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## SYSTEM AND METHOD OF STANDSTILL ENGAGEMENT OF STEERING SYSTEM

## Abstract

A computer-implemented method that, when executed by data processing hardware, causes the data processing hardware to perform operations comprising detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed, determining an intended path of the vehicle, determining an initial steering angle, calculating a desired steering angle based on the intended path, calculating a commanded steering angle, evaluating the initial steering angle versus the desired steering angle, and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle based on the commanded steering angle before initiating the driving maneuver.

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## Background/Summary

INTRODUCTION

[0001] The information provided in this section is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0002] The present disclosure relates generally to a system and method for determining whether engagement of a steering system of a vehicle at standstill or low speed is necessary before a driving maneuver is initiated.

[0003] Vehicles are often equipped with automated driving systems that may be enabled while the vehicle is at rest (i.e., standstill) or traveling at low speeds. Upon enabling the automated driving system, a steering angle (i.e., road wheel angle) of the vehicle oftentimes does not align with or is not commensurate with the steering angle that would provide for good trajectory following with respect to an intended path set forth by the automated driving system. The shortcomings of existing systems and methods are addressed by principles of the present disclosure.

SUMMARY

[0004] One aspect of the disclosure provides a computer-implemented method that, when executed by data processing hardware, causes the data processing hardware to perform operations. These operations include detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed, determining an intended path of the vehicle, determining an initial steering angle, calculating a desired steering angle based on the intended path, calculating a commanded steering angle, evaluating the initial steering angle versus the desired steering angle, and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle based on the commanded steering angle before initiating the driving maneuver.

[0005] Implementations of the disclosure may include one or more of the following optional features. For example, adjusting the steering angle may further include a vehicle steering system that is configured for adjusting the initial steering angle before initiating the driving maneuver.

[0006] In some implementations, adjusting the steering angle before initiating the driving maneuver may include instructing an operator of the vehicle to manually adjust the initial steering angle based on the commanded steering angle before initiating the driving maneuver.

[0007] In some examples, the method may further include evaluating a path tracking quality index. When the path tracking quality index is between a first threshold and a second threshold the driving maneuver may be initiated with the initial steering angle. When the path tracking quality index is between a second threshold and a third threshold, a vehicle steering system configured to adjust the steering angle may adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated. When the path tracking quality index is greater than a fourth threshold and less than a third threshold a vehicle management system configured to instruct an operator of the vehicle may instruct the operator to manually adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated.

[0008] According to at least one aspect, evaluating the path tracking quality index may be a function of predicted future vehicle states and intended future trajectory.

[0009] According to an example, evaluating the path tracking quality index may further include assessing the initial steering angle of the vehicle using a predictive controller and a low-speed vehicle model.

[0010] Another aspect of the disclosure provides a system having data processing hardware and memory hardware in communication with the data processing hardware, the memory hardware storing instructions that, when executed on the data processing hardware, cause the data processing hardware to perform operations. These operations include detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed, determining an intended path of the vehicle, determining an initial steering angle, calculating a desired steering angle based on the intended path, calculating a commanded steering angle, evaluating the initial steering angle versus the desired steering angle, and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle based on the commanded steering angle before initiating the driving maneuver.

[0011] Implementations of the disclosure may include one or more of the following optional features. For example, adjusting the steering angle may further include a vehicle steering system that is configured for adjusting the initial steering angle before initiating the driving maneuver.

[0012] In some implementations, adjusting the steering angle before initiating the driving maneuver may include instructing an operator of the vehicle to manually adjust the initial steering angle based on the commanded steering angle before initiating the driving maneuver.

[0013] In some examples, the system may further include evaluating a path tracking quality index. When the path tracking quality index is between a first threshold and a second threshold the driving maneuver may be initiated with the initial steering angle. When the path tracking quality index is less than a second threshold and greater than or equal to a third threshold, a vehicle steering system configured to adjust the steering angle may adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated. When the path tracking quality index is greater than a fourth threshold and less than a third threshold a vehicle management system configured to instruct an operator of the vehicle may instruct the operator to manually adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated.

