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(54) **VEHICLE YAW RATE ESTIMATION SYSTEM**

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CPC ***B60W 40/114*** (2013.01); *B60W 2520/125* (2013.01); *B60W 2520/28* (2013.01); *B60W 2540/18* (2013.01)

(58) **Field of Classification Search**
CPC B60W 40/114; B60W 2520/18; B60W 2520/28; B60W 2520/25
See application file for complete search history.

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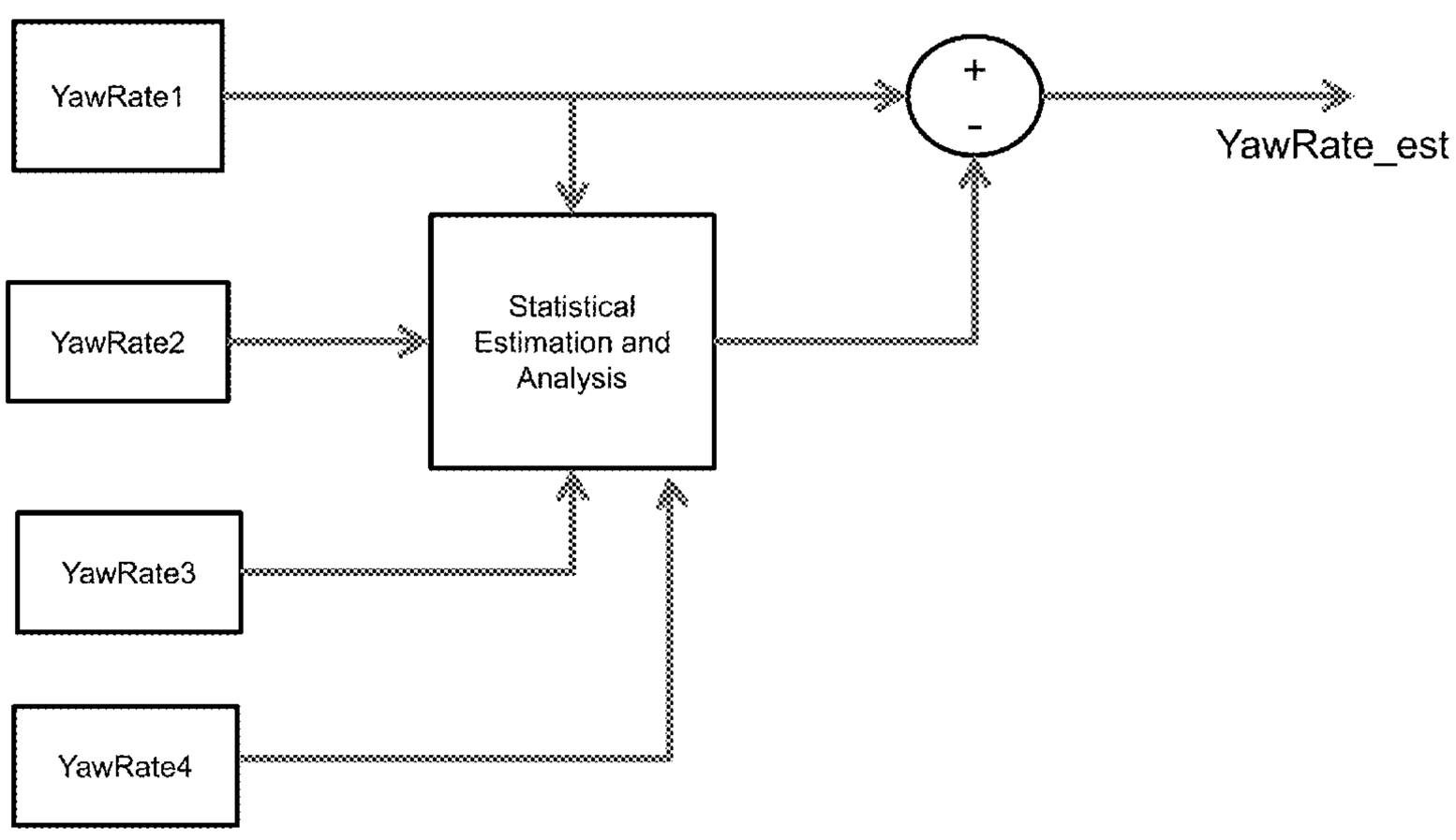
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(57) **ABSTRACT**

A yaw rate estimation system for a vehicle includes a control receiving inputs indicative of (i) a first yaw rate determined by a yaw rate sensor of the vehicle, (ii) a second yaw rate derived from ABS wheel sensors of the vehicle, (iii) a third yaw rate derived from a lateral acceleration of the vehicle and (iv) a fourth yaw rate derived from a steering wheel angle, wheel angle and rate of change of steering wheel angle. The control is operable to process the inputs to estimate the yaw rate of the vehicle, with the estimated yaw rate derived from the inputs.

