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(54) **SYSTEM AND METHOD FOR ESTIMATING AN ENGINE OPERATING PARAMETER USING A PHYSICS-BASED MODEL AND ADJUSTING THE ESTIMATED ENGINE OPERATING PARAMETER USING AN EXPERIMENTAL MODEL**

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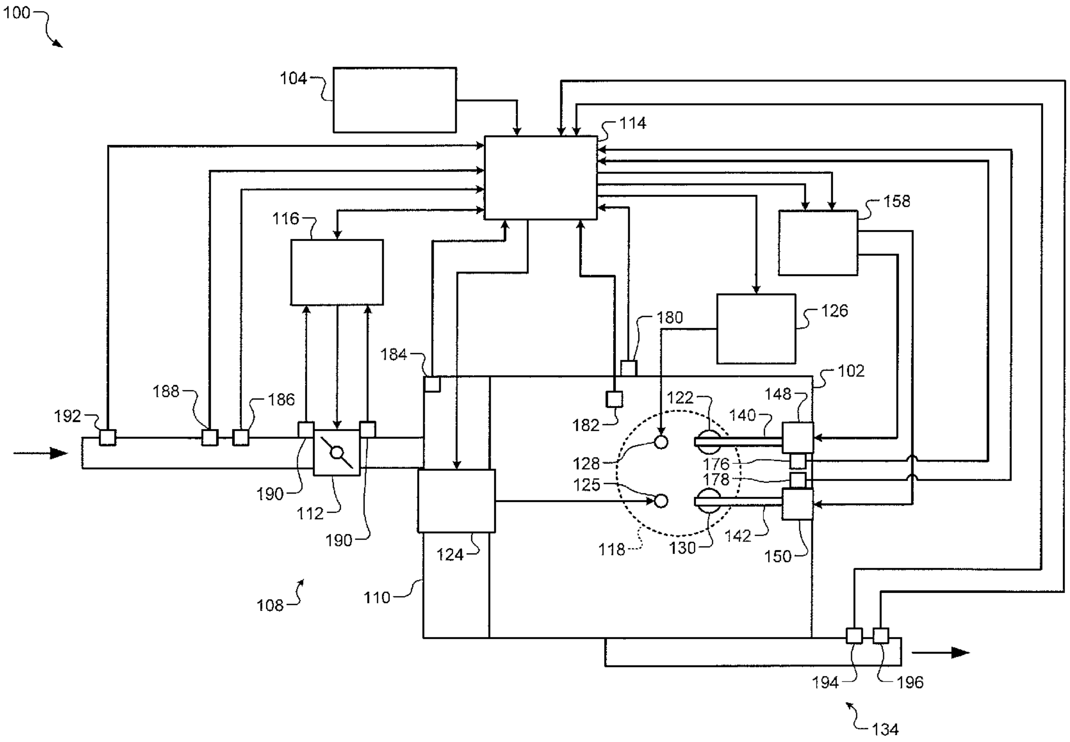
(57) **ABSTRACT**

A system according to the present disclosure includes an engine parameter estimation module, an error magnitude module, an engine parameter adjustment module, and an engine actuator control module. The engine parameter estimation module estimates an engine operating parameter using a physics-based model. The error magnitude module determines a magnitude of error between the estimated engine operating parameter and an actual value of the engine operating parameter using an experimental model. The engine parameter adjustment module adjusts the estimated engine operating parameter based on the error magnitude. The engine actuator control module controls an actuator of the engine based on the estimated engine operating parameter as adjusted.



