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Interval Type-2 Fuzzy System and its Applications

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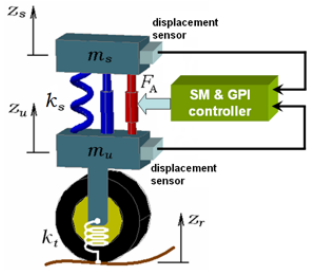
Outlines

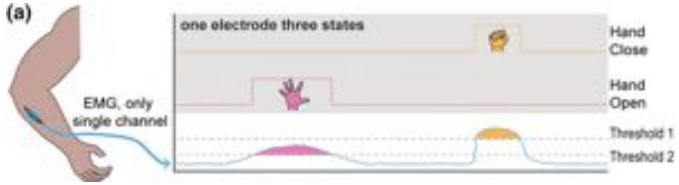
- Introduction of fuzzy logic systems
  - Fundamentals and basic components
  - Basic working principles
  - Type-1, interval type-2 and general type-2 fuzzy sets
- Fuzzy rule-based applications
- Fuzzy-model-based applications

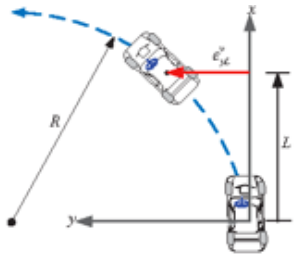
What is Fuzzy Logic?

- Fuzzy logic can represent human spirit/knowledge/expertise and realise intelligence
  - Information of Illness, uncertainty, vagueness
    - small, medium, big, large, short, long, fast, very fast, more or less



- Applications
  - Control of cars, robots
  - Classification
    - Biomedical signals: EMG, ECG
  - Decision marking
    - Investment
  - Time series prediction
    - Stock market price predict
  - Machine learning
    - As a framework to represent knowledge/intelligence
  - Many many more . . .





Sources: Figures are from Internet; Roche, Aidan D., et al. "Prosthetic myoelectric control strategies: a clinical perspective." *Current Surgery Reports* 2.3 (2014): 44.

What is Fuzzy Logic?

Example: Drive a car and keep a safe distance

Linguistic Rules:

Rule 1: **If** distance is *small* **Then** speed is *low*

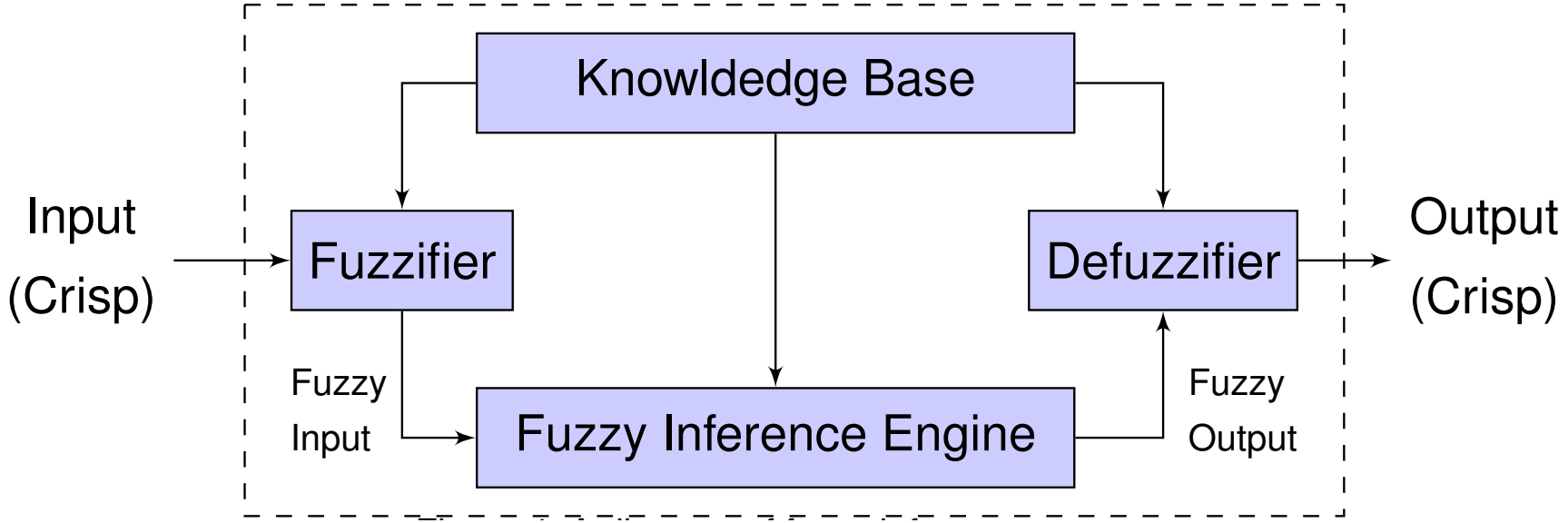
Rule 2: **If** distance is *medium* **Then** speed is *steady*

