

TORQUE CONTROL METHODS FOR VEHICLES HAVING A CONTINUOUSLY VARIABLE PLANETARY

CROSS-REFERENCE

[0001] The present application claims the benefit of U.S. Provisional Application No. 62/236,584, filed October 2, 2015, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] Automatic and manual transmissions are commonly used in the automotive market. Those transmissions have become more and more complicated since the engine speed has to be properly adjusted to improve fuel economy and minimize the emissions. This finer control of the engine speed in conventional transmissions can typically be done by adding extra gears but with increased overall complexity and cost. Thus, the number of gears for a usual manual transmission became six, seven or more for automatic transmissions.

[0003] In addition to these more conventional transmissions, Continuously Variable Transmissions (CVT) have been developed. CVTs are of many types including: belts with variable pulleys, toroidal, conical, etc. The main working principle of a CVT is that it enables the engine to run at its most efficient rotation speed by steplessly changing the transmission ratio as a function of the vehicle speed. However there are still limitations regarding torque peaks and controllability of the speed ratio of the CVT in a number of different applications. Thus there is a need for an improved method of control.

SUMMARY OF THE INVENTION

[0004] The CVT can shift to a ratio providing more power if higher acceleration is needed. A CVT can change the ratio from the minimum to the maximum ratio without any interruption of power, unlike conventional transmissions which cause an interruption of power during ratio shifts. A specific use of CVTs is the Infinite Variable Transmission (IVT). Whereas the CVT is limited at positive speed ratios, the IVT configuration can perform a neutral gear and even reverse ratios continuously. A CVT can also be used as an IVT in some driveline configurations.

[0005] Provided herein is a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions; a

plurality of sensors comprising: a vehicle direction sensor configured to sense a vehicle direction, a vehicle speed sensor configured to sense a vehicle speed, a brake pedal position sensor configured to sense a brake pedal position, an accelerator pedal position sensor configured to sense an accelerator pedal position, a CVP carrier position sensor configured to sense a CVP carrier position, a parking brake status sensor configured to sense a parking brake status, an engine speed sensor configured to sense an engine speed, a first speed sensor configured to sense a CVP input speed, a second speed sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed are adapted to provide a CVP speed ratio, and a CVP reaction torque sensor configured to sense a CVP reaction torque; wherein the software module monitors the CVP carrier position and the CVP speed ratio; and wherein the software module commands a change in the shift position of the CVP based at least in part on the CVP reaction torque. In some embodiments of the computer-implemented system, the software module is configured to execute instructions from a CVT torque control sub-module, wherein the CVT torque control sub-module determines a command for a CVP shift actuator based at least in part on the CVP reaction torque. In some embodiments of the computer-implemented system, the CVP reaction torque is a measured signal provided by a CVP shift actuator. In some embodiments of the computer-implemented system, the CVP reaction torque is a pressure signal. In some embodiments of the computer-implemented system, the CVP reaction torque is an electrical current signal. In some embodiments of the computer-implemented system, a shift actuator control sub-module is configured to determine a commanded CVP carrier position based on the CVP reaction torque. In some embodiments of the computer-implemented system, a torque measurement correction sub-module is configured to learn and correct a relationship between the CVP reaction torque and the CVP carrier position. In some embodiments of the computer-implemented system, the torque measurement correction sub-module comprises a control process, the control process comprising the steps of: reading a map from memory, the map configured to store values indicative of a torque correction factor based at least in part on the CVP carrier position; measuring the CVP reaction torque; and determining a torque correction factor. In some embodiments of the computer-implemented system, the control process further comprises comparing the measured CVP carrier reaction torque to a torque value, the torque value read from the memory, wherein the comparison forms the torque correction factor. In some embodiments of the computer-implemented system, the control process further comprises storing the torque correction factor in memory. In some embodiments of the computer-implemented system, the map is a piecewise linear function of torque based at least in part on the CVP carrier position.

[0006] Provided herein is a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions; a plurality of sensors comprising: a CVP carrier position sensor configured to sense a carrier position, a CVP input speed sensor configured to sense a CVP input speed, a CVP output speed sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed form a CVP speed ratio, and a CVP shift actuator force sensor configured to sense a CVP shift actuator force; wherein the software module monitors the CVP carrier position and the CVP speed ratio; and wherein the software module commands a change in a shift position of the CVP based at least in part on the CVP shift actuator force. In some embodiments of the computer-implemented system, the plurality of sensors further comprises: a gear lever indicator configured to sense a gear lever position, a vehicle speed sensor configured to sense a vehicle speed, a brake pedal position sensor configured to sense a brake pedal position, and an accelerator pedal position sensor configured to sense an accelerator pedal position. In some embodiments of the computer-implemented system, the software module further comprises a carrier torque sub-module, the carrier torque sub-module configured to determine a carrier reaction torque based at least in part on the CVP shift actuator force. In some embodiments of the computer-implemented system, the software module further comprises a CVP control sub-module, the CVP control sub-module configured to determine a commanded CVP position signal based at least in part on the carrier reaction torque. In some embodiments of the computer-implemented system, the software module further comprises a calibration map, the calibration map configured to store values of a desired output torque based at least in part on the accelerator pedal position. In some embodiments of the computer-implemented system, a difference between the desired output torque and the carrier reaction torque form a torque error. In some embodiments of the computer-implemented system, the software module further comprises a CVP control sub-module, the CVP control sub-module configured to determine a commanded CVP carrier position based at least in part on the torque error. In some embodiments of the computer-implemented system, the CVP control sub-module comprises a PID controller. In some embodiments of the computer-implemented system, the software module further comprises an actuator manager sub-module, the actuator manager sub-module adapted to determine the CVP shift actuator force and a measured CVP carrier position. In some embodiments of the

computer-implemented system, the software module is configured to execute a control process, the control process comprising the steps of: determining a desired output torque based at least in part on a driver's input; measuring a carrier reaction force based on the CVP shift actuator force; measuring the CVP carrier position; determining a carrier reaction torque based at least in part on the carrier reaction force and the carrier position; comparing the desired output torque to the carrier reaction torque; and determining a carrier position set point based at least in part on a comparison between the carrier reaction torque and the desired torque.

[0007] Provided herein is a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions; a plurality of sensors comprising: a vehicle speed sensor configured to sense a vehicle speed, a first sensor configured to sense a CVP input speed, an engine torque indicator configured to provide an engine torque, an accelerator pedal position sensor configured to provide an accelerator pedal position, a second sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed form a CVP speed ratio, and a brake pedal position sensor configured to sense a brake pedal position; wherein the software module is configured to execute instructions provided by a torque-based control module; and wherein the torque-based control module includes a plurality of calibration maps, each calibration map configured to store values of a desired output torque based at least in part on the sensors. In some embodiments of the computer-implemented system, the software module further comprises a speed ratio-based control module, wherein the speed ratio-based control module includes a plurality of calibration maps, each calibration configured to store values of a desired CVP speed ratio based at least in part on the sensors. In some embodiments of the computer-implemented system, the software module is configured to transition between the torque-based control module and the speed ratio-based control module based at least in part on vehicle speed.

INCORPORATION BY REFERENCE

[0008] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0010] **Figure 1** is a side sectional view of a ball-type variator.

[0011] **Figure 2** is a plan view of a carrier member that can be used in the variator of Figure 1.

[0012] **Figure 3** is an illustrative view of different tilt positions of the ball-type variator of Figure 1.

[0013] **Figure 4** is a block diagram of a basic driveline configuration of a continuously variable transmission (CVT) used in a vehicle.

[0014] **Figure 5** is a schematic diagram depicting reaction forces on a ball used in the variator of Figure 1.

[0015]

[0016] **Figure 6** is a block diagram of a vehicle control system implementing the variator of Figure 1.

[0017] **Figure 7** is a block diagram of a transmission control module that can be implemented in the vehicle control system of Figure 7.

[0018] **Figure 8** is a flow chart depicting a control process that can be implemented in the vehicle control system of Figure 7.

[0019] **Figure 9** is a block diagram of a transmission controller that can be implemented in the vehicle control system of Figure 7.

[0020] **Figure 10** is a chart depicting the relationship between a carrier position and reaction torque.

[0021] **Figure 11** is a flow chart depicting a control process that can be implemented in the transmission controller of Figure 10.

[0022] **Figure 12** is a chart depicting a transition between a torque based control strategy and a speed based control strategy.

DETAILED DESCRIPTION OF THE INVENTION

[0023] This invention relates to controlling the operating conditions of a Continuous Variable Transmission with an electronic control system configured to receive signals and execute commands based at least in part on a driver's torque or load request. The driver can give input to the vehicle in three ways: the brake pedal, the accelerator pedal, and the joystick (operating auxiliaries). The brake pedal and accelerator pedal input signals are mainly related to the

requested total vehicle action; the joystick signals are mainly related to operation of auxiliary devices equipped on the vehicle. The auxiliary devices are, for example: hydraulic functions, additional power consumers, etc. In general, the auxiliary devices use power from the engine. The controller described herein uses a plurality of measurements available which give information on this vehicle status. Some of the measurements or signals are: engine speed, transmitted torque, transmission output speed, temperatures, gearbox settings, brake pedal position, accelerator pedal position (sometimes referred to as a gas pedal), engine throttle position, among others.

[0024] The preferred embodiments will now be described with reference to the accompanying figures, wherein like numerals refer to like elements throughout. The terminology used in the descriptions below is not to be interpreted in any limited or restrictive manner simply because it is used in conjunction with detailed descriptions of certain specific embodiments of the invention. Furthermore, embodiments of the invention can include several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the inventions described.

[0025] Provided herein are configurations of CVTs based on a ball type variators, also known as CVP, for continuously variable planetary. Basic concepts of a ball type Continuously Variable Transmissions are described in United States Patent No. 8,469,856 and 8,870,711 incorporated herein by reference in their entirety. Such a CVT, adapted herein as described throughout this specification, comprises a number of balls (planets, spheres) 1, depending on the application, two ring (disc) assemblies contact the balls, as input 2 and output 3, and an idler (sun) assembly 4 as shown on **FIG. 1**. The balls are mounted on tiltable axles 5, themselves held in a carrier (stator, cage) assembly having a first carrier member 6 operably coupled to a second carrier member 7. The first carrier member 6 can rotate with respect to the second carrier member 7, and vice versa. In some embodiments, the first carrier member 6 can be substantially fixed from rotation while the second carrier member 7 is configured to rotate with respect to the first carrier member, and vice versa. In some embodiments, the first carrier member 6 is provided with a number of radial guide slots 8. The second carrier member 9 is provided with a number of radially offset guide slots 9. The radial guide slots 8 and the radially offset guide slots 9 are adapted to guide the tiltable axles 5. The axles 5 are adjusted to achieve a desired ratio of input speed to output speed during operation of the CVT. In some embodiments, adjustment of the axles 5 involves control of the position of the first and second carrier members to impart a tilting of the axles 5 and thereby adjusts the speed ratio of the variator. Other types of ball CVTs also exist, like the one produced by Milner, but are slightly different.