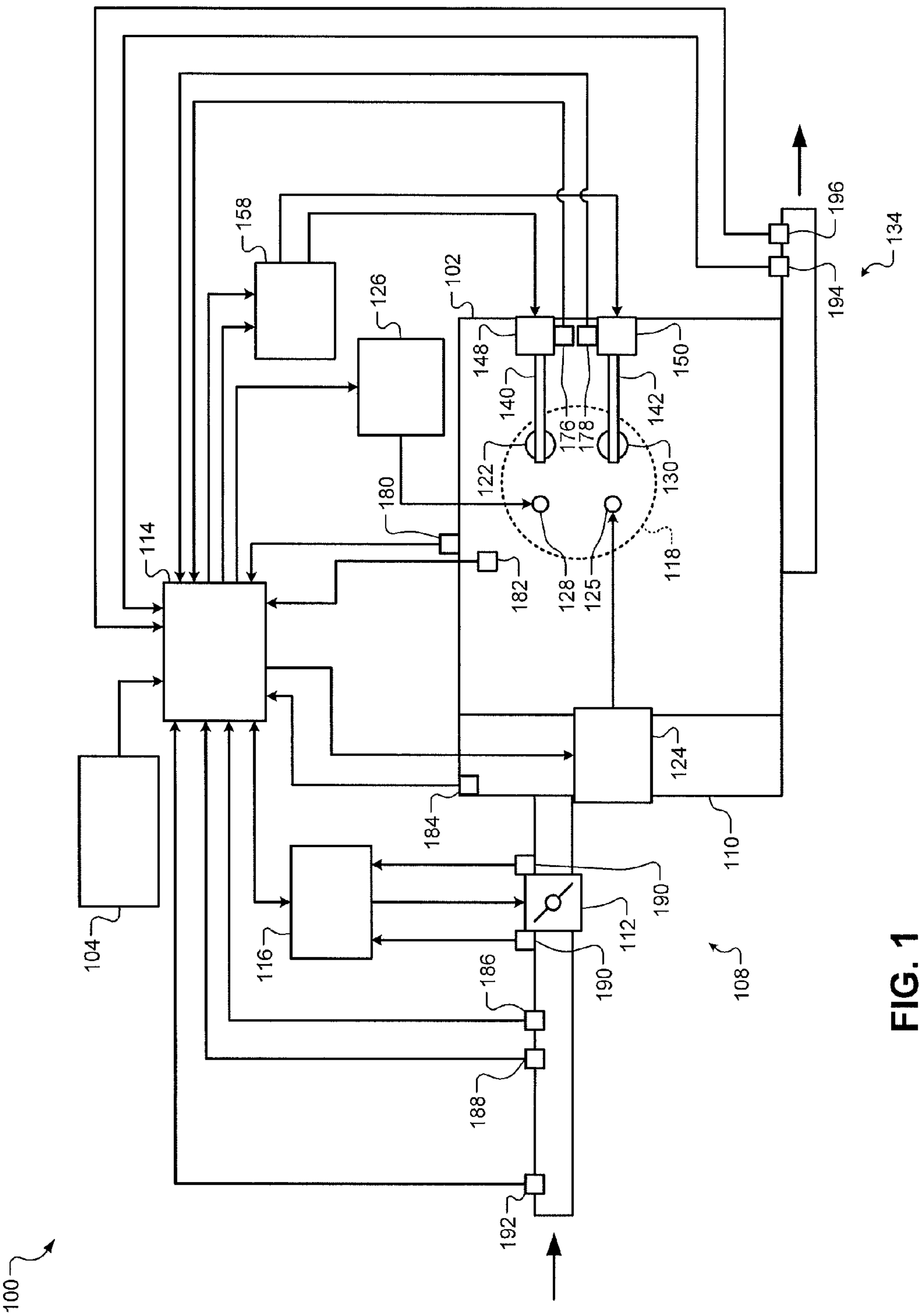

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FIG. 1

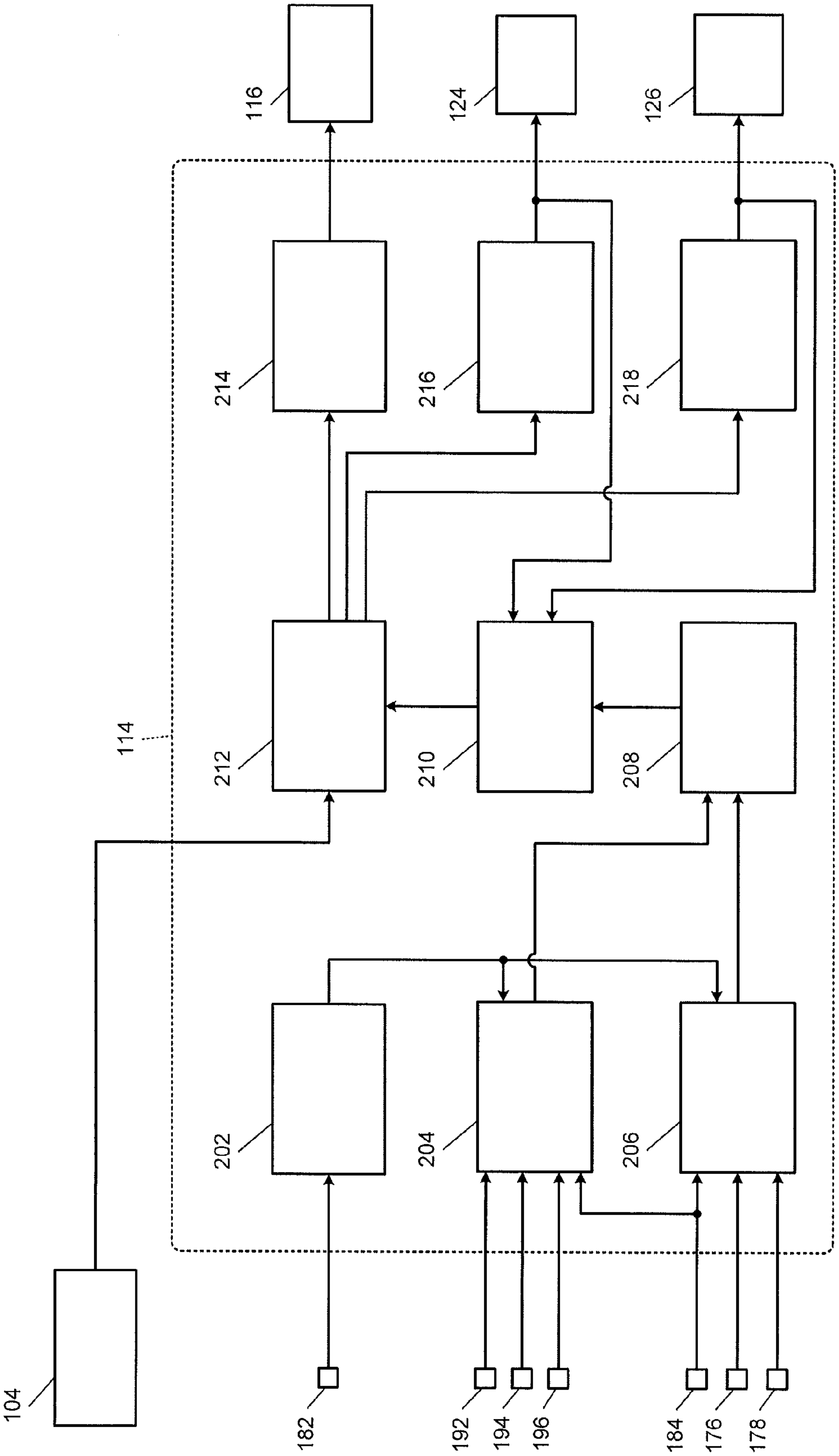
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FIG. 2