[0014] An additional aspect of the disclosure provides a vehicle management system. The vehicle management system includes a steering system configured to adjust a steering angle of a vehicle, data processing hardware, and memory hardware in communication with the data processing hardware, the memory hardware storing instructions that, when executed on the data processing hardware, cause the data processing hardware to perform operations. These operations include detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed, determining an intended path of the vehicle, determining an initial steering angle, calculating a desired steering angle based on the intended path, calculating a commanded steering angle, evaluating the initial steering angle versus the desired steering angle, and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle before initiating the driving maneuver.

[0015] Implementations of the disclosure may include one or more of the following optional features. For example, adjusting the steering angle before initiating the driving maneuver comprises instructing an operator of the vehicle to manually adjust the initial steering angle based on the commanded steering angle before initiating the driving maneuver.

[0016] In some implementations, the vehicle management system further includes evaluating a path tracking quality index. When the path tracking quality index is between a first threshold and a second threshold the driving maneuver may be initiated with the initial steering angle. When the path tracking quality index is less than the second threshold and greater than or equal to a third threshold, a vehicle steering system configured to adjust the steering angle may adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated. When the path tracking quality index is greater than a fourth threshold and less than the third threshold, a vehicle management system configured to instruct an operator of the vehicle may instruct the operator to manually adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated.

## Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The drawings described herein are for illustrative purposes only of selected configurations and are not intended to limit the scope of the present disclosure.

[0018] FIG. **1** is a schematic diagram of a vehicle environment including a vehicle and a vehicle management system of the vehicle according to the principles of the present disclosure;

[0019] FIG. **2**A is an enlarged schematic diagram showing an example of the vehicle management system according to the principles of the present disclosure;

[0020] FIG. **2**B is an enlarged schematic diagram of a model predictive controller of FIG. **2**A;

[0021] FIG. **3**A is a top view of the vehicle of FIG. **1** on a road according to the principles of the present disclosure;

[0022] FIG. **3**B is a top view of the vehicle of FIG. **1** on a road according to the principles of the present disclosure;

[0023] FIG. **3**C is a top view of the vehicle of FIG. **1** on a road according to the principles of the present disclosure;

[0024] FIG. **3**D is a top view of the vehicle of FIG. **1** at an intersection according to the principles of the present disclosure; and

[0025] FIG. **4** is a flow diagram showing operations of the vehicle management system of FIG. **2**A.

[0026] Corresponding reference numerals indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

[0027] Example configurations will now be described more fully with reference to the accompanying drawings. Example configurations are provided so that this disclosure will be thorough, and will fully convey the scope of the disclosure to those of ordinary skill in the art. Specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of configurations of the present disclosure. It will be apparent to those of ordinary skill in the art that specific details need not be employed, that example configurations may be embodied in many different forms, and that the specific details and the example configurations should not be construed to limit the scope of the disclosure.

[0028] The terminology used herein is for the purpose of describing particular exemplary configurations only and is not intended to be limiting. As used herein, the singular articles “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. Additional or alternative steps may be employed.

[0029] When an element or layer is referred to as being “on,” “engaged to,” “connected to,” “attached to,” or “coupled to” another element or layer, it may be directly on, engaged, connected, attached, or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly engaged to,” “directly connected to,” “directly attached to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0030] The terms “first,” “second,” “third,” etc. may be used herein to describe various elements, components, regions, layers and/or sections. These elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as “first,” “second,” and other numerical terms do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example configurations.

[0031] In this application, including the definitions below, the term “module” may be replaced with the term “circuit.” The term “module” may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; memory (shared, dedicated, or group) that stores code executed by a processor; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

[0032] The term “code,” as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term “shared processor” encompasses a single processor that executes some or all code from multiple modules. The term “group processor” encompasses a processor that, in combination with additional processors, executes some or all code from one or more modules. The term “shared memory” encompasses a single memory that stores some or all code from multiple modules. The term “group memory” encompasses a memory that, in combination with additional memories, stores some or all code from one or more modules. The term “memory” may be a subset of the term “computer-readable medium.” The term “computer-readable medium” does not encompass transitory electrical and electromagnetic signals propagating through a medium, and may therefore be considered tangible and non-transitory memory. Non-limiting examples of a non-transitory memory include a tangible computer readable medium including a nonvolatile memory, magnetic storage, and optical storage.

