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ENGINE EFFECTOR POSITION MEASUREMENT

Abstract

A system for engine effector position measurement including an effector actuator of an engine, the effector actuator comprising a house and one or more movable elements for changing an effector position of an effector coupled to the effector actuator and a time-of-flight (TOF) sensor within a housing of the effector actuator and positioned to measure a distance between the TOF sensor and a reflecting surface within the housing to determine the effector position of the effector.

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Background/Summary

FIELD OF THE DISCLOSURE

[0001] The present subject matter relates generally to engines, and specifically to engine effector position measurement.

BACKGROUND

[0002] Turbine engines can include variable geometry effectors such as variable pitch blades that can be actuated to affect engine output and fuel consumption. Precise control of these effectors is important in optimizing engine performance.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] A full and enabling description of the present disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0004] FIG. **1** is a cross-sectional side view of an embodiment of a propulsion system according to some embodiments;

[0005] FIG. **2** is a simplified block diagram of an engine control system according to some embodiments;

[0006] FIG. **3** is a flow diagram of a method for effector position measurement and control according to some embodiments;

[0007] FIGS. **4**A and **4**B are illustrations of engine effectors in accordance with some embodiments; and

[0008] FIGS. **5**A and **5**B are illustrations of sensor systems with calibration in accordance with some embodiments.

DETAILED DESCRIPTION

[0009] Reference now will be made in detail to embodiments of the present disclosure, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the present disclosure, not limitation of the disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure without departing from the scope or spirit of the disclosure. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present disclosure covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0010] As used herein, the terms “first,” “second,” “third,” etc. may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components.

[0011] The terms “coupled,” “fixed,” “attached to,” and the like refer to both direct coupling, fixing, or attaching, as well as indirect coupling, fixing, or attaching through one or more intermediate components or features, unless otherwise specified herein.

[0012] The singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise.

[0013] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about,” “approximately,” “almost,” and “substantially” are not to be limited to the precise value specified. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value. For example, the approximating language may refer to being within a 1, 2, 4, 10, 15, or 20 percent margin. These approximating margins may apply to a single value, either or both endpoints defining numerical ranges, and/or the margin for ranges between endpoints. Here and throughout the specification and claims, range limitations are combined and interchanged. Such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other.

[0014] For variable geometry engines, variable geometry effectors, such as variable pitch vanes and blades, can be controlled based on a feedback loop including an effector position sensor such as a pitch measurement sensor. In such engines, the accuracy of the sensor affects the control precision of the engine variable geometry. The sensor design also affects the overall form, reliability, and durability of the engine.

[0015] Effector position measurement can be made via mechanical linkage, optical sensors, or magnetic sensors. However, existing methods often face challenges such as mechanical wear and tear, susceptibility to environmental conditions, and interference from other engine components.

[0016] In some aspects, an effector position measurement system is provided for a variable geometry propulsion application. The system may include associated hardware, one or more sensing elements, associated signal processing software or hardware modules, and a computing device for obtaining effector position such as pitch angle (also known as beta). In some embodiments, a position measurement system determines actuator position through measuring axial displacement of an actuation system.

[0017] In some embodiments, the system measures pitch angle through one or more ultrasonic sensors located inside the actuator cylinder, measuring the distance to an associated surface inside the actuator where the mechanical wave is reflected. The actuator cylinder may be filled with pressurized oil or other working fluid. By measuring the "time of flight" of the mechanical wave traveling from the sensor to the reflecting surface and back, axial displacement (and hence the effector position) may be obtained.

[0018] In some embodiments, the sensing system is configured for self-calibration to be more robust and accurate in different mediums of varying properties. In some embodiments, the sensor includes a reflecting surface at a known distance from the sensor for calibration. In some embodiments, the sensor system includes an additional layer of a known medium adjacent to the reflecting surface where the total energy is distributed such that some energy is reflected, and part of the energy goes through the additional medium towards the reflecting surface. The delta time between the time of flight of the reflected signals on the reference medium and the reflecting surface may be used to calibrate variations in time of flight for distance measurements.

[0019] Referring now to FIG. **1**, a schematic cross-sectional view of a gas turbine engine **100** is provided according to an example embodiment of the present disclosure. Effector position measuring methods and systems described herein may be implemented within one or more actuators of the engine **100**.

[0020] It will be appreciated, however, that the exemplary single rotor unducted engine **100** depicted in FIG. **1** is by way of example only, and that in other exemplary embodiments, the engine **100** may have any other suitable configuration, including, for example, any other suitable number of shafts or spools, turbines, compressors, etc.; fixed-pitch blades, a direct-drive configuration (i.e., may not include the gearbox **155**); etc. For example, in other exemplary embodiments, the engine **100** may be a three-spool engine, having an intermediate speed compressor and/or turbine. In such a configuration, it will be appreciated that the terms "high" and "low," as used herein with respect to the speed and/or pressure of a turbine, compressor, or spool are terms of convenience to differentiate between the components, but do not require any specific relative speeds and/or pressures, and are not exclusive of additional compressors, turbines, and/or spools or shafts.

