(51) International Patent Classification:
F02N 11/08 (2006.01) B60W 50/10 (2012.01)
B60W 30/18 (2012.01) B60W 10/06 (2006.01)

(21) International Application Number:
PCT/EP2017/062134

(22) International Filing Date:
19 May 2017 (19.05.2017)

(25) Filing Language:
English

(26) Publication Language:
English

(30) Priority Data:
1610406.9 15 June 2016 (15.06.2016) GB

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Published:
with international search report (Art. 21(3))

(54) Title: VEHICLE PROVIDED WITH AN INTERNAL COMBUSTION ENGINE, A START-STOP FUNCTION, WHEREIN THE MOVEMENT OF THE DRIVER'S FOOT IS DETECTED

(57) Abstract: A torque actuator restart system for a torque actuator of a vehicle drive train is described. The torque actuator restart system comprises: an input device configured to allow a driver of the vehicle to input a driver torque request to the torque actuator; a sensing device configured to detect the positioning of the driver's foot; and a control module configured to determine an intention of the driver to request torque based on the positioning of the driver's foot. The torque actuator is operable between an on state in which the torque actuator is responsive to the driver torque request and an off state in which the torque actuator is unresponsive to the driver torque request. The system is configured so that, upon the determination module determining an intention of the driver based on the positioning of the driver's foot, the torque actuator is switched to the on state so that the torque actuator is responsive to an anticipated driver torque request so as to actuate the drivetrain.

Figure 4
VEHICLE PROVIDED WITH AN INTERNAL COMBUSTION ENGINE, A START-STOP FUNCTION, WHEREIN THE MOVEMENT OF THE DRIVER'S FOOT IS DETECTED

TECHNICAL FIELD

The present disclosure relates to a system for use on a vehicle and particularly, but not exclusively, to a system for improving drivability in vehicles equipped with the ability to enter a coasting state with the torque actuator turned off. Aspects of the invention relate to a torque actuator restart system, to a control module for a torque actuator restart system, to a vehicle drive train system, to a vehicle and to a method of operating a torque restart system.

BACKGROUND

A vehicle in motion is said to be in a coasting state (i.e. 'coasting') if the internal combustion engine (or other form of torque actuator) is disconnected from the vehicle drivetrain.

Electric hybrid vehicles combine a conventional internal combustion engine propulsion system with an electric propulsion system to provide an efficient and economical vehicle type. In particular, electric hybrid vehicles are equipped with the ability to turn the engine off during coasting in order to reduce fuel consumption. In such circumstances, when the driver applies pressure to the accelerator pedal to request torque to be provided by the engine, the engine is restarted and then reconnected to the drive train to provide the required torque to the wheels of the vehicle.

Whilst such vehicles benefit from fuel efficiency savings, the time it takes for the engine to be restarted and reconnected means that torque is not provided immediately when the driver depresses the accelerator pedal. The perception of this delay by the driver impacts negatively on the driving feel and experience.

It is one object of the present invention to mitigate or overcome the above-mentioned problem.
SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide a torque actuator restart system, a control module for a torque actuator restart system, a vehicle drive train system, a vehicle and a method of operating a torque actuator restart system.

According to an aspect of the present invention there is provided a torque actuator restart system for a torque actuator of a vehicle drive train. The torque actuator restart system comprises: an input device configured to allow a driver of the vehicle to input a driver torque request to the torque actuator; a sensing device configured to detect the positioning of the driver’s foot; and a control module configured to determine an intention of the driver to request torque based on the positioning of the driver’s foot. The torque actuator is operable between an on state in which the torque actuator is responsive to the driver torque request and an off state in which the torque actuator is unresponsive to the driver torque request. The system is configured so that, upon the control module determining an intention of the driver, the torque actuator is switched to the on state so that the torque actuator is responsive to an anticipated driver torque request so as to actuate the drivetrain.

The torque actuator system of the present invention anticipates driver torque requests by determining if the driver intends to request torque. Based on an anticipated driver torque request, the system primes the torque actuator in an on state in which the torque actuator is responsive to the anticipated driver torque request. Therefore, the driver experiences torque immediately when requested. In this way, the system provides an improved driver experience.

The invention is particularly, but not exclusively, relevant to hybrid electric vehicles combining an internal combustion engine (torque actuator) with an electric propulsion system. In particular, the invention is especially relevant to hybrid electric vehicles equipped with the ability to turn the internal combustion engine off during coasting.

The input device may be a vehicle pedal operable by the driver’s foot.
In one embodiment the sensing device may include a sensor configured to detect the position of the driver's foot relative to the input device.

Alternatively, or in addition, the sensing device may include a sensor configured to detect a trajectory of movement of the driver's foot towards the input device.