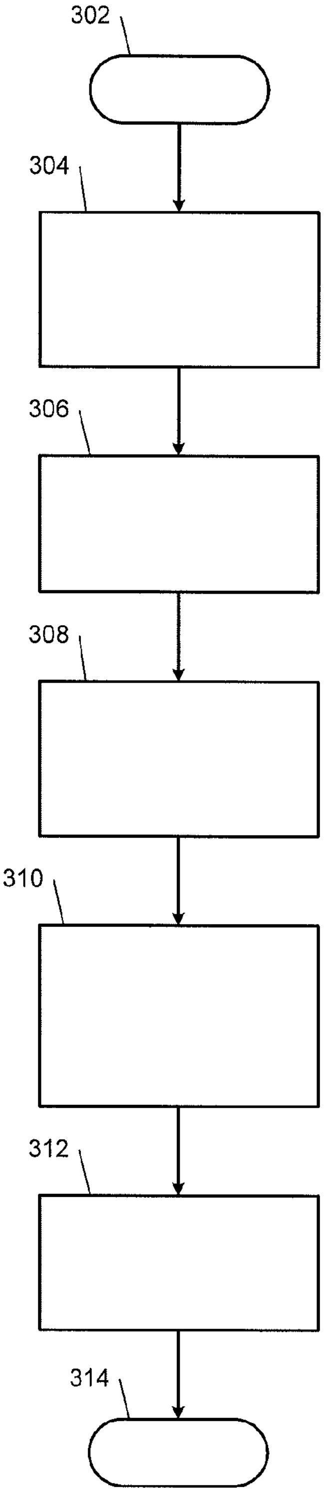

FIG. 3

SYSTEM AND METHOD FOR ESTIMATING AN ENGINE OPERATING PARAMETER USING A PHYSICS-BASED MODEL AND ADJUSTING THE ESTIMATED ENGINE OPERATING PARAMETER USING AN EXPERIMENTAL MODEL

FIELD

[0001] The present disclosure relates to internal combustion engines, and more particularly, to systems and methods for estimating an engine operating parameter using a physics-based model and adjusting the estimated engine operating parameter using an experimental model.

BACKGROUND

[0002] The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0003] Engine control systems estimate various operating parameters of an engine and control various actuators of the engine based on the estimated engine operating parameters. For example, an engine control system may estimate an amount of air in each cylinder of an engine, and control a throttle valve, a fuel injector, and a spark plug based on the estimated air per cylinder. Thus, inaccuracies in the estimated engine operating parameters may cause engine control systems to control engine actuators less accurately than desired.

[0004] Engine control systems typically estimate engine operating parameters using either a physics-based model or an experimental model. The complexity of a physics-based model is limited by the processing power of an engine control system. Thus, estimating engine operating parameters using a physics-based model may not yield a desired degree of accuracy. Estimating the engine operating parameter using an experimental model may require a significant amount of calibration work in order to develop an experimental model that achieves a desired degree of accuracy.

SUMMARY

[0005] A system according to the present disclosure includes an engine parameter estimation module, an error magnitude module, an engine parameter adjustment module, and an engine actuator control module. The engine parameter estimation module estimates an engine operating parameter using a physics-based model. The error magnitude module determines a magnitude of error between the estimated engine operating parameter and an actual value of the engine operating parameter using an experimental model. The engine parameter adjustment module adjusts the estimated engine operating parameter based on the error magnitude. The engine actuator control module controls an actuator of the engine based on the estimated engine operating parameter as adjusted.

[0006] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0008] FIG. **1** is a functional block diagram of an example engine system according to the principles of the present disclosure;

[0009] FIG. **2** is a functional block diagram of an example control system according to the principles of the present disclosure; and

[0010] FIG. **3** is a flowchart illustrating an example control method according to the principles of the present disclosure.

[0011] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0012] A system and method according to the present disclosure estimates an engine operating parameter using a physics-based model and adjusts the estimated engine operating parameter using an experimental model. In one example, the system and method estimates an amount of air in each cylinder of an engine using a physics-based model and adjusts the estimated air per cylinder using an experimental model. The system and method then controls an actuator of the engine, such as a throttle valve, based on the estimated engine operating parameter as adjusted. Estimating and adjusting the engine operating parameter in the manner described above decreases the amount of calibration work required to develop the experimental model while ensuring that the engine operating parameter is estimated as accurately as desired.

[0013] Referring now to FIG. **1**, an engine system **100** includes an engine **102** that combusts an air/fuel mixture to produce drive torque for a vehicle. The amount of drive torque produced by the engine **102** is based on a driver input from a driver input module **104**. The driver input may be based on a position of an accelerator pedal. The driver input may also be based on a cruise control system, which may be an adaptive cruise control system that varies vehicle speed to maintain a predetermined following distance.

[0014] Air is drawn into the engine **102** through an intake system **108**. The intake system **108** includes an intake manifold **110** and a throttle valve **112**. The throttle valve **112** may include a butterfly valve having a rotatable blade. An engine control module (ECM) **114** controls a throttle actuator module **116**, which regulates opening of the throttle valve **112** to control the amount of air drawn into the intake manifold **110**.

[0015] Air from the intake manifold **110** is drawn into cylinders of the engine **102**. While the engine **102** may include multiple cylinders, for illustration purposes a single representative cylinder **118** is shown. For example only, the engine **102** may include 2, 3, 4, 5, 6, 8, 10, and/or 12 cylinders. The ECM **114** may deactivate some of the cylinders, which may improve fuel economy under certain engine operating conditions.

[0016] The engine **102** may operate using a four-stroke cycle. The four strokes, described below, are named the intake stroke, the compression stroke, the combustion stroke, and the exhaust stroke. During each revolution of a crankshaft (not shown), two of the four strokes occur within the cylinder **118**. Therefore, two crankshaft revolutions are necessary for the cylinder **118** to experience all four of the strokes.