[0021] Additionally, or alternatively, in other exemplary embodiments, any other suitable gas turbine engine may be provided. For example, in other exemplary embodiments, the gas turbine engine may be a turboshaft engine, a turboprop engine, a turbojet engine, a rotorcraft engine, a ducted engine with variable pitch blades, etc. Moreover, for example, although the engine is depicted as a single unducted rotor engine, in other embodiments, the engine may include a multi-stage open rotor configuration or a ducted engine, and aspects of the disclosure described herein below may be incorporated therein.

[0022] FIG. **1** provides an engine **100** having a rotor assembly with a single stage of unducted rotor blades. In such a manner, the rotor assembly may be referred to herein as an “unducted fan,” or the entire gas turbine engine **100** may be referred to as an “unducted engine,” or an engine having an open rotor propulsion system **102**. In addition, the engine of FIG. **1** includes a mid-fan stream extending from the compressor section to a rotor assembly flowpath over the turbomachine, as will be explained in more detail below. It is also contemplated that, in other exemplary embodiments, the present disclosure is compatible with an engine having a duct around the unducted fan. It is also contemplated that, in other exemplary embodiments, the present disclosure is compatible with a turbofan engine having a third stream as described herein.

[0023] For reference, the gas turbine engine **100** defines an axial direction A, a radial direction R, and a circumferential direction C. Moreover, the gas turbine engine **100** defines an axial centerline or longitudinal axis **112** that extends along the axial direction A. In general, the axial direction A extends parallel to the longitudinal axis **112**, the radial direction R extends outward from and inward to the longitudinal axis **112** in a direction orthogonal to the axial direction A, and the circumferential direction extends three hundred sixty degrees) (360° around the longitudinal axis **112**. The gas turbine engine **100** extends between a forward end **114** and an aft end **116**, e.g., along the axial direction A.

[0024] The gas turbine engine **100** includes a turbomachine **120**, also referred to as a core of the gas turbine engine **100**, and a rotor assembly, also referred to as a fan section **150**, positioned upstream thereof. Generally, the turbomachine **120** includes, in serial flow order, a compressor section, a combustion section, a turbine section, and an exhaust section. Particularly, as shown in FIG. **1**, the turbomachine **120** includes a core cowl **122** that defines an annular core inlet **124**. The core cowl **122** further encloses at least in part a low pressure system and a high pressure system. For example, the core cowl **122** depicted encloses and supports at least in part a booster or low pressure (“LP”) compressor **126** for pressurizing the air that enters the turbomachine **120** through core inlet **124**. A high pressure (“HP”), multi-stage, axial-flow compressor **128** receives pressurized air from the LP compressor **126** and further increases the pressure of the air. The pressurized air stream flows downstream to a combustor **130** of the combustion section where fuel is injected into the pressurized air stream and ignited to raise the temperature and energy level of the pressurized air and produce high energy combustion products.

[0025] It will be appreciated that as used herein, the terms “high/low speed” and “high/low pressure” are used with respect to the high pressure/high speed system and low pressure/low speed system interchangeably. Further, it will be appreciated that the terms “high” and “low” are used in this same context to distinguish the two systems, and are not meant to imply any absolute speed and/or pressure values.

[0026] The high energy combustion products flow from the combustor **130** downstream to a high pressure turbine **132**. The high pressure turbine **132** drives the high pressure compressor **128** through a high pressure shaft **136**. In this regard, the high pressure turbine **132** is drivingly coupled with the high pressure compressor **128**. The high energy combustion products then flow to a low pressure turbine **134**. The low pressure turbine **134** drives the low pressure compressor **126** and components of the fan section **150** through a low pressure shaft **138**. In this regard, the low pressure turbine **134** is drivingly coupled with the low pressure compressor **126** and components of the fan section **150**. The LP shaft **138** is coaxial with the HP shaft **136** in this example embodiment. After driving each of the turbines **132**, **134**, the combustion products exit the turbomachine **120** through a core or turbomachine exhaust nozzle **140**.

[0027] Accordingly, the turbomachine **120** defines a working gas flowpath or core duct **142** that extends between the core inlet **124** and the turbomachine exhaust nozzle **140**. The core duct **142** is an annular duct positioned generally inward of the core cowl **122** along the radial direction R. The core duct **142** (e.g., the working gas flowpath through the turbomachine **120**) may be referred to as a second stream.