[0026] The working principle of such a CVP of FIG. 1 is shown on **FIG. 2**. The CVP itself works with a traction fluid. The lubricant between the ball and the rings acts as a solid at high pressure, transferring the power from the input ring, through the balls, to the output ring. By tilting the balls' axes, the ratio is changed between input and output. When the axis is horizontal the ratio is one, illustrated in **FIG. 3**, when the axis is tilted the distance between the axis and the contact point change, modifying the overall ratio. All the balls' axes are tilted at the same time with a mechanism included in the carrier and/or idler. Embodiments of the invention disclosed here are related to the control of a variator and/or a CVT using generally spherical planets each having a tiltable axis of rotation that is adjusted to achieve a desired ratio of input speed to output speed during operation. In some embodiments, adjustment of said axis of rotation involves angular misalignment of the planet axis in a first plane in order to achieve an angular adjustment of the planet axis in a second plane that is substantially perpendicular to the first plane, thereby adjusting the speed ratio of the variator. The angular misalignment in the first plane is referred to here as “skew”, “skew angle”, and/or “skew condition”. In some embodiments, a control system coordinates the use of a skew angle to generate forces between certain contacting components in the variator that will tilt the planet axis of rotation. The tilting of the planet axis of rotation adjusts the speed ratio of the variator.

[0027] Upon reading this disclosure, one skilled in the art will recognize that the present invention includes a continuously variable transmission that may be employed in connection with any type of machine that is in need of a transmission. For example, the transmission may be used in (i) a motorized vehicle such as an automobile, motorcycle, ATV, utility, hybrid or watercraft, (ii) a non-motorized vehicle such as a bicycle, tricycle, exercise equipment or (iii) industrial equipment, such as an end mill, lathe, drill press, pumps, power generating equipment, paper or textile mill to name a few machines that utilize transmissions.

[0028] As used here, the terms “operationally connected,” “operationally coupled”, “operationally linked”, “operably connected”, “operably coupled”, “operably linked,” and like terms, refer to a relationship (mechanical, linkage, coupling, etc.) between elements whereby operation of one element results in a corresponding, following, or simultaneous operation or actuation of a second element. It is noted that in using said terms to describe inventive embodiments, specific structures or mechanisms that link or couple the elements are typically described. However, unless otherwise specifically stated, when one of said terms is used, the term indicates that the actual linkage or coupling may take a variety of forms, which in certain instances will be readily apparent to a person of ordinary skill in the relevant technology.

[0029] For description purposes, the term “radial” is used here to indicate a direction or position that is perpendicular relative to a longitudinal axis of a transmission or variator. The term “axial” as used here refers to a direction or position along an axis that is parallel to a main or longitudinal axis of a transmission or variator. For clarity and conciseness, at times similar components labeled similarly (for example, a control piston 123A and a control piston 123B) will be referred to collectively by a single label (for example, control pistons 123).

[0030] It should be noted that reference herein to “traction” does not exclude applications where the dominant or exclusive mode of power transfer is through “friction.” Without attempting to establish a categorical difference between traction and friction drives here, generally these may be understood as different regimes of power transfer. Traction drives usually involve the transfer of power between two elements by shear forces in a thin fluid layer trapped between the elements. The fluids used in these applications usually exhibit traction coefficients greater than conventional mineral oils. The traction coefficient (μ) represents the maximum available traction force which would be available at the interfaces of the contacting components and is the ratio of the maximum available drive torque per contact force. Typically, friction drives generally relate to transferring power between two elements by frictional forces between the elements. For the purposes of this disclosure, it should be understood that the CVTs described here may operate in both tractive and frictional applications. For example, in the embodiment where a CVT is used for a bicycle application, the CVT can operate at times as a friction drive and at other times as a traction drive, depending on the torque and speed conditions present during operation.

[0031] As used herein, “creep”, “ratio droop”, or “slip” is the discrete local motion of a body relative to another and is exemplified by the relative velocities of rolling contact components such as the mechanism described herein. In traction drives, the transfer of power from a driving element to a driven element via a traction interface requires creep. Usually, creep in the direction of power transfer is referred to as “creep in the rolling direction.” Sometimes the driving and driven elements experience creep in a direction orthogonal to the power transfer direction, in such a case this component of creep is referred to as “transverse creep.” It should be understood, that speed ratio droops with increasing torque due to the local shearing of the traction fluid at the contacting components. As speed ratio droops the torque ratio rises, and thus the CVP naturally exhibits some degree of response to changing torque demands. Control methods described herein are optionally configured to account for the speed ratio droop through appropriate feedback and mapping of the transmission hardware.

[0032] For description purposes, the terms “electronic control unit”, “ECU”, “Driving Control Manager System” or “DCMS” are used interchangeably herein to indicate a vehicle’s electronic

system that controls subsystems monitoring or commanding a series of actuators on an internal combustion engine to ensure optimal engine performance. It does this by reading values from a multitude of sensors within the engine bay, interpreting the data using multidimensional performance maps (called lookup tables), and adjusting the engine actuators accordingly. Before ECUs, air-fuel mixture, ignition timing, and idle speed were mechanically set and dynamically controlled by mechanical and pneumatic means. As used herein, a sensor is optionally configured to be a physical device, a virtual device, or any combination of the two. For example, a physical device is optionally configured to provide information to form a parameter for use in an electronic module. In some embodiments, as used herein, a speed sensor is either a physical device or a virtual device implemented in software to sense a speed of a rotating component.

[0033] Those of skill will recognize that brake position and throttle position sensors are electronic, and in some cases, well-known potentiometer type sensors. These sensors provide a voltage or current signal that is indicative of a relative rotation and/or compression/depression of driver control pedals, for example, brake pedal and/or throttle pedal. Often, the voltage signals transmitted from the sensors are scaled. A convenient scale used in the present application as an illustrative example of one implementation of the control system uses a percentage scale 0%-100%, where 0% is indicative of the lowest signal value, for example a pedal that is not compressed, and 100% is indicative of the highest signal value, for example a pedal that is fully compressed. In some embodiments, there may be implementations of the control system where the brake pedal is effectively fully engaged with a sensor reading of 20%-100%. Likewise, in some embodiments, a fully engaged throttle pedal corresponds to a throttle position sensor reading of 20%-100%. The sensors, and associated hardware for transmitting and calibrating the signals, are optionally selected in such a way as to provide a relationship between the pedal position and signal to suit a variety of implementations. Numerical values given herein are included as examples of one implementation and not intended to imply limitation to only those values. For example, in some embodiments, a minimum detectable threshold for a brake pedal position is 6% for a particular pedal hardware, sensor hardware, and electronic processor. Whereas an effective brake pedal engagement threshold is 14%, and a maximum brake pedal engagement threshold begins at or about 20% compression. As a further example, in some embodiments, a minimum detectable threshold for an accelerator pedal position is 5% for a particular pedal hardware, sensor hardware, and electronic processor. In some embodiments, similar or completely different pedal compression threshold values for effective pedal engagement and maximum pedal engagement are also applied for the accelerator pedal.

[0034] As used herein, and unless otherwise specified, the term "about" or "approximately" means an acceptable error for a particular value as determined by one of ordinary skill in the art, which depends in part on how the value is measured or determined. In certain embodiments, the term "about" or "approximately" means within 1, 2, 3, or 4 standard deviations. In certain embodiments, the term "about" or "approximately" means within 30%, 25%, 20%, 15%, 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.1%, or 0.05% of a given value or range. In certain embodiments, the term "about" or "approximately" means within 40.0 mm, 30.0 mm, 20.0 mm, 10.0 mm, 5.0 mm, 1.0 mm, 0.9 mm, 0.8 mm, 0.7 mm, 0.6 mm, 0.5 mm, 0.4 mm, 0.3 mm, 0.2 mm or 0.1 mm of a given value or range. In certain embodiments, the term "about" or "approximately" means within 20. degrees, 15.0 degrees, 10.0 degrees, 9.0 degrees, 8.0 degrees, 7.0 degrees, 6.0 degrees, 5.0 degrees, 4.0 degrees, 3.0 degrees, 2.0 degrees, 1.0 degrees, 0.9 degrees, 0.8 degrees, 0.7 degrees, 0.6 degrees, 0.5 degrees, 0.4 degrees, 0.3 degrees, 0.2 degrees, 0.1 degrees, 0.05 degrees of a given value or range.

[0035] In certain embodiments, the term "about" or "approximately" means within 5.0 mA, 1.0 mA, 0.9 mA, 0.8 mA, 0.7 mA, 0.6 mA, 0.5 mA, 0.4 mA, 0.3 mA, 0.2 mA, 0.1 mA, 0.09 mA, 0.08 mA, 0.07 mA, 0.06 mA, 0.05 mA, 0.04 mA, 0.03 mA, 0.02 mA or 0.01 mA of a given value or range.

[0036] As used herein, "about" when used in reference to a velocity of the moving object or movable substrate means variation of 1%-5%, of 5%-10%, of 10%-20%, and/or of 10%-50% (as a percent of the percentage of the velocity, or as a variation of the percentage of the velocity). For example, in some embodiments, if the percentage of the velocity is "about 20%", the percentage may vary 5%-10% as a percent of the percentage i.e. from 19% to 21% or from 18% to 22%; alternatively the percentage may vary 5%-10% as an absolute variation of the percentage i.e. from 15% to 25% or from 10% to 30%.

[0037] In certain embodiments, the term "about" or "approximately" means within 0.01 sec., 0.02 sec, 0.03 sec., 0.04 sec., 0.05 sec., 0.06 sec., 0.07 sec., 0.08 sec. 0.09 sec. or 0.10 sec of a given value or range. In certain embodiments, the term "about" or "approximately" means within 0.5 rpm/sec, 1.0 rpm/sec, 5.0 rpm/sec, 10.0 rpm/sec, 15.0 rpm/sec, 20.0 rpm/sec, 30 rpm/sec, 40 rpm/sec, or 50 rpm/sec of a given value or range.

[0038] Those of skill will recognize that in some embodiments, the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein, including with reference to the transmission control system described herein, for example, are implemented as electronic hardware, software stored on a computer readable medium and executable by a processor, or combinations of both. To clearly illustrate this

interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention. For example, various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein are implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. In some embodiments, a processor will be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some embodiments, software associated with such modules resides in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other suitable form of storage medium known in the art. In some embodiments, an exemplary storage medium is coupled to the processor such that the processor reads information from, and writes information to, the storage medium. In alternative embodiments, the storage medium is integral to the processor. In some embodiments, the processor and the storage medium reside in an ASIC. For example, in some embodiments, a controller for use of control of the IVT comprises a processor (not shown).