20 Claims, 8 Drawing Sheets



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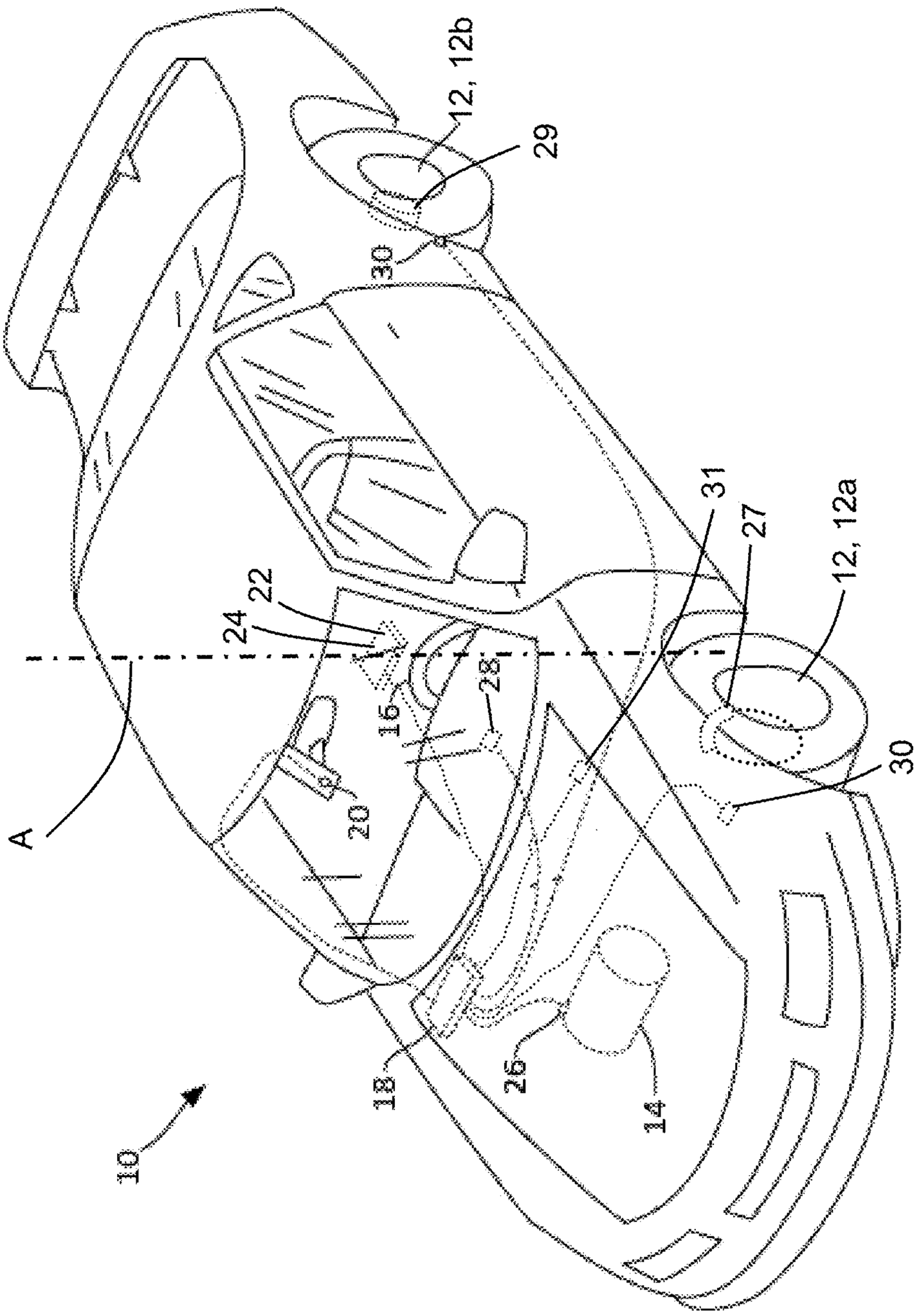