[0017] During the intake stroke, air from the intake manifold **110** is drawn into the cylinder **118** through an intake valve **122**. The ECM **114** controls a fuel actuator module **124**, which regulates fuel injections performed by a fuel injector **125** to achieve a desired air/fuel ratio. Fuel may be injected into the intake manifold **110** at a central location or at multiple locations, such as near the intake valve **122** of each of the cylinders. In various implementations, fuel may be injected directly into the cylinders or into mixing chambers associated with the cylinders. The fuel actuator module **124** may halt injection of fuel to cylinders that are deactivated.

[0018] The injected fuel mixes with air and creates an air/fuel mixture in the cylinder **118**. During the compression stroke, a piston (not shown) within the cylinder **118** compresses the air/fuel mixture. The engine **102** may be a compression-ignition engine, in which case compression in the cylinder **118** ignites the air/fuel mixture. Alternatively, the engine **102** may be a spark-ignition engine, in which case a spark actuator module **126** energizes a spark plug **128** to generate a spark in the cylinder **118** based on a signal from the ECM **114**, which ignites the air/fuel mixture. The timing of the spark may be specified relative to the time when the piston is at its topmost position, referred to as top dead center (TDC).

[0019] The spark actuator module **126** may be controlled by a spark timing signal specifying how far before or after TDC to generate the spark. Because piston position is directly related to crankshaft rotation, operation of the spark actuator module **126** may be synchronized with crankshaft angle. In various implementations, the spark actuator module **126** may halt provision of spark to deactivated cylinders.

[0020] Generating the spark may be referred to as a firing event. The spark actuator module **126** may have the ability to vary the timing of the spark for each firing event. The spark actuator module **126** may even be capable of varying the spark timing for a next firing event when the spark timing signal is changed between a last firing event and the next firing event. In various implementations, the engine **102** may include multiple cylinders and the spark actuator module **126** may vary the spark timing relative to TDC by the same amount for all cylinders in the engine **102**.

[0021] During the combustion stroke, combustion of the air/fuel mixture drives the piston down, thereby driving the crankshaft. The combustion stroke may be defined as the time between the piston reaching TDC and the time at which the piston returns to bottom dead center (BDC). During the exhaust stroke, the piston begins moving up from BDC and expels the byproducts of combustion through an exhaust valve **130**. The byproducts of combustion are exhausted from the vehicle via an exhaust system **134**.

[0022] The intake valve **122** may be controlled by an intake camshaft **140**, while the exhaust valve **130** may be controlled by an exhaust camshaft **142**. In various implementations, multiple intake camshafts (including the intake camshaft **140**) may control multiple intake valves (including the intake valve **122**) for the cylinder **118** and/or may control the intake valves (including the intake valve **122**) of multiple banks of cylinders (including the cylinder **118**). Similarly, multiple exhaust camshafts (including the exhaust camshaft **142**) may control multiple exhaust valves for the cylinder **118** and/or may control exhaust valves (including the exhaust valve **130**) for multiple banks of cylinders (including the cylinder **118**).

[0023] The time at which the intake valve **122** is opened may be varied with respect to piston TDC by an intake cam phaser **148**. The time at which the exhaust valve **130** is opened may be varied with respect to piston TDC by an exhaust cam phaser **150**. A valve actuator module **158** may control the intake and exhaust cam phasers **148**, **150** based on signals from the ECM **114**. When implemented, variable valve lift may also be controlled by the valve actuator module **158**.

[0024] The ECM **114** may deactivate the cylinder **118** by instructing the valve actuator module **158** to disable opening of the intake valve **122** and/or the exhaust valve **130**. The valve actuator module **158** may disable opening of the intake valve **122** by decoupling the intake valve **122** from the intake camshaft **140**. Similarly, the valve actuator module **158** may disable opening of the exhaust valve **130** by decoupling the exhaust valve **130** from the exhaust camshaft **142**. In various implementations, the valve actuator module **158** may control the intake valve **122** and/or the exhaust valve **130** using devices other than camshafts, such as electromagnetic or electrohydraulic actuators.

[0025] The engine system **100** may measure the position of the intake cam phaser **148** using an intake cam phaser position (ICAM) sensor **176**. The position of the exhaust cam phaser **150** may be measured using an exhaust cam phaser position (ECAM) sensor **178**. The position of the crankshaft using a crankshaft position (CKP) sensor **180**. The temperature of the engine coolant may be measured using an engine coolant temperature (ECT) sensor **182**. The ECT sensor **182** may be located within the engine **102** or at other locations where the coolant is circulated, such as a radiator (not shown).

[0026] The pressure within the intake manifold **110** may be measured using a manifold absolute pressure (MAP) sensor **184**. In various implementations, engine vacuum, which is the difference between ambient air pressure and the pressure within the intake manifold **110**, may be measured. The mass flow rate of air flowing into the intake manifold **110** may be measured using a mass air flow (MAF) sensor **186**. The MAF sensor **186** may be located in a housing that also includes the throttle valve **112**. The pressure of air at an inlet of the throttle valve **112** may be measured using a throttle inlet air pressure (TIAP) sensor **188**.

[0027] The throttle actuator module **116** may monitor the position of the throttle valve **112** using one or more throttle position sensors (TPS) **190**. The ambient temperature of air being drawn into the engine **102** may be measured using an intake air temperature (IAT) sensor **192**. The temperature of exhaust gas expelled from the engine **102** may be measured using an exhaust gas temperature (EGT) sensor **194**. The pressure of exhaust gas expelled from the engine **102** may be measured using an exhaust gas pressure (EGP) sensor **196**.