Certain Definitions

[0039] Unless otherwise defined, all technical terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. As used in this specification and the appended claims, the singular forms “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise. Any reference to “or” herein is intended to encompass “and/or” unless otherwise stated.

Digital processing device

[0040] In some embodiments, the Control System for a Vehicle equipped with an infinitely variable transmission described herein includes a digital processing device, or use of the same. In

further embodiments, the digital processing device includes one or more hardware central processing units (CPU) that carry out the device's functions. In still further embodiments, the digital processing device further comprises an operating system configured to perform executable instructions. In some embodiments, the digital processing device is optionally connected a computer network. In further embodiments, the digital processing device is optionally connected to the Internet such that it accesses the World Wide Web. In still further embodiments, the digital processing device is optionally connected to a cloud computing infrastructure. In other embodiments, the digital processing device is optionally connected to an intranet. In other embodiments, the digital processing device is optionally connected to a data storage device.

[0041] In accordance with the description herein, suitable digital processing devices include, by way of non-limiting examples, server computers, desktop computers, laptop computers, notebook computers, sub-notebook computers, netbook computers, netpad computers, set-top computers, media streaming devices, handheld computers, Internet appliances, mobile smartphones, tablet computers, personal digital assistants, video game consoles, and vehicles. Those of skill in the art will recognize that many smartphones are suitable for use in the system described herein. Those of skill in the art will also recognize that select televisions, video players, and digital music players with optional computer network connectivity are suitable for use in the system described herein. Suitable tablet computers include those with booklet, slate, and convertible configurations, known to those of skill in the art.

[0042] In some embodiments, the digital processing device includes an operating system configured to perform executable instructions. The operating system is, for example, software, including programs and data, which manages the device's hardware and provides services for execution of applications. Those of skill in the art will recognize that suitable server operating systems include, by way of non-limiting examples, FreeBSD, OpenBSD, NetBSD[®], Linux, Apple[®] Mac OS X Server[®], Oracle[®] Solaris[®], Windows Server[®], and Novell[®] NetWare[®]. Those of skill in the art will recognize that suitable personal computer operating systems include, by way of non-limiting examples, Microsoft[®] Windows[®], Apple[®] Mac OS X[®], UNIX[®], and UNIX-like operating systems such as GNU/Linux[®]. In some embodiments, the operating system is provided by cloud computing. Those of skill in the art will also recognize that suitable mobile smart phone operating systems include, by way of non-limiting examples, Nokia[®] Symbian[®] OS, Apple[®] iOS[®], Research In Motion[®] BlackBerry OS[®], Google[®] Android[®], Microsoft[®] Windows Phone[®] OS, Microsoft[®] Windows Mobile[®] OS, Linux[®], and Palm[®] WebOS[®]. Those of skill in the art will also recognize that suitable media streaming device operating systems include, by way of non-limiting examples, Apple TV[®], Roku[®], Boxee[®], Google TV[®], Google Chromecast[®],

Amazon Fire[®], and Samsung[®] HomeSync[®]. Those of skill in the art will also recognize that suitable video game console operating systems include, by way of non-limiting examples, Sony[®] PS3[®], Sony[®] PS4[®], Microsoft[®] Xbox 360[®], Microsoft Xbox One, Nintendo[®] Wii[®], Nintendo[®] Wii U[®], and Ouya[®].

[0043] In some embodiments, the device includes a storage and/or memory device. The storage and/or memory device is one or more physical apparatuses used to store data or programs on a temporary or permanent basis. In some embodiments, the device is volatile memory and requires power to maintain stored information. In some embodiments, the device is non-volatile memory and retains stored information when the digital processing device is not powered. In further embodiments, the non-volatile memory comprises flash memory. In some embodiments, the non-volatile memory comprises dynamic random-access memory (DRAM). In some embodiments, the non-volatile memory comprises ferroelectric random access memory (FRAM). In some embodiments, the non-volatile memory comprises phase-change random access memory (PRAM). In other embodiments, the device is a storage device including, by way of non-limiting examples, CD-ROMs, DVDs, flash memory devices, magnetic disk drives, magnetic tapes drives, optical disk drives, and cloud computing based storage. In further embodiments, the storage and/or memory device is a combination of devices such as those disclosed herein.

[0044] In some embodiments, the digital processing device includes a display to send visual information to a user. In some embodiments, the display is a cathode ray tube (CRT). In some embodiments, the display is a liquid crystal display (LCD). In further embodiments, the display is a thin film transistor liquid crystal display (TFT-LCD). In some embodiments, the display is an organic light emitting diode (OLED) display. In various further embodiments, on OLED display is a passive-matrix OLED (PMOLED) or active-matrix OLED (AMOLED) display. In some embodiments, the display is a plasma display. In other embodiments, the display is a video projector. In still further embodiments, the display is a combination of devices such as those disclosed herein.

[0045] In some embodiments, the digital processing device includes an input device to receive information from a user. In some embodiments, the input device is a keyboard. In some embodiments, the input device is a pointing device including, by way of non-limiting examples, a mouse, trackball, track pad, joystick, game controller, or stylus. In some embodiments, the input device is a touch screen or a multi-touch screen. In other embodiments, the input device is a microphone to capture voice or other sound input. In other embodiments, the input device is a video camera or other sensor to capture motion or visual input. In further embodiments, the input

device is a Kinect, Leap Motion, or the like. In still further embodiments, the input device is a combination of devices such as those disclosed herein.

Non-transitory computer readable storage medium

[0046] In some embodiments the Control System for a Vehicle equipped with an infinitely variable transmission disclosed herein includes one or more non-transitory computer readable storage media encoded with a program including instructions executable by the operating system of an optionally networked digital processing device. In further embodiments, a computer readable storage medium is a tangible component of a digital processing device. In still further embodiments, a computer readable storage medium is optionally removable from a digital processing device. In some embodiments, a computer readable storage medium includes, by way of non-limiting examples, CD-ROMs, DVDs, flash memory devices, solid state memory, magnetic disk drives, magnetic tape drives, optical disk drives, cloud computing systems and services, and the like. In some cases, the program and instructions are permanently, substantially permanently, semi-permanently, or non-transitorily encoded on the media.

Computer program

[0047] In some embodiments, the Control System for a Vehicle equipped with an infinitely variable transmission disclosed herein includes at least one computer program, or use of the same. A computer program includes a sequence of instructions, executable in the digital processing device's CPU, written to perform a specified task. Computer readable instructions may be implemented as program modules, such as functions, objects, Application Programming Interfaces (APIs), data structures, and the like, that perform particular tasks or implement particular abstract data types. In light of the disclosure provided herein, those of skill in the art will recognize that a computer program may be written in various versions of various languages.

[0048] The functionality of the computer readable instructions may be combined or distributed as desired in various environments. In some embodiments, a computer program comprises one sequence of instructions. In some embodiments, a computer program comprises a plurality of sequences of instructions. In some embodiments, a computer program is provided from one location. In other embodiments, a computer program is provided from a plurality of locations. In various embodiments, a computer program includes one or more software modules. In various embodiments, a computer program includes, in part or in whole, one or more web applications, one or more mobile applications, one or more standalone applications, one or more web browser plug-ins, extensions, add-ins, or add-ons, or combinations thereof.

[0049] Referring now to **FIG. 4**, in some embodiments, a vehicle can be equipped with a driveline having a torsional damper between an engine and an infinitely or continuously variable

transmission (CVT) to avoid transferring torque peaks and vibrations that could damage the CVT (called variator in this context as well). In some configurations this damper is optionally coupled with a clutch for the starting function or to allow the engine to be decoupled from the transmission. In yet other embodiments, a torque converter may be used in place of the torsional damper. Other types of CVT's (apart from ball-type traction drives) are optionally used as the variator in this layout. In addition to the configurations above where the variator is used directly as the primary transmission, other architectures are possible. Various powerpath layouts are optionally introduced by adding a number of gears, clutches and simple or compound planetaries. In such configurations, the overall transmission provides several operating modes; a CVT, an IVT, a combined mode and so on. A control system for use in an infinitely or continuously variable transmission will now be described.

[0050] Moving now to **FIG. 5**, during operation of the CVP, the first carrier member 6 is adapted to rotate relative to the second carrier member 7. The first carrier member 6 and the second carrier member 7 impart forces on the axles of the ball. The reaction forces in the x-y plane are as follows:

- The left end of the ball axle (when viewed with respect to FIG. 5) puts a reaction force R_L on carrier 1.
- The right end ball axle puts a reaction force R_R on carrier 2.
- The ball surface puts a reaction force F_L on the input ring.
- The ball surface puts a reaction force F_R on the output ring.

[0051] In some embodiments, a shift actuator (not shown) is optionally implemented to control the position of the first carrier member 6 with respect to the second carrier member 7. Control of the actuator is optionally configured to be a cascade of a position controller, speed controller and a current controller or a combination of these loops in both feedback and feedforward variants. Generally speaking the driver circuit of an electric actuator receives a control command which relates to a certain setpoint for a carrier position (" β " angle), to be able to set the speed ratio. The shift actuator is optionally an electromotor or a solenoid, for example. In other embodiments, a hydraulic actuator may be implemented and the operating pressure of the hydraulic actuator may be used to position the carrier member.

[0052] The amount of force or torque the shift actuator instantaneously requires is related to the reaction torque exerted on the carriers by the balls and the acceleration of the actuator and carrier. In steady state operation the acceleration is zero. A higher torque required for the shift actuator to reach the commanded set point indicates a higher reaction torque on the carrier. Thus, the torque applied by the shift actuator is a measure of the reaction torque on the first carrier

member 6, for example. For electric shift actuators, the torque output of the shift actuator is in relation to its electrical current consumption. The electrical current draw is optionally used to measure the reaction torque. For hydraulic shift actuators, the torque output of the shift actuator is in relation to its hydraulic pressure. The hydraulic pressure is optionally used to measure the reaction force on the shift actuator and thereby determine the reaction torque on the carrier. A control algorithm that uses the shift actuator force to measure carrier reaction torque comprises a method to compensate for dynamic effects during actuation, for example, inertial effects, transients due to actuation mechanism, dead time, among others, and hysteresis effects.

[0053] Referring now to **FIG. 6**, in some embodiments a vehicle control system 10 includes an engine controller 11 and a transmission controller 12. The engine controller 11 and the transmission controller 12 is configured to send and receive a number of signals. In some embodiments, the transmission controller 12 is configured to pass command signals to a shift actuator manager 13. The shift actuator manager 13 is adapted to coordinate a shift actuator coupled to the CVP. The shift actuator is optionally an electric motor or a hydraulic actuator system (not shown). The shift actuator controls the relative position of the first carrier member 6 with respect to the second carrier member 7 and thereby controls the speed ratio of the CVP. In some embodiments, the shift actuator is optionally used to measure the reaction torque of the first carrier member 6 and the second carrier member 7.