[0033] The apparatuses and methods described in this application may be partially or fully implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on at least one non-transitory tangible computer readable medium. The computer programs may also include and/or rely on stored data.

[0034] A software application (i.e., a software resource) may refer to computer software that causes a computing device to perform a task. In some examples, a software application may be referred to as an “application,” an “app,” or a “program.” Example applications include, but are not limited to, system diagnostic applications, system management applications, system maintenance applications, word processing applications, spreadsheet applications, messaging applications, media streaming applications, social networking applications, and gaming applications.

[0035] The non-transitory memory may be physical devices used to store programs (e.g., sequences of instructions) or data (e.g., program state information) on a temporary or permanent basis for use by a computing device. The non-transitory memory may be volatile and/or non-volatile addressable semiconductor memory. Examples of non-volatile memory include, but are not limited to, flash memory and read-only memory (ROM)/programmable read-only memory (PROM)/erasable programmable read-only memory (EPROM)/electronically erasable programmable read-only memory (EEPROM) (e.g., typically used for firmware, such as boot programs). Examples of volatile memory include, but are not limited to, random access memory (RAM), dynamic random access memory (DRAM), static random access memory (SRAM), phase change memory (PCM) as

well as disks or tapes.
[0036] These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms “machine-readable medium” and “computer-readable medium” refer to any computer program product, non-transitory computer readable medium, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term “machine-readable signal” refers to any signal used to provide machine instructions and/or data to a programmable processor.
[0037] Various implementations of the systems and techniques described herein can be realized in digital electronic and/or optical circuitry, integrated circuitry, specially designed ASICS (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.
[0038] The processes and logic flows described in this specification can be performed by one or more programmable processors, also referred to as data processing hardware, executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit). Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Computer readable media suitable for storing computer program instructions and data include all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto optical disks; and CD ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.
[0039] To provide for interaction with a user, one or more aspects of the disclosure can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube), LCD (liquid crystal display) monitor, or touch screen for displaying information to the user and optionally a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer. Other kinds of devices can be used to provide interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user's client device in response to requests received from the web browser.
[0040] Referring to FIG. **1**, an example vehicle operating environment **10** is provided for

illustration of the principles of the present disclosure. The vehicle operating environment **10** includes a vehicle **100** and a vehicle service center **20**. For the sake of illustration, the vehicle operating environment **10** is shown as including a single vehicle service center **20**. However, in other examples, the vehicle operating environment **10** may include a plurality of vehicle service centers **20** in communication over a network **40** (e.g., the Internet, cellular networks).

[0041] The vehicle **100** includes a vehicle management system **110**, a sensor system **120**, a steering system **140**, a vehicle dynamics system **150**, and an advanced driver-assistance system (ADAS) **160**. While the vehicle **100** maneuvers about the environment **10**, the sensor system **120** includes various sensor subsystems **122**, **122***a*-**122***c* configured to gather sensor data **123**, **123***a*-**123***c* relating to characteristics of the environment **10** and/or a status of the vehicle **100**. For instance, the sensor subsystems **122** include a vehicle exterior sensor subsystem **122***a* configured to measure or obtain external environmental data **123***a*, such as lane markings or surrounding objects (e.g., vehicles, pedestrians), an interior sensor subsystem **122***b* configured to measure interior environmental data **123***b*, such as vehicle occupancy, and/or an ADAS sensor subsystem **122***c* configured to measure or obtain vehicle operating data **123***c*, such as operating parameters. The ADAS sensor subsystem **122***c* can include an inertial measurement unit (IMU), one or more wheel speed sensors, as well as other sensors for obtaining vehicle operating data such as wheel speed, steering wheel position, yaw rate, and lateral acceleration. As the sensor system **120** gathers the sensor data **123**, a computing system **130** is configured to store, process, and/or communicate the sensor data **123** within the vehicle operating environment **10**. In order to perform computing tasks related to the sensor data **123**, the computing system **130** of the vehicle **100** includes data processing hardware **132** and memory hardware **134**. The data processing hardware **132** is configured to execute instructions stored in the memory hardware **134** to perform computing tasks related to operation and management of the vehicle **100**. Generally speaking, the computing system **130** refers to one or more locations of data processing hardware **132** and/or memory hardware **134**.