In another embodiment, the sensing device may be configured to detect the speed of movement of the driver's foot in addition, or as an alternative, to detecting the trajectory of movement and/or the position of the foot relative to the input device. In the case of the sensing device being configured to detect the speed of movement of the driver's foot, this provides the means for detecting or monitoring the positioning of the driver's foot.

The sensing device may comprise an image capture device. In other embodiments, the sensing device may comprise an ultrasonic sensor, a capacitive sensor or a laser sensor.

The control module may be configured to output a control signal to the torque actuator in dependence on the anticipated driver torque request.

The torque actuator restart system may comprise a data store for storing a one or more indicators that the intention of the driver is to request torque. In this case, the control module may comprise a comparator unit for comparing an output derived from the sensing device with the indicator(s) so as to determine whether there is an intention of the driver to request torque.

The comparator unit may be configured to determine that there is an intention of the driver to request torque when the output indicates that the driver's foot is within a predetermined distance of the input device.

The comparator unit may be configured to determine that there is an intention of the driver to request torque when the output indicates that the driver's foot is following a predetermined trajectory of movement towards the input device.
The control module may comprise a learning module. This allows the torque actuator restart system to adapt to a particular driver’s behaviour in order to detect more accurately the driver’s intentions to request torque.

The learning module may be configured to determine whether the determined intention of the driver to request torque is followed by a subsequent driver request for torque. In this case, the learning module may be configured to update the indicators in response to the determination.

The learning module may be configured to determine that the determined intention of the driver to request torque corresponds to an actual request for torque if the determined intention is identified within a predetermined period prior to the actual request.

According to another aspect of the invention, there is provided a control module for a torque actuator restart system according to the previously-described aspect.

According to a further aspect of the invention, there is provided a vehicle drive train system comprising the torque actuator restart system of the first-described aspect.

According to yet another aspect of the invention, there is provided a vehicle comprising the drive train system of the previous aspect.

The torque actuator may be configured for disconnection from the drive train so that the vehicle adopts a coasting state when the torque actuator is disconnected from the drive train.

According to a still further aspect of the invention, there is provided a method of controlling a torque actuator restart system for a torque actuator of a vehicle drive train. The torque actuator is controlled by means of a driver torque request at an input device and is operable between an on state in which the torque actuator is responsive to the driver torque request and an off state in which the torque actuator is unresponsive to the driver torque request. The method comprises: detecting the positioning of the driver’s foot; determining an intention of the driver to request torque
based on the positioning of the driver's foot; and, upon determining an intention of the driver, switching the torque actuator to the on state so that the torque actuator is responsive to an anticipated driver torque request so as to actuate the drivetrain.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a vehicle comprising a torque actuator restart system in accordance with an embodiment of the invention;

Figure 2 is a flowchart showing steps of a process that may be performed by the torque actuator restart system of Figure 1;

Figures 3a, 3b and 3c are a series of schematic diagrams illustrating various states of the operation of the torque actuator restart system of Figure 1 in use;

Figure 4 is a schematic diagram showing features of an embodiment of the torque actuator restart system of Figure 1 in more detail;

Figure 5 is a schematic diagram showing features of an alternative embodiment of the torque actuator restart system; and
Figure 6 is a flow diagram illustrating steps of a process that may be performed by the torque actuator restart system of Figure 1.

DETAILED DESCRIPTION

Referring to Figure 1, a vehicle 10 is shown comprising a torque actuator in the form of an engine 12, and a drivetrain 14 comprising the group of components that deliver power from the engine 12 to the driving wheels 16 of the vehicle 10.

The engine 12 is coupled to the drivetrain 14 under the control of an engine control unit (ECU) 18 including a connection interface module 20. The ECU 18 is operable to connect and disconnect the engine 12 from the drivetrain 14 depending on the operating circumstances. When the vehicle 10 is in motion and the engine 12 is disconnected from the drivetrain 14, the vehicle 10 is said to be in a 'coasting state'. When the engine 12 is connected to the drivetrain 14, the vehicle is said to be in a 'drive state'.

The driver of the vehicle 10 operates an input device in the form of a driver request pedal (or accelerator pedal) 22 which provides signals to the ECU 18 to determine whether torque is provided by the engine 12 to the wheels 16 via the drivetrain 14, and the extent of the torque to be provided. That is, the pedal 22 allows the driver to request torque to be provided by the engine 12 and to indicate to the engine the desired torque to be provided. To request torque, the driver depresses the pedal 22 by applying pressure to the pedal 22 with his foot.

The vehicle 10 is also provided with a sensing device to detect the positioning of the driver's foot. In this example, the sensing device comprises a foot sensor 24 configured to detect the position of the driver's foot relative to the pedal 22.

In addition, the engine 12 can either be in an 'on' state or an 'off' state. This vehicle 10 is equipped with the ability to turn the engine 12 off during coasting in order to reduce fuel consumption. If the engine 12 is disconnected from the drivetrain 14 and the engine 12 is off, then the vehicle 10 is said to be in an 'off-coasting' state. In contrast, if
the engine 12 is disconnected from the drivetrain 14 but the engine 12 is on, the vehicle 10 is said to be in an 'idle-coasting' state.