[0054] In some embodiments, the vehicle control system 10 receives a number of user input signals equipped on the vehicle. For example, the vehicle control system 10 receives an accelerator pedal position signal 14, a brake pedal position signal 15, and a gear selector signal 16, among others. The vehicle control system 10 receives a number of signals indicative of engine operation. For example, the vehicle control system 10 receives a throttle position signal 17, an engine power signal 18, and an engine temperature signal 19. The vehicle control system 10 receives a number of signals indicative of CVP operation. For example, the vehicle control system 10 receives a vehicle speed signal 20, a CVP temperature signal 21, a CVP input speed signal 22, and a CVP output speed signal 23, among others. In some embodiments, the vehicle control system 10 receives a number of signals indicative of shift actuator operation. For example, the vehicle control system 10 receives a carrier position signal 24 and an actuator force signal 25, among others.

[0055] Referring now to **FIG. 7**, in some embodiments a transmission control module 30 is implemented in the transmission controller 12, for example. The transmission control module 30 receives a number of input signals, such as an accelerator pedal position signal 31. In some embodiments, the transmission control module 30 is optionally configured to receive a brake

pedal position signal, a throttle position signal, and a gear lever position signal, among others, that communicate a driver's demand or request for torque. The transmission control module 30 includes a torque map 32 that receives the accelerator pedal position signal 31, for example. The torque map 32 is a calibration map read from memory or a map determined in a sub-module of the transmission controller 12. In some embodiments, the torque map 32 contains values for torque based at least in part on the accelerator pedal position signal 31. The torque map 32 passes a signal indicative of a desired torque ("Tdesired") to an error block 33. The error block 33 determines the difference between the desired torque and a measured carrier torque ("Tcarrier"). The measured carrier torque is determined in a carrier torque sub-module 34. The difference determined in error block 33 is a torque error signal ("Terror"). The torque error signal is passed to a CVP control sub-module 35. The CVP control sub-module 35 contains a number of algorithms and control functions, such as a PID, to determine a commanded CVP position signal based at least in part on the torque error signal and a carrier position signal. As used herein, a PID controller is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value $e(t)$ as the difference between a desired setpoint and a measured process variable. In some embodiments, a PID controller, otherwise known as a proportional-integral-derivative controller, is configured for receiving a difference between a set point and a controlled variable of a process to be controlled and delivering a manipulated variable to the process, the process being operated by the manipulated variable to produce the controlled variable. The commanded CVP position signal is passed to an actuator manager sub-module 36. The actuator manager sub-module 36 is configured to control a shift actuator of the CVP and coordinate the sending and receiving of command signals to the shift actuator and carrier position sensor. In some embodiments, the shift actuator is optionally a hydraulic actuator equipped with pressure signal feedback. In other embodiments, the shift actuator is optionally an electric motor. The actuator manager sub-module 36 passes a carrier force signal to the carrier torque sub-module 34. The carrier torque sub-module 34 determines the reaction torque on the carrier (Tcarrier) based at least in part on the measured carrier force signal. In some embodiments, the measured carrier torque is determined by a shift actuator force signal and carrier position signal.

[0056] Referring now to **FIG. 8**, in some embodiments the transmission controller 12 implements a control process 40 that begins at a start state 41 and proceeds to a block 42 where a number of signals are received. In some embodiments, the signals received at the block 42 are indicative of a driver's input, for example, an accelerator pedal position, a brake pedal position, a gear lever position, among other signals provided in the vehicle. The control process 40 proceeds

to a block 43 where a desired torque is determined. The desired torque is based at least in part on the signals received in the block 42. The control process 40 proceeds to a block 44 where a shift actuator reaction force and a carrier position is measured. In some embodiments, the carrier position is monitored to evaluate hard stops for the actuator (not shown). The control process 40 proceeds to a block 45 where a reaction torque on the carrier is determined. In some embodiments, the reaction torque on the carrier is based at least in part on an actuator force and a carrier position. The control process 40 proceeds to an evaluation block 46 where the desired torque and the reaction torque on the carrier is compared. If the desired torque and the reaction torque on the carrier are equal, the evaluation block 46 passes a true, or “yes” signal and the control process 40 proceeds to an end state 47. If the desired torque and the reaction torque on the carrier are not equal, the evaluation block 46 passes a false, or “no” signal and the control process 40 proceeds to a block 48. The block 48 determines a shift actuator set point signal. The control process 40 proceeds to a block 49 where a command is sent to the shift actuator based at least in part on the shift actuator set point signal determined in the block 48. The control process 40 returns to the block 42 and the control process 40 repeats until the end state 47 is reached.

[0057] Provided herein is a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device to create an application comprising a software module configured to manage a plurality of vehicle driving conditions; a plurality of sensors configured to monitor vehicle parameters comprising: CVP carrier position, CVP speed ratio, and CVP shift actuator force; wherein the software module monitors the CVP carrier position and a CVP speed ratio; and wherein the software module commands a change in a shift position of the CVP based at least in part on the CVP shift actuator force.

[0058] In some embodiments of the computer-implemented system, the plurality of sensors further comprises: gear lever indicator, vehicle speed, brake pedal position, and accelerator pedal position.

[0059] In some embodiments of the computer-implemented system, a carrier torque sub-module is provided, the carrier torque sub-module configured to determine a carrier reaction torque based at least in part on the shift actuator force.

[0060] In some embodiments of the computer-implemented system, a CVP control sub-module is provided, the CVP control sub-module configured to determine a commanded CVP position signal based at least in part on the carrier reaction torque.

[0061] In some embodiments of the computer-implemented system, a calibration map is provided, the calibration map configured to store values of a desired torque based at least in part on the accelerator pedal position.

[0062] In some embodiments of the computer-implemented system, the desired torque and the carrier reaction torque form a torque error.

[0063] In some embodiments of the computer-implemented system, a CVP control sub-module, the CVP control sub-module configured to determine a commanded CVP carrier position based at least in part on the torque error.

[0064] In some embodiments of the computer-implemented system, the CVP control sub-module comprises a PID controller.

[0065] In some embodiments of the computer-implemented system, an actuator manager sub-module is provided, the actuator manager sub-module adapted to determine the CVP shift actuator force and the CVP carrier position.

[0066] In some embodiments of the computer-implemented system, the software module is configured to execute a control process, the control process comprising: receiving a plurality of signals, each signal indicative of a driver's input; determining a desired torque based at least in part on the driver's input; measuring a carrier reaction force; measuring a carrier position; determining a carrier reaction torque based at least in part on the carrier reaction force and the carrier position; comparing the desired torque to the carrier reaction torque; and determining a carrier position set point based at least in part on the comparison between the carrier reaction torque and the desired torque.

[0067] Turning now to **FIG. 9**, in some embodiments a transmission control sub-module 100 is implemented in the transmission controller 12. The transmission control sub-module 100 is optionally configured to receive a commanded engine speed signal 101 and a measured engine speed signal 102. The commanded engine speed signal 101 is optionally derived in a sub-module (not shown) of the transmission control sub-module 100. In some embodiments, the commanded engine speed signal 101 is determined in an engine control module (not shown) and passed to the transmission control sub-module 100. The measured engine speed signal 102 is indicative of the actual speed of the engine. The transmission control sub-module 100 is optionally configured to receive a commanded output speed signal 103 and a measured output speed signal 104. The commanded output speed 103 is optionally determined in a sub-module (not shown) of the transmission control sub-module 100. In some embodiments, the commanded output speed signal 103 is determined in a vehicle control module (not shown). The measured output speed signal 104 is optionally received from a speed sensor equipped on the vehicle. A difference

between the commanded engine speed signal 101 and the measured engine speed signal 102 forms an engine speed error signal. The engine speed error signal is passed to a CVT torque sub-module 105. The CVT torque sub-module 105 also receives an output speed error signal that is formed by the difference between the commanded output speed signal 103 and the measured output speed signal 104.

[0068] In some embodiments, the CVT torque sub-module 105 determines a target CVT torque based at least in part on the engine speed error signal and the output speed error signal. The target CVT torque, as discussed previously, is related to the position of the carrier assembly. The transmission control sub-module 100 includes a torque measurement correction sub-module 106. The torque measurement correction sub-module 106 implements methods for learning and correcting the relationship between a measured reaction torque on the carrier and the carrier position. The torque measurement correction sub-module 106 passes a torque correction factor. The torque correction factor is applied to the target CVT torque signal and the resulting signal is passed to a shift actuator control sub-module 107. The shift actuator control sub-module 107 determines a commanded carrier position signal that is passed to the shift actuator 108.

[0069] Referring now to **FIG. 10**, the relationship between the carrier position (β -angle) and the reaction torque T_R is a piecewise linear relationship. The slopes depend on the torque damping provided in the CVP. In some embodiments, torque damping is provided by a passive means such as a spring system operably coupled to the carrier assembly. In other embodiments, torque damping is actively controlled. For either passive or active damping control systems, the relationship between reaction torque and carrier position may change over the life of the CVP. To compensate for these effects, and to avoid persistent servicing of a CVT system with spring mechanisms, a learning method is optionally implemented. Although various methods and variants are optionally used, the general principle is explained here.

[0070] In some embodiments, the piecewise linear relationship for the shift actuator setpoint is corrected depending on the response of the shift actuator as measured by the electric actuator. The electromotor actuates one or both of the carriers of the ball-type CVT unit. It rotates a carrier to change the relative rotational position between both carriers. The torque damping system (not shown) will generate an additional $\Delta \beta$ creating a resulting speed ratio.

[0071] In some embodiments, a method for learning the relationship between the carrier position and the reaction torque on the carrier includes the following steps or processes:

1. **INITIALIZATION** Store the design-specific piecewise linear relation between β -angle and T_R in a matrix. The function can be mathematically defined; values in between are

linearly interpolated. Amongst others, the relation can be compensated for the effect of input speed ω_{in} at which the CVT is rotating.

2. **TORQUE MEASUREMENT** During actuation of the CVT, the output of the reaction torque measurement comprises two values: current set β -angle, estimated torque $\hat{T}_R$. Other parameters that influence the relation may include measured input speed ω_{in} .
3. **CORRECTION** For a particular β -angle, a difference between measured reaction torque and pre-defined reaction torque will be found. For a particular speed, a correction is applied. The two nearest breakpoints of the piecewise linear function close to the current β -angle are corrected. The two nearest breakpoints are determined by: the first occurring breakpoint larger and the first breakpoint smaller than the current β -angle. The correction is such that the T_R -value of the two found breakpoints is corrected towards the newly found measurement. The magnitude of the correction of the T_R -value of a breakpoint is proportional to the distance of the β -angle of the breakpoint to the current β -angle. Also, the correction amount is defined by a particular gain value. This gain (or rate) should be small such that the convergence occurs in the timescale of several running hours of the unit. It is also clear that a larger offset will generate a larger correction.