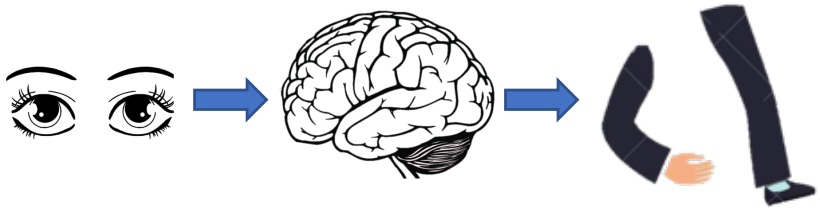
Rule 3: **If** distance is *large* **Then** speed is *high*

Fuzzy Logic System

- To implement knowledge/expertise
- To perform reasoning and the realization of intelligence

- A block diagram of Fuzzy Logic System





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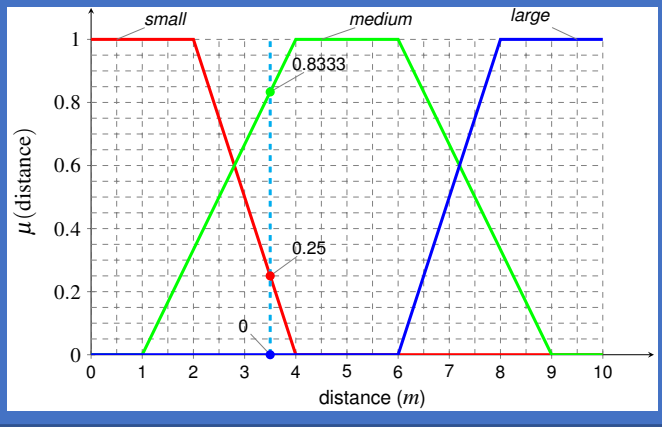
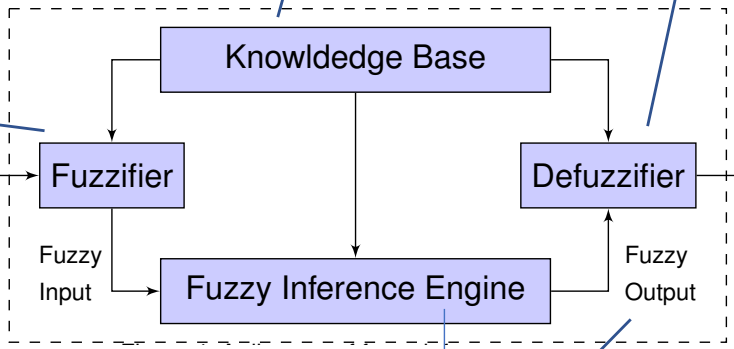


Rule 1: **If** distance is *small* **Then** speed is *low*

Rule 2: **If** distance is *medium* **Then** speed is *steady*

Rule 3: **If** distance is *large* **Then** speed is *high*

Output:
20 miles/hour



Input: 3.5m

Level of Distance	Speed
0.25 of Small	A little bit Low
0.8333 of Medium	More Steady
0 of Large	Definitely not High

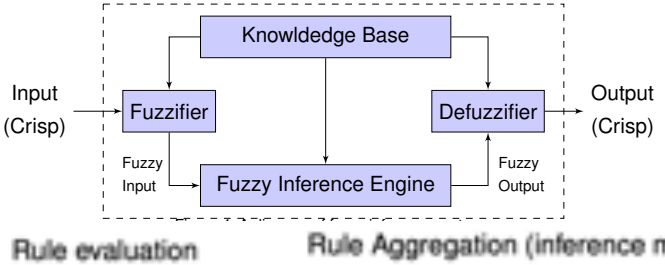
Speed should be a bit Low, more towards Steady but definitely not High