[0028] The ECM **114** uses signals from the sensors to make control decisions for the engine system **100**. In one example, the ECM **114** estimates an engine operating parameter based on the signals using a physics-based model. The engine operating parameter may be the amount of air delivered to each cylinder of the engine **102**, referred to as air per cylinder. The ECM **114** then determines a magnitude of error between the estimated engine operating parameter and an actual value of the engine operating parameter based on the signals using an experimental model. The ECM **114** then adjusts the estimated engine operating parameter based on the error magnitude, and controls the torque output of the engine **102** based on the estimated engine operating parameter as adjusted.

[0029] Referring now to FIG. **2**, the ECM **114** includes an engine speed module **202**, an engine parameter estimation module **204**, an error magnitude module **206**, and an engine parameter adjustment module **208**. The engine speed module **202** determines the speed of the engine **102** based on the crankshaft position from the CKP sensor **180**. For example, the engine speed module **202** may calculate the engine speed (or crankshaft speed) based on a period that elapses as the crankshaft completes one or more revolutions. The engine speed module **202** outputs the engine speed.

[0030] The engine parameter estimation module **204** estimates an operating parameter of the engine **102** using a physics-based model. For example, the engine parameter estimation module **204** may estimate an amount of air in each cylinder of the engine **102**, a torque output of the engine **102**, or an air/fuel ratio of the engine **102** using a physics-based model. The engine parameter estimation module **204** outputs the estimated engine operating parameter.

[0031] The engine parameter estimation module **204** may estimate the amount of air trapped in each cylinder of the engine **102** when an intake valve of each cylinder is closed at the end of their respective intake strokes, referred to as the air per cylinder. The engine parameter estimation module **204** may estimate the air per cylinder using a relationship based on the ideal gas law such as

$$m_c = \frac{M_a P_c V_c}{R T_c} \tag{1}$$

where m_c is the mass of air per cylinder, M_a is the molar mass of air, P_c is the pressure in each cylinder at the end of their respective intake stroke, V_c is the volume in each cylinder at the end of their respective intake stroke, R is the universal gas constant, and T_c is the temperature of air in each cylinder at the end of their respective intake stroke.

[0032] The engine parameter estimation module **204** may estimate the volume in each cylinder for a given crank angle using a relationship such as

$$V_c = \frac{1}{4}\pi B^2\left[r\cdot(1-\cos(\omega t)) + l - \sqrt{l^2 - r^2\sin^2(\omega t)}\right] + \frac{V_d}{(r-1)} \tag{2}$$

where B is the cylinder bore diameter, ω is the crankshaft speed, t is time, l is the connecting rod length, r is the crank radius (or one-half of the piston stroke), and V_d is the displacement volume of the cylinder. The time t is relative to a predetermined starting time, and the product of the time t and the crankshaft speed yields the crank angle for which the cylinder volume is determined using relationship (2).

[0033] The engine parameter estimation module **204** may estimate the pressure in each cylinder using a relationship based on the law of conservation of mass such as

$$\dot{m}_c = \dot{m}_e + \dot{m}i \tag{3}$$

where ṁ$_e$ is the rate of air mass change in the cylinder, ṁ$_e$ is the mass flow rate of air through the exhaust valve of the cylinder, and al; is the mass flow rate of air through the intake valve of the cylinder.

[0034] The engine parameter estimation module **204** may estimate the rate of air mass change in the cylinder by combining relationships (1) and (2), and differentiating the mass of air per cylinder with respect to time to yield a relationship such as

$$\dot{m}_c = \frac{1}{RT_c}\left\{\left[\frac{1}{4}\pi B^2\left[r\cdot(1-\cos(\omega t)) + l - \sqrt{l^2 - r^2\sin^2(\omega t)}\right] + \frac{V_d}{(r-1)}\right]\frac{d(P_c)}{dt} + \left[\frac{1}{4}\pi B^2 r\omega\cdot\sin(\omega t)\left(1 + \frac{r\cos(\omega t)}{\sqrt{l^2 - r^2\sin^2(\omega t)}}\right)\right]P_c\right\} \tag{4}$$

[0035] The engine parameter estimation module **204** may estimate the mass flow rate of air through the exhaust valve of the cylinder using a relationship such as

$$\dot{m}_e = \mathrm{sgn}(P_e - P_c)\sqrt{\frac{2\gamma}{\gamma-1}\left\{\left[\frac{\min(P_e, P_c)}{\max(P_e, P_c)}\right]^{\frac{2}{\gamma}} - \left[\frac{\min(P_e, P_c)}{\max(P_e, P_c)}\right]^{\frac{\gamma+1}{\gamma}}\right\}}\left(\sqrt{\frac{1}{RT_e}}\right)c_p A_e \max(P_e, P_c) \tag{5}$$

where sgn( ) is the signum function, P_e is the exhaust port pressure, γ is the ratio of specific heats for air, T_e is the exhaust port temperature, c_p is the specific heat of air, and A_e is the area of the exhaust port. The exhaust gas temperature and the exhaust gas pressure from the EGT sensor **194** and the EGP sensor **196**, respectively, may be used as approximations of the exhaust port pressure and the exhaust port temperature, respectively.

[0036] The engine parameter estimation module **204** may estimate the mass flow rate of air through the intake valve of the cylinder using a relationship such as

$$\dot{m}_l = \mathrm{sgn}(P_i - P_c)\sqrt{\frac{2\gamma}{\gamma-1}\left\{\left[\frac{\min(P_i, P_c)}{\max(P_i, P_c)}\right]^{\frac{2}{\gamma}} - \left[\frac{\min(P_i, P_c)}{\max(P_i, P_c)}\right]^{\frac{\gamma+1}{\gamma}}\right\}}\left(\sqrt{\frac{1}{RT_c}}\right)c_p A_i \max(P_i, P_c) \tag{6}$$

where P_i is the intake port pressure, T_i is the intake port temperature, and A_i is the area of the intake port. The manifold pressure and the intake air temperature from the MAP sensor **184** and the IAT sensor **192**, respectively, may be used as approximations of the intake port pressure and the intake port temperature, respectively. Relationships (5) and (6) are based on the Navier-Stokes equations.