[0042] In some examples, the computing system **130** is a local system located on the vehicle **100**. When located on the vehicle **100**, the computing system **130** may be centralized (i.e., in a single location/area on the vehicle **100**, for example, a vehicle control unit), decentralized (i.e., located at various locations about the vehicle **100**), or a hybrid combination of both (e.g., with a majority of centralized hardware and a minority of decentralized hardware). To illustrate some differences, a decentralized computing system **130** may allow processing to occur at an activity location while a centralized computing system **130** may allow for a central processing hub that communicates to systems located at various positions on the vehicle **100**.

[0043] Additionally or alternatively, the computing system **130** includes computing resources that are located remotely from the vehicle **100**. For instance, the computing system **130** may communicate via the network **40** with a remote vehicle computing system **30** (e.g., a remote computer/server or a cloud-based environment). Much like the computing system **130**, the remote vehicle computing system **30** includes remote computing resources such as remote data processing hardware **32** and remote memory hardware **34**. Here, sensor data **123** or other processed data (e.g., data processed locally by the computing system **130**) may be stored in the remote vehicle computing system **30** and may be accessible to the computing system **130**. In some examples, the computing system **130** is configured to utilize the remote resources **32**, **34** as extensions of the computing resources **132**, **134** such that resources of the computing system **130** may reside on resources of the remote vehicle computing system **30**.

[0044] With reference to FIG. **1**, one or more wheels **102** (i.e., front wheels **102***a* and rear wheels **102***b*) are coupled to a suspension **104** the vehicle **100**. The steering system **140** is capable of monitoring and controlling the positon and/or direction of the wheels **102**. For instance, the steering system **140** can include a steering column **142** coupled to the suspension **104** and a steering wheel **144** coupled to the steering column **142**. The steering system **140** may include one or more additional components such as a steering box **146** and steering gear **148** so that torque can be applied to the steering column **143**, whether that be by a motor coupled to the steering column **142** or by a driver through the steering wheel **144**, to maintain control and position of the front wheels **102**_a_.

[0045] The vehicle dynamics control system **150** is capable of monitoring and controlling one or more electronic aspects of the vehicle **100**, such as continuously monitoring and/or controlling a state **152** of the vehicle **100**, as shown in FIG. **2**A. The steering system **140** can provide an actual road wheel angle **149** as an input to the vehicle dynamics control system **150**, which can change the state **152** of the vehicle **100**. The state **152** can include a lateral position **152**_a_, a rate of lateral position **152**_b_, a heading **152**_c_, and/or a rate of heading change **152**_d_, for example.

[0046] The ADAS **160** is capable of monitoring and controlling one or more electronic aspects of the vehicle **100**. For instance, the ADAS **160** can monitor and control one or more subsystems of the vehicle **100**, such as the steering system **140**. In other words, the ADAS **160** can communicate with the steering system **140** to maintain good trajectory following after a vehicle automated driving system is enabled by the driver while the vehicle **100** is at rest or at a low speed, for example. With reference to FIGS. **1** and **2**A, the ADAS **160** may include one or more modules for determining one or more operating parameters of the vehicle **100**. For instance, the ADAS **160** may be configured to include a trajectory control module **161**, an automated driving module **162**, and a steering control module **166**. The automated driving module **162** may be configured to communicate with the sensor system **120** and provide a planned or intended path **163** for the vehicle **100**. The planned path **163** may be accompanied with a reference trajectory **164**, **164**_a_-**164**_d_, which may be provided as an input to the trajectory control module **161**. The trajectory control module **161** can receive the state **152**, **152**_a_-**152**_d_ from the vehicle dynamics control system **150** and the reference trajectory **164**, **164**_a_-**164**_d_ from the automated driving module **162** and calculate a commanded steering angle **165**. The commanded steering angle **165** can be provided to the steering control module **166** for calculating a torque **168** for the steering system **140**. The steering system **140** can change the calculated torque **168** and adjust the road wheel angle **149** accordingly.

