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Report title: Slip angle measurement with an S-sensor and a yaw rate sensor

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Summary: The S-sensor will measure the slip angle only when mounted directly in the vehicle's center of gravity. For any other mounting position, the yaw rate of the vehicle and the sensor coordinates in the center-of-gravity coordinate system will have to be included in the calculation. This report demonstrates how the slip angle is derived from the given parameters and, therefore, serves as a verification of the equation given in the S-sensor data sheets.
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1. Introduction

When a CORREVIT[®] S-sensor is mounted in a vehicle's center of gravity, the sideslip angle, i. e. the angle between velocity vector and longitudinal vehicle axis, can be derived directly from the measurement of the transversal and longitudinal velocity components. However, this mounting position is not very realistic. For other positions, the yaw rate as well as the sensor coordinates in the center-of-gravity system must be included in the calculation. A sensor measuring on the outside (inside) of the curve goes around it a longer (shorter) way and will therefore measure too high (low) a velocity. The yaw rate sensor can be mounted at an arbitrary position, for example inside the S-sensor, as is realized in the CORREVIT[®] S-CE with fiber gyro. The following shows how a vector calculation yields the sideslip angle expressed by all these parameters.

2. Calculation

2.1 Purely rectilinear vehicle motion

Fig. 1 shows a vehicle in rectilinear motion. Depending on the driving situation, longitudinal and transversal components can be measured by the S-sensor. The sensor measures the velocity above ground, i. e. the velocity of the center of gravity. The figure also shows the common convention for the vehicle coordinate system, in which the +x-axis points to the front of the vehicle, the +y-axis to the left, and the +z-axis upwards (right-hand system).

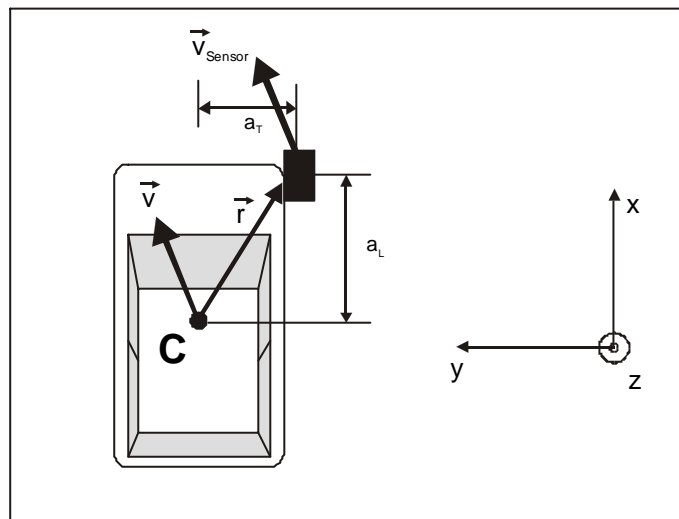


Figure 1: Measured vector velocity for a rectilinear motion. Vehicle coordinate system. \vec{r} defines the mounting position of the sensor. C: center of gravity.

The vehicle velocity (center of gravity) can be written with its longitudinal and transversal components, v_{long} and v_{trans} , as:

$$\vec{v} = (v_{\text{long}}, v_{\text{trans}}, 0) . \quad (1)$$

2.2 Pure yaw

With an additional yaw motion, the sensor rotates around the center of gravity as rotational center. (Fig. 2). This yields additional longitudinal and transversal velocity components. The position of the sensor in the center-of-gravity system is:

$$\vec{r} = (a_L, a_T, 0) . \quad (2)$$

The angular velocity $\dot{\mathbf{Y}}$ leads to a circular velocity \vec{v}_{yaw} of:

$$\vec{v}_{yaw} = \dot{\mathbf{Y}} \times \vec{r} \quad (3)$$

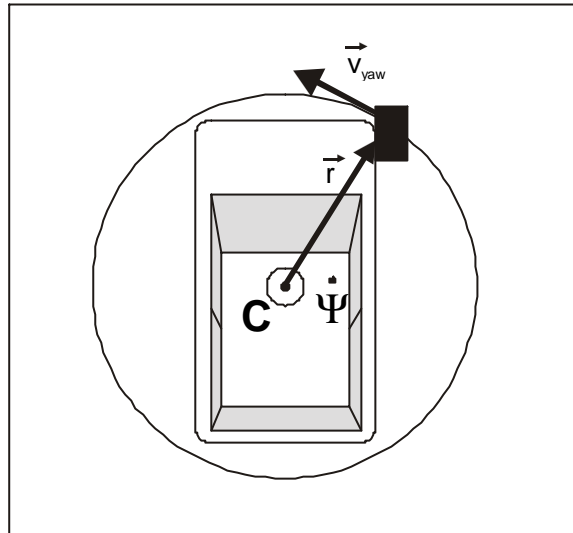


Figure 2: Vehicle yaw: Longitudinal and transversal velocity components develop due to the rotation of the sensor around the vehicle's center of gravity.

Inserting Eq. (2) into Eq. (3) yields:

$$\begin{aligned} \vec{v}_{yaw} &= \dot{\mathbf{Y}} \times \vec{r} \\ &= (0, 0, \dot{\mathbf{Y}}) \times (a_L, a_T, 0) \\ &= (0 \cdot 0 - \dot{\mathbf{Y}} \cdot a_T, \dot{\mathbf{Y}} \cdot a_L - 0 \cdot 0, 0 \cdot a_T - 0 \cdot a_L) \\ &= (-\dot{\mathbf{Y}} \cdot a_T, \dot{\mathbf{Y}} \cdot a_L, 0) \end{aligned} \quad (4)$$

2.3 Superposition: Cornering vehicle

Upon cornering, the total vehicle velocity is composed of both sideslip and yaw. Thus, the total velocity \vec{v}_{Sensor} is given by:

$$\vec{v}_{Sensor} = \vec{v} + \vec{v}_{yaw} \quad (5)$$

which yields with Eq. (1):

$$\vec{v}_{Sensor} = (v_{long} - \dot{\mathbf{Y}} \cdot a_T, v_{trans} + \dot{\mathbf{Y}} \cdot a_L, 0) \quad (6)$$

Written in individual components:

$$v_{Sensor,x} = v_{long} - \dot{Y} \cdot a_T, \quad (7)$$

and

$$v_{Sensor,y} = v_{trans} + \dot{Y} \cdot a_L. \quad (8)$$

Thus, the longitudinal and transversal components of the center-of-gravity velocity are:

$$v_{long} = v_{Sensor,x} + \dot{Y} \cdot a_T, \quad (9)$$

and

$$v_{trans} = v_{Sensor,y} - \dot{Y} \cdot a_L. \quad (10)$$

The slip angle therefore becomes:

$$\mathbf{b} = \arctan \frac{v_{trans}}{v_{long}} = \arctan \frac{v_{Sensor,y} - \dot{Y} \cdot a_L}{v_{Sensor,x} + \dot{Y} \cdot a_T}. \quad (11)$$

2.3 Discussion

Table 1 lists the sign conventions for the parameters of Eq. (11).

Table 1: Signs for the parameters in Eq. (11). Mounting positions relative to the center of gravity, cw: clockwise, ccw, counter-clockwise.

Parameter	Mounting position / Rotational direction	Sign
a_L	Front	+
	Rear	-
a_T	Left	+
	Right	-
\dot{Y}	ccw	+
	cw	-