Fig. 1

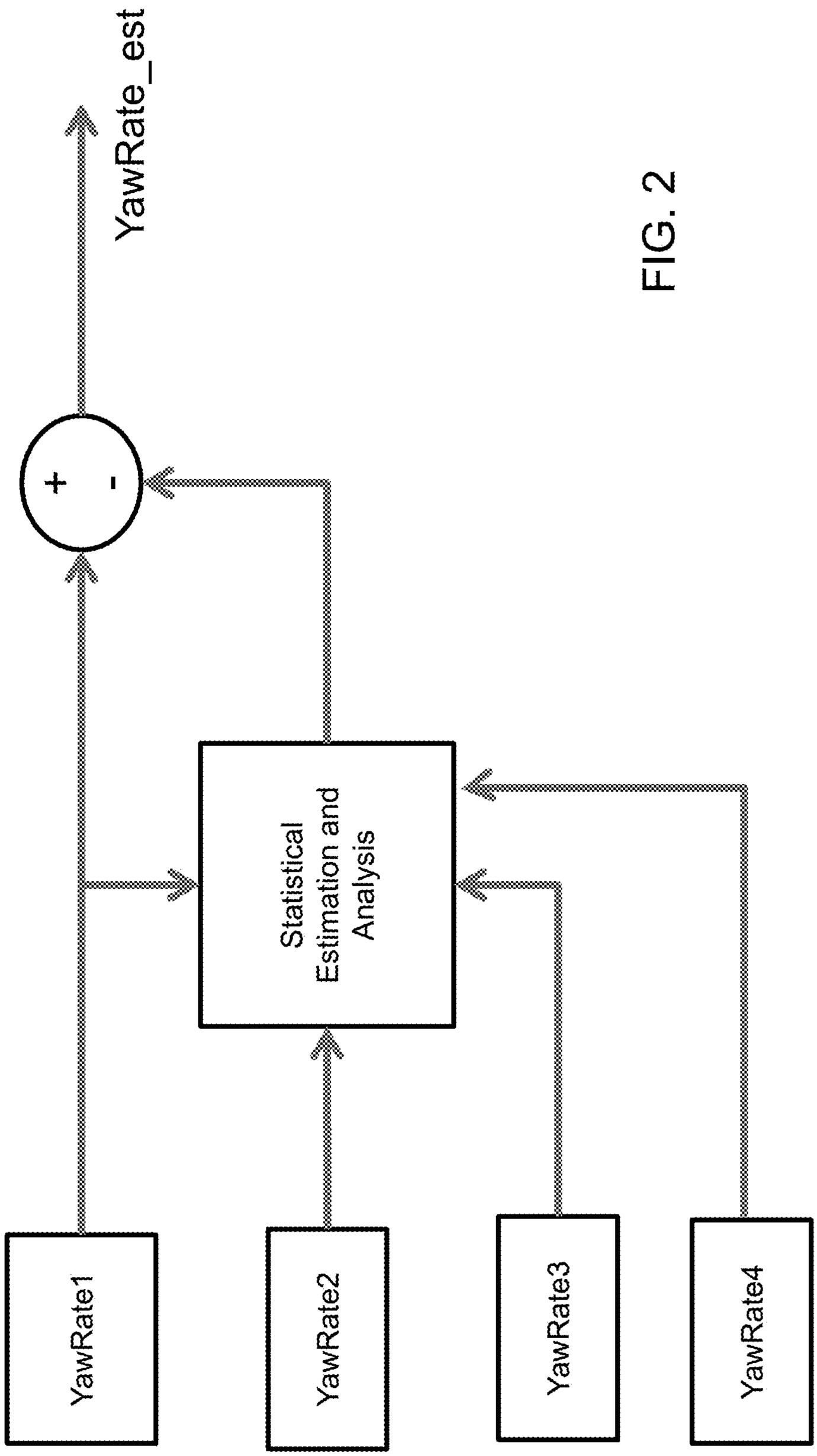
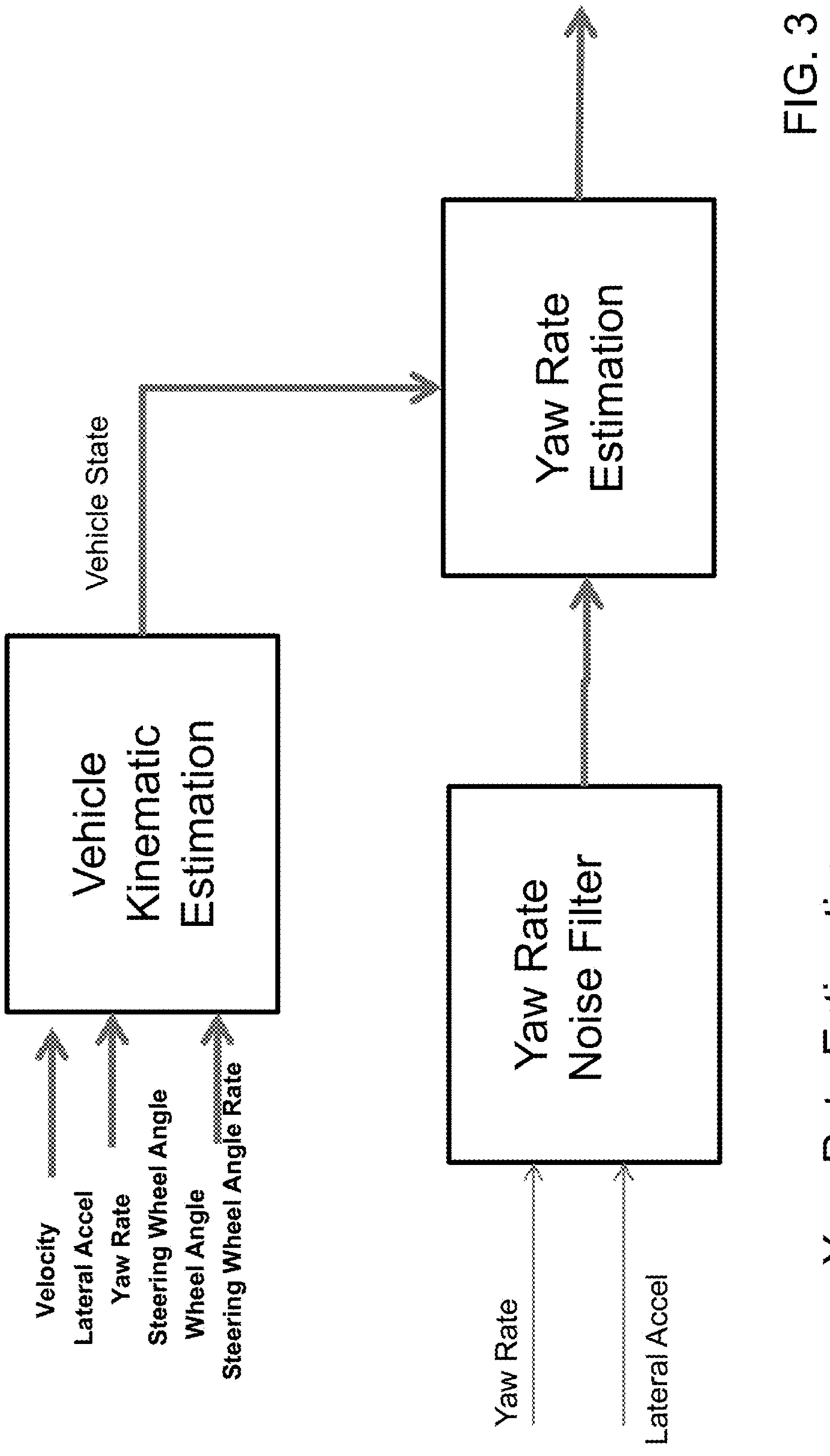

YawRate_est
+
-
Statistical Estimation and Analysis
YawRate1
YawRate2
YawRate3
YawRate4

FIG. 2

FIG. 3


Vehicle Kinematic Estimation
Vehicle State
Yaw Rate Estimation
Yaw Rate Noise Filter
Yaw Rate Estimation
Velocity
Lateral Accel
Yaw Rate
Steering Wheel Angle
Wheel Angle
Steering Wheel Angle Rate
Yaw Rate
Lateral Accel