As discussed above, some vehicles equipped with this ability suffer from a sub-optimal driver experience when the vehicle is in the off-coasting state because the driver of the vehicle perceives a delay when requesting torque due to the time it takes for the engine to be restarted. In order to mitigate this problem, the vehicle 10 is provided with a torque actuator restart system in accordance with the invention in the form of an engine restart system, features of which will now be described with continued reference to Figure 1.

The ECU 18 is operable to control the connection interface module 20 to connect and disconnect the engine 12 from the drivetrain 14 and also to control the state of the engine 12 itself (to restart or switch off the engine 12). The ECU 18 also includes a determination module 26, the function of which will be described later, which may comprise a learning module 28. The ECU 18 may control various other aspects of the function of the engine 12.

It should be noted at this stage that the accompanying figures are schematic and have been simplified for the purposes of clarity and to avoid unnecessary detail obscuring the principle form of the invention. For example, the skilled person will appreciate that although the ECU 18 is shown in Figure 1 as a discrete self-contained block, aspects of the ECU 18 may be spatially distributed throughout the vehicle 10. Additionally or alternatively, functional aspects described herein as forming part of the ECU 18 may be performed within other control systems of the vehicle 10. That is to say, the functional architecture illustrated in Figure 1 is not intended to limit the invention to a specific hardware or software architecture, platform or processing environment. The system architecture discussed here is used merely as an example to illustrate the technical functionality of the invention and the invention may be implemented by a system having a different specific architecture.

The ECU 18 is arranged to monitor (i.e. receive data signals related to) a number of parameters in order to control the various aspects of the function of the engine 12. By
way of example, the ECU 18 receives inputs from the driver request pedal 22 and the foot sensor 24.

The ECU 18 is configured to control the connection interface module 20 based on the output of the pedal 22. In particular, if the pedal output indicates that the driver is not applying pressure to the pedal 22 then the ECU 18 is configured to control the connection interface module 20 such that the engine 12 is disconnected from the drivetrain 14. Thus, the vehicle 10 enters a coasting state. Conversely, if the driver is applying pressure to the pedal 22, then the ECU 18 is configured to control the connection interface module 20 such that the engine 12 is connected to the drivetrain 14. Thus, when the driver requests torque, the vehicle 10 enters a drive state in which the extent of the pressure applied to the pedal 22 determines the extent of the torque applied by the engine 12 in a conventional manner.

The ECU 18 also receives an input from the foot sensor 24, which monitors the position of a foot of the driver of the vehicle 10 in order to detect an intention of the driver to request torque. In this embodiment, the foot sensor 24 determines the positions of the driver’s foot relative to the request pedal 22, but in other embodiments the foot sensor 24 may determine the position of the driver’s foot relative to another reference position. As will be described in more detail, in the context of the engine restart system, the role of the ECU 18 is to control the function of the engine 12 such that during coasting the vehicle 10 adopts the appropriate coasting state (off or idle) based on the output of the foot sensor 24.

The skilled person will appreciate that in a practical implementation of the invention, the ECU 18 may receive one or more additional inputs in order to control the function of the engine 12, for example from an ignition switch of the vehicle 10.

The principle of the invention will now be described in more detail with reference to Figure 2 which shows a flow diagram showing steps of a process that may be carried out by the engine restart system shown in Figure 1.

The system determines, at step 100, whether the vehicle 10 is in a coasting state (that is, whether the engine 12 is disconnected from the drivetrain 14).
If the system determines that the vehicle 10 is not in a coasting state, then the system enters a loop 102 and continues to monitor the engine 12 until the vehicle 10 enters a coasting state. Thus, the further steps of the process only influence the function of the engine 12 when the vehicle 10 is in a coasting state. In this way, the engine restart system does not interfere with the function of the engine 12 when the vehicle 10 is in a drive state. On the other hand, if the system determines, at step 100, that the vehicle 10 is in a coasting state then the process continues as described below.

The system determines, at step 104, if the driver intends to request torque. This determination is based on the position of the driver’s foot, as detected by the foot sensor 24; that is, as indicated by the output 106 of the sensor 24. In particular, the system determines that the driver intends to request torque if the sensor output 106 indicates that the driver will (or is likely to) imminently apply pressure to the accelerator pedal 22. As will be described in more detail, there are a number of ways in which the sensor 24 may be configured to detect this driver intention.

If the system determines, at step 104, that the driver does not intend to request torque, then the system outputs, at step 108, an off-coasting signal to the engine 12. In compliance with this signal, the engine 12 switches off and thus, the vehicle 10 enters an off-coasting state. In the off-coasting state, the engine 12 is not immediately responsive to a driver torque request in the respect that, on requesting torque, the driver will perceive a delay before torque is provided by the drivetrain 14 to the driving wheels 16 of the vehicle 10.