[0028] The fan section **150** includes a fan **152**, which is the primary fan in this example embodiment. For the depicted embodiment of FIG. **1**, the fan **152** is an open rotor or unducted fan **152**. As depicted, the fan **152** includes an array of fan blades **154**. The fan blades **154** are rotatable, e.g., about the longitudinal axis **112**. In FIG. **1**, the fan **152** is drivingly coupled with the low pressure turbine **134** via the LP shaft **138**. The fan **152** can be directly coupled with the LP shaft **138**, e.g., in a direct-drive configuration. However, for the embodiments shown in FIG. **1**, the fan **152** is coupled with the LP shaft **138** via a speed reduction gearbox **155**, e.g., in an indirect-drive or geared-drive configuration.

[0029] Moreover, the fan blades **154** can be arranged in equal spacing around the longitudinal axis **112**. Each fan blade **154** has a root and a tip and a span defined therebetween. Each fan blade **154** defines a central blade axis **156**. For this embodiment, each fan blade **154** of the fan **152** is rotatable about their respective central blade axis **156**, e.g., in unison with one another. One or more actuators **158** are provided to facilitate such rotation and therefore may be used to change a pitch of the fan blades **154** about their respective central blade axis **156**.

[0030] The fan section **150** further includes a fan guide vane array **160** that includes fan guide vanes **162** (only one shown in FIG. **1**) disposed around the longitudinal axis **112**. For this embodiment, the fan guide vanes **162** are not rotatable about the longitudinal axis **112**. Each fan guide vane **162** has a root and a tip and a span defined therebetween. The fan guide vanes **162** may be unshrouded as shown in FIG. **1** or, alternatively, may be shrouded, e.g., by an annular shroud spaced outward from the tips of the fan guide vanes **162** along the radial direction R or attached to the fan guide vanes **162**.

[0031] Each fan guide vane **162** defines a central blade axis **164**. For this embodiment, each fan guide vane **162** of the fan guide vane array **160** is rotatable about their respective central blade axis **164**, e.g., in unison with one another. One or more actuators **166** are provided to facilitate such rotation and therefore may be used to change a pitch of the fan guide vane **162** about their respective central blade axis **164**. However, in other embodiments, each fan guide vane **162** may be fixed or unable to be pitched about its central blade axis **164**. The fan guide vanes **162** are mounted to a fan cowl **170**.

[0032] As shown in FIG. **1**, in addition to the fan **152**, which is unducted, a ducted fan **184** is included aft of the fan **152**, such that the gas turbine engine **100** includes both a ducted and an unducted fan which both serve to generate thrust through the movement of air without passage through at least a portion of the turbomachine **120** (e.g., the HP compressor **128** and combustion section for the embodiment depicted). The ducted fan **184** may be at about the same axial location as the fan blade **154** or the vanes **162**, and radially inward of the fan blade **154** or the vanes **162**. The ducted fan **184**, for the embodiment depicted, is driven by the low pressure turbine **134** (e.g., coupled to the LP shaft **138**).

[0033] The fan cowl **170** annularly encases at least a portion of the core cowl **122** and is generally positioned outward of at least a portion of the core cowl **122** along the radial direction R. Particularly, a downstream section of the fan cowl **170** extends over a forward portion of the core cowl **122** to define a fan flow path or fan duct **172**. The fan flowpath or fan duct **172** may be referred to as a third stream of the gas turbine engine **100**.

[0034] Incoming air may enter through the fan duct **172** through a fan duct inlet **176** and may exit through a fan exhaust nozzle **178** to produce propulsive thrust. The fan duct **172** is an annular duct positioned generally outward of the core duct **142** along the radial direction R. The fan cowl **170** and the core cowl **122** are connected together and supported by a plurality of substantially radially-extending, circumferentially-spaced stationary struts **174** (only one shown in FIG. **1**). The stationary struts **174** may each be aerodynamically contoured to direct air flowing thereby. Other struts in addition to the stationary struts **174** may be used to connect and support the fan cowl **170** and/or core cowl **122**. In many embodiments, the fan duct **172** and the core duct **142** may at least partially co-extend (generally axially) on opposite sides (e.g., opposite radial sides) of the core cowl **122**. For example, the fan duct **172** and the core duct **142** may each extend directly from a leading edge **144** of the core cowl **122** and may partially co-extend generally axially on opposite radial sides of the core cowl.

[0035] The gas turbine engine **100** also defines or includes an inlet duct **180**. The inlet duct **180** extends between an engine inlet **182** and the core inlet **124**/fan duct inlet **176**. The engine inlet **182** is defined generally at the forward end of the fan cowl **170** and is positioned between the fan **152** and the fan guide vane array **160** along the axial direction A. The inlet duct **180** is an annular duct that is positioned inward of the fan cowl **170** along the radial direction R. Air flowing downstream along the inlet duct **180** is split, not necessarily evenly, into the core duct **142** and the fan duct **172** by a splitter or leading edge **144** of the core cowl **122**. The inlet duct **180** is wider than the core duct **142** along the radial direction R. The inlet duct **180** is also wider than the fan duct **172** along the radial direction R.