[0072] The “INITIALIZATION” step occurs when the firmware is flashed into the transmission controller 12 right after manufacturing. The breakpoints of the piecewise linear function are those defined by design. The CVT should be able to operate with these values. During the lifetime of the vehicle incorporated with the CVT, the “TORQUE MEASUREMENT” and “CORRECTION” step are performed sequentially and in a loop. The reaction torque measurement generates the corrected value of $\hat{T}_R$ for an angle β . As depicted in FIG. 10, the measured torque is lower than the pre-defined relationship. A correction is applied. The two nearest breakpoints are selected, represented by β_1 and β_2 . Their respective reaction torque values are T_{R1} and T_{R2} . The breakpoint values T_{R1} and T_{R2} are corrected to new values. One exemplary method for correcting is as follows:

$$\begin{aligned} T'_{R1} &= T_{R1} + (\hat{T}_R - T_{R1}) \left(\frac{\beta - \beta_2}{\beta_1 - \beta_2} \right) \varepsilon \\ T'_{R2} &= T_{R2} - (\hat{T}_R - T_{R2}) \left(\frac{\beta - \beta_1}{\beta_1 - \beta_2} \right) \varepsilon \end{aligned} \quad (1)$$

Equation (1) describes an elementary method to correct the reaction torque values of the two nearest breakpoints of the estimated torque, where the correction is proportional to:

- The magnitude of the error $\hat{T}_R - T_{R1}$
- The proximity of the angle β to the breakpoints β_1 and β_2
- A gain ε , which represents the rate of the learning.

The transmitted torque can be calculated through the reaction torque T_R . This can be done via a kinematic model:

$$T_{in} = f(T_R, \gamma, \dots)$$

wherein the input torque T_{in} of the CVP is related to the reaction torque T_R , the angle γ and a kinematic model of the system. Then, the output torque is related to the input torque T_{in} of the CVP, the angle γ and a kinematic model of the system:

$$T_{out} = f(T_{in}, \gamma, \dots)$$

[0073] Referring now to **FIG. 11**, in some embodiments the torque measurement correction sub-module 106 optionally implements a control process that begins at a start state 110 and proceeds to a block 111 where a number of signals indicative of transmission operation are received. The process proceeds to a block 112 where a map or relationship between reaction torque on the carrier and carrier position is read from memory. The process proceeds to a block 113 where a measurement of the force applied by the shift actuator and the carrier position is made. The process proceeds to a block 114 where the carrier torque is determined based at least in part on the measured shift actuator force and the carrier position. The process proceeds to an evaluation block 115 where the stored value for the reaction torque on the carrier at the measured carrier position is compared to the measured reaction torque on the carrier. If the two values are equal, the process proceeds to an end state 116. If the two values are not equal, the process proceeds to a block 117 where the difference between the two values is determined to form a correction value. The process proceeds to a block 118 where the correction value is stored to memory.

[0074] Provided herein is a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device to create an application comprising a software module configured to manage a plurality of vehicle driving conditions; a plurality of sensors configured to monitor vehicle parameters comprising: vehicle direction, vehicle speed, brake pedal position, accelerator pedal position, CVP carrier position, parking brake status, engine speed, CVP speed ratio, and CVP reaction torque; wherein the software module monitors the CVP carrier position and a CVP speed ratio; and wherein the software module commands a change in a shift position of the CVP based at least in part on the CVP reaction torque.

[0075] In some embodiments of the computer-implemented system, the software module is configured to execute instructions from a CVT torque control sub-module, the CVT torque control sub-module commands a CVP shift actuator based at least in part on the CVP reaction torque.

[0076] In some embodiments of the computer-implemented system, the CVP reaction torque is a measured signal based at least in part on a shift actuator.

[0077] In some embodiments of the computer-implemented system, the CVP reaction torque is a pressure signal.

[0078] In some embodiments of the computer-implemented system, the CVP reaction torque is an electrical current signal.

[0079] In some embodiments of the computer-implemented system, a shift actuator control sub-module is provided.

[0080] In some embodiments of the computer-implemented system, a torque measurement correction sub-module is provided.

[0081] In some embodiments of the computer-implemented system, a shift actuator control sub-module.

[0082] In some embodiments of the computer-implemented system, the torque measurement correction sub-module comprises a control process, the control process comprising: receiving a plurality of input signals, the input signals indicative of operating conditions of the CVP; reading a map from memory, the map configured to store values indicative of torque based at least in part on the CVP carrier position; measuring a carrier reaction force; and determining a torque correction factor.

[0083] In some embodiments of the computer-implemented system, the control process further comprises determining a measured carrier torque based at least in part on the measured carrier reaction force and the CVP carrier position.

[0084] In some embodiments of the computer-implemented system, the control process further comprises comparing the measured carrier torque to a torque value read from the memory.

[0085] In some embodiments of the computer-implemented system, the control process further comprises storing the torque correction factor in memory.

[0086] In some embodiments of the computer-implemented system, the map is a piecewise linear function of torque based at least in part on the CVP carrier position.

[0087] Passing now to **FIG. 12**, the CVT torque module 105 is configured to implement a control process that combines a torque-based control mode and a speed ratio-based control mode. As depicted in the chart of FIG. 12, it may be desirable under certain operating conditions to

control the CVP based on a speed ratio-based mode, where speed ratio of the CVP is used as a feedback variable for control. For example, at higher operating speeds, when the load on the system is relatively low, it may be desirable to use speed feedback to determine the operating condition of the CVP. At lower speeds, and higher load conditions, it may be desirable to use torque-based control mode to determine the operating condition of the CVP. In the torque-based control mode, output torque is used as a feedback variable for control. Transitioning between these two control modes may be achieved by applying weighting factors. It should be noted that the transmission controller 12 is optionally configured to implement both operating modes simultaneously during operation. An illustrative example to characterize the difference between a torque-based control mode and a speed ratio-based control mode, is the extreme driving condition that a vehicle is obstructed by a curb, for example the front tires are pressed up against the curb, the vehicle is at zero speed, and the driver presses the accelerator pedal to demand more torque in order to drive the vehicle over the curb. In this example, the vehicle is at zero speed and therefore the measured speed ratio for the transmission is zero as well. For a torque-based control mode, the driver's request for more torque produces a change in the CVP carrier position to thereby increase the torque delivered to the rear wheels and propel the vehicle over the curb. For a speed ratio-based control mode, the driver's request for more torque produces no change in CVP carrier position and therefore no change in the torque delivered to the rear wheels of the vehicle.

[0088] Provided herein is a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device to create an application comprising a software module configured to manage a plurality of vehicle driving conditions; a plurality of sensors configured to monitor vehicle parameters comprising: vehicle speed, CVP input speed, engine torque, accelerator pedal position, CVP speed ratio, and brake pedal position; wherein the software module is configured to execute instructions provided by a torque-based control module; and wherein the torque-based control module includes a plurality of calibration maps, each calibration map configured to store values of a desired torque based at least in part on the vehicle parameters monitored by the plurality of sensors.

[0089] In some embodiments of the computer-implemented system, a speed ratio-based control module is provided, wherein the speed ratio-based control module includes a plurality of

calibration maps, each calibration configured to store values of a desired CVP speed ratio based at least in part on the vehicle parameters monitored by the plurality of sensors.

[0090] In some embodiments of the computer-implemented system, the software module is configured to transition between the torque-based control module and the speed ratio-based control module based at least in part on vehicle speed.

[0091] It should be noted that the description above has provided dimensions for certain components or subassemblies. The mentioned dimensions, or ranges of dimensions, are provided in order to comply as best as possible with certain legal requirements, such as best mode. However, the scope of the inventions described herein are to be determined solely by the language of the claims, and consequently, none of the mentioned dimensions is to be considered limiting on the inventive embodiments, except in so far as any one claim makes a specified dimension, or range of thereof, a feature of the claim.

[0092] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS

WHAT IS CLAIMED IS:

1. A computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising:
 - a digital processing device comprising an operating system configured to perform executable instructions and a memory device;
 - a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions;
 - a plurality of sensors comprising:
 - a vehicle direction sensor configured to sense a vehicle direction,
 - a vehicle speed sensor configured to sense a vehicle speed,
 - a brake pedal position sensor configured to sense a brake pedal position,
 - an accelerator pedal position sensor configured to sense an accelerator pedal position,
 - a CVP carrier position sensor configured to sense a CVP carrier position,
 - a parking brake status sensor configured to sense a parking brake status,
 - an engine speed sensor configured to sense an engine speed,
 - a first speed sensor configured to sense a CVP input speed,
 - a second speed sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed are adapted to provide a CVP speed ratio, and
 - a CVP reaction torque sensor configured to sense a CVP reaction torque;

wherein the software module monitors the CVP carrier position and the CVP speed ratio; and

wherein the software module commands a change in the shift position of the CVP based at least in part on the CVP reaction torque.
2. The computer-implemented system of Claim 1, wherein the software module is configured to execute instructions from a CVT torque control sub-module, wherein the CVT torque control sub-module determines a command for a CVP shift actuator based at least in part on the CVP reaction torque.

3. The computer-implemented system of Claim 1, wherein the CVP reaction torque is a measured signal provided by a CVP shift actuator.
4. The computer-implemented system of Claim 3, wherein the CVP reaction torque is a pressure signal.
5. The computer-implemented system of Claim 3, wherein the CVP reaction torque is an electrical current signal.
6. The computer-implemented system of Claim 2, further comprising a shift actuator control sub-module configured to determine a commanded CVP carrier position based on the CVP reaction torque.
7. The computer-implemented system of Claim 6, further comprising a torque measurement correction sub-module configured to learn and correct a relationship between the CVP reaction torque and the CVP carrier position.
8. The computer-implemented system of Claim 7, wherein the torque measurement correction sub-module comprises a control process, the control process comprising the steps of:
 - reading a map from the memory, the map configured to store values indicative of a torque correction factor based at least in part on the CVP carrier position;
 - measuring the CVP reaction torque; and
 - determining a torque correction factor.
9. The computer-implemented system of Claim 8, wherein the control process further comprises comparing the measured CVP reaction torque to a torque value, the torque value read from the memory, wherein the comparison forms the torque correction factor.
10. The computer-implemented system of Claim 9, wherein the control process further comprises storing the torque correction factor in the memory.
11. The computer-implemented system of Claim 8, wherein the map is a piecewise linear function of torque based at least in part on the CVP carrier position.
12. A computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising:
 - a digital processing device comprising an operating system configured to perform executable instructions and a memory device;
 - a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions;

a plurality of sensors comprising:

- a CVP carrier position sensor configured to sense a carrier position,
- a CVP input speed sensor configured to sense a CVP input speed,
- a CVP output speed sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed form a CVP speed ratio, and
- a CVP shift actuator force sensor configured to sense a CVP shift actuator force;

wherein the software module monitors the CVP carrier position and the CVP speed ratio; and

wherein the software module commands a change in a shift position of the CVP based at least in part on the CVP shift actuator force.