In contrast, if the system determines, at step 104, that the driver intends to request torque, then the system outputs, at step 110, an idle-coasting signal to the engine 12. In compliance with this signal, the engine 12 switches on and thus, the vehicle enters an idle-coasting state.

In an idle-coasting state, the engine 12 is responsive to (or primed for) a driver torque request. When the driver requests torque to be provided by the engine 12, the engine 12 is already in the on state and can be connected to the drivetrain 14 to provide torque to the driving wheels 16 of the vehicle 10 without perceptible delay. By
controlling the function of the engine 12 such that the vehicle 10 enters an idle-coasting state when it is detected that the driver intends to request torque, the engine restart system thus provides an improved driver experience compared with the prior art.

The system is configured such that the above-described process is continuously performed. Thus, the system ensures that the vehicle adopts the appropriate coasting state based on the detected intentions of the driver at any moment in time.

It should be noted that the above-described process is one example of a process that may be carried out by an engine restart system in accordance with an embodiment of the invention. The skilled person will be able to envisage appropriate alternative processes that may be performed by the engine restart system to achieve the aims of the invention.

The principle of the invention will now be described in more detail with reference to Figures 3a, 3b and 3c, a series of schematic diagrams illustrating stages of a driver torque request, and in particular the different positions of the driver’s foot.

Referring initially to Figure 3a, the position of the foot sensor 24 relative to the driver request pedal 22 can be seen. In addition, a foot 30 of a driver of the vehicle 10 is shown. As shown in Figure 3a, the driver’s foot 30 is not applying pressure to the pedal 22 and the pedal output indicates to the ECU 18 that this is the case. In such circumstances, the ECU 18 controls the connection interface module 20 such that the engine 12 is disconnected from the drivetrain 14. Thus, the vehicle 10 is in a coasting state.

Furthermore, the position of the driver’s foot 30 is such that the foot sensor 24 does not detect an intention of the driver to request torque from the engine 12. This is because the foot 30 is positioned a sufficient distance from the pedal 22 that no imminent request for torque can occur through pressure being applied to the driver request pedal 22. The sensor output provides this indication to the ECU 18; the ECU 18 outputs an off-coasting signal to the engine 12 and the engine 12 adopts the ‘off state’. As such, the vehicle 10 enters an off coasting. This is the appropriate coasting
state based on the output of the sensor 24 since the driver does not intend to request torque. Adopting the off coasting state in these circumstances reduces the fuel consumption of the vehicle 10.

Turning now to Figure 3b, the driver’s foot 30 is positioned closer to the pedal 22. The previous position 30a of the driver’s foot 30 is also indicated in Figure 3b for comparison and it can be seen that the foot 30 is positioned closer to the pedal 22 in this scenario. However, the driver’s foot 30 is not applying pressure to the pedal 22. As described previously, the pedal output provides an indication of this to the ECU 18. Because the driver’s foot 30 is not applying pressure to the pedal 22, the connection interface module 20 is controlled so that the engine 12 remains disconnected from the drivetrain 14 and the vehicle 10 is in a coasting state.

However, based on the position of the driver’s foot 30 being close to the pedal 22, the foot sensor 24 detects that the driver intends to request torque from the engine 12. As a consequence, the engine restart system primes the engine 12 to respond to the anticipated torque request when it occurs. In particular, the sensor output indicates to the ECU 18 that the driver intends to request torque and the ECU 18 sends an ‘idle-coasting’ signal to the engine 12. In compliance with this signal, the engine 12 adopts the ‘on state’ and the vehicle 10 enters an idle-coasting state. In this state, the engine 12 is responsive to the anticipated driver torque request when it occurs.

Referring now to Figure 3c, the driver’s foot 30 is shown applying pressure to the pedal 22. As such, the driver is requesting torque. The previous positions 22b, 30b of the pedal 22 and driver’s foot 30 are also shown for comparison. The pedal 22 output indicates to the ECU 18 that the pedal 22 is depressed and based on this output, the ECU 18 controls the connection interface module 20 such that the engine 12 is connected to the drivetrain 14. Thus, the vehicle 10 enters a drive state in which torque can be provided by the drivetrain 14 to the wheels 16 of the vehicle 10 in accordance with the driver’s request. Since the engine 12 is primed in the on state state it is immediately responsive to the driver’s torque request and the driver experiences torque immediately when requested. In this way, the engine restart system provides an improved driver experience.
Now that the function of the engine restart system has been discussed in general, features of the invention will now be described in more detail. In particular, possible configurations of the foot sensor 24 will now be discussed with reference to Figures 4 and 5.

Turning first to Figure 4, this shows a schematic representation of the footwell 32 of the vehicle 10. The driver request pedal 22, foot sensor 24 and driver's foot 30 can be seen.

