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Driver directional control during brake-to-steer manual driving using model predictive control

Abstract

Disclosed is a number of variations that may include a method, system, or computer product useful in determining an intended yaw or yaw rate that a driver desires using a model, comparing the yaw or yaw rate with the actual vehicle yaw or yaw rate to determining a yaw error or yaw rate error, using the yaw error or yaw rate error in a model predictive control to determine the brake pressure required to minimize or reduced to zero the yaw error or the yaw rate error.

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Background/Summary

TECHNICAL FIELD

(1) The field to which the disclosure generally relates to includes vehicle steering and braking control.

BACKGROUND

(2) Some methods used in a vehicle to determine brake pressures required to achieve an intended yaw control depend upon traditional methods such as pressure tables based on velocity and lateral acceleration, such methods do not actively reduce yaw error in terms of yaw movement that the driver desires the vehicle to make.

SUMMARY OF ILLUSTRATIVE VARIATIONS

(3) A number of variations may include a method, system, or computer product useful in determining an intended yaw or yaw rate that a driver desires using a model, comparing the yaw or yaw rate with the actual vehicle yaw or yaw rate to determining a yaw error or yaw rate error, using a model predictive control to determine the brake pressure required to minimize or reduced to zero the yaw error or the yaw rate error.

(4) Other illustrative variations within the scope of the invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while disclosing variations of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Select examples of variations within the scope of the invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

(2) FIG. 1 illustrates a method and system according to a number of variations.

(3) FIG. 2 depicts an illustrative variation of a system and vehicle with a steer-by-wire system.

(4) FIG. 3 depicts an illustrative variation of a system and a vehicle with a connected power steering system.

DETAILED DESCRIPTION OF ILLUSTRATIVE VARIATIONS

(5) The following description of the variations is merely illustrative in nature and is in no way intended to limit the scope of the invention, its application, or uses.

(6) A number of variations may use a vehicle equipped with electrical power assisted steering system having either traditional system with an intermediate connecting shaft between column and steering rack or a steer by wire system, the steering system can fail either electrically or mechanically. In these cases, the driver can utilize brake-to-steer (BTS) to achieve lateral control of the vehicle. Lateral control of the vehicle may be achieved using differential braking, for example, but not limited to, when using a brake by wire system. However, the methods, systems, and computer products described herein may use model predictive control to determine brake pressure and or powertrain commands even when components of the vehicle have not failed.

(7) In case of connected steering system that has failed, the driver inputs a torque in the steering wheel which then drives the steering rack causing a yaw movement of the vehicle along with certain lateral acceleration. This yaw rate thus achieved will be less than normal yaw rate for a system that has full primary steering system that is functional. In a number of variations, the ideal yaw rate can be estimated by using the vehicle velocity/lateral acceleration and/or a predictive bicycle model or by characterizing the vehicle. The ideal yaw rate can then be compared to actual yaw rate. The error thus calculated may be passed to a Model Predictive Control (MPC) block or module that will use a state-space based representation of the vehicle operating a BTS system to predict the best set of brake pressures on all wheels to achieve a zero yaw rate error or minimize the yaw rate error.

(8) In case of a steer by wire system method described above for a mechanically connected steering system will be the same except, the driver is unable to induce any yaw in the vehicle because the steering column is not mechanically connected to the steering rack and the steering rack has failed. In this case the predicted yaw can be estimated from a steering column angle sensor as an input parameter to the vehicle velocity/lateral acceleration and/or a predictive bicycle model or by characterizing the vehicle. This method can also be used in connected systems where an external/redundant column angle (steering angle) sensor is available.

(9) The bicycle model takes a 4-wheel model and combines the front and rear wheels respectively to form a two-wheeled model (hence the name bicycle model). MPC helps the vehicle to predict and plan for future events by continuously generating a series of control actions that will get the vehicle closer to its desired trajectory. MPC algorithm can handle non-linear and complex vehicle dynamics like tire force models and actuator models, allowing precise and accurate trajectory tracking. At each timestamp, the MPC receives the measured outputs to predict the current states. Then it computes the series of control inputs, which minimizes the cost over the prediction horizon by solving a constrained optimization problem. The optimization problem relies on the vehicle model, references and the current state. Eventually, the MPC controller or module applies the first computed control input to the vehicle, ignoring the following ones. The process repeats for the following timestamps. Stated in another way, MPC predicts the control inputs over the prediction horizon, in a way that the predicted output will merge with the reference trajectory. Then, MPC uses the predicted control input at the then present time only for actuation.