[0037] The engine parameter estimation module **204** may insert relationships (4), (5), and (6) into relationship (3) to obtain the following relationship

$$\left\{\left[\frac{1}{4}\pi B^2\frac{1}{RT_c}\left[r\cdot(1-\cos(\omega t))+l-\sqrt{l^2-r^2\sin^2(\omega t)}\right]+\frac{V_d}{(r-1)}\frac{1}{RT_c}\right]\frac{d(P_c)}{dt}+\left[\frac{1}{4}\pi B^2 r\omega\cdot\sin(\omega t)\left(1+\frac{r\cos(\omega t)}{\sqrt{l^2-r^2\sin^2(\omega t)}}\right)\right]P_c\right\}=$$
$$\operatorname{sgn}(P_e-P_c)\sqrt{\frac{2\gamma}{\gamma-1}\left\{\left[\frac{\min(P_e,P_c)}{\max(P_e,P_c)}\right]^{\frac{2}{\gamma}}-\left[\frac{\min(P_e,P_c)}{\max(P_e,P_c)}\right]^{\frac{\gamma+1}{\gamma}}\right\}}\left(\sqrt{\frac{1}{RT_e}}\right)c_pA_e\max(P_e,P_c)+$$
$$\operatorname{sgn}(P_i-P_c)\sqrt{\frac{2\gamma}{\gamma-1}\left\{\left[\frac{\min(P_i,P_c)}{\max(P_i,P_c)}\right]^{\frac{2}{\gamma}}-\left[\frac{\min(P_i,P_c)}{\max(P_i,P_c)}\right]^{\frac{\gamma+1}{\gamma}}\right\}}\left(\sqrt{\frac{1}{RT_c}}\right)c_pA_i\max(P_i,P_c) \tag{7}$$

The engine parameter estimation module **204** may estimate the cylinder pressure at any given crank angle represented by (ωt) using relationship (7).

[0038] The engine parameter estimation module **204** may estimate the temperature of air in each cylinder and the end of its intake stroke using a relationship such as

$$T_c=\frac{1}{1-\left(1-\frac{T_i}{T_e}\right)\frac{P_e 1}{P_i\gamma}}T_i \tag{8}$$

Relationship (8) is based on the ideal gas law and the laws of conservation of energy and mass.

[0039] Thus, the engine parameter estimation module **204** may determine the volume, pressure, and temperature of a cylinder at the end of its intake stroke using relationships (4), (7), and (8), respectively. The engine parameter estimation module **204** may then insert these values into relationship (1) to estimate the amount of air trapped in the cylinder at the end of its intake stoke. Alternatively, relationships (1), (4), (7), and (8) may be combined, and the engine parameter estimation module **204** may use the combined relationship to estimate the air per cylinder.

[0040] The error magnitude module **206** determines a magnitude (e.g., percentage) of error between the estimated engine operating parameter and an actual value of the engine operating parameter using an experimental model. The experimental model may be developed experimentally through calibration work performed in a laboratory or using a specially instrumented vehicle on a road. For example, the vehicle may include instrumentation that measures the engine operating parameter which is not normally present on a production vehicle. The experimental model may be developed independent of physical laws such as the ideal gas law and the laws of conservation of mass and energy. The error magnitude module **206** outputs the error magnitude.

[0041] In one example, the error magnitude module **206** may determine the magnitude of error between the estimated air per cylinder and an actual value of the air per cylinder using an experimental model. The error magnitude module **206** may determine the error magnitude of the estimated air per cylinder based on the engine speed, the manifold pressure, the intake cam position of the respective cylinder, and the exhaust cam position of the respective cylinder. The error magnitude module **206** may receive the engine speed, the manifold pressure, the intake cam phaser position, and the exhaust cam phaser position from the engine speed module **202**, the MAP sensor **184**, the ICAM sensor **176**, and the ECAM sensor **178**, respectively.

[0042] The engine parameter adjustment module **208** adjusts the estimated engine operating parameter based on the error magnitude. For example, the engine parameter adjustment module **208** may set an error correction factor to an amount that is equal in magnitude and opposite in sign relative to the error magnitude, and adjust the estimated engine operating parameter based on the error correction factor. The engine parameter adjustment module **208** may adjust the estimated engine operating parameter based on the error correction factor by adding the error correction factor to the estimated engine operating parameter. The engine parameter adjustment module **208** outputs the estimated engine operating parameter as adjusted.

[0043] The example implementation of the ECM **114** shown in FIG. **2** further includes a torque estimation module **210**, and a torque request module **212**, a throttle control module **214**, a fuel control module **216**, and a spark control module **218**. The torque estimation module **210** estimates the torque output of the engine **102** based on the estimated engine operating parameter as adjusted. For example, the torque estimation module **210** may estimate the engine torque output based on the estimated amount of air per cylinder, a commanded fueling amount per cylinder, and a commanded spark timing per cylinder using a predetermined relationship. The predetermined relationship may be embodied in a lookup table and/or an equation. The torque estimation module **210** may receive the commanded fueling amount and the commanded spark timing from the fuel control module **216** and the spark control module **218**, respectively. The torque estimation module **210** outputs the estimated torque output of the engine **102**.

[0044] The torque request module **212** determines a torque request based on the driver input from the driver input module **104**. For example, the torque request module **212** may store one or more mappings of accelerator pedal position to desired torque and determine the torque request based on a selected one of the mappings. The torque request module **212** may select one of the mappings based on the engine speed and/or vehicle speed.