[0047] The automated driving module **162** may be enabled by the driver or otherwise while the vehicle **100** is at rest or while traveling at low speeds so an initial road wheel angle **149**_a_ may be different than a desired or calculated steering angle **201** (discussed in more detail below). In some instances, if the vehicle **100** were to initiate travel with the initial road wheel angle **149**_a_, the vehicle **100** may deviate from the intended path **163** provided by the automated driving module **162**. Thus, as will be discussed below, the commanded steering angle **165** may be calculated so that the road wheel angle **149** may be adjusted by the steering system **140** before the vehicle or driver initiates travel.

[0048] With reference to FIG. **2**A, the commanded steering angle **165** can be calculated using a controller, such as model predictive controller (MPC) **200**. The model predictive controller **200** can be configured with constraints **202**, a low speed plant model **204**, as well as weights and horizons **206**. The constraints **202** may be desirable for maintaining the position of the vehicle **100** within a lane on a road and/or prevent the vehicle **100** from traveling off the road. In general, the low speed plant model **204** is a model of the vehicle **100**, which can help make predictions about behavior (e.g., trajectory following) of the vehicle **100**. The weights and horizons **206** may be calibrated and used by the MPC **200** and, more particularly, by a cost equation **208** to determine which predicted path (i.e., commanded steering angle) is desirable for the vehicle **100**. Cost V may be calculated using the following equation:

[00001] $V = \frac{1}{2} \sum_{k=1}^{p} \{(y - y_{\mathrm{ref}})^2 W_y + (u - u_{\mathrm{ref}})^2 W_u + (u_k - u_{k-1})^2 W_{\Delta u} + \in^2 W_{\in}\}$

[0049] Cost V may be referred to as a weighted square sum of one or more variables or the sum of the input, output, input rate, and slack variable, for example. In the present example, the input can be the road wheel angle **149** and the output can be the lateral position **152**_a_, the rate of lateral position **152***b*, the heading **152***c*, and the rate of heading change **152***d* of the vehicle **100**. The slack variable may be provided so that the lateral position **152***a*, the rate of lateral position **152***b*, the heading **152***c*, and the rate of heading change **152***d* tracks or is close to the desired reference value for the lateral position **164***b*.

[0050] A path tracking quality index (PTQI) **210** may also be used to determine whether it is necessary to adjust the road wheel angle **149** before engagement of the automated driving system. In the present example, the PTQI **210** is a non-dimensional nominal value (i.e., **0** to **1**). PTQI **210** may be determined using the following equation:

[00002] $$\mathrm{PTQI} = \left(1 - w_1 \frac{y_m}{y_{\mathrm{engage}}}\right) \times \left(1 - w_2 \frac{t_m}{t_{\max}}\right) \times \left(1 - w_3 \frac{\mathrm{abs}({}_0 - {}_{\mathrm{opt}})}{\mathrm{abs}(\max({}_0, {}_{\mathrm{opt}}))}\right)$$

[0051] PTQI **210** may be referred to as a product of lateral deviation, merge time, and steering angle. y.sub.m may be referred to as a maximum distance to a nominal path. y.sub.engage may be referred to as a maximum distance threshold for engaging. t.sub.m may be referred to as the time taken to merge with the desired path depending on system inertia and road condition (e.g., bank, grade, and surface friction). t.sub.max may be referred to as a maximum allowed time to merge with the desired path. δ.sub.0 may be used to refer to the initial road wheel angle **149***a* and δ.sub.opt may be used to refer to the calculated steering angle **201**. w.sub.1, w.sub.2, w.sub.3, are weights that may be referred to as a relevance factor of each parameter. These weights should sum up to one (1) and may be adjusted or calibrated as necessary.