The foot sensor 24 includes a transmitter element 34 mounted in a cover 35 which forms a part of the vehicle interior, and a corresponding detector element (not shown) mounted in the floor 36 of the footwell 32. The transmitter element 34 transmits a beam of radiation 38 towards the detector element which is sensitive to the radiation 38 transmitted by the transmitter element 34. If the beam of radiation 38 is broken, and no signal is detected at the detector element, or if a reduced intensity signal is detected at the detector element, this provides an indication that there is an obstruction to the beam of radiation 38. This indication is interpreted as movement of the driver's foot 30 into the path of the beam 38, indicating that the driver is moving their foot 30 into a position in which pressure is to be applied to the pedal 22. As a result, a signal is provided to the ECU 18 which controls the engine to put the vehicle 10 into the idle-coasting state (with the engine 12 in the on state), so that it is primed to provide torque as soon as pressure is actually applied to the pedal 22.

In another embodiment, as shown in Figure 5, the sensor system is based on video-camera technology, for example CCD or CMOS technology, and may be capable of mono (2D) or stereo (3D) monitoring. In this case, rather than a beam of radiation being monitored, the sensor system comprises a camera element 40 mounted in the cover 35 of the vehicle interior which provides image data to the ECU 18 as a means of determining the position of the driver's foot 30 within the footwell 32, and in particular the position of the driver's foot 30 relative to the pedal 22.

In other embodiments (not shown), the sensor system may include an ultrasonic sensor for monitoring the position of the driver's foot 30 based on ultra sound signals, or a capacitive sensor.
Based on the detected position of the driver’s foot 30, the engine restart system determines whether the driver intends to request torque. The ECU 18 comprises an appropriate processing facility, in the form of the determination module 26, to interpret the output of the foot sensor 24 (whatever form this may take) and determine if the driver intends to request torque. In other embodiments, the determination module 26 may be provided as part of an integrated sensor package. In this case, the processing of the raw sensor output signal occurs within the sensor package and the output of the sensor package provides an indication to the ECU 18 about whether or not the driver intends to request torque.

It should be appreciated that the determination module 26 may include a memory area on which suitable software is stored and an execution environment to run the control software. A set of instructions could be provided which, when executed, cause the determination module 26 to implement the techniques described herein (including the method(s) described below). The set of instructions may be embedded in one or more electronic processors, or alternatively, the set of instructions could be provided as software to be executed by one or more electronic processor(s). For example, a first function may be implemented in software run on one or more electronic processors, and one or more other functions may also be implemented in software run on one or more electronic processors, optionally the same one or more processors as the first controller. It will be appreciated, however, that other arrangements are also useful, and therefore, the present invention is not intended to be limited to any particular arrangement. In any event, the set of instructions described above may be embedded in a computer-readable storage medium (e.g., a non-transitory storage medium) that may comprise any mechanism for storing information in a form readable by a machine or electronic processors/computational device, including, without limitation: a magnetic storage medium (e.g., floppy diskette); optical storage medium (e.g., CD-ROM); magneto optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (e.g., EPROM ad EEPROM); flash memory; or electrical or other types of medium for storing such information/instructions.
In order to determine whether the driver intends to request torque, the determination module 26 may implement various forms of determination process. Some examples will now be described by way of illustration.

The determination module may include a memory area or data store on which one or more ‘indicators’ that the intention of the driver is to request torque are stored. These indicators are behaviours that typically indicate that a driver of a vehicle intends to request torque. The determination module includes a comparator unit configured to compare the output of the foot sensor 24 with the one or more indicators to determine whether the driver intends to request torque.

For example, according to one embodiment of the invention, the determination module 26 determines that the driver intends to request torque if the driver's foot 30 is within a predetermined distance of the accelerator pedal 22, referred to hereafter as the ‘indicative distance’. The region of space within the indicative distance from the pedal defines an ‘indicative zone’. In a simple embodiment, the indicative distance is a fixed distance in all directions from the pedal. According to other embodiments, the indicative distance is a function of direction. That is to say, the indicative distance need not be the same in every direction from the pedal 22. In particular, the indicative zone may extend further from the pedal 22 in some directions compared to others, defining an irregularly shaped indicative zone.

In other embodiments, the determination module 26 implements a more sophisticated determination process to determine more accurately when the driver intends to request torque. For example, the trajectory of movement of the driver's foot 30 may be monitored to determine the driver's intention. One such embodiment is described below by way of example.