[0036] Next referring to FIG. **2**, a block diagram of an implementation of the engine **100** is shown. The engine **100** includes an engine controller **210** configured to receive input from a time-of-flight (TOF) sensor **250** and control the position of one or more effectors **265** via effector actuators **260**. In some embodiments, the engine controller **210** includes a processor and one or more memory storage devices storing executable codes that cause the processor to perform one or more steps described with reference to FIG. **3** herein. The engine controller **210** may be configured to send control signals to the effector actuator **260** based on effector positions determined according to signals from the TOF sensor **250**. In some embodiments, the engine controller **210** is a processor-based control system of an engine, such as a full-authorization digital engine control (“FADEC”) of the engine **100**. In some embodiments, the engine controller **210** may include an effector control circuit separate from the FADEC and/or an effector control software module executed by the FADEC. In some embodiments, the engine controller **210** is configured to change the position of the effector **265** in response to a signal (e.g., throttle) from an aircraft controller and/or based on a predetermined schedule. In some embodiments, to change the effector **265** to a select position, the engine controller **210** may incrementally increase or decrease an angle of the effector **265** via effector actuator **260** until the sensor **250** senses effector **265** at the select position. It should be noted that FIG. **2** is only a simplified block diagram, the engine controller **210** may further be configured to control other engine components.

[0037] The effector actuator **260** is an engine component that physically alters the position of an effector **265**. In some embodiments, the effector actuator **260** includes components for converting electrical power to effector **265** movement based on a signal received from the engine controller **210**. In some embodiments, the effector **265** may include variable geometry devices with geometry (e.g., pitch) that can be physically manipulated by the effector actuator **260** to effect thrust or airflow of the engine **100**. In some embodiments, the effector actuator **260** includes a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, or a variable nozzle actuator. In some embodiments, the effector actuator **260** is coupled to rotating fan blades of the engine such as fan blade **154** described with reference to FIG. **1**. In some embodiments, the effector actuator **260** is coupled to stationary vanes of the engine such as fan guide vanes **162** described with reference to FIG. **1**. In some embodiments, the effector actuator **260** may be actuator **158** or actuator **166** described with reference to FIG. **1**. In some embodiments, the effector **265** may include one or more of variable pitch blades, variable stator vanes, inlet guide vanes, outlet guide vanes, a bleed valve, a variable nozzle, etc.

[0038] The effector actuator **260** may include one or more static portions and one or more movable elements. Generally, the static portion remains in the same position relative to the housing of the effector actuator **260** and/or the engine **100**. For example, the static portion may include a part of the housing of the effector actuator **260** and/or a mount coupled to the housing. The movable element may generally be an element that moves relative to the static portion with the actuation of the effector **265**. In some embodiments, the movable element is a linear motion component of the effector actuator. For example, the movable element may be a piston rod, a crank arm, or a stem that linearly displaces with the changing of the effector position. In some embodiments, in addition to linear displacement, the movable element is also rotating within the housing of the effector actuator. For example, the movable element may be part of the actuator **158** coupled to and rotates with the rotating fan blades of the fan **152**.

[0039] The TOF sensor **250** is generally positioned to measure the distance from the TOF sensor **250** to a reflecting surface within the effector actuator **260**. The TOF sensor **250** is configured to send out an energy wave (e.g., ultrasound) through a medium (e.g., working fluid) towards a reflecting surface and measures the time for the wave to travel to the reflecting surface and back to the sensor. The travel time is then converted to a distance based on a known or calibrated speed of the wave through the medium. In some embodiments, the TOF sensor **250** is an ultrasonic range sensor such as a MEMS (micro-electromechanical system) PMUT (Piezoelectric Micromachined Ultrasonic Transducer) sensor. In some embodiments, the TOF sensor **250** may include other types of range sensors, such as an optical, laser, acoustic, and/or electromagnetic TOF sensor.

[0040] In some embodiments, the TOF sensor **250** is mounted on a movable element of the effector actuator **260** and the reflecting surface is a surface of the static portion of the effector actuator **260**. For example, in FIG. **4**A, a piston **400** representing an effector actuator **260** is shown. The piston **400** includes a cylinder **410** and a piston rod **420**. The cylinder **410** encloses a cavity **430** filled with a working fluid (e.g., fluid oil, gas, air, water or oil-based solution, etc.) and is coupled to kinematics **415** for affecting the position of an effector **265**. In the embodiment shown in FIG. **4**A, the sensor **250**A is mounted on the movable piston rod **420** and the reflecting surface **255**A is a static surface of the cylinder **410**.