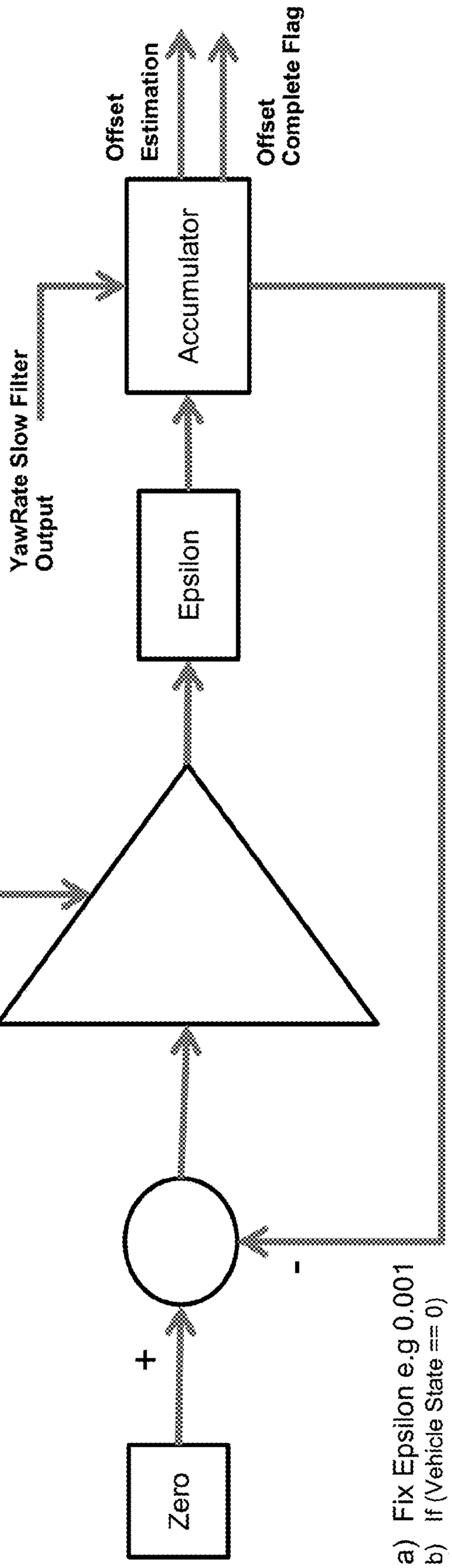


FIG. 4

Yaw Rate Offset Estimation

a) Fix Epsilon e.g 0.001
b) If (Vehicle State == 0)
{
Flag = 0;
while error > abs(epsilon)
{
Perform PID Loop
}
Offset = Accumulator
Flag = 1;
}
c) OffsetArray[i] = Offset;
d) OFFSET = function(OffsetArray);

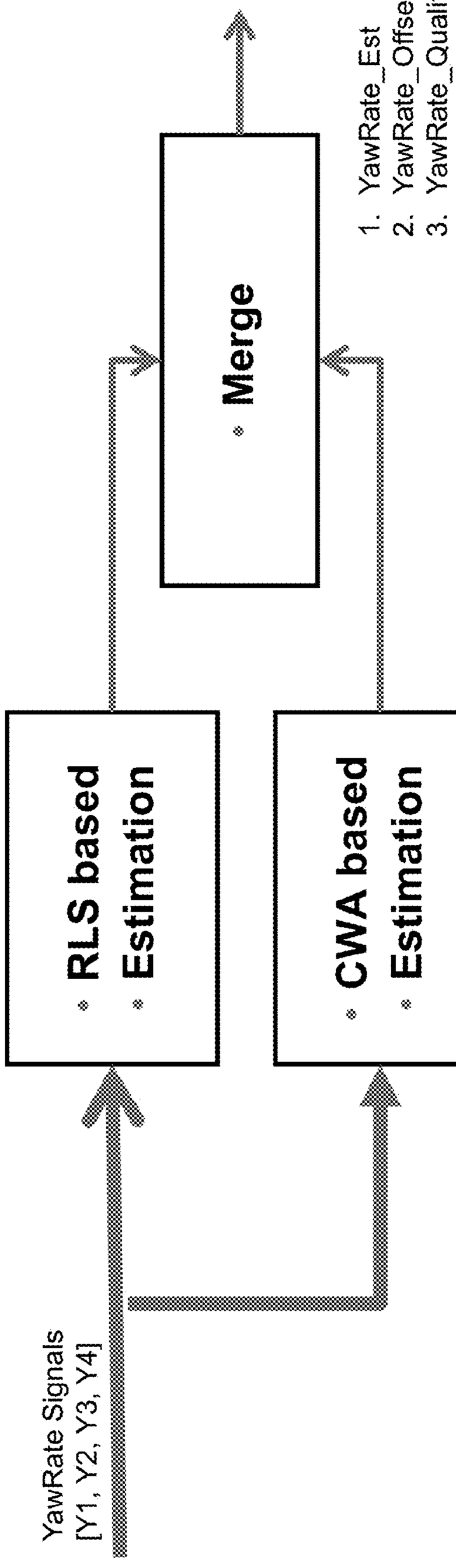
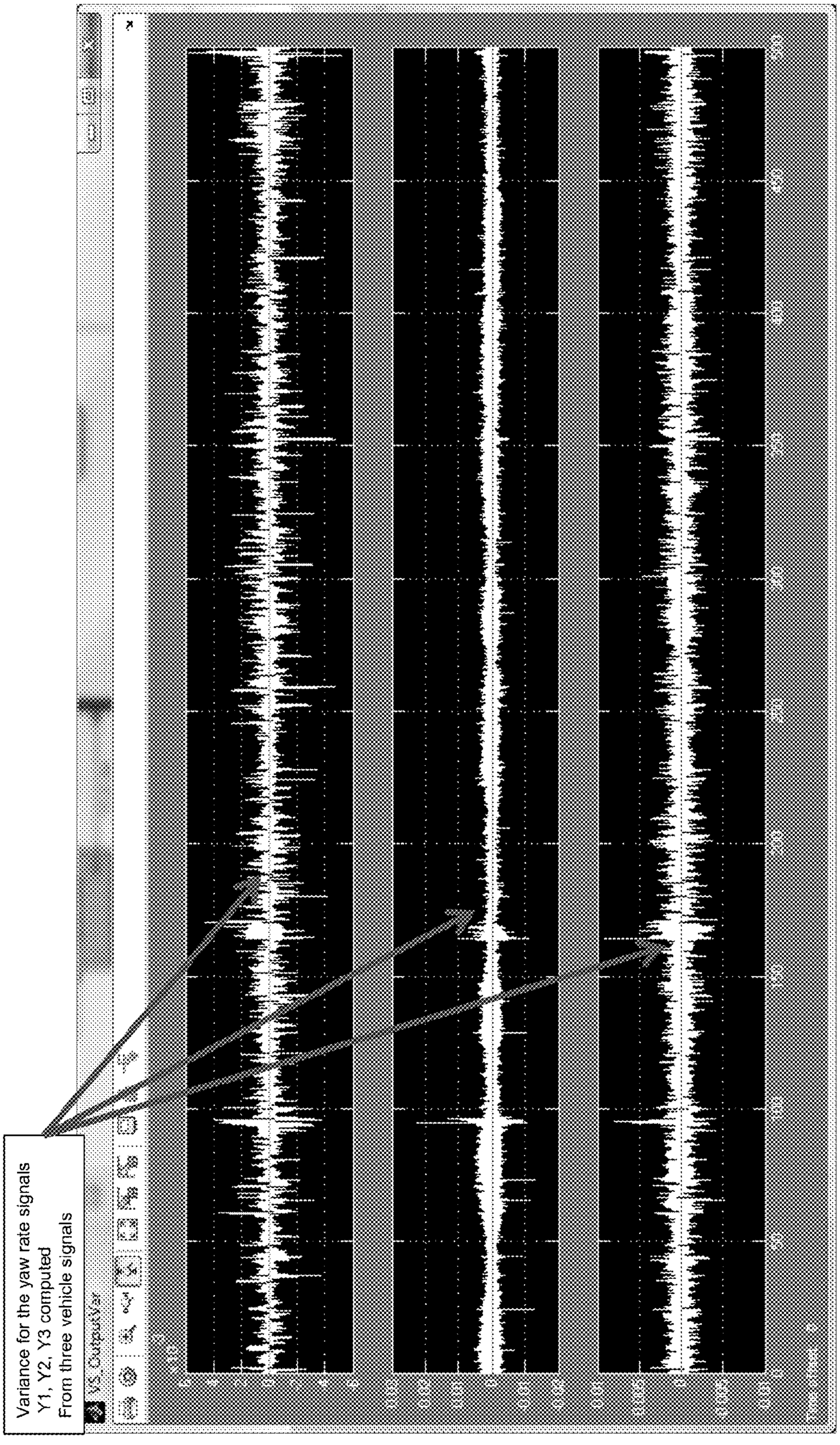