[0052] With reference to FIG. **3**A, a first path **301**A of the vehicle **100** to a center of a lane **304** is shown based on the initial road wheel angle **149***a*, a second path **302**A of the vehicle **100** to the center of the lane **304** is shown based on the calculated steering angle **201**, and a third path **303**A of the vehicle **100** to the center of the lane **304** is shown based on the commanded steering angle **165**. In general, if the difference between the first path **301**A and the second path **302**A is not significant and lane excursion is unlikely, then the steering system **140** may use to the initial road wheel angle **149***a* because engaging the vehicle steering system **140** based on the commanded steering angle **165** would not result in a significant change in the state **152** of the vehicle **100**. PTQI **210** may be used to determine whether standstill engagement of the steering system **140** or driver intervention is necessary to modify the steering angle. If PTQI **210** is less than or equal to a first threshold (e.g., 1) and greater than a second threshold (e.g., 0.75) or between the first and second thresholds and one (1), a driving maneuver with the initial road wheel angle **149***a* may be initiated because good trajectory following of the intended path **163** is likely, for example.

[0053] With reference to FIG. **3**B, a first path **301**B of the vehicle **100** to the center of the lane **304** is shown based on the initial road wheel angle **149***a*, a second path **302**B of the vehicle **100** to the center of the lane **304** is shown based on the calculated steering angle **201**, and a third path **303**B of the vehicle **100** to the center of the lane **304** is shown based on the commanded steering angle **165**. In general, if the difference between the first path **301**B and the second path **302**B is significant and lane excursion is possible, then engaging the steering system **140** based on the commanded steering angle **165** may be desirable so that good trajectory following of the vehicle **100** may be maintained. PTQI **210** may be used to determine whether standstill engagement of the steering system **140** or driver intervention is necessary to modify the steering angle. If PTQI **210** is less than the second threshold (e.g., **0**.**75**) and greater than or equal to a third threshold (e.g., **0**.**50**) or between the second and third threshold, the steering control module **166** may provide the torque **168** to steering system **140** based on the commanded steering angle **165** before initiating a driving maneuver.

[0054] With reference to FIG. **3**C, a first path **301**C of the vehicle **100** to the center of the lane **304** is shown based on the initial road wheel angle **149***a*, a second path **302**C of the vehicle **100** to the center of the lane **304** is shown based on the calculated steering angle **201**, and a third path **303**C of the vehicle **100** to the center of the lane **304** is shown based on the commanded steering angle **165**. In general, if the difference between the first path **301**C and the second path **302**C is excessive and lane excursion is likely, then, in the present example, engaging the steering system **140** based on the commanded steering angle **165** may be desirable so that good trajectory following of the vehicle **100** may be maintained. In this example, engaging the steering system **140** may require the driver of the vehicle **100** to adjust the steering wheel **144**. PTQI **210** may be used to determine whether standstill engagement of the steering system **140** or driver intervention is necessary to modify the steering angle. If PTQI **210** is less than the third threshold (e.g., **0**.**50**) and greater than or equal to a fourth threshold (e.g., **0**), the operator or driver may need to apply torque to the steering system **140** via the steering wheel **144** based on the commanded steering angle **165** before initiating a drive maneuver. The vehicle management system may be configured to instruct the driver of the vehicle **100** via the user interface **170** to manually adjust the steering angle to the commanded steering angle **165** via the steering wheel **144**.

[0055] Additionally or alternatively, the path tracking quality index may be defined as a function of predicted future vehicle states (e.g., lateral position, rate of lateral position, heading, and rate of heading change) and intended future trajectory (e.g., right turn, left turn, straight, etc.).

[0056] With reference to FIG. **3**D, situational awareness of the vehicle **100** may be desirable to engage the steering system **140**. For example, when the vehicle **100** is at an intersection in a left hand turn lane, it may be desirable to engage the steering system **140** so that the vehicle **100** can exhibit good trajectory following as it initiates a driving maneuver to complete a left hand turn. As shown in FIG. **3**D, a first path **301**D of the vehicle **100** to the center of the lane **304** is shown based on the initial road wheel angle **149***a*, a second path **302**D of the vehicle **100** to the center of the lane **304** is shown based on the calculated steering angle **201**, and a third path **303**D of the vehicle **100** to the center of the lane **304** is shown based on the commanded steering angle **165**. In general, if the difference between the first path **301**D and the second path **302**D is excessive and significant path deviation is likely, then, in the present example, engaging the steering system **140** based on the commanded steering angle **165** may be desirable so that good trajectory following of the vehicle **100** may be maintained.