[0041] In some embodiments, the TOF sensor **250** is mounted on a static portion of the effector actuator **260** and the reflecting surface is a surface of a movable element of the effector actuator **260**. For example, as shown in FIG. **4**B, the sensor **250**B may be mounted on the cylinder **410** of the piston **400** and the reflecting surface **255**B may be part of the piston rod **420**.

[0042] In some embodiments, the engine **100** further includes a calibration mechanism to calibrate the distance measurement of the TOF sensor **250** to account for variations in the speed of the wave traveling through the working fluid at different temperatures, pressures, and aeration levels. The calibration mechanism may include a calibration surface and/or a second calibration TOF sensor. In some embodiments, the calibration mechanism may include operating condition sensors and a software algorithm. Further details of example calibration mechanisms are described with reference to FIG. **3**, FIGS. **5**A, and **5**B herein.

[0043] Next referring to FIG. **3**, a method **300** for engine effector position measurement and control is shown. In some embodiments, one or more steps of FIG. **3** are performed with a processor-based control system of an engine, such as the engine controller **210** of the engine **100**.

[0044] In step **320**, the distance between a TOF sensor **250** within a housing of an effector actuator **260** and a reflecting surface is measured. The TOF sensor **250** may be an ultrasonic range sensor such as a MEMS PMUT sensor. In some embodiments, the TOF sensor **250** may be other types of sensors capable of measuring distance through a medium. In some embodiments, the distance is measured based on TOF=2*L/C, wherein L represents length and C represents speed of sound in the medium.

[0045] In some applications of the described system and method, the medium through which the TOF sensor **250** measures the distance includes a primary medium with an oil temperature of between −40° F. to 300° F. and a pressure of up to about 2000 psia. In some embodiments, the oil temperature may be up to 320° F. or 350° F. The speed of sound in the working fluid may be around 1,450 m/s in ambient conditions. However, the speed of sound may vary up to ˜30% based on operating conditions (e.g., temperature, pressure, aeration, etc.). The actuator stroke may be 0.5 to 7.0 inches (1.27 to 17.78 centimeters), in which case the total travel distance of the TOF sensor wave is two times the stroke, which is around 1 to 14 inches (2.54 to 35.56 centimeters). The TOF of the sensor wave from the sensor to the reflecting surface and back may be 17.5 to 242.5 us (microseconds). In some embodiments, with up to 30% tolerance, the TOF may be between 12.2 us to 314.4 us. The carrier frequency range may be 1 to 10 megahertz (MHz). In some embodiments, the carrier frequency range may be 1 to 20 MHz. In some embodiments, the carrier frequency range may be selected based on the medium and length to be measured to increase resolution/accuracy and reduce attenuation. In some embodiments, the engine controller **210** may include circuitry capable of computing TOF with a resolution of 1 microsecond (us) to obtain accuracies of around 0.75 mm in oil. For a six-inch (15.24 cm) stroke actuation, such processor provides around 0.5% in accuracy due to the resolution. For a seven-inch (17.78 centimeters) stroke actuation, such processor provides around 0.4% accuracy. In some embodiments, the TOF may have a field of view (FoV) of 5° or lower, as the location of the reflecting surface is known and aligned with the sensor.

[0046] In some embodiments, in step **310**, a calibration is performed. In some embodiments, the calibration may be based on determining the speed of the wave through a medium. As described above, operating conditions of the effector actuator **260** may affect the speed of a wave through the working fluid of the effector actuator **260**. To obtain an accurate distance measurement, the engine controller **210** may calibrate the measured TOF in step **310**. In some embodiments, the speed may be determined via the operating conditions of the effector actuator **260**. For example, the engine **100** and/or the effector actuator **260** may include one or more sensors for measuring operating condition (e.g., temperature, pressure, aeration, etc.). The measured operating conditions may be used to determine the speed of the sensor wave in the medium. The distance is then calculated based on the TOF measured by the effector actuator **260** and the determined speed under the measured conditions. In some embodiments, the speed of the wave in the medium may be determined based on an equation or a lookup table using the measured operating conditions.

