.Fusion of Tire Lateral Force Estimation and Integral Sliding Mode Control for Improved Vehicle Handling

Jinmin Kim1), Hyunseup Jo1) and Sang Won Yoon2)\*

1)Department of Automotive Engineering (Automotive – Computer Convergence), Hanyang University, Seoul 04763, Korea

2)Department of Electrical and Computer Engineering, Seoul National University, Seoul 08826, Korea

(Received date ; Revised date ; Accepted date ) \* Please leave blank

**ABSTRACT−**Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here.Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. Type the abstract here. [Capital letter at the beginning of each sentence, put a period at the end, Please write in 100 ~ 200 words, Times New Roman, 9pt]

**KEY WORDS** : Type key words here, Type key words here, Type key words here, Type key words here [Capital letter at the beginning of each keyword, Do not put a period at the end, Times New Roman, 9pt]

**[Main Body : Times New Roman, 10pt]**

nomenclature

[All should have small letters, Times New Roman, 10pt]

A : area, m2

subscripts

|  |
| --- |
| [All should have small letters, Times New Roman, 10pt]  A,B,C,P : nodal point |
| \* *Corresponding author*. e-mail: type e-mail address [Official E-mail Address] |

1. INTRODUCTION [All should have capital letters, Times New Roman, 10pt]

The manuscript elements have been formatted for you through the “styles” capability of the software. To use the styles, select the text you wish to apply a style to, then, using the mouse, point to the style box on the toolbar. Click once on the downward pointing arrow to the right, and select the appropriate style.

2. Section TITLE [All should have capital letters, Times New Roman, 10pt]

The “body” text portion should be organized using styles named Body. The first paragraph of the section should not be indented. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here (Belytschko and Leviathan, 1994).

2.1. Subheading [Capital letter at the beginning of each keyword, Times New Roman, 10pt]

Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here (Follansbee, 1978; Kang *et al*., 1998, 1999).

2.1.1. Sub-subheading [Capital letter at the beginning of the sentence, Times New Roman, 10pt]

Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here.

This is an example of the figure.



Figure 1. Type the caption here. Type the caption here. Type the caption here. [Capital letter at the beginning of each sentence, put a period at the end, Times New Roman, 10pt]

This is an example of the table.

Table 1. Type the caption here. Type the caption here. [Capital letter at the beginning of each sentence, put a period at the end, Times New Roman, 10pt]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | A  (MPa) | B  (MPa) | n | C | C1 | C2 | M |
| SPCEN | 208 | 350 | 0.48 | 0.140 | 0.080 | 0.007 | 0.31 |
| 60TRIP | 432 | 800 | 0.59 | 0.075 | 0.030 | 0.012 | 0.55 |
| 60C | 463 | 800 | 0.63 | 0.036 | 0.037 | 0.004 |  |

2.1.2. Sub-subheading [Capital letter at the beginning of the sentence, Times New Roman, 10pt]

Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here.

2.2. Subheading [Capital letter at the beginning of each keyword, Times New Roman, 10pt]

Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here.

This is an example of the equation.

 (1)

Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here. Type the contents of the section here.

 (2)

3. Torque-vectoring

The implementation of Torque Vectoring requires a control strategy capable of accurately distributing torque between individual wheels to achieve the desired yaw rate. A typical driving environment is subject to various disturbances, and due to the inability to fully sense some aspects of driving dynamics in real time, these parts remain uncertain. Therefore, the controller must ensure robustness to maintain performance under these conditions. To satisfy these requirements, this paper employs a Sliding Mode Controller (SMC) to calculate the yaw moment. However, the use of SMC introduces a chattering problem, where the control input rapidly switches between different values, deteriorating vehicle ride comfort and the durability of vehicle components. To address these challenges, this paper utilizes the lateral tire force (Fy) estimated by the Extended Kalman Filter (EKF), as detailed in Section 2

3.1. Sliding Mode Controller

A SMC can be developed based on the vehicle's yaw moment balance equation

|  |  |
| --- | --- |
|  | (X) |

~~where~~  ~~is the vehicle yaw moment of inertia;~~ ~~is the lateral tire force;~~  ~~is the lateral tire force;~~  ~~is the steer angle at the wheels; FL,FR.RL,and RR are position of front left, front right, rear left, rear right;~~  ~~and~~  ~~are the front and rear wheelbases, respectively; and a and b are the front and rear lengths of the wheelbase and the mass center.sds~~