YawRate Signals
[Y1, Y2, Y3, Y4]
RLS based
Estimation
CWA based
Estimation
Merge
1. YawRate_Est
2. YawRate_Offset
3. YawRate_Quality
Estimation Block

FIG. 5



Variance of the signals. FIG. 6

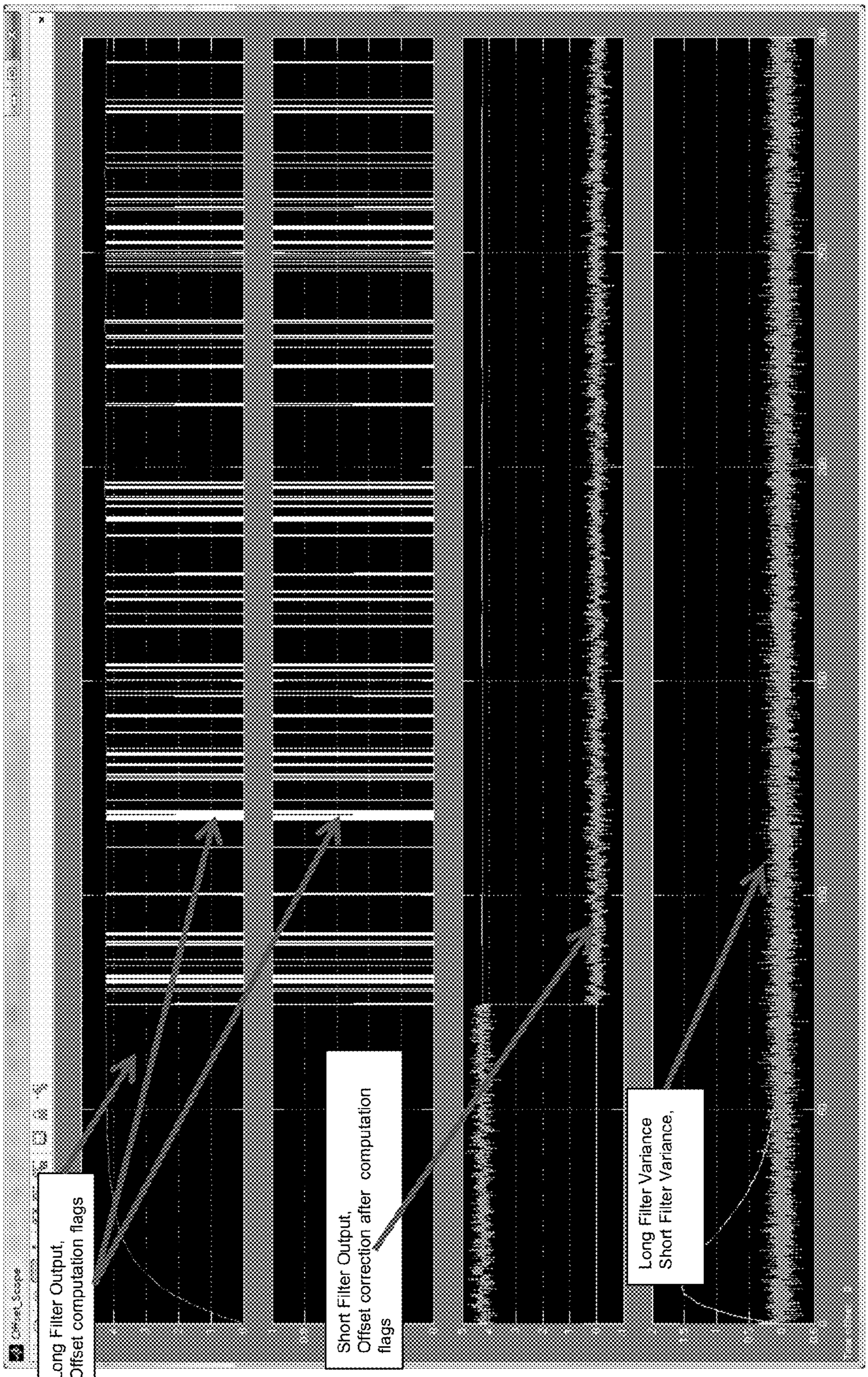


FIG. 7

Offset Correction

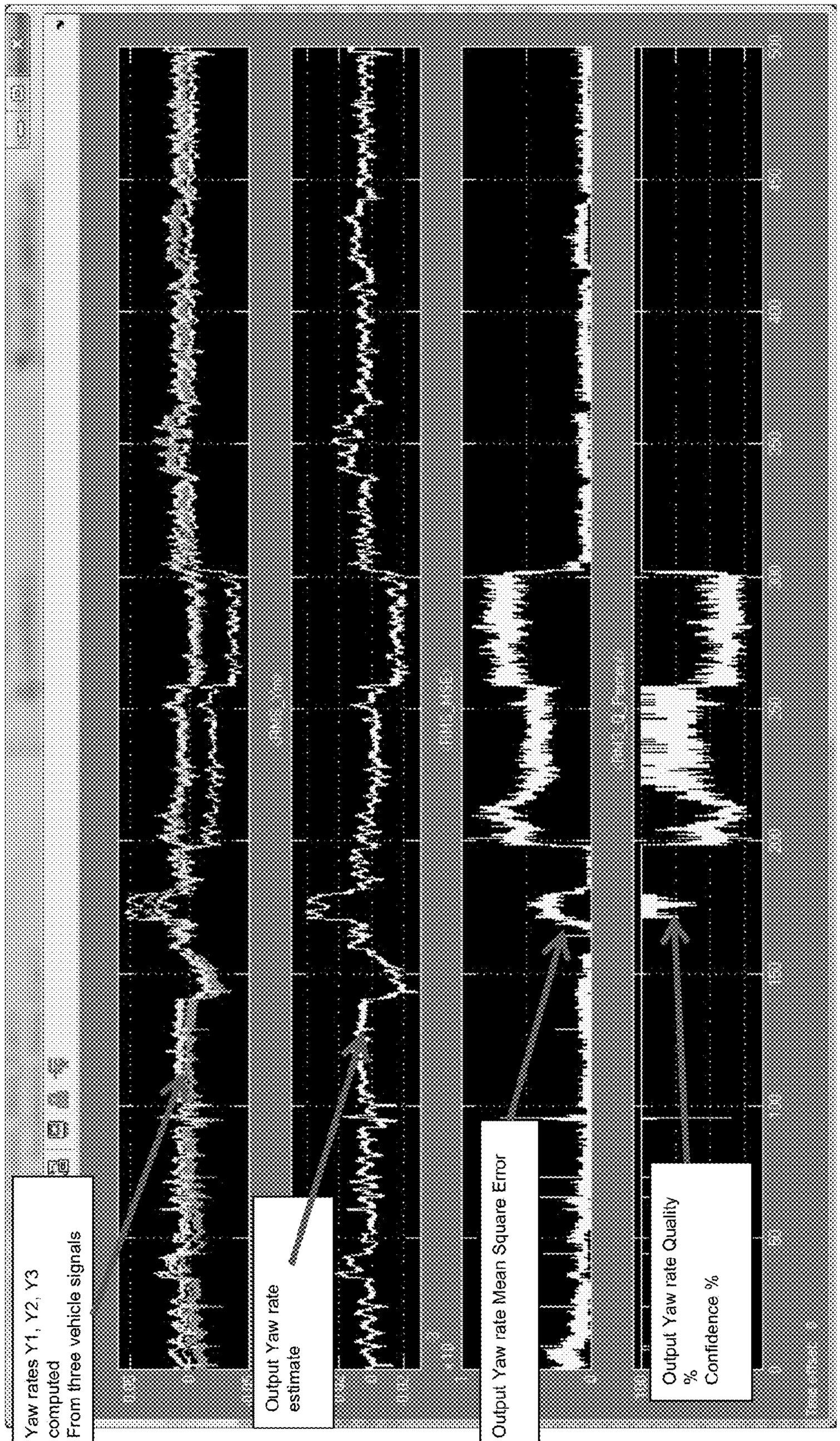


FIG. 8

Results – 2: Yaw Rate Estimation Output

VEHICLE YAW RATE ESTIMATION SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

The present application claims the filing benefits of U.S. provisional application Ser. No. 62/120,574, filed Feb. 25, 2015, which is hereby incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates generally to a yaw rate determination system for a vehicle.

BACKGROUND OF THE INVENTION

Sensing yaw rate is important to land-based vehicles, and specifically, to road-going vehicles. Vehicle systems, such as collision avoidance systems, collision mitigation systems and stability control systems, may require accurate values of yaw rate to correctly determine the projected path of vehicle travel. Yaw rate sensors are susceptible to error, and if the measured yaw rate has significant error, then these kinds of vehicle systems may perform poorly or even fail.

SUMMARY OF THE INVENTION

The present invention provides a yaw rate estimation system that is operable to compute or determine an estimated yaw rate using additional vehicle signals and vehicle kinematics to compute the estimated yaw rate (and the system does this without using a forward facing or viewing camera or imager). Because the forward viewing camera is a recipient of the estimated yaw rate, known forward viewing camera yaw rate methods are dependent on this estimation, and thus cannot be used for this estimation. The system of the present invention processes multiple yaw rates derived from different vehicle systems and a yaw rate sensor to determine an estimated yaw rate of the vehicle.

