LAB MEETING

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Fuzzy Super Twisting Sliding Mode Control (Fuzzy STSMC) 종방향 속도 제어기 구현





Fuzzy STSMC 참고 논문

A Fuzzy Super Twisting Sliding Mode Control Scheme for Velocity Regulation in Autonomous Vehicles

mode control scheme for addressing these limitation is implemented here to be

Accidents involving rochaman life and significant society. According to the million people are killed an are injured in road accident are injured in road accident issually caused by num bottlenecks at the inters fatigue, inexperience and o potential to reduce noise, i and save power, autonom widespread interest in recen

Speed control is critical Vehicles (AVs). Also know of the speed of an AV is activities such as overtaki response to road signs and needs to increase and ma another vehicle, platooni speed to avoid crashing v from their counterparts, down at traffic lights as reasons, the impoveremphasized.

The controller's gains are adjusted to make sure the sliding variable converges to zero in finite time. Consider a nonlinear system as shown in equation 2.

 $x_2 = f(x_1, x_2) + u$

The variables x2 and x2 represent the system state variables while u is the control force and $f(x_i, x_2)$ is the system disturbance. The major aim of SMC is to design a control equation that will drive the state va

 $\sigma = x_2 + cx_1$ In control design, minimizing a sective. Therefore, the state vari rms of the error value, e, which is

desired out and the plant output

Equation (3) can be rewritten $\sigma = \dot{e} + ce$ Equation 5 is referred to as the

surface in which the state variable designed control law. The control on the feedback control equation :

variable, o. However, since the cor along the sliding surface at $\sigma = 0$. The a sign function and the control equals

Where,

Here, U is the control gain. It of

The chattering effect asso minimized by substituting a sigm function in equation 7. This substitu

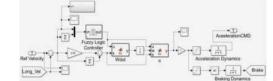
 $u = -Usat(\sigma) = \frac{\sigma}{|\sigma| + s}$ Here, the variable ε is a small p

However, the substitution of the gmoid function leads to a reduction rawback, another technique emp chattering is by the implementation of such techniques is the Super Twi algorithm ensures the sliding varia finite time while at the same time effect. The Super Twisting SMC equations 9 and 10.

 $u = -\lambda \sqrt{|\sigma|} sign(\sigma) + v$

 $\hat{v} = -Wsian(\sigma)$ $\lambda = \sqrt{U}$ and W = 1.1U

The pain (11) of the Super Twisting SMC is selected manually by the user. This gain needs to be large enough to provide accurate control performance. However, in some cases, the gain is selected to be too high or too low. A gain that is too high results in unnecessarily high computational requirements. A gain that is too low results in a sup-optimal performance. Because of this, engineers



The output of the STSMC is fed into saturation blocks in hich the positive and negative values are respectively sent to transfer functions representing the acceleration and braking fyramics. These outputs determine if the vehicle will increase its speed or slow down,

C. Velocity Reference Tracking and Error Value Convergence

The main objective of the adaptive STSMC is to ensure that the error value converges to zero. This convergence implies that the reference velocity is equivalent to output velocity. Figure 11 shows the reference tracking of the velocity signal while Figure 12 shows the convergence of the

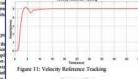


Figure 12: Error Convergence

In terms of the reference tracking of the velocity, it can be seen from Figure 11 that the system has a satisfactory reference tracking performance. The system exhibited a rise time of 1.484 seconds and an overshoot of 3.646 %. This implies that the system will take 1.383 seconds to go from 0.5 m/s to 4.5 m/s. Additionally, the overshoot implies that when

the vehicle starts moving, it will overshoot its final value and reach a velocity of 5.17 m/s before eventually settling down

takes 12.95 seconds to settle to its steady state value. This is also the amount of time it takes for the error value to converge to zero. The system converges with an Integrated Squan Error (ISE) of 23-18 over a simulation time of 50 seconds

The performance of the adaptive STSMC was commune with that of the traditional SMC. A gain of 300 was selected for the traditional STSMC. The results showed that the adaptive controller performed better in terms of the ISE and rise time, while the traditional controller gave better settling time and overshoot values. A summary of the system response results for both controllers is presented in Table II.