(10) FIG. 1 illustrates a system and method **10** which may include a model predictive control module **16** which receives vehicle data **14** which may include, but not limited to, steering angle, yaw, yaw rate, vehicle speed or velocity, wheel speed, lateral acceleration, brake pressure at individual vehicle roadwheels, and/or powertrain data or commands. The model predictive control module uses vehicle data **14** to predict and plan for future events by continuously generating a series of control actions that will get the vehicle closer to its desired trajectory intended by a driver which may be determined based on the vehicle data **14**. For example, the model predictive control module may use an algorithm for determining an intended yaw or yaw rate that a driver desires using a model, which may be based on vehicle speed or velocity and lateral acceleration, or based

upon a bicycle model, or other characterization of the vehicle, the model predictive control module carries out a method which may include comparing the driver intended yaw or yaw rate with the actual vehicle yaw or yaw rate to determine a yaw error or yaw rate error. Thereafter, the model predictive control module uses the yaw error or yaw rate error to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error. The model predictive control module may send brake pressure commands **18** to a brake-to-steer module **20** which may use the brake pressure commands along with other vehicle data to send a second set of commands **22** to individual brakes **24** to steer the vehicle or assist in a steering the vehicle. The model predictive control module **16** may also determine powertrain or propulsion commands **26** which may be sent to a powertrain module **28** which may use the powertrain or propulsion commands **26** along with other vehicle data to send a second set of powertrain commands **30** to a powertrain system **32**. Alternatively, brake pressure commands **18** may be sent directly to the brakes **24**, and powertrain commands **26** may be sent directly to a powertrain system **32**.

(11) FIG. 2 illustrates a vehicle having steer-by-wire functionality and a system for carrying out method described herein. FIG. 3 illustrates a vehicle with a mechanical steering linkage and a system for carrying out method described herein. The components and systems of FIGS. 2 and 3 may be interchanged provided that the vehicle in FIG. 2 retains steer-by-wire functionality and the vehicle in FIG. 3 retains a mechanical steering linkage.

(12) FIG. 2 depicts an illustrative variation of various portions of a vehicle equipped with hardware sufficient for carrying out at least some of the systems and methods described herein. A vehicle **750** may include a controller **712** constructed and arranged to provide Brake-to-Steer functionality in a vehicle **750**. The controller **712** may be in operable communication with a steer-by-wire system **715**, and an electronic braking system **716**. The steer-by-wire system **715** may be composed of handwheel actuator **746** and roadwheel actuator **714**. The steer-by-wire system **715** may be constructed and arranged to turn at least one road wheel **742**. The electronic braking system **716** may apply brake force or brake torque **710** to determine appropriate roadwheels **742**. A driver may utilize a handwheel **744** including at least one handwheel actuator **746** to provide driver input **734** for lateral movement and send steering commands to the steer-by-wire system **715** and roadwheel actuator **714**. The electronic braking system **716** may be in operable communication with the controller **712** and a driver braking input system **752**, such as a brake pedal system, to receive driver braking input. According to some variations, the handwheel actuator **746** may be in operable communication with the controller **712**, the steer-by-wire roadwheel actuator **714**, or the electronic braking system **716**. In some variations, the handwheel actuator **746** may be disconnected or in a failure state **748** from or unable to communicate with the steer-by-wire roadwheel actuator **714**. In such a variation, the handwheel actuator **746** may communicate steering commands to the controller **712**, which may receive steer-by-wire system **715** health status information. Where the controller **712** has received steer-by-wire system **715** information indicative of steer-by-wire system **715** failure **748** or roadwheel actuator **714** failure, the controller **712** may convert steering commands from the handwheel actuator **746** to brake force or brake torque commands to be communicated to the electronic braking system **716**. Controller **712** may include instructions that may include an algorithm to carryout MPC. The electronic braking system **716** may apply brake force or brake torque **710** to determined appropriate roadwheels **742** to effectuate lateral movement of the vehicle as input **734** by the driver via the handwheel **744**. Controller **712** may also send powertrain commands to a powertrain system **708**. Control **712** and any other control, for example controller **768**, may be provided to carry out one or more functions described herein and may include a processor **760**, memory **762**, wherein the instructions **764** stored in the memory **762** are executable by the processor **760**.