[0045] The torque request module **212** may adjust the torque request based on the estimated torque output of the engine **102**. For example, the torque request module **212** may adjust the torque request to minimize a difference between the unadjusted torque request and the estimated torque output of the engine **102**. The torque request module **212** outputs the torque request as adjusted.

[0046] The throttle control module **214** controls the throttle valve **112** by instructing the throttle actuator module **116** to achieve a desired throttle area. The fuel control module **216** controls the fuel injector **125** by instructing the fuel actuator module **124** to achieve a desired pulse width. The spark control module **218** controls the spark plug **128** by instructing the spark actuator module **126** to achieve desired spark timing. The throttle valve **112**, the fuel injector **125**, and the spark plug **128** may be referred to as engine actuators, and the throttle control module **214**, the fuel control module **216**, and the spark control module **218** may be referred to as engine actuator control modules.

[0047] The throttle control module **214** and the spark control module **218** may adjust the desired throttle area and the desired spark timing, respectively, based on the torque request. The throttle control module **214** may increase or decrease the desired throttle area when the torque request increases or decreases, respectively. The spark control module **218** may advance or retard the spark timing when the torque request increases or decreases, respectively.

[0048] The fuel control module **216** may adjust the desired pulse width to achieve a desired air/fuel ratio such as a stoichiometric air/fuel ratio. For example, the fuel control module **216** may adjust the desired pulse width to minimize a difference between an actual air/fuel ratio and the desired air/fuel ratio. Controlling the air/fuel ratio in this way may be referred to as closed-loop control of the air/fuel ratio.

[0049] Referring now to FIG. **3**, an example method for estimating an engine operating parameter using a physics-based model and adjusting the estimated engine operating parameter using an experimental model begins at **302**. The method of FIG. **3** is described in the context of the modules included in the example implementation of the ECM **114** shown in FIG. **2**. However, the particular modules that perform the steps of the method of FIG. **3** may be different than the modules mentioned below and/or the method of FIG. **3** may be implemented apart from the modules of FIG. **3**.

[0050] At **304**, the engine parameter estimation module **204** estimates an operating parameter of the engine **102** using a physics-based model. For example, the engine parameter estimation module **204** may estimate the amount of air in each cylinder of the engine **102**, the torque output of the engine **102**, or the air/fuel ratio of the engine **102** using a physics-based model. The engine parameter estimation module **204** may estimate the air per cylinder using relationships (1) through (8) discussed above.

[0051] At **306**, the error magnitude module **206** a magnitude (e.g., percentage) of error between the estimated engine operating parameter and an actual value of the engine operating parameter using an experimental model. The experimental model is developed experimentally through calibration work performed in a laboratory or using a specially instrumented vehicle on a road. The experimental model may be developed independent of physical laws such as the ideal gas law and the laws of conservation of mass and energy.

[0052] At **308**, the engine parameter adjustment module **208** adjusts the estimated engine operating parameter based on the error magnitude. For example, the engine parameter adjustment module **208** may adjust the estimated engine operating parameter by an amount that is equal in magnitude and opposite in sign relative to the error magnitude.

[0053] At **310**, the torque request module **212** determines a torque request based on the estimated engine operating parameter as adjusted. For example, the torque request module **212** may determine the torque request based on the driver input from the driver input module **104** and adjust the torque request based on the estimated engine operating parameter as adjusted. As discussed above, the estimated engine operating parameter may be an estimated torque output of the engine **102**. Alternatively, the estimated engine operating parameter may be an estimated air per cylinder, and the torque estimation module **210** may estimate the torque output of the engine **102** based on the estimated air per cylinder as adjusted. In either case, the torque request module **212** may adjust the torque request based on the estimated torque output to minimize a difference between the unadjusted torque request and the estimated torque output of the engine **102**.

[0054] At **312**, an engine actuator control module controls an engine actuator based on the torque request. For example, the throttle control module **214**, the fuel control module **216**, and the spark control module **218** may control the throttle valve **112**, the fuel injector **125**, and the spark plug **128**, respectively, based on the torque request. At **314**, the method ends.

[0055] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean "at least one of A, at least one of B, and at least one of C." It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

[0056] In this application, including the definitions below, the term "module" or the term "controller" may be replaced with the term "circuit." The term "module" may refer to, be part of, or include: an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor circuit (shared, dedicated, or group) that executes code; a memory circuit (shared, dedicated, or group) that stores code executed by the processor circuit; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

[0057] The module may include one or more interface circuits. In some examples, the interface circuits may include wired or wireless interfaces that are connected to a local area network (LAN), the Internet, a wide area network (WAN), or combinations thereof. The functionality of any given module of the present disclosure may be distributed among multiple modules that are connected via interface circuits. For example, multiple modules may allow load balancing. In a further example, a server (also known as remote, or cloud) module may accomplish some functionality on behalf of a client module.

[0058] The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, data structures, and/or objects. The term shared processor circuit encompasses a single processor circuit that executes some or all code from multiple modules. The term group processor circuit encompasses a processor circuit that, in combination with additional processor circuits, executes some or all code from one or more modules. References to multiple processor circuits encompass multiple processor circuits on discrete dies, multiple processor circuits on a single die, multiple cores of a single processor circuit, multiple threads of a single processor circuit, or a combination of the above. The term shared memory circuit encompasses a single memory circuit that stores some or all code from multiple modules. The term group memory circuit encompasses a memory circuit that, in combination with additional memories, stores some or all code from one or more modules.