[0047] In some embodiments, the calibration may be performed based on a calibration measurement taken inside the effector actuator **260**. In some embodiments, the calibration measurement may be made contemporaneously with the distance measurement in step **320**. In some embodiments, the calibration measurement may be performed at lower, same, or higher frequency compared to the distance measurement in step **320**. In some embodiments, as shown in FIG. **5**A, the effector actuator **260** includes a separate calibration sensor **510** positioned at a known distance Lc from a calibration surface **515**. The calibration sensor **510** may be a second TOF sensor. The calibration surface **515** may be an existing static part of the effector actuator **260** or a surface specifically added to the effector actuator **260** for calibration. For example, the calibration surface **515** may be coupled to the calibration sensor **510** at a fixed distance. The engine controller **210** may use the travel time (TOFc) measured by the calibration sensor **510** and the known distance (Lc) to the calibration surface **515** to determine the speed of the wave through the medium (C) at the current operating condition based on TOFc=2*Lc/C. For example, if a calibration sensor **510** positioned at 4 cm from a calibration surface **515** measures a TOFc of 1 ms, C of the medium under that current operating condition may be determined to be 0.0125 s/m. The speed of the wave through the medium may then be used to determine the distance L between the TOF sensor **250** and the reflecting surface **255** being measured. For example, when the TOF sensor **250** measures a TOF of 2 ms under the sane operating condition, L can be determined according to TOF/2/0.125 s/m=8 cm.

[0048] In other embodiments, as shown in FIG. **5**B, instead of a separate calibration sensor, the effector actuator **260** may include a calibration surface **515***a* configured to reflect a part of a wave transmitted by the TOF sensor **250** while allowing a remaining wave to pass through to the reflecting surface **255** being measured. The calibration surface **515***a* may, for example, be a low-density or mixed-density solid. The speed of the wave through the medium (C) can be similarly derived based on the known Lc to the calibration surface **515***a* in this configuration to calibrate the distance L measurement.

[0049] In step **330**, the engine controller **210** determines an effector position based on the distance measured in step **320**. In some embodiments, the engine controller **210** may store an equation or a lookup table for converting the measured distance to the reflecting surface (e.g., centimeter) to an effector position (e.g., pitch angle).

[0050] In step **340**, the engine controller **210** sends a signal to change the effector position at least partially based on the effector position determined in step **330**. For example, the engine controller **210** may compare the measured position with a target position determined based on an engine schedule and/or flight control input. The engine controller **210** may actuate the effector **265** open or close to match the target position based on the measured effector position. In some embodiments, the engine controller **210** may incrementally instruct the effector actuator **260** to modify the position of the effector **265** until the measured effector position reaches the target position. In some embodiments, the engine controller **210** may use the measured effector position to confirm successful actuation of the effector **265** and generate an alert or modify the controls of other effectors if the target effector position cannot be achieved.

[0051] With the system shown in FIG. **2** and the process shown in FIG. **3**, a compact sensor system is provided within an effector actuator **260**, which reduces overall sensor envelope and increases sensor reliability. The sensor system may further be self-correcting/compensating to maintain distance measurement accuracy under different operating conditions.

[0052] Further aspects of the disclosure are provided by the subject matter of the following clauses:

[0053] A system for engine effector position measurement includes an effector actuator of an engine, the effector actuator including a house and one or more movable elements for changing an effector position of an effector coupled to the effector actuator; and a time-of-flight (TOF) sensor within a housing of the effector actuator and positioned to measure a distance between the TOF sensor and a reflecting surface within the housing to determine the effector position of the effector.

[0054] The system of any preceding clauses, wherein the TOF sensor is mounted on a static portion of the effector actuator and the reflecting surface is a surface of a movable element.

[0055] The system of any preceding clauses, wherein the TOF sensor is mounted on a movable element and the reflecting surface is a surface of a static portion of the effector actuator.

[0056] The system of any preceding clauses, wherein the effector actuator includes a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, or a variable nozzle actuator.

[0057] The system of any preceding clauses, wherein the one or more movable elements include a linear motion component of the effector actuator.

[0058] The system of any preceding clauses, wherein the TOF sensor includes an ultrasonic sensor.

[0059] The system of any preceding clauses, further includes a calibration sensor including a second TOF sensor and a calibration surface at a known distance from the second TOF sensor, wherein the distance is measured based on calibrating a travel time measured by the TOF sensor based on a calibration travel time measured by the calibration sensor.

[0060] The system of any preceding clauses, further includes a calibration surface at a known distance from the TOF sensor, and wherein the distance is measured based on calibrating a travel time associated with the reflecting surface based on a calibration travel time associated with the calibration surface.

[0061] The system of any preceding clauses, wherein the calibration surface is configured to reflect a part of a wave transmitted by the TOF sensor while allowing a remaining wave to pass through to the reflecting surface.

[0062] The system of any preceding clauses, wherein the TOF sensor is positioned inside a cavity filled with a working fluid of the effector actuator.

[0063] The system of any preceding clauses, wherein the one or more movable elements include a piston that linearly displaces with changing of the effector position.

[0064] The system of any preceding clauses, wherein the effector actuator is coupled to rotating fan blades of the engine.

[0065] The system of any preceding clauses, wherein the effector actuator is coupled to stationary vanes of the engine.

[0066] The system of any preceding clauses, wherein the reflecting surface is rotating within the housing of the effector actuator.