The determination module 26 includes a memory area on which a set of ‘indicative trajectories’ is stored. The indicative trajectories are foot trajectories that typically indicate that a driver of a vehicle intends to request torque. The indicative trajectories may be determined prior to use of the vehicle 10 and may typically be loaded onto the memory area of the determination module 26 at the point of manufacture, or may be downloadable to the memory area when the user is performing an initial configuration.
of the vehicle 10. Input means may be provided for the user to select appropriate pre-
determined indicative trajectories prior to use of the vehicle 10, for example depending
on the type of shoe being worn by the driver at the time or the identity of the driver of
the vehicle 10. The input means may be embodied within the human machine interface
(HMI) of the vehicle 10 which typically resides within the vehicle cabin. Alternatively, a
particular set of pre-determined indicative trajectories may be selected automatically in
dependence on one or more vehicle settings, for example the position of the driver’s
seat. Alternatively or additionally, a particular set of pre-determined indicative
trajectories may be selected in dependence on the identity of the driver of the vehicle
10 as detected by an appropriate vehicle system, for example based on a detected
device such as a key fob.

When in use, the determination module 26 uses the input from the sensor 24 to
determine if the detected trajectory of the driver’s foot 30 corresponds to one of the
pre-stored indicative trajectories. In order to do so, the determination module 26
performs one or more algorithms to compare the trajectory of the driver’s foot 30, as
indicated by the output of the foot sensor 24, with the set of indicative trajectories. If
the determination module 26 determines that the trajectory of the driver’s foot 30
corresponds with one of the pre-stored set of indicative trajectories, then the
determination module 26 determines that the driver intends to request torque and the
ECU 18 primes the engine 12 accordingly so that torque is provided immediately via
the drivetrain 14 when pressure is applied to the pedal 22.

In some embodiments of the invention, the determination module 26 may determine
whether the driver intends to request torque based on the distance of the driver’s foot
30 relative to the accelerator pedal 22 as well as the trajectory of movement of the
driver’s foot 30. For example, the determination module 26 may determine that the
driver intends to request torque only if both conditions are met; that is to say, if the
driver’s foot 30 is within an indicative distance of the accelerator pedal 22 and the
movement of the driver’s foot 30 corresponds to one of a pre-stored set of indicative
trajectories. Alternatively, the determination module 26 may determine that the driver
intends to request torque if either condition is met: if the driver’s foot 30 is within an
indicative distance of the pedal 22 or the driver’s foot 30 corresponds to an indicative
trajectory.
The skilled person will appreciate that various alternative determination processes may be performed by the determination module 26 in other embodiments. For example, the engine restart system may be configured to account in various ways for the typical driving behaviour of different drivers and in particular, the typical foot positions and foot movement trajectories of different drivers. In some embodiments, the determination module 26 includes a learning module 28 for updating the indicative trajectories based on the position of the driver’s foot 30 during periods prior to the comparison taking place. An example of such an embodiment will now be described with reference to Figure 6 which shows steps of a process that may be carried out by the engine restart system.

At step 200, the determination module 26 determines whether the conditions are satisfied to suggest that the driver intends to request torque. This is done, for example, by checking whether the detected trajectory of the driver’s foot 30 corresponds to one of the pre-stored indicative trajectories, as described above. In response to this determination, the system outputs an idle-coasting signal 202 or off-coasting signal 204 to the engine 12 as appropriate in order to prime the engine 12 accordingly.

As mentioned above, the determination module 26 in this embodiment includes a learning module 28 for updating the set of indicative trajectories to adapt to the typical driving behaviours of a particular driver. The set of indicative trajectories is updated based on the performance of the system over a prior period. More specifically, the set of indicative trajectories is updated based on whether previously detected driver intentions have developed into torque requests, and also on whether torque has previously been requested by the driver without an intention being detected beforehand. In this way, the set of indicative trajectories can be updated to adapt to the driving style of a driver over the course of a journey, or over a series of several journeys. An example of a process carried out by the learning module 28 to update the set of indicative trajectories will now be described with reference to steps 206 to 218 shown in Figure 6.

If it is determined, at step 200, that the detected trajectory of the driver’s foot 30 corresponds to one of the indicative trajectories, then the learning module 28
establishes, at step 206, whether the detected intention of the driver actually culminates in a torque request. In particular, the learning module 28 establishes whether the accelerator pedal 22 is depressed within a certain time period following the determination of the driver's intention at step 200. For example, if the accelerator pedal 22 is depressed within a predetermined time period following determination that the trajectory of the driver's foot 30 corresponds to an indicative trajectory then the learning module 28 verifies that the accelerator pedal 22 has been depressed as a result of the detected trajectory. This time period may be fixed or may vary, for example in dependence on the indicative trajectory with which the detected trajectory of the driver's foot 30 corresponds. That is to say, there may be an expectation that certain indicative trajectories will result in a torque request sooner than others.

If the detected driver intention does culminate in a driver torque request, then this is an indication that the detected trajectory of the driver's foot 30 may be correctly classified as an indicative trajectory as the driver's intention was verified by the subsequent torque request. That is to say, this event reinforces the supposition that this trajectory typically indicates that the driver of the vehicle intends to request torque. Therefore, if the learning module 28 verifies, at step 206, that the detected driver intention culminates in a driver torque request, then the learning module 28 designates this event, at step 208, as a reason to continue to include the detected trajectory within the set of indicative trajectories.