[0057] With reference to FIG. **4**, a method **400** for determining whether engagement of a steering system of the vehicle **100** at standstill or low speed is necessary before a driving maneuver is initiated is provided. At **402**, the method **400** is initiated. In practical terms, the method **400** may be initiated upon powering-up of the vehicle **100** by the vehicle operator.

[0058] At **404**, a driver input to enable the automated driving system may be detected by the vehicle management system **110**. For instance, the driver of the vehicle **100** may enable the automated driving system via the steering wheel **144** (e.g., pressing a button) or via the user interface **170**.

[0059] At **406**, the intended path **163** of the vehicle **100** may be generated with the automated driving module **162** with sensor data **123** of the sensor system **120**.

[0060] At **408**, the reference trajectory **164** may be determined at the automated driving module **162** and provided to the trajectory control module **161**.

[0061] At **410**, any geometric error with respect to the intended path **163** may be determined and provided to the MPC **200** for determining the calculated steering angle **201**.

[0062] At **412**, the commanded steering angle **165** may be determined based on the intended path of the vehicle.

[0063] At **414**, the path tracking quality index **210** may be calculated. As mentioned above, the PTQI **210** may be desirable for determining whether the steering system should be engaged based on the commanded steering angle **165** or whether the initial road wheel angle **149***a* can be used to initiate a steering maneuver. Again, when the PTQI **210** is between 0.75 and 1 the driving maneuver is initiated with the initial steering angle. When the PTQI **210** is between 0.50 and 0.75, the vehicle steering system **140** is engaged to adjust the steering angle based on the commanded steering angle **165** before the driving maneuver is initiated. When the PTQI **210** is between 0 and 0.5, the vehicle management system **110** may be configured to instruct an operator of the vehicle **100** to manually adjust the steering angle based on the commanded steering angle **165** before the

driving maneuver is initiated.
[0064] At **416**, trajectory following may be affected by one or more factors such as road type and weather, for example. Evaluating one or more extraneous factors via the sensor system **120** and predicting any performance degradation may be desirable so that road wheel angle **149** may be adjusted accordingly.
[0065] At **418**, the calculated steering angle **201** may be determined at the trajectory control module **161**.
[0066] At **420**, the vehicle **100** may or may not engage the steering system **140** to adjust the steering angle of the vehicle **100** before initiating a driving maneuver. In other words, whether the vehicle **100** or driver adjusts the road wheel angle **149** based on the commanded steering angle **165** may be achieved at **420**. In standstill engagement vehicle scenarios (e.g., FIGS. **3**A-**3**C) or in situation awareness engagement vehicle scenarios (FIG. **3**D), the road wheel angle may or may not be adjusted based on the commanded steering angle **165**.
[0067] The method **400** is completed at **422**.
[0068] A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the disclosure. Accordingly, other implementations are within the scope of the following claims.
[0069] The foregoing description has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular configuration are generally not limited to that particular configuration, but, where applicable, are interchangeable and can be used in a selected configuration, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

## Claims

**1**. A computer-implemented method that, when executed by data processing hardware, causes the data processing hardware to perform operations comprising: detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed; determining an intended path of the vehicle; determining an initial steering angle; calculating a desired steering angle based on the intended path; calculating a commanded steering angle; evaluating the initial steering angle versus the desired steering angle; and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle based on the commanded steering angle before initiating the driving maneuver.
**2**. The method of claim 1, wherein adjusting the steering angle further comprises a vehicle steering system that is configured for adjusting the initial steering angle before initiating the driving maneuver.
**3**. The method of claim 1, wherein adjusting the steering angle before initiating the driving maneuver further comprises instructing an operator of the vehicle to manually adjust the initial steering angle based on the commanded steering angle before initiating the driving maneuver.
**4**. The method of claim 1, wherein the method further includes evaluating a path tracking quality index.
**5**. The method of claim 4, wherein when the path tracking quality index is between a first threshold and a second threshold the driving maneuver is initiated with the initial steering angle.
**6**. The method of claim 4, wherein when the path tracking quality index is less than a second threshold and greater than or equal to a third threshold, a vehicle steering system configured to adjust the steering angle adjusts the steering angle based on the commanded steering angle before the driving maneuver is initiated.
**7**. The method of claim 4, wherein when the path tracking quality index is greater than a fourth