This Equation can be partitioned into two components: one is , which consis of , and the other is , which consists of . of the  can be predicted with driven motor torque and brake pressure. So we can use this part for the control, as dscriben in the following:

|  |  |
| --- | --- |
|  | (X) |

 of the is estimated by the EKF, as dscribed in the following:

|  |  |
| --- | --- |
|  | (X) |

For torque vectoring, a sliding surface is designed to achieve the desired yaw rate as follows.

|  |  |
| --- | --- |
|  | (X) |

The process of setting the control input involves following two steps. First, establish the equivalnt control, which ensures  under the assumtion of no disturbances and can be determined by imposing . Next, add a switching term to eliminate disturbances

|  |  |
| --- | --- |
|  | (X) |
|  | (X) |
|  | (X) |

Where is the control gain for slidng mode control.  is the disturbances, and  is error of the EKF results

To ensure the sliding surface converges in finite time, Lyapunov functions V(s) are used. According to equation (x), control gain must be over the .

|  |  |
| --- | --- |
|  | (X) |

3.2. Torque Distribution

In Section 2.1, the desired momentum is generated by SMC. To achieve this momentum, the vehicle utilizes both steering and torque distribution. However, the maximum momentum is limited by the frictional force between the tires and the road, which is determined by the frictional coefficient and the normal force. As a result various distribution startagies can be employed. [who gonna same, who gonna adaptive, references is here]. In this paper, torque is generally distributed equally, but if the tire force exceeds the maximum force, the excess value is edistributed to the other motor. The maximum force is estimated using Fz derived​ from the EKF and frictional coefficients.

4. Simulation and result

4.1. Simulation setup

This section includeed Simulation setup and

4.2. EKF

This section includeed EKF setup and results

4.3. Torque Vectoring

4.3.1 Sliding Mode Control Setup

Robustness of SMC can be guaranteed by adopting an appropriate control gain.

5. CONCLUSION

Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here. Type the contents of the conclusion here.

**ACKNOWLEDGEMENT−**This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government (MSIT) (No.2022-0-01053, Development of Network Load Balancing Techniques Based on Multiple Communication/Computing/Storage Resources)

REFERENCES

\* The Harvard System of references is to be used.

\* In the body of the text a paper is to be referred to by the author’s Last Name with the year of publication in parentheses.

Example :

-One author (Last Name, Year)

-Two authors (Last Name and Last Name, Year)

-More than three authors (Last Name *et al*., Year)

Example :

-One author : (Huh, 2000)

-Two authors : (Incropera and DeWitt, 1990)

-More than three authors : (Park *et al*., 2002)

\* References should be listed together at the end of the paper in alphabetical order by author’s Last Name.

-Type in all Author’s name and Paper title

-Type in reference of this paper in the text.

-Transactions of the Korean Society of Automotive Engineers : *Trans. Korean Society of Automotive*

*Engineers*

IJAT : *Int. J. Automotive Technology*

\* Citing a minimum of one citation from the International Journal of Automotive Technology (IJAT) is recommended.

**1. Journals**

All Author(s)(Type Last Name, then first and middle initials). (Year). Paper title(Capital letter at the beginning of sentence). *Journal Name(Italic)* **Volume number(bold)**, **Issue number(bold)**, pp.−pp.

Example :

Huh, H. (2000). Identification of autobody crashworthiness for space- framed vehicle models by finite element limit analysis. *Int. J. Automotive Technology* **1**, **1**, 101−112.

**2. Books**

All Author(s)(Type Last Name, then first and middle initials). (Year). *Book Title(Italic, Capital letter at the beginning of each keyword)*. Edition number. Publisher. The Location of Publisher(City).

Example :

Incropera, F. P. and DeWitt, D. P. (1990*). Fundamentals of Heat and Mass Transfer*. 3rd edn. John Wiley & Sons. New York.

**3. Website**

All Author(s) or Title (Access Year). Detailed Address.

Example :

PermaPure LLC (2006). http://www.permapure.com/

Presentations/Fuel%20Cell%20Humidification%20

presentation.ppt

**4. Reports and User Guide**

All Author/Organization or Title (Year). Title. Organization. Serial number.

Example :

Green, P. (1980). A Computer Simulation of Headlamp Variables and Drivers Sight Distances: Operating Instructions. HSRI Technical Report. UM-HSRI-80-44.

AVL (2006). BOOST Ver. 5.0 User Guide.