On the other hand, if the detected driver intention does not culminate in a driver torque request, then this is an indication that the detected trajectory may be incorrectly classified as an indicative trajectory. Therefore, if the learning module 28 fails to verify, at step 206, that the detected driver intention culminates in a driver torque request, then the learning module 28 designates this event, at step 210, as a reason to remove the detected trajectory from the set of indicative trajectories.

A corresponding process is carried out if the determination module 26 determines, at step 200, that the detected foot trajectory does not correspond to one of the set of indicative trajectories. In this case, the learning module 28 establishes, at step 212, whether the driver proceeds to request torque. In particular, the learning module 28 establishes whether the accelerator pedal 22 is depressed within a certain time period.
following the determination of the driver’s intention at step 200, in a similar process to the one described above in relation to step 206.

If the learning module 28 establishes, at step 212, that the driver does proceed to request torque following the determination then this is an indication that the detected foot trajectory may be incorrectly classified as it was determined at step 200 that the driver did not intend to request torque. Therefore, the learning module 28 designates this event, at step 214, as a reason to include the detected foot trajectory within the set of indicative trajectories.

On the other hand, if the learning module 28 establishes, at step 212, that the driver does not proceed to request torque following the determination, at step 200, that the driver does not intend to request torque, then this is an indication that the detected foot trajectory is correctly classified. Therefore, the learning module 28 designates this event, at step 216, as a reason to maintain the present classification of the detected foot trajectory as outside the set of indicative trajectories.

Based on the designations, at steps 208, 210, 214 and 216, of various events as reasons to include or disclude certain trajectories from the set of indicative trajectories, the learning module 28 modifies, at step 218, the set of indicative trajectories. The correct modification may be determined in a number of ways. In one embodiment of the invention, the designation of a single event as a reason to include or disclude a certain trajectory from the set of indicative trajectories will result in the learning module 28 modifying the set of indicative trajectories by including or removing that trajectory.

In other embodiments, the satisfaction of an additional requirement may be required before updating the set of indicative trajectories. For example, there may be a predetermined threshold number of events that are required before the learning module 28 updates the set of indicative trajectories. This maintains the resilience of the set of indicative trajectories to the influence of anomalous events. The number of events designated as a reason to include a certain trajectory within the set of indicative trajectories may be compared with the number of events designated as a reason to disclude that trajectory from the set of indicative trajectories. The determination may depend on the number of appropriately designated events over a period of time, or the frequency of certain designations.
According to other embodiments of the invention, the learning module 28 may employ an appropriate statistical method to modify the set of indicative trajectories. This allows the updating process to be sufficiently sensitive to adapt to driver behaviour without excessive sensitivity to anomalous events. For example, the learning module 28 may employ the principles of the up/down counter or 'leaky bucket' model. Other methods such as cumulative sum (CUSUM) are also applicable.

Thus, as described above, the learning module 28 is configured to update the set of indicative trajectories based on driver behaviour over a period of time. As such, when the system makes a comparison between a detected foot trajectory and the indicative trajectories, the set of indicative trajectories is appropriately updated based on driver behaviour over a period (or periods) of time prior to the comparison taking place. This allows the system to adapt to a particular driver's behaviour in order to detect more accurately the driver's intentions to request torque. The system is also able to adapt to changes in a driver's behaviour over a longer period of time.

As discussed above, an appropriate set of indicative trajectories may be selected based on the identity of the driver. Therefore, the system is capable of adapting to the driving behaviour of more than one driver by maintaining and updating a separate set of indicative trajectories for each driver.

Additionally or alternatively, the determination module 26 may include a learning module 28 that updates the indicative distance (i.e. the distance from the pedal 22 within which it is determined that the driver intends to request torque). This updating process may be based on a similar process to the one described above in relation to updating a set of indicative trajectories. The skilled person will be able to envisage how such a process may be applied to the updating of the indicative distance. As such, the size and shape of the indicative zone can be appropriately adjusted according to the typical driving behaviour of the driver as learnt over a period of time. In this way, the engine restart system can account for the usual position of the driver's foot 30 when the driver is not requesting torque or intending to request torque. The indicative distance would therefore be different for a driver who typically positions their foot 30
relatively close to the pedal 22 compared to a driver who typically positions their foot 30 further away from the pedal 22.

The determination module 26 may take into account various additional factors depending on the sophistication of the engine restart system, for example the speed of movement of the driver’s foot 30.

The sensing device (or a part thereof) and any associated electronics, may be implemented using printed electronics (such techniques being well known to the person skilled in the art), or may be implemented entirely using discrete components.