(13) Referring now to FIG. 3, an illustrative variation of a vehicle equipped with hardware that allows it to carry out at least some of the methods disclosed herein is shown. A vehicle **801** is equipped with roadwheels **802** and a handwheel **803** for turning the roadwheels **802** via a pinion

804 that engages a rack **805** that is constructed and arranged to turn the roadwheels **802**. In the illustrative variation shown, the handwheel **803** is equipped with a hand wheel torque sensor **806** and a hand wheel angle sensor **807** so that any turning of the handwheel may produce sensor data that may be communicated to or accessed by a controller **808**. Controller **808** may provide all other functionality described herein including MPC, steer-by-wire control, powertrain control, braking control, and/or control a vehicle system, or one or more other controllers may be provided to do the same. Although, in this illustrative variation, the controller **808** is shown onboard the vehicle, the controller may also be located somewhere apart from the vehicle and communicate with wirelessly by the sensors or the vehicle. Pinion **804** may be equipped with a pinion torque sensor **809** so that any turning of the pinion may be observed by or communicated to the controller **808** and utilized by the methods described herein. In the illustrative variation shown, rack **805** is equipped with a rack force sensor **810** so that any rack forces detected during driving may be observed by or communicated to the controller **808** and utilized by the methods described herein. The vehicle may have a steering shaft **814** connecting the steering wheel or steering interface **803** to pinion **804**. An electric power steering assist or hydraulic power steering device **836** may be connected to the shaft **814** to assist the driver in steering the roadwheels of the vehicle by reducing the force or torque the driver would need to apply to the steering wheel or steering interface **803** if the power steering device **836** was not present. Also shown in this illustrative variation, the roadwheels **802** may be equipped with roadwheel sensors so that any roadwheel data detected during driving may be observed by or communicated to the controller **808** and utilized by the methods described herein. Additionally, in the illustrative variation shown, brakes **812** are located near roadwheels **802**.

Another controller **818** may be provided and may include a processor **820**, memory **822**, wherein the instructions **824** stored in the memory **822** are executable by the processor **820** to determine if the hand wheel angle sensor **807** or if the pinion **804**, rack **805**, pinion sensor **809**, or rack sensor **810** have failed. Furthermore, wherein the instructions **824** stored in memory **822** are executable by the processor **820** to carry out any of the methods or achieve any functionality described herein.

(14) Modules and controllers described herein may include software, hardware, or a computing device including non-transitory computer readable medium, such as but not limited to memory, having instructions stored there on, and a processor for executing the instructions to perform the acts, steps, methods and functionality described herein. Multiple modules and controllers and their associated acts, steps, methods, and functionality may be contained in or achieved by one or more computing devices.

(15) The following description of variants is only illustrative of components, elements, acts, product and methods considered to be within the scope of the invention and are not in any way intended to limit such scope by what is specifically disclosed or not expressly set forth. The components, elements, acts, product and methods as described herein may be combined and rearranged other than as expressly described herein and still are considered to be within the scope of the invention.

(16) Variation 1 may include a method including determining an intended yaw or yaw rate that a driver desires using a model; comparing the intended yaw or yaw rate with the actual vehicle yaw or yaw rate to determine a yaw error or yaw rate error; using the determined yaw error or yaw rate error in a model predictive control module to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.

(17) Variation 2 may include a method as set forth in Variation 1 wherein the model is a vehicle bicycle model.

(18) Variation 3 may include a method as set forth in Variation 1 wherein the model is based on vehicle velocity and lateral acceleration.

(19) Variation 4 may include a method as set forth in Variation 1 further comprising sending brake commands based on the determined brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.

- (20) Variation 5 may include a method as set forth in Variation 1 further comprising sending powertrain commands to achieve the intended yaw or yaw rate.
- (21) Variation 6 may include a computer readable medium comprising non-transitory memory operable for machine instructions that are to be executed by an electronic processor, the instructions when executed by the electronic processor implement the following functions including determining an intended yaw or yaw rate that a driver desires using a model; comparing the intended yaw or yaw rate with the actual vehicle yaw or yaw rate to determine a yaw error or yaw rate error; using the determined yaw error or yaw rate error in a model predictive control module to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.
- (22) Variation 7 may include a computer readable medium as set forth in Variation 6 wherein the model is a vehicle bicycle model.
- (23) Variation 8 may include a computer readable medium as set forth in Variation 6 wherein the model is based on vehicle velocity and lateral acceleration.
- (24) Variation 9 may include a computer readable medium as set forth in Variation 6 further comprising sending brake commands based on the determined brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.
- (25) Variation 10 may include a computer readable medium as set forth in Variation 6 further comprising sending powertrain commands to achieve the intended yaw or yaw rate.
- (26) Variation 11 may include a system including a predictive model control module, wherein the predict model control model includes non-transitory memory with instruction stored thereon and executable by an electronic processor to carry out the acts of: receiving vehicle data and determining from the data an intended yaw or yaw rate that a driver desires using a model; comparing the intended yaw or yaw rate with the actual vehicle yaw or yaw rate to determine a yaw error or yaw rate error; using the determined yaw error or yaw rate error to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.
- (27) Variation 12 may include a system as set forth in Variation 11 wherein the predictive model control module uses a vehicle bicycle model.
- (28) Variation 13 may include a system as set forth in Variation 11 wherein the predictive model control module uses vehicle velocity and lateral acceleration.
- (29) Variation 14 may include a system as set forth in Variation 11 further comprising sending brake commands based on the determined brake pressure to minimize or reduced to zero the yaw error or the yaw rate error to a brake-to-steer module.
- (30) Variation 15 may include a system as set forth in Variation 11 further comprising sending powertrain commands to a powertrain module to achieve the intended yaw or yaw rate.
- (31) The above description of select examples of the invention is merely illustrative in nature and, thus, variations or variants thereof are not to be regarded as a departure from the spirit and scope of the invention.