These and other objects, advantages, purposes and features of the present invention will become apparent upon review of the following specification in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view of a vehicle with a vision system that incorporates cameras in accordance with the present invention;

FIG. **2** is a block diagram showing processing of the yaw rate inputs to estimate the yaw rate in accordance with the present invention;

FIG. **3** is a block diagram showing the yaw rate estimation of the present invention, using vehicle kinematic estimations and yaw rate noise filters;

FIG. **4** is a block diagram of estimation of the yaw rate offset in accordance with the present invention;

FIG. **5** is a block diagram of estimation of the yaw rate, the yaw rate offset and the yaw rate quality in accordance with the present invention;

FIG. **6** shows graphs of the variance for the yaw rate signals derived from three vehicle signals;

FIG. **7** shows graphs showing the offset correction; and

FIG. **8** shows graphs of the yaw rate estimation outputs.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and the illustrative embodiments depicted therein, FIG. **1** illustrates a vehicle **10** equipped with the system of the present invention. In this example, the vehicle **10** is a passenger car, but in other examples, the vehicle may be a truck, bus, van, motorcycle, or any other kind of vehicle. In the illustrated embodiment, the equipped vehicle **10** includes a body, a passenger area, wheels **12** (including front wheels **12***a* and rear wheels **12***b*), an internal combustion engine and/or an electric motor to drive the vehicle **10**, a transmission **14** to convey power from the engine or motor to the wheels **12**, a steering wheel **16** to turn the front wheels **12***a*, as well as other components for powering and controlling the vehicle **10**. Clearly, the equipped vehicle may have other systems or components, such as, for example, steering of the rear wheels **12***b* or the like, without affecting the scope of the present invention.