13. The computer-implemented system of Claim 12, wherein the plurality of sensors further comprises:

- a gear lever indicator configured to sense a gear lever position,
- a vehicle speed sensor configured to sense a vehicle speed,
- a brake pedal position sensor configured to sense a brake pedal position, and
- an accelerator pedal position sensor configured to sense an accelerator pedal position.

14. The computer-implemented system of Claim 13, wherein the software module further comprises a carrier torque sub-module, the carrier torque sub-module configured to determine a carrier reaction torque based at least in part on the CVP shift actuator force.

15. The computer-implemented system of Claim 14, wherein the software module further comprises a CVP control sub-module, the CVP control sub-module configured to determine a commanded CVP position signal based at least in part on the carrier reaction torque.

16. The computer-implemented system of Claim 15, wherein the software module further comprises a calibration map, the calibration map configured to store values of a desired output torque based at least in part on the accelerator pedal position.

17. The computer-implemented system of Claim 16, wherein a difference between the desired output torque and the carrier reaction torque form a torque error.

18. The computer-implemented system of Claim 17, wherein the software module further comprises a CVP control sub-module, the CVP control sub-module configured to determine a commanded CVP carrier position based at least in part on the torque error.

19. The computer-implemented system of Claim 18, wherein the CVP control sub-module comprises a PID controller.

20. The computer-implemented system of Claim 18, wherein the software module further comprises an actuator manager sub-module, the actuator manager sub-module adapted to determine the CVP shift actuator force and a measured CVP carrier position.
21. The computer-implemented system of Claim 12, wherein the software module is configured to execute a control process, the control process comprising the steps of:
- determining a desired output torque based at least in part on a driver's input;
 - measuring a carrier reaction force based on the CVP shift actuator force;
 - measuring the CVP carrier position;
 - determining a carrier reaction torque based at least in part on the carrier reaction force and the carrier position;
 - comparing the desired output torque to the carrier reaction torque; and
 - determining a carrier position set point based at least in part on a comparison between the carrier reaction torque and the desired torque.
22. A computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising:
- a digital processing device comprising an operating system configured to perform executable instructions and a memory device;
 - a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions;
 - a plurality of sensors comprising:
 - a vehicle speed sensor configured to sense a vehicle speed,
 - a first sensor configured to sense a CVP input speed,
 - an engine torque indicator configured to provide an engine torque,
 - an accelerator pedal position sensor configured to provide an accelerator pedal position,
 - a second sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed form a CVP speed ratio, and
 - a brake pedal position sensor configured to sense a brake pedal position;
- wherein the software module is configured to execute instructions provided by a torque-based control module; and

wherein the torque-based control module includes a plurality of calibration maps, each calibration map configured to store values of a desired output torque based at least in part on the plurality of sensors.

23. The computer-implemented system of Claim 22, wherein the software module further comprises a speed ratio-based control module, wherein the speed ratio-based control module includes a plurality of calibration maps, each calibration configured to store values of a desired CVP speed ratio based at least in part on the plurality of sensors.
24. The computer-implemented system of Claim 23, wherein the software module is configured to transition between the torque-based control module and the speed ratio-based control module based at least in part on the vehicle speed.