Claims

1. A method comprising: providing a vehicle having roadwheels, a steer-by-wire system having a roadwheel actuator, a handwheel for turning the roadwheels connected to the roadwheel actuator, the handwheel including a handwheel actuator to receive steering input from a driver of the vehicle, an electronic brake system, and an electronic controller having written instructions to convert steering commands from the handwheel actuator to brake force or brake torque commands; receiving, by the electronic controller, steering commands from the handwheel actuator; determining, by the electronic controller, an intended yaw or yaw rate of a driver of the vehicle, based on the steering input from the driver to the handwheel actuator, using a model; comparing, by the electronic controller, the intended yaw or yaw rate with the actual vehicle yaw or yaw rate to

determine a yaw error or yaw rate error; using, by the electronic controller, the determined yaw error or yaw rate error in a model predictive control module to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error; sending, by the electronic controller, the brake force or brake torque commands to the electronic brake system to apply the determined brake pressure.

2. A method as set forth in claim 1 wherein the model is a vehicle bicycle model wherein the bicycle model takes a 4-wheel model and combines the front and rear wheels respectively to form a two-wheeled model.

3. A method as set forth in claim 1 wherein the model is based on vehicle velocity and lateral acceleration.

4. A method as set forth in claim 1 wherein the model is a predictive bicycle model that takes a 4-wheel model and combines the front and rear wheels respectively to form a two-wheeled model.

5. A method as set forth in claim 1 further comprising sending powertrain commands to achieve the intended yaw or yaw rate.

6. A computer readable medium comprising non-transitory memory operable for machine instructions that are to be executed by an electronic processor, the instructions when executed by the electronic processor implement the following functions comprising: receiving steering commands from a handwheel actuator of a steer-by-wire steering system; determining an intended yaw or yaw rate of a driver of the vehicle, based on handwheel actuator input by the driver, using a model; comparing the intended yaw or yaw rate with the actual vehicle yaw or yaw rate to determine a yaw error or yaw rate error; using the determined yaw error or yaw rate error in a model predictive control module to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.

7. A computer readable medium as set forth in claim 6 wherein the model is a vehicle bicycle model.

8. A computer readable medium as set forth in claim 6 wherein the model is based on vehicle velocity and lateral acceleration.

9. A computer readable medium as set forth in claim 6 further comprising sending brake commands based on the determined brake pressure to minimize or reduced to zero the yaw error or the yaw rate error.

10. A computer readable medium as set forth in claim 6 further comprising sending powertrain commands to achieve the intended yaw or yaw rate.

11. A vehicle comprising: roadwheels, a steer-by-wire system having a roadwheel actuator, a handwheel for turning the roadwheels connected to the roadwheel actuator, the handwheel including a handwheel actuator, an electronic brake system to apply brake force or brake torque to the roadwheels, and an electronic controller including an electronic processor; a predictive model control module, wherein the model predictive control model includes non-transitory memory with instruction stored thereon and executable by the electronic processor to carryout the acts of: receiving vehicle data and determining from the data an intended yaw or yaw rate of a driver of the vehicle, based on handwheel actuator input from the driver, using a model; comparing the intended yaw or yaw rate with the actual vehicle yaw or yaw rate to determine a yaw error or yaw rate error; using the determined yaw error or yaw rate error to determine the brake pressure to minimize or reduced to zero the yaw error or the yaw rate error; sending brake force or brake torque commands, by the electronic control, to the electronic brake system to apply the determined brake pressure.

12. A system as set forth in claim 11 wherein the predictive model control module uses a vehicle bicycle model that takes a 4-wheel model and combines the front and rear wheels respectively to form a two-wheeled model.

13. A system as set forth in claim 11 wherein the predictive model control module uses vehicle velocity and lateral acceleration.

14. A system as set forth in claim 11 further comprising sending brake commands based on the

determined brake pressure to minimize or reduced to zero the yaw error or the yaw rate error to brake-to-steer module.

15. A system as set forth in claim 11 further comprising sending powertrain commands to a powertrain module to achieve the intended yaw or yaw rate.