STSMC STSMC 50 secs Time 4.521 secs Rise Time 11.6 secs

In this paper, an adaptive Super Twisting Sliding Mode Control (STSMC) scheme was developed. This control technique was implemented for velocity control is autonomous vehicles. The adaptive feature of the controlle was achieved using Fuzzy Logic, which adjusted the gain of the STSMC based on the error value. The vehicle and the control system were fully modelled in Simulink. The system was simulated using the Unreal Engine provided by MATLAB. The results of the study showed that the developed control system was able to ensure convergence of the error value to zero. This in turn provided a good reference tracking capability of the controller. In comparison to the traditional STSMC, the adaptive system performed better in terms of the rise time and ISE, but was the traditional controller gave better settling time and overshoot results. Future research works will focus on prototype development and comparative analysi with other popular control schemes.

The authors wish to acknowledge Tertiary Education Trust Fund (TETFUND), Nigeria for funding this research under the project titled 'Novel Road Accident Monitoring and

논문 아키텍쳐

- 1. 엑추에이터 손상, 제어 효율 저하, 불안정성 증가 등을 초래하는 고전 SMC 채터링 단점 언급.
- 2. Fuzzy Logic Algorithm을 통해 적응형 제어 이득 기법 제안.
- 3. 위 단점을 보완하는 Fuzzy Super Twisting Sliding Mode Control 기법 제안.

🕨 논문 주요 키워드

- Super Twisting Sliding Mode Control(STSMC)
- Fuzzy Logic Algorithm
- Mamdani FIS
- Fuzzification
- Fuzzy Rule-Based
- Fuzzy Inference
- Defuzzification
- Triangular Membership Functions(MFs)

Super Twisting Sliding Mode Control(STSMC)

- 1. 고차 슬라이딩 모드 제어(HOSMC)의 한 형태
- 2. 전통적인 SMC에서 발생되는 채터링을 해결하기 위한 제어 기법

System Model

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = f(x_1, x_2) + bu$$

X1, x2: 시스템 상태 변수

f(x1,x2): 비선형 시스템 함수

b: 시스템 이득

u: 제어 입력

Sliding Surface

$$\sigma = C_1 e + C_2 \dot{e}$$

Sigma: 슬라이딩 변수(슬라이딩 표면)

e: 오차 (Reference velocity와 Ego velocity의 차이)

C1, C2: 슬라이딩 계수

Super Twisting Sliding Mode Control Algorithm

$$\lambda = \sqrt{U}$$

W = 1.10 U: STSMC 제어 이득, Fuzzy Logic 적용 파라미터

$$\dot{v} = -W sign(\sigma)$$

$$u = -\lambda \sqrt{|\sigma|} sign(\sigma) + v$$
 : STSMC의 최종 출력





Fuzzy Super Twisting Sliding Mode Control(Fuzzy STSMC)

Fuzzy Logic Algorithm

- 1. 불확실하고 모호한 정보 처리를 위한 수학적 기법
- 2. '참'과 '거짓 ' 사이의 연속적인 상태를 가질 수 있게 하여 복잡한 문제를 모델링 가능.
- 3. Fuzzy sets, Fuzzification, Rule-based System, Defuzzification, centroid method 등 주요 개념 존재.

Fuzzy Logic Gain Selector(Mamdani FIS)

- 1. 참고 논문에선 MATLAB Logic Toolbox를 통해 Fuzzy Logic Gain Selector 구현.
- 2. Fuzzy Logic Algorithm이자, 추론화 시스템인 Mamdani FIS 활용.

퍼지화 (Fuzzification)



퍼지 규칙 기반 (Fuzzy Rule-Based)



퍼지 추론 (Fuzzy Inference)



디퍼지화 (Defuzzification)

- Fuzzification

삼각형 멤버십 함수(MFs)를 통해 입력값을 퍼지 집합으로 변환.

- Fuzzy Rule-Based

오차와 제어 동작(제어 이득)이 비례한다는 판단에 기초하여 규칙 정의.