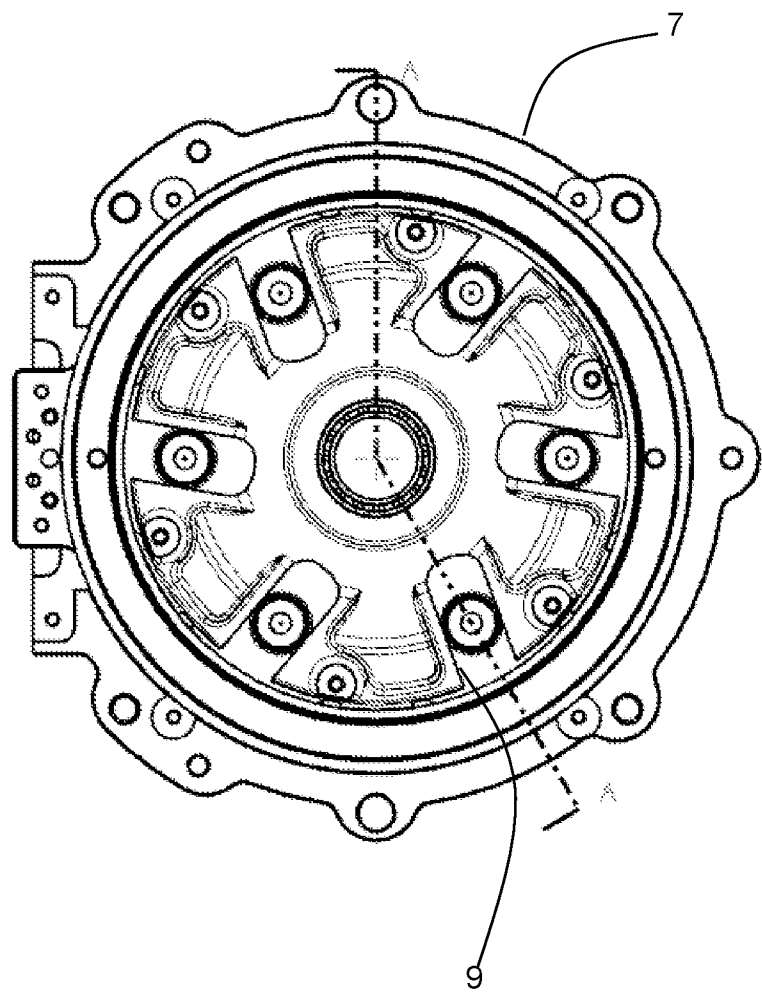


Figure 2

3/8

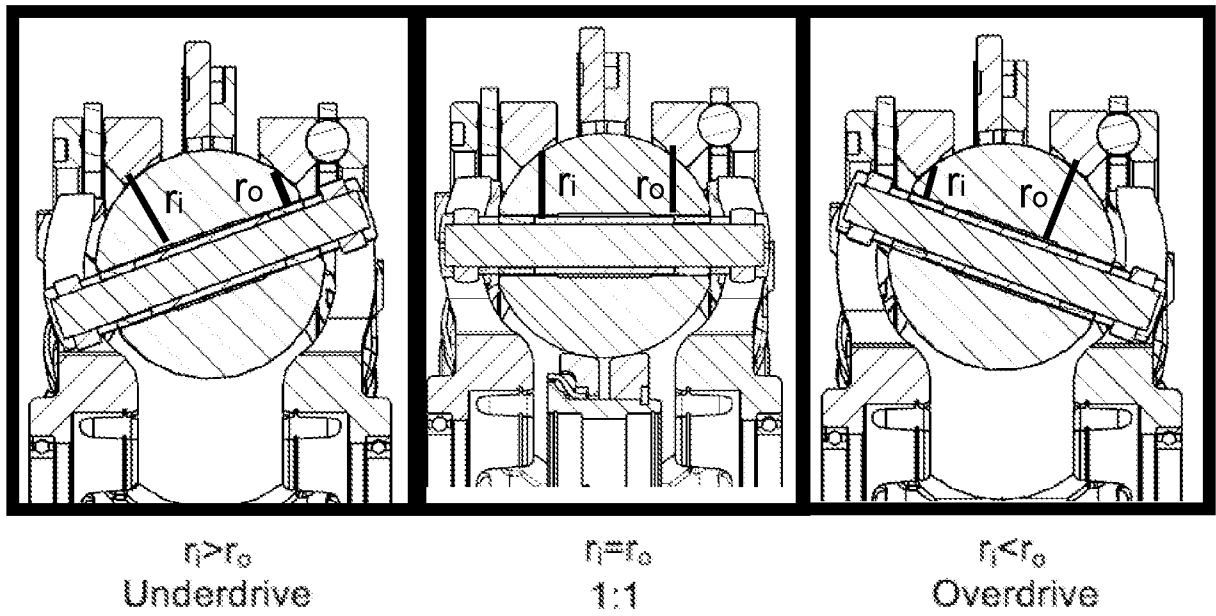


Figure 3

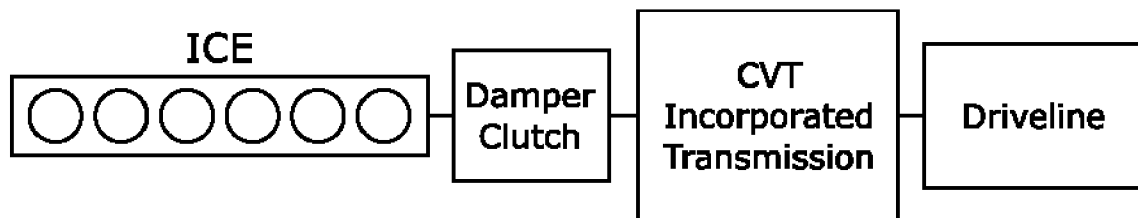


Figure 4

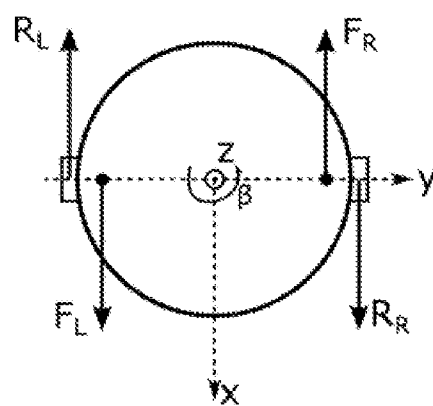


Figure 5

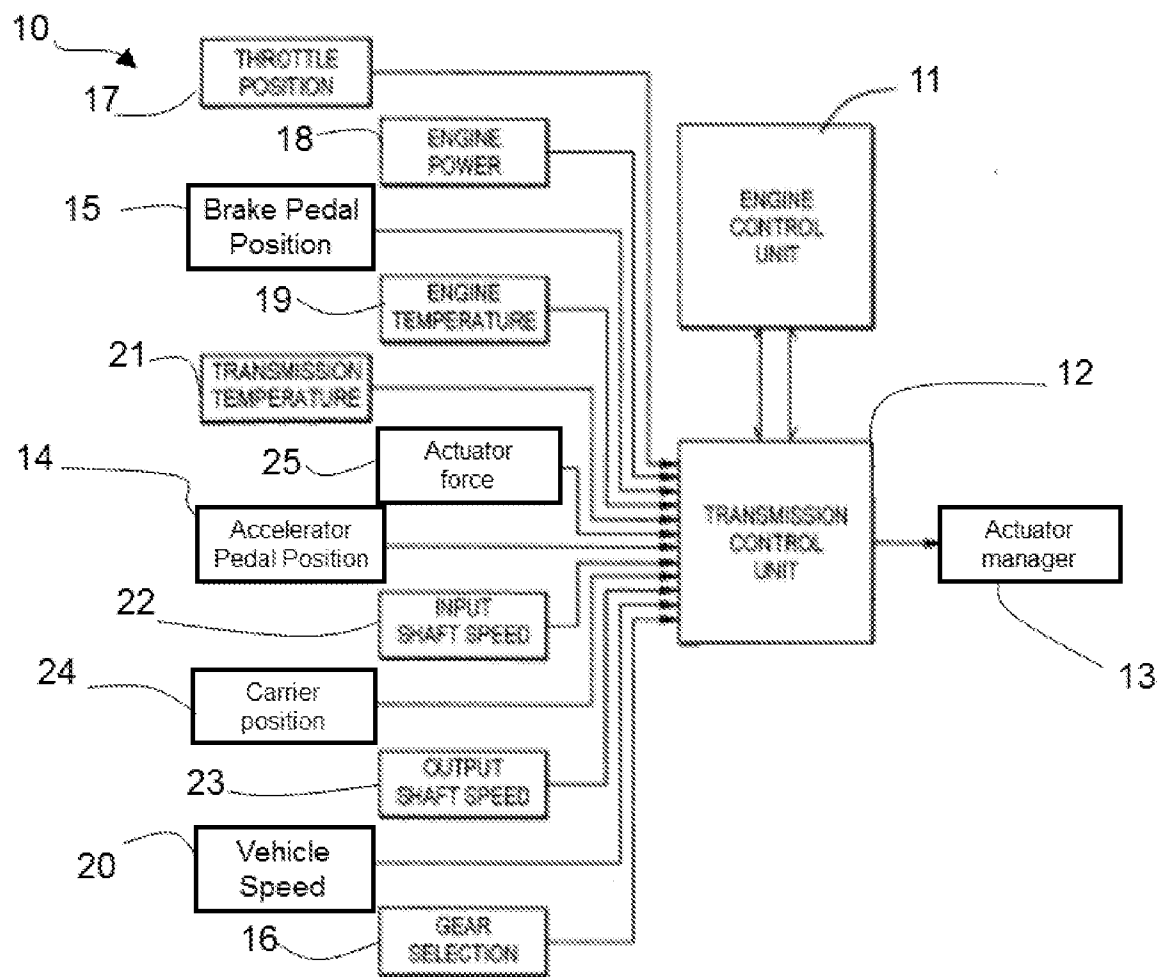


Figure 6

5/8

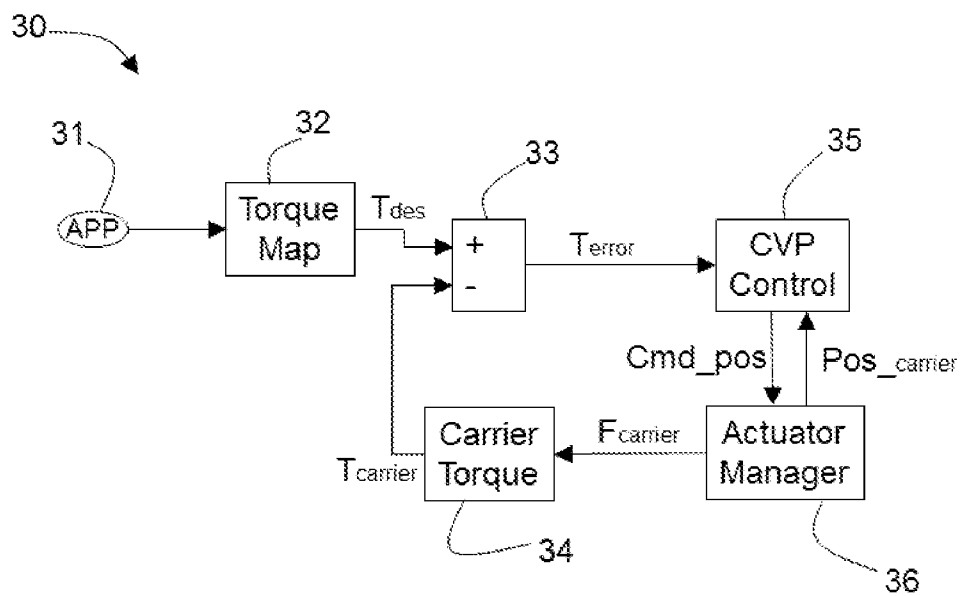


Figure 7

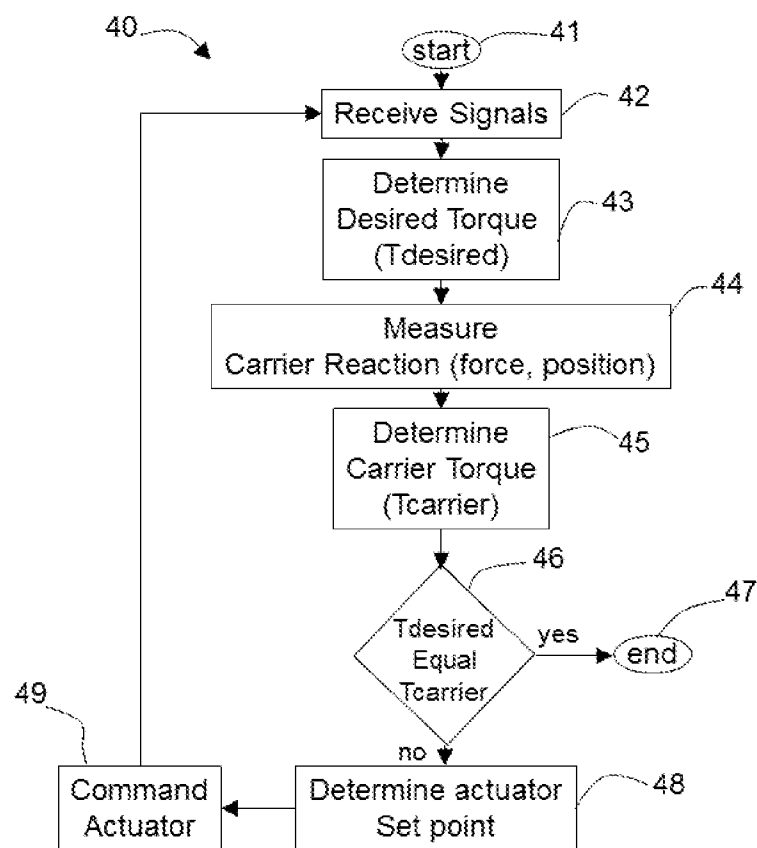


Figure 8

6/8

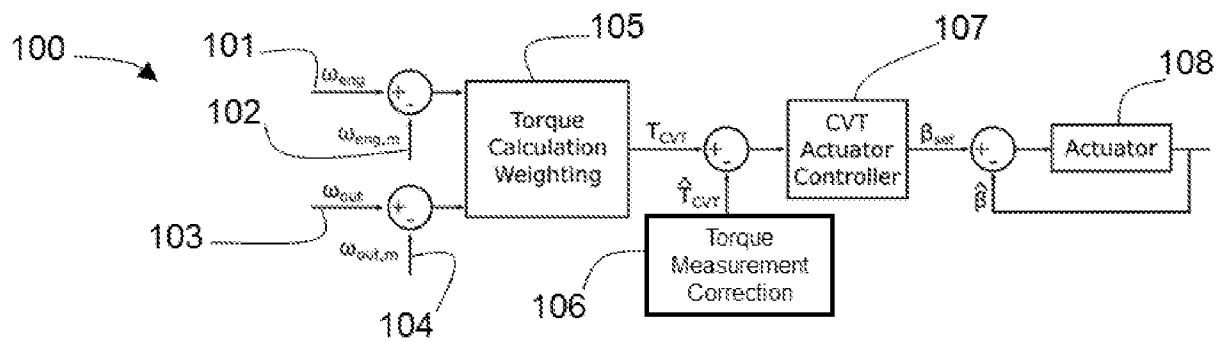


Figure 9

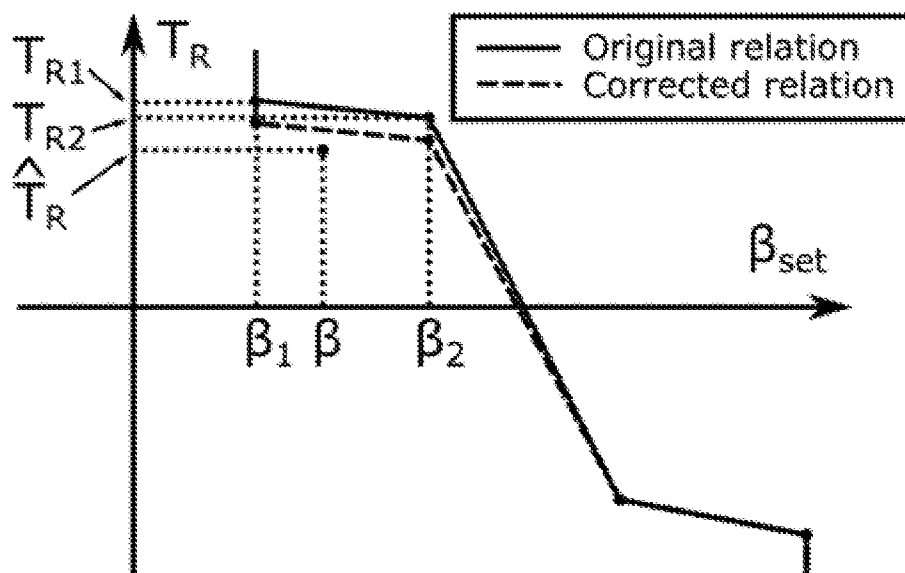


Figure 10

7/8

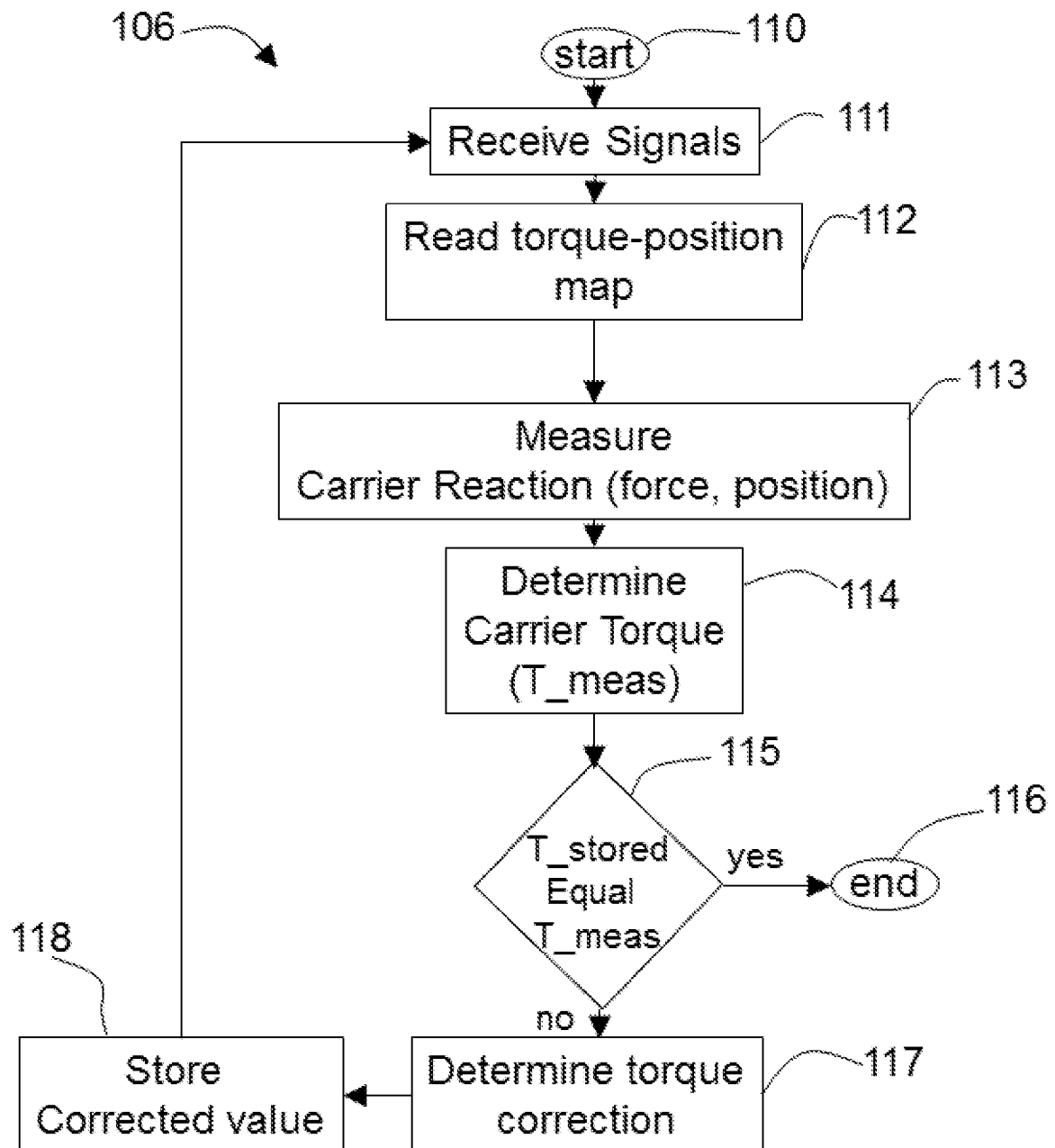


Figure 11

8/8

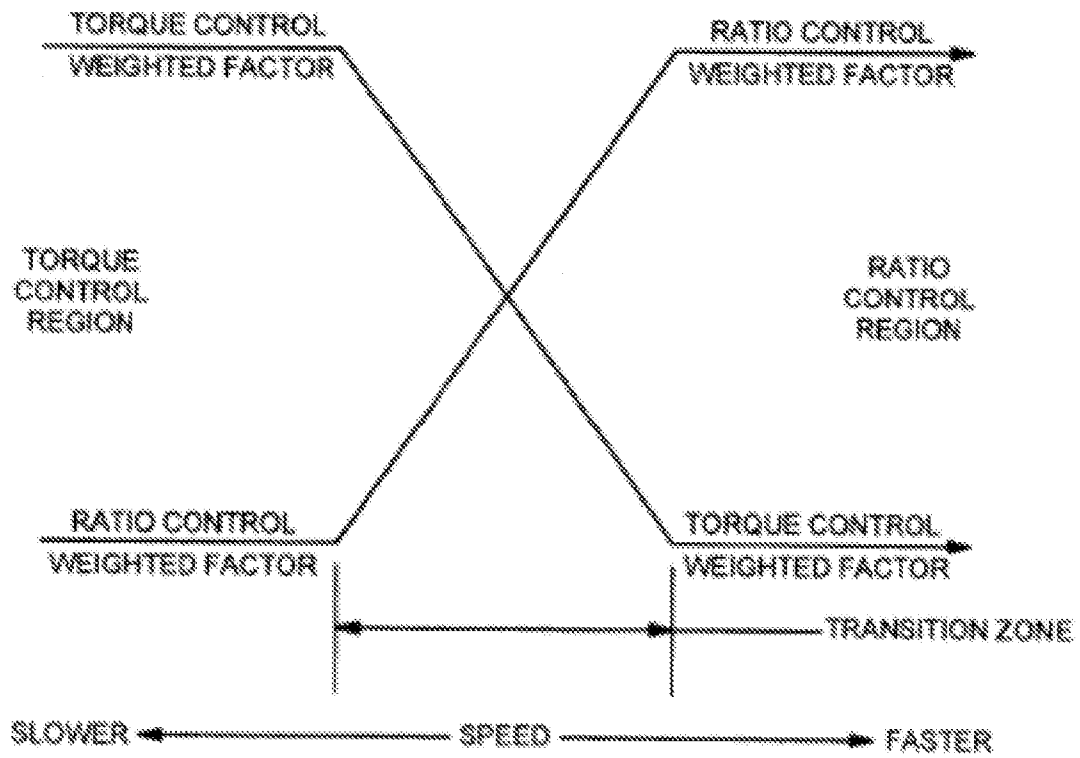


Figure 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/054095

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F16H 15/00; F16H 15/02; F16H 15/40; F16H 15/48; F16H 15/50; F16H 15/52 (2016.01)

CPC - F16H 15/00; F16H 15/02; F16H 15/40; F16H 15/48; F16H 15/50; F16H 15/52 (2016.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC - F16H 15/00; F16H 15/02; F16H 15/40; F16H 15/48; F16H 15/50; F16H 15/52

CPC - F16H 15/00; F16H 15/02; F16H 15/40; F16H 15/48; F16H 15/50; F16H 15/52

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 475/185; 475/189; 475/196; 475/207; 475/214; 476/36; 476/38 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Orbit, Google Patents, Google

Search terms used: vehicle, engine, continuously variable transmission, ball planetary variator, reaction torque

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/0251747 A1 (IMAI et al) 13 October 2011 (13.10.2011) entire document	1-11
Y	US 2010/0131164 A1 (CARTER et al) 27 May 2010 (27.05.2010) entire document	1-11
Y	US 20140/329637 A1 (FALLBROOK INTELLECTUAL PROPERTY COMPANY LLC) 06 November 2014 (06.11.2014) entire document	2-11
Y	WO 2014/041326 A1 (CITY UNIVERSITY) 20 March 2014 (20.03.2014) entire document	4
Y	US 2006/0189432 A1 (TSUCHIYA et al) 24 August 2006 (24.08.2006) entire document	6-11
Y	WO 2014/172422 A1 (FALLBROOK INTELLECTUAL PROPERTY COMPANY LLC) 23 October 2014 (23.10.2014) entire document	7-11
Y	US 2002/0117339 A1 (NAKASHIMA) 29 August 2002 (29.08.2002) entire document	8-11
Y	US 9,096,135 B1 (SIMONINI) 04 August 2015 (04.08.2015) entire document	11
A	US 2011/0105274 A1 (LOHR et al) 05 May 2011 (05.05.2011) entire document	1-11
A	US 5,890,468 A (OZAWA) 06 April 1999 (06.04.1999) entire document	1-11
A	US 6,030,313 A (SAWADA et al) 29 February 2000 (29.02.2000) entire document	1-11
A	US 2015/0039191 A1 (TOYOTA MOTOR ENGINEERING & MANUFACTURING NORTH AMERICA, INC.) 05 February 2015 (05.02.2015) entire document	1-11

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 January 2017

Date of mailing of the international search report

16 FEB 2017

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, VA 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/054095

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See supplemental page

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-11

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/054095

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-11, drawn to a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator.

Group II, claims 12-21, drawn to a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device.