[0059] The term memory circuit is a subset of the term computer-readable medium. The term computer-readable medium, as used herein, does not encompass transitory electrical or electromagnetic signals propagating through a medium (such as on a carrier wave); the term computer-readable medium may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory, tangible computer-readable medium are nonvolatile memory circuits (such as a flash memory circuit, an erasable programmable read-only memory circuit, or a mask read-only memory circuit), volatile memory circuits (such as a static random access memory circuit or a dynamic random access memory circuit), magnetic storage media (such as an analog or digital magnetic tape or a hard disk drive), and optical storage media (such as a CD, a DVD, or a Blu-ray Disc).

[0060] The apparatuses and methods described in this application may be partially or fully implemented by a special purpose computer created by configuring a general purpose computer to execute one or more particular functions embodied in computer programs. The functional blocks, flowchart components, and other elements described above serve as software specifications, which can be translated into the computer programs by the routine work of a skilled technician or programmer.

[0061] The computer programs include processor-executable instructions that are stored on at least one non-transitory, tangible computer-readable medium. The computer programs may also include or rely on stored data. The computer programs may encompass a basic input/output system (BIOS) that interacts with hardware of the special purpose computer, device drivers that interact with particular devices of the special purpose computer, one or more operating systems, user applications, background services, background applications, etc.

[0062] The computer programs may include: (i) descriptive text to be parsed, such as HTML (hypertext markup language) or XML (extensible markup language), (ii) assembly code, (iii) object code generated from source code by a compiler, (iv) source code for execution by an interpreter, (v) source code for compilation and execution by a just-in-time compiler, etc. As examples only, source code may be written using syntax from languages including C, C++, C#, Objective C, Haskell, Go, SQL, R, Lisp, Java®, Fortran, Pert, Pascal, Curl, OCaml, Javascript®, HTML5, Ada, ASP (active server pages), PHP, Scala, Eiffel, Smalltalk, Erlang, Ruby, Flash®, Visual Basic®, Lua, and Python®.

[0063] None of the elements recited in the claims are intended to be a means-plus-function element within the meaning of 35 U.S.C. §112(f) unless an element is expressly recited using the phrase "means for," or in the case of a method claim using the phrases "operation for" or "step for."

What is claimed is:

1. A system comprising:

an engine parameter estimation module that estimates an engine operating parameter using a physics-based model;

an error magnitude module that determines a magnitude of error between the estimated engine operating parameter and an actual value of the engine operating parameter using an experimental model;

an engine parameter adjustment module that adjusts the estimated engine operating parameter based on the error magnitude; and

an engine actuator control module that controls an actuator of the engine based on the estimated engine operating parameter as adjusted.

2. The system of claim **1** wherein the engine parameter adjustment module:

determines an error correction factor based on the error magnitude; and

adjusts the estimated engine operating parameter based on the error correction factor.

3. The system of claim **2** wherein the engine operating parameter includes at least one of an amount of air in a cylinder of an engine, a torque output of the engine, and an air/fuel ratio of the engine.

4. The system of claim **3** wherein the engine operating parameter includes the amount of air trapped in the cylinder when an intake valve of the cylinder is closed.

5. The system of claim **4** wherein the engine parameter estimation module estimates the amount of air in the cylinder based on a pressure in the cylinder, a volume of the cylinder, and a temperature of air in the cylinder using the physics-based model.

6. The system of claim **5** wherein the engine parameter estimation module estimates the pressure in the cylinder and the temperature of air in the cylinder based on an intake air temperature, an intake manifold pressure, an exhaust gas temperature, an exhaust gas pressure, and engine speed.

7. The system of claim **6** wherein the error magnitude module determines the error magnitude based on an intake cam phaser position and an exhaust cam phaser position using the experimental model.

8. The system of claim **7** wherein the error magnitude module determines the error magnitude further based on the intake manifold pressure and the engine speed using the experimental model.

9. The system of claim **4** further comprising a torque estimation module that estimates the torque output of the engine based on the estimated amount of air in the cylinder as adjusted, wherein the engine actuator control module controls the engine actuator based on the estimated torque output.

10. The system of claim **9** further comprising a torque request module that determines a torque request based on the estimated torque output and a driver torque request, wherein the engine actuator control module controls the engine actuator based on the torque request.

11. A method comprising:

estimating an engine operating parameter using a physics-based model;

determining a magnitude of error between the estimated engine operating parameter and an actual value of the engine operating parameter using an experimental model;

adjusting the estimated engine operating parameter based on the error magnitude; and

controlling an actuator of the engine based on the estimated engine operating parameter as adjusted.

12. The method of claim **11** further comprising:

determines an error correction factor based on the error magnitude; and

adjusts the estimated engine operating parameter based on the error correction factor.

13. The method of claim **12** wherein the engine operating parameter includes at least one of an amount of air in a cylinder of an engine, a torque output of the engine, and an air/fuel ratio of the engine.

14. The method of claim **13** wherein the engine operating parameter includes the amount of air trapped in the cylinder when an intake valve of the cylinder is closed.

15. The method of claim **14** further comprising estimating the amount of air in the cylinder based on a pressure in the cylinder, a volume of the cylinder, and a temperature of air in the cylinder using the physics-based model.

16. The method of claim **15** further comprising estimating the pressure in the cylinder and the temperature of air in the cylinder based on an intake air temperature, an intake manifold pressure, an exhaust gas temperature, an exhaust gas pressure, and engine speed.

17. The method of claim **16** further comprising determining the error magnitude based on an intake cam phaser position and an exhaust cam phaser position using the experimental model.

18. The method of claim **17** further comprising determining the error magnitude further based on the intake manifold pressure and the engine speed using the experimental model.

19. The method of claim **14** further comprising:

estimating the torque output of the engine based on the estimated amount of air in the cylinder as adjusted; and

controlling the engine actuator based on the estimated torque output.

20. The method of claim **19** further comprising:

determining a torque request based on the estimated torque output and a driver torque request; and

controlling the engine actuator based on the torque request.

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