As shown in FIG. **1**, the vehicle **10** further includes a control system **18**, a camera **20**, a yaw rate sensor **22**, a longitudinal accelerometer **24**, a transmission sensor **26**, a steering angle sensor **28**, a speed sensor **30** and a brake sensor **31**. The camera **20**, yaw rate sensor **22**, longitudinal accelerometer **24**, transmission sensor **26**, steering angle sensor **28**, and speed sensor **30** are each connected to the control system **18** to provide sensed information to the control system **18**. Such connections may be by way of conductive wires or wireless signals. A bus, such as a Controller-Area Network (CAN) bus or a Local Interconnect Network (LIN) bus or the like, may be used for communication between the sensors and the control system **18**. The system may utilize aspects of the systems described in U.S. Pat. No. 8,694,224, which is hereby incorporated herein by reference in its entirety.

The yaw rate sensor **22** is operable to sense the left and right yaw rate of the vehicle **10** (in other words, to sense the positive and negative angular rotational velocity of the vehicle about a local vertical axis A of the vehicle). Output of the yaw rate sensor **22** to the control system **18** may comprise a voltage within a range of voltages, or a data message sent over a communications bus or network bus of the vehicle, such as a CAN bus or the like. The yaw rate sensor **22** may include any type of device, such as piezoelectric device, a micromechanical device, a microelectromechanical device, or similar. The longitudinal accelerometer **24** is operable to sense the longitudinal (forward or reverse) acceleration of the vehicle **10** and provide a signal indicative of a magnitude of such acceleration to the control system **18**. The longitudinal accelerometer **24** may include any type of device, such as piezoelectric device, a micromechanical device, a microelectromechanical device, or similar. The longitudinal accelerometer **24** may be part of a multi-axis accelerometer.

The system of the present invention provides yaw rate estimation using vehicle signals and statistical analysis techniques. The system provides yaw rate offset correction and noise filtering, and provides robust yaw rate estimation using vehicle signals. The system of the present invention thus improves the resolution of the yaw rate signal and provides fault tolerant yaw rate signals with better quality. Because the signals from individual yaw rate sensors may have poor resolution and offsets, the resolutions and offsets may be out of tolerance for lane keeping features and

forward viewing camera applications. The present invention uses multiple yaw rate signals to provide an enhanced estimate of the yaw rate.

The vehicle signals used may include:

Wheel speeds for all four wheels (Vfl, Vrl, Vfr, Vrr).

Wheel radius and wheel speeds for all four wheels.

Yaw Rate Raw from the Yaw Rate Sensor.

Yaw Rate Offset from the Yaw Rate Sensor.

Lateral Acceleration.

Yaw Rate Temperature from the Yaw Rate Sensor.

Steering wheel angle, steering wheel rate of change, steering ratio for the entire speed range.

Wheel angle.

Vehicle stationary, engine running flags.

Vehicle driving straight flags.

Vehicle velocity.

The yaw rates may be estimated from the following equations, where YawRate_1 is the yaw rate from the yaw rate sensor and YawRate_2 is the yaw rate derived from the wheel sensors (such as anti-lock braking system (ABS) wheel sensors) and YawRate_3 is the yaw rate derived from the lateral acceleration of the vehicle and YawRate_4 is derived from the steering wheel angle, wheel angle and the rate of change of steering wheel angle.

$$YawRate2:\ y_{r2} = \frac{Vx}{R}$$

$$YawRate3:\ y_{r3} = \frac{Vx^2}{R}$$

Computation of radius of curvature R:

$$\frac{1}{R} = \frac{2}{L}\left(\frac{\frac{V_{rl}}{V_{rr}} - 1}{\frac{V_{rl}}{V_{rr}} + 1}\right),$$

$$V_x = \frac{\omega_{rl} + \omega_{rr}}{2} r$$

where V_{fl}, V_{fr}, . . . , V_{rr} wheel velocity m/s for four wheels, and, w_{fl}, w_{fr}, . . . , w_{rr} wheel rotation.
V_x=longitudinal velocity, r=radius nominal rear wheel

The yaw rate data analysis provides a "vehicle state" that is a function of the yaw rate, the SWA, SWA_Rate, the lateral acceleration and wheel velocity.

The system uses signal conditioning, with a sampling frequency of about 100 Hz and a desired cut off frequency of about 0.5 Hz to about 2 Hz or thereabouts. The system uses two filters:

The Long Time Period Filter (60-180) sec.=[0.0167-0.005] Hz

i) Compute Offset At Standstill (Velocity=0);

ii) Compute Offset when driving straight (Steering Angle~=0) (Steering Rate of Change~=0);

iii) Compute Variance of noise;

iv) Estimate the offset using a PID controller; and

v) Define weights on the estimate from (i) and (ii).

The Short Time IIR filter is around 2.0 Hz.

The system calculates offset estimates using weights and statistics.

As shown in FIG. **2**, the system processes the four yaw rates via statistical estimation and analysis to determine the estimated yaw rate. The system may use adaptive offset estimation using Recursive Least Squares (RLS), confidence weighted average combined with Recursive Least Squares. FIGS. **3-5** show the yaw rate estimation process, the yaw rate offset estimation process and the estimation block in accordance with the present invention. FIGS. **6-8** are graphs showing the variance of the yaw rate signals (FIG. **6**), the offset correction (FIG. **7**) and the yaw rate estimation output (FIG. **8**).

The system may provide additional outputs, such as, for example, a driving state: stable flag or output, a vehicle stationary engine running output, a vehicle driving straight and level output, a detection of sensor faults, such as a residual error (MSE) based confidence measure.

The system of the present invention may utilize aspects of the systems described in U.S. Pat. No. 8,694,224 and/or U.S. Publication Nos. US-2015-0291215 and/or US-2014-0350834, which are hereby incorporated herein by reference in their entireties.

Changes and modifications in the specifically described embodiments can be carried out without departing from the principles of the invention, which is intended to be limited only by the scope of the appended claims, as interpreted according to the principles of patent law including the doctrine of equivalents.