Group III, claims 22-24, drawn to a computer-implemented system for a vehicle having an engine coupled to a continuously variable transmission having a ball-planetary variator (CVP), the computer-implemented system comprising: a digital processing device comprising an operating system configured to perform executable instructions and a memory device; a computer program including instructions executable by the digital processing device, the computer program comprising a software module configured to manage a plurality of vehicle driving conditions.

The inventions listed as Groups I, II and III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: a vehicle direction sensor configured to sense a vehicle direction; a parking brake status sensor configured to sense a parking brake status; a CVP reaction torque sensor configured to sense a CVP reaction torque as claimed therein is not present in the invention of Groups II and III. The special technical feature of the Group II invention: a CVP shift actuator force sensor configured to sense a CVP shift actuator force; and wherein the software module commands a change in a shift position of the CVP based at least in part on the CVP shift actuator force as claimed therein is not present in the invention of Groups I or III. The special technical feature of the Group III invention: wherein the torque-based control module includes a plurality of calibration maps, each calibration map configured to store values of a desired output torque based at least in part on the plurality of sensors as claimed therein is not present in the invention of Groups I or II.

Groups I, II and III lack unity of invention because even though the inventions of these groups require the technical feature of a vehicle speed sensor configured to sense a vehicle speed, - a brake pedal position sensor configured to sense a brake pedal position, - an accelerator pedal position sensor configured to sense an accelerator pedal position, - a CVP carrier position sensor configured to sense a CVP carrier position; an engine speed sensor configured to sense an engine speed, - a first speed sensor configured to sense a CVP input speed, - a second speed sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed are adapted to provide a CVP speed ratio, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2015/0039191 A1 (TOYOTA MOTOR ENGINEERING AND MANUFACTURING NORTH AMERICA, INC.) 05 February 2015 (05.02.2015) teaches a vehicle speed sensor configured to sense a vehicle speed (Para. 15), a brake pedal position sensor configured to sense a brake pedal position (Para. 15), an accelerator pedal position sensor configured to sense an accelerator pedal position (Para. 15), a CVP carrier position sensor configured to sense a CVP carrier position; an engine speed sensor configured to sense an engine speed (Para. 6), - a first speed sensor configured to sense a CVP input speed, - a second speed sensor configured to sense a CVP output speed, wherein the CVP input speed and the CVP output speed are adapted to provide a CVP speed ratio (Paras. 22-24).

Since none of the special technical features of the Group I, II or III inventions are found in more than one of the inventions, unity of invention is lacking.