- Fuzzy Inference

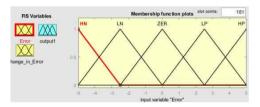
퍼지 규칙 기반으로 입력값에 대한 출력값 도출(추론), 보편적으로 사용되는 MIN-MOD-MAX 방법 사용.

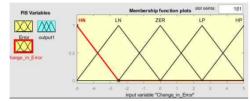
- Defuzzification

퍼지화된 출력값을 제어기에서 사용 가능한 명확한 값으로 변환, 보편적으로 사용되는 중심법(Centroid method) 사용.

Fuzzy Logic Gain Selector 구현

Fuzzification





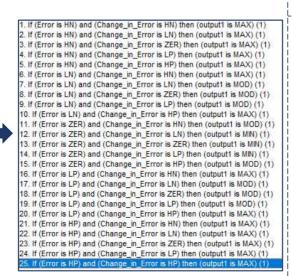
입력 변수(오차, 오차 변화율) 범위는 -5~5로 정의.

입력 변수 각각 5개의 멤버십 함수(MFs)를 포함.

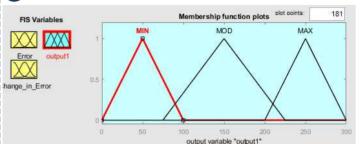
높은 음수(High Negative, HN), 낮은 음수(LN), 제로(ZER), 낮은 양수(LP), 높은 양수(HP) 출력 변수는 3개의 멤버십 함수(MFs)를 포함.

Fuzzy Rule-Based

Error/Change in Error	HN	LN	ZER	LP	HP
HN	MAX	MAX	MAX	MAX	MAX
LN	MAX	MOD	MOD	MOD	MAX
ZER	MOD	MIN	MIN	MIN	MOD
LP	MAX	MOD	MOD	MOD	MAX
HP	MAX	MAX	MAX	MAX	MAX



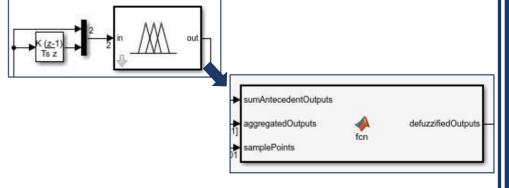
Fuzzy Inference



출력 변수(제어 이득(U)) 범위는 0~300으로 정의.

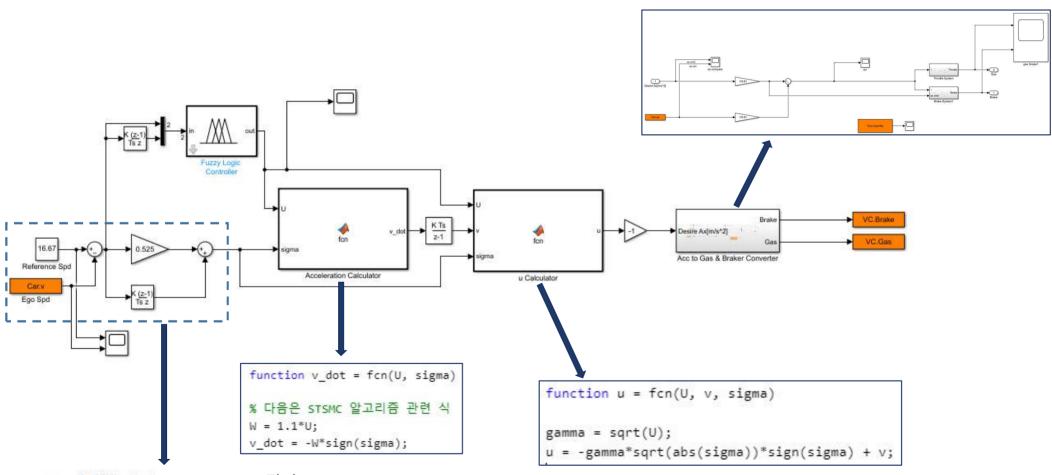
최소 동작(Minimal Action, MIN), 중간 동작(MOD), 최대 동작(MAX)