The invention claimed is:

1. A yaw rate estimation system for a vehicle, said yaw rate estimation system comprising:

a yaw rate sensor disposed at a vehicle equipped with said yaw rate estimation system;

wheel sensors disposed at wheels of the equipped vehicle;

an acceleration sensor disposed at the equipped vehicle and operable to determine lateral acceleration of the equipped vehicle;

a steering wheel angle sensor disposed at the equipped vehicle and operable to determine an angle of a steering wheel of the equipped vehicle;

a control system disposed at the equipped vehicle and receiving inputs indicative of (i) a first yaw rate determined by said yaw rate sensor of the equipped vehicle, (ii) a second yaw rate derived from said wheel sensors of the equipped vehicle, (iii) a third yaw rate derived from a lateral acceleration of the equipped vehicle as determined by said acceleration sensor, and (iv) a fourth yaw rate derived from a steering wheel angle, wheel angle and rate of change of steering wheel angle as determined by said steering wheel angle sensor; and

wherein said control system processes said inputs to estimate the actual yaw rate of the equipped vehicle, and wherein the estimated actual yaw rate is derived from said inputs.

2. The yaw rate estimation system of claim **1**, wherein said control system processes said inputs to estimate the actual yaw rate of the equipped vehicle without use of image data captured by a forward viewing camera.

3. The yaw rate estimation system of claim **1**, wherein said control system is operable to estimate the actual yaw rate of the equipped vehicle using statistical estimation and analysis of said first, second, third and fourth yaw rates.

4. The yaw rate estimation system of claim **3**, wherein said control system is operable to provide an adaptive offset estimation using Recursive Least Squares and Confidence Weighted Average combined with Recursive Least Squares.

5. The yaw rate estimation system of claim **1**, wherein said wheel sensors comprise wheel sensors of an anti-lock brake system of the equipped vehicle, and wherein said second yaw rate is derived from said anti-lock brake system wheel sensors of the equipped vehicle.

6. The yaw rate estimation system of claim 1, wherein said yaw rate sensor is operable to sense the left and right yaw rate of the equipped vehicle.

7. The yaw rate estimation system of claim 1, wherein said yaw rate sensor is operable to sense positive and negative angular rotational velocity of the equipped vehicle about a local vertical axis of the equipped vehicle.

8. The yaw rate estimation system of claim 1, wherein output of said yaw rate sensor is communicated to said control system via a communication bus of the equipped vehicle.

9. The yaw rate estimation system of claim 1, wherein said control system, responsive to estimation of the actual yaw rate, provides yaw rate offset correction to correct said first yaw rate.

10. The yaw rate estimation system of claim 1, wherein said control system, responsive to estimation of the actual yaw rate, provides noise filtering for said input from said yaw rate sensor.

11. A yaw rate estimation system for a vehicle, said yaw rate estimation system comprising:

a yaw rate sensor disposed at a vehicle equipped with said yaw rate estimation system;

wheel sensors disposed at wheels of the equipped vehicle;

an acceleration sensor disposed at the equipped vehicle and operable to determine lateral acceleration of the equipped vehicle;

a steering wheel angle sensor disposed at the equipped vehicle and operable to determine an angle of a steering wheel of the equipped vehicle;

a control system disposed at the equipped vehicle and receiving inputs indicative of a first yaw rate determined by said yaw rate sensor of the equipped vehicle and receiving inputs indicative of at least two of (i) a second yaw rate derived from said wheel sensors of the equipped vehicle, (ii) a third yaw rate derived from a lateral acceleration of the equipped vehicle as determined by said acceleration sensor and (iii) a fourth yaw rate derived from a steering wheel angle, wheel angle and rate of change of steering wheel angle as determined by said steering wheel angle sensor; and

wherein said control system processes said inputs to estimate the actual yaw rate of the equipped vehicle, and wherein the estimated actual yaw rate is derived from said inputs.

12. The yaw rate estimation system of claim 11, wherein said control system processes said inputs to estimate the actual yaw rate of the equipped vehicle without use of image data captured by a forward viewing camera.

13. The yaw rate estimation system of claim 11, wherein said control system is operable to estimate the actual yaw rate of the equipped vehicle using statistical estimation and analysis of said first yaw rate and said at least two of said second, third and fourth yaw rates.

14. The yaw rate estimation system of claim 11, wherein output of said yaw rate sensor is communicated to said control system via a communication bus of the equipped vehicle.

15. The yaw rate estimation system of claim 11, wherein said control system, responsive to estimation of the actual yaw rate, provides yaw rate offset correction to correct said first yaw rate.

16. The yaw rate estimation system of claim 11, wherein said control system, responsive to estimation of the actual yaw rate, provides noise filtering for said input from said yaw rate sensor.

17. The yaw rate estimation system of claim 11, wherein said control system, responsive to estimation of the actual yaw rate, provides enhanced resolution of said input indicative of said first yaw rate.

18. A yaw rate estimation system for a vehicle, said yaw rate estimation system comprising:

a yaw rate sensor disposed at a vehicle equipped with said yaw rate estimation system;

wheel sensors disposed at wheels of the equipped vehicle;

an acceleration sensor disposed at the equipped vehicle and operable to determine lateral acceleration of the equipped vehicle;

a steering wheel angle sensor disposed at the equipped vehicle and operable to determine an angle of a steering wheel of the equipped vehicle;

a control system disposed at the equipped vehicle and receiving inputs indicative of (i) a first yaw rate determined by said yaw rate sensor of the equipped vehicle, (ii) a second yaw rate derived from said wheel sensors of the equipped vehicle, (iii) a third yaw rate derived from a lateral acceleration of the equipped vehicle as determined by said acceleration sensor and (iv) a fourth yaw rate derived from a steering wheel angle, wheel angle and rate of change of steering wheel angle as determined by said steering wheel angle sensor;

wherein said control system receives at least some of said inputs via a communication bus of the equipped vehicle;

wherein said control system processes said inputs to estimate the actual yaw rate of the equipped vehicle, and wherein the estimated actual yaw rate is derived from said inputs; and

wherein said control system is operable to estimate the actual yaw rate of the equipped vehicle using statistical estimation and analysis of said inputs indicative of said first, second, third and fourth yaw rates.

19. The yaw rate estimation system of claim 18, wherein said control system processes said inputs to estimate the actual yaw rate of the equipped vehicle without use of image data captured by a forward viewing camera.

20. The yaw rate estimation system of claim 18, wherein said control system, responsive to estimation of the actual yaw rate, provides at least one of (i) yaw rate offset correction to correct said first yaw rate, (ii) noise filtering for said input from said yaw rate sensor and (iii) enhanced resolution of said input indicative of said first yaw rate.

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