta} \geq 0 \\ -1 & , \quad \dot{\theta} < 0 \end{cases} \quad (5)$$

As is well known, the engine crankshaft states are solved by the following successive integration:

$$T_q^{\text{Total}} = T_q^{\text{Pumping}}(\theta_{i-1}) + k T_q^{\text{Friction}} \quad (6)$$

$$\ddot{\theta}_{i-1} = T_q^{\text{Total}} / \text{Inertia} \quad (7)$$

$$\dot{\theta}_i = \dot{\theta}_{i-1} + \Delta t_i * \ddot{\theta}_{i-1} \quad (8)$$

$$\theta_i = \theta_{i-1} + \Delta t_i * \dot{\theta}_i \quad (9)$$

Pumping Torque

Pumping torque is cyclical and is repeatable for the same gas exchange conditions such as valve open/closing times and manifold pressures. It can either be tabulated vs. crank angle or a geometric functional approximation can be used such as