[0067] A method for engine effector position measurement includes measuring, with a time-of-flight (TOF) sensor within a housing of an effector actuator of an engine, a distance between the TOF sensor and a reflecting surface within the housing, wherein the effector actuator including a static portion and one or more movable elements for changing an effector position of an effector coupled to the effector actuator; and determining, with a processor, the effector position of the effector based on the distance measured by the TOF sensor; and controlling, from the processor, the effector actuator based on the effector position.

[0068] The method of any preceding clauses, wherein the effector actuator includes a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, and a variable nozzle actuator.

[0069] The method of any preceding clauses, wherein the distance is measured based on calibrating a travel time measured by the TOF sensor based on a calibration travel time measured by a calibration sensor, wherein the calibration sensor including a second TOF sensor and a calibration surface at a known distance from the second TOF sensor.

[0070] The method of any preceding clauses, further wherein the distance is measured based on calibrating a travel time associated with the reflecting surface using a speed of wave traveling through a medium determined based on a calibration travel time associated with a calibration surface at a known distance from the TOF sensor.

[0071] The method of any preceding clauses, wherein the calibration surface is configured to reflect a part of a wave transmitted by the TOF sensor while allowing a remaining wave to pass through to the reflecting surface.

[0072] The method of any preceding clauses, wherein the TOF sensor is positioned inside a cavity filled with a working fluid of the effector actuator.

[0073] A system for engine effector position measurement including: a time-of-flight (TOF) sensor within a housing of an effector actuator of an engine, the effector actuator including a static portion and one or more movable elements for changing an effector position of an effector coupled to the effector actuator, wherein the TOF sensor is positioned to measure a distance between the TOF sensor and a reflecting surface within the housing; and a processor configured to determine the effector position of the effector based on the distance measured by the TOF sensor.

[0074] The system of any of the preceding clauses, wherein the TOF sensor is mounted on the static portion of the effector actuator and the reflecting surface is a surface of a movable element.

[0075] The system of any of the preceding clauses, wherein the TOF sensor is mounted on a movable element of the effector actuator and the reflecting surface is a surface of the static portion.

[0076] The system of any of the preceding clauses, wherein the effector actuator includes a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, or a variable nozzle actuator.

[0077] The system of any of the preceding clauses, wherein the one or more movable elements include a linear motion component of the effector actuator.

[0078] The system of any of the preceding clauses, wherein the TOF sensor includes an ultrasonic sensor.

[0079] The system of any of the preceding clauses, further including a calibration sensor including a second TOF sensor and a calibration surface at a known distance from the second TOF sensor, wherein the distance is measured based on calibrating a travel time measured by the TOF sensor based on a calibration travel time measured by the calibration sensor.

[0080] The system of any of the preceding clauses, further including a calibration surface at a known distance from the TOF sensor, and wherein the distance is measured based on calibrating a travel time associated with the reflecting surface based on a calibration travel time associated with the calibration surface.

[0081] The system of any of the preceding clauses, wherein the calibration surface is configured to reflect a part of a wave transmitted by the TOF sensor while allowing a remaining wave to pass through to the reflecting surface.

[0082] The system of any of the preceding clauses, wherein the TOF sensor is positioned inside a cavity filled with a working fluid of the effector actuator.

[0083] The system of any of the preceding clauses, wherein the one or more movable elements include a piston that linearly displaces with changing of the effector position.

[0084] The system of any of the preceding clauses, wherein the effector actuator is coupled to rotating fan blades of the engine.

[0085] The system of any of the preceding clauses, wherein the effector actuator is coupled to stationary vanes of the engine.

[0086] The system of any of the preceding clauses, wherein the reflecting surface is rotating within the housing of the effector actuator.

[0087] A method for engine effector position measurement, the method including measuring, with a time-of-flight (TOF) sensor within a housing of an effector actuator of an engine, a distance between the TOF sensor and a reflecting surface within the housing, wherein the effector actuator includes a static portion and one or more movable elements for changing an effector position of an effector coupled to the effector actuator; and determining, with a processor, the effector position of the effector based on the distance measured by the TOF sensor.

[0088] The method of any of the preceding clauses, wherein the TOF sensor is mounted on the static portion of the effector actuator and the reflecting surface is a surface of a movable element.

[0089] The method of any of the preceding clauses, wherein the TOF sensor is mounted on a movable element of the effector actuator and the reflecting surface is a surface of the static portion.

[0090] The method of any of the preceding clauses, wherein the effector actuator includes a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, and a variable nozzle actuator.

[0091] The method of any of the preceding clauses, wherein the one or more movable elements include a linear motion component of the effector actuator.

[0092] The method of any of the preceding clauses, wherein the TOF sensor includes an ultrasonic sensor.