Defuzzification





Fuzzy STSMC Simulink 구조도

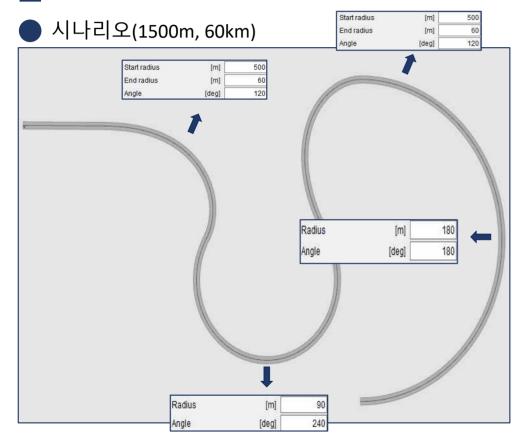


 $\sigma = 0.525e + \dot{e}$: Sliding Surface 정의



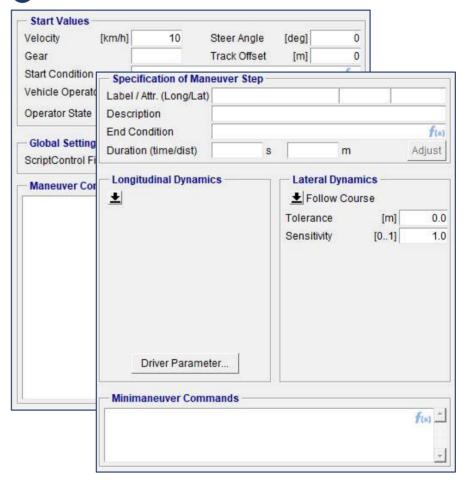
Fuzzy Super Twisting Sliding Mode Control(Fuzzy STSMC)





Carmaker Setting

Manuever





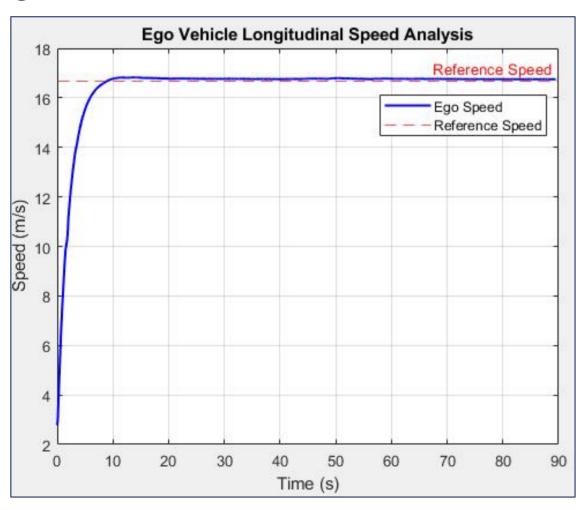


Sliding Mode Control(SMC) 횡방향 제어기 구현 및 성능 분석



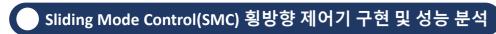
Fuzzy Super Twisting Sliding Mode Control(Fuzzy STSMC)

- Fuzzy STSMC 종방향 제어 성능 분석
- Fuzzy STSMC 종방향 속도 성능 분석



V (max)	V (mean)	V(rise time)	V(settling time)	V(overshoot)
13.8922	1.5653	4.4s	89.5s	0.95%

Parameter	Adaptive STSMC	Traditional STSMC	
Simulation Time	50 secs	50 secs	
Rise Time	1.484 secs	4.521 secs	
Settling Time	12.95 secs	11.6 secs	
Overshoot	3.646 %	0.839 %	
ISE	23.18	25.02	





Fuzzy STSMC 문제점 및 고도화 방안

- 문제점
 - 1. Fuzzy Logic Algorithm의 이해 및 분석 부족.
 - 2. 상용차에 맞춰진 Low Controller.
 - 3. Fuzzy Gain Selector의 높은 이득 연산 및 STSMC의 과도한 연산량 발생.

● 고도화 방안

- 1. Fuzzy Logic Algorithm 분석을 통한 MFs, Rule 고도화.
- 2. Low Controller의 파라미터 튜닝.
- 3. LQR(Linear Quadratic Regulator), PSO(Particle Swarm Optimization) 등과 같은 새로운 알고리즘 적용.

감사합니다.

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