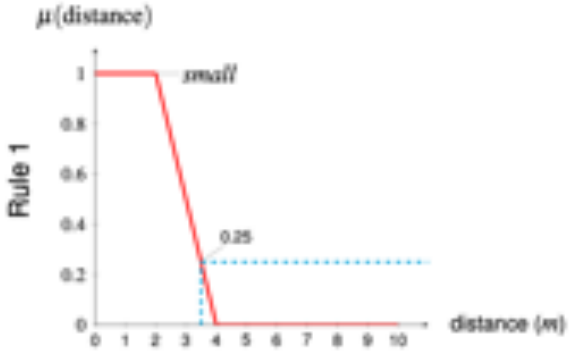
Linguistic Rules:

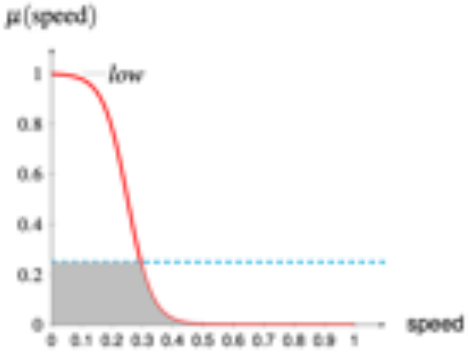
Rule 1: **If** distance is *small* **Then** speed is *low*

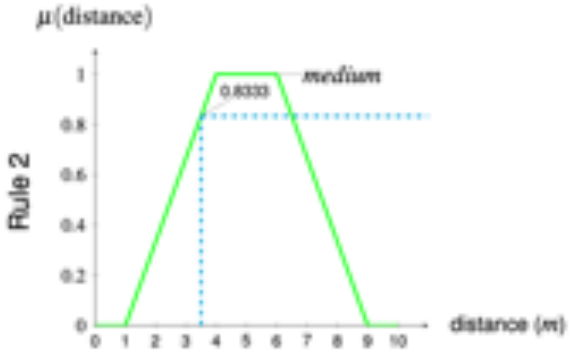
Rule 2: **If** distance is *medium* **Then** speed is *steady*

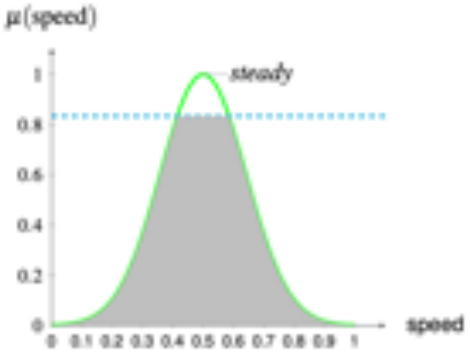
Rule 3: **If** distance is *large* **Then** speed is *high*

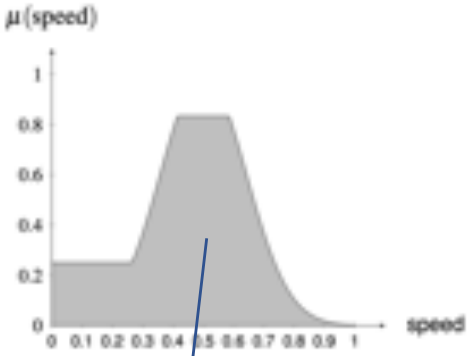


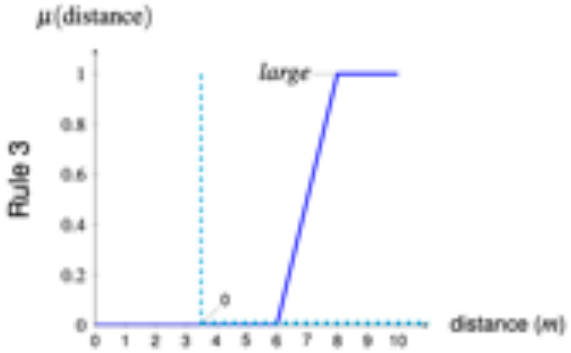