[0093] The method of any of the preceding clauses, wherein the distance is measured based on calibrating a travel time measured by the TOF sensor based on a calibration travel time measured by a calibration sensor, wherein the calibration sensor includes a second TOF sensor and a calibration surface at a known distance from the second TOF sensor.

[0094] The method of any of the preceding clauses, further wherein the distance is measured based on calibrating a travel time associated with the reflecting surface based on a calibration travel time associated with a calibration surface at a known distance from the TOF sensor.

[0095] The method of any of the preceding clauses, wherein the calibration surface is configured to reflect a part of a wave transmitted by the TOF sensor while allowing a remaining wave to pass through to the reflecting surface.

[0096] The method of any of the preceding clauses, wherein the TOF sensor is positioned inside a cavity filled with a working fluid of the effector actuator.

[0097] The method of any of the preceding clauses, wherein the one or more movable elements

include a piston that linearly displaces with changing of the effector position.
[0098] The method of any of the preceding clauses, wherein the effector actuator is coupled to rotating fan blades of the engine.
[0099] The method of any of the preceding clauses, wherein the effector actuator is coupled to stationary vanes of the engine.
[0100] The method of any of the preceding clauses, wherein the reflecting surface is rotating within the housing of the effector actuator.
[0101] This written description uses examples to disclose the present disclosure, including the best mode, and also to enable any person skilled in the art to practice the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

Claims

1. A system for engine effector position measurement, the system comprising: an effector actuator of an engine, the effector actuator comprising a house and one or more movable elements for changing an effector position of an effector coupled to the effector actuator; and a time-of-flight (TOF) sensor within a housing of the effector actuator and positioned to measure a distance between the TOF sensor and a reflecting surface within the housing to determine the effector position of the effector.
2. The system of claim 1, wherein the TOF sensor is mounted on a static portion of the effector actuator and the reflecting surface is a surface of a movable element.
3. The system of claim 1, wherein the TOF sensor is mounted on a movable element and the reflecting surface is a surface of a static portion of the effector actuator.
4. The system of claim 1, wherein the effector actuator comprises a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, or a variable nozzle actuator.
5. The system of claim 1, wherein the one or more movable elements comprise a linear motion component of the effector actuator.
6. The system of claim 1, wherein the TOF sensor comprises an ultrasonic sensor.
7. The system of claim 1, further comprises a calibration sensor comprising a second TOF sensor and a calibration surface at a known distance from the second TOF sensor, wherein the distance is measured based on calibrating a travel time measured by the TOF sensor based on a calibration travel time measured by the calibration sensor.
8. The system of claim 1, further comprises a calibration surface at a known distance from the TOF sensor, and wherein the distance is measured based on calibrating a travel time associated with the reflecting surface based on a calibration travel time associated with the calibration surface.
9. The system of claim 8, wherein the calibration surface is configured to reflect a part of a wave transmitted by the TOF sensor while allowing a remaining wave to pass through to the reflecting surface.
10. The system of claim 1, wherein the TOF sensor is positioned inside a cavity filled with a working fluid of the effector actuator.
11. The system of claim 1, wherein the one or more movable elements comprise a piston that linearly displaces with changing of the effector position.
12. The system of claim 1, wherein the effector actuator is coupled to rotating fan blades of the engine.

13. The system of claim 1, wherein the effector actuator is coupled to stationary vanes of the engine.

14. The system of claim 1, wherein the reflecting surface is rotating within the housing of the effector actuator.

15. A method for engine effector position measurement, the method comprising: measuring, with a time-of-flight (TOF) sensor within a housing of an effector actuator of an engine, a distance between the TOF sensor and a reflecting surface within the housing, wherein the effector actuator comprising a static portion and one or more movable elements for changing an effector position of an effector coupled to the effector actuator; and determining, with a processor, the effector position of the effector based on the distance measured by the TOF sensor; and controlling, from the processor, the effector actuator based on the effector position.

16. The method of claim 15, wherein the effector actuator comprises a blade pitch actuator, a stator vane actuator, an inlet guide vane pitch actuator, an outlet guide vane pitch actuator, a bleed valve actuator, and a variable nozzle actuator.

17. The method of claim 15, wherein the distance is measured based on calibrating a travel time measured by the TOF sensor based on a calibration travel time measured by a calibration sensor, wherein the calibration sensor comprising a second TOF sensor and a calibration surface at a known distance from the second TOF sensor.

18. The method of claim 15, further wherein the distance is measured based on calibrating a travel time associated with the reflecting surface using a speed of wave traveling through a medium determined based on a calibration travel time associated with a calibration surface at a known distance from the TOF sensor.

19. The method of claim 18, wherein the calibration surface is configured to reflect a part of a wave transmitted by the TOF sensor while allowing a remaining wave to pass through to the reflecting surface.

20. The method of claim 15, wherein the TOF sensor is positioned inside a cavity filled with a working fluid of the effector actuator.