threshold and less than a third threshold a vehicle management system configured to instruct an operator of the vehicle instructs the operator to manually adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated.

**8**. The method of claim 4, wherein evaluating the path tracking quality index is a function of predicted future vehicle states and intended future trajectory.

**9**. The method of claim 4, wherein evaluating the path tracking quality index further includes assessing the initial steering angle of the vehicle using a predictive controller and a low-speed vehicle model.

**10**. A system comprising: data processing hardware; and memory hardware in communication with the data processing hardware, the memory hardware storing instructions that, when executed on the data processing hardware, cause the data processing hardware to perform operations comprising: detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed; determining an intended path of the vehicle; determining an initial steering angle; calculating a desired steering angle based on the intended path; calculating a commanded steering angle; evaluating the initial steering angle versus the desired steering angle; and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle before initiating the driving maneuver.

**11**. The system of claim 10, wherein adjusting the steering angle further comprises a vehicle steering system that is configured for adjusting the initial steering angle before initiating the driving maneuver.

**12**. The system of claim 10, wherein adjusting the steering angle before initiating the driving maneuver comprises instructing an operator of the vehicle to manually adjust the initial steering angle based on the commanded steering angle before initiating the driving maneuver.

**13**. The system of claim 10, wherein the system further includes evaluating a path tracking quality index.

**14**. The system of claim 13, wherein when the path tracking quality index is between a first threshold and a second threshold the driving maneuver is initiated with the initial steering angle.

**15**. The system of claim 13, wherein when the path tracking quality index is less than a second threshold and greater than or equal to a third threshold, a vehicle steering system configured to adjust the steering angle adjusts the steering angle based on the commanded steering angle before the driving maneuver is initiated.

**16**. The system of claim 13, wherein when the path tracking quality index is greater than a fourth threshold and less than a third threshold a vehicle management system configured to instruct an operator of the vehicle instructs the operator to manually adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated.

**17**. A vehicle management system comprising: a steering system configured to adjust a steering angle of a vehicle; data processing hardware; and memory hardware in communication with the data processing hardware, the memory hardware storing instructions that, when executed on the data processing hardware, cause the data processing hardware to perform operations comprising: detecting a request to enable an automated driving system of a vehicle while the vehicle is at rest or at a low speed; determining an intended path of the vehicle; determining an initial steering angle; calculating a desired steering angle based on the intended path; calculating a commanded steering angle; evaluating the initial steering angle versus the desired steering angle; and either (i) initiating a driving maneuver with the initial steering angle, or (ii) adjusting the steering angle before initiating the driving maneuver.

**18**. The system of claim 17, wherein adjusting the steering angle before initiating the driving maneuver comprises instructing an operator of the vehicle to manually adjust the initial steering angle based on the commanded steering angle before initiating the driving maneuver.

**19**. The system of claim 17, wherein the vehicle management system further includes evaluating a path tracking quality index.

**20**. The system of claim 19, wherein when the path tracking quality index is between a first and a second threshold the driving maneuver is initiated with the initial steering angle, wherein when the path tracking quality index is less than the second threshold and greater than or equal to a third threshold, a vehicle steering system configured to adjust the steering angle adjusts the steering angle based on the commanded steering angle before the driving maneuver is initiated, wherein when the path tracking quality index is greater than a fourth threshold and less than the third threshold a vehicle management system configured to instruct an operator of the vehicle instructs the operator to manually adjust the steering angle based on the commanded steering angle before the driving maneuver is initiated.