Many modifications may be made to the above examples without departing from the scope of the present invention as defined in the accompanying claims.
CLAIMS

1. A torque actuator restart system for a torque actuator of a vehicle drive train, the torque actuator restart system comprising:
   an input device configured to allow a driver of the vehicle to input a driver torque request to the torque actuator; and
   a sensing device configured to detect the positioning of the driver’s foot; and
   a control module configured to determine an intention of the driver to request torque based on the positioning of the driver’s foot;
wherein the torque actuator is operable between an on state in which the torque actuator is responsive to the driver torque request and an off state in which the torque actuator is unresponsive to the driver torque request,
and wherein the system is configured so that, upon the control module determining an intention of the driver, the torque actuator is switched to the on state so that the torque actuator is responsive to an anticipated driver torque request so as to actuate the drivetrain.

2. The torque actuator restart system as claimed in Claim 1, wherein the input device is a vehicle pedal operable by the driver’s foot.

3. The torque actuator restart system as claimed in Claim 1 or Claim 2, wherein the sensing device includes a sensor configured to detect the position of the driver’s foot relative to the input device.

4. The torque actuator restart system as claimed in any of Claims 1 to 3, wherein the sensing device includes a sensor configured to detect a trajectory of movement of the driver’s foot towards the input device.

5. The torque actuator restart system as claimed in any of Claims 1 to 4, wherein the sensing device is configured to detect the speed of movement of the driver’s foot.

6. The torque actuator restart system as claimed in any of Claims 1 to 5, wherein the sensing device comprises an image capture device.
7. The torque actuator restart system as claimed in any of Claims 1 to 6, wherein control module is configured to output a control signal to the torque actuator in dependence on the anticipated driver torque request.

8. The torque actuator restart system as claimed in any of Claims 1 to 7, comprising a data store for storing a one or more indicators that the intention of the driver is to request torque.

9. The torque actuator restart system as claimed in Claim 8, wherein the control module comprises a comparator unit for comparing an output derived from the sensing device with the indicators so as to determine whether there is an intention of the driver to request torque.

10. The torque actuator restart system as claimed in Claim 9, wherein the comparator unit is configured to determine that there is an intention of the driver to request torque when the output indicates that the driver’s foot is within a predetermined distance of the input device.

11. The torque actuator restart system as claimed in Claim 9, wherein the comparator unit is configured to determine that there is an intention of the driver to request torque when the output indicates that the driver’s foot is following a predetermined trajectory of movement towards the input device.

12. The torque actuator restart system as claimed in any of Claims 1 to 11, wherein the control module comprises a learning module for determining whether the determined intention of the driver to request torque is followed by a subsequent driver request for torque, the learning module being configured to update the indicators in response to the determination.

13. The torque actuator restart system as claimed in Claim 12, wherein the learning module is configured to determine that the determined intention of the driver to request torque corresponds to an actual request for torque if the determined intention is identified within a predetermined period prior to the actual request.
14. A control module for a torque actuator restart system as claimed in any of Claims 1 to 13.

15. A vehicle drive train system comprising the torque actuator restart system of any of Claims 1 to 13.

16. The vehicle drive train system of claim 15 wherein the torque actuator is an internal combustion engine and is operable between the on state where the internal combustion engine is on and an off state in which the internal combustion engine is off.

17. A vehicle comprising the drive train system of Claim 15 or claim 16.

18. The vehicle of Claim 17, wherein the torque actuator is configured for disconnection from the drive train so that the vehicle adopts a coasting state when the torque actuator is disconnected from the drive train.

19. A method of controlling a torque actuator restart system for a torque actuator of a vehicle drive train, the torque actuator being controlled by means of a driver torque request at an input device and being operable between an on state in which the torque actuator is responsive to the driver torque request and an off state in which the torque actuator is unresponsive to the driver torque request, the method comprising:

detecting the positioning of the driver’s foot;

determining an intention of the driver to request torque based on the positioning of the driver’s foot; and,

upon determining an intention of the driver, switching the torque actuator to the on state so that the torque actuator is responsive to an anticipated driver torque request so as to actuate the drivetrain.
Figure 1
Is vehicle in coasting state?

yes

Driver intention to request torque?

no

Output off coasting signal to engine

yes

Output idle coasting signal to engine

Figure 2
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02N11/08 B60W30/18 B60W50/10 B60W10/06

ADD.

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)

F02N B60W

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>WO 2010/066350 A1 (BAYERISCHE MOTOREN WERKE AG [DE]; BOLLIG MARCUS [DE]; POGGEL JUERGEN []) 17 June 2010 (2010-06-17) abstract; claim 4; figure 1 page 7, lines 4-21</td>
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Date of the actual completion of the international search

3 August 2017

Date of mailing of the international search report

24/08/2017

Authorized officer

Mineau, Christophe

*X* 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

"*A*" document member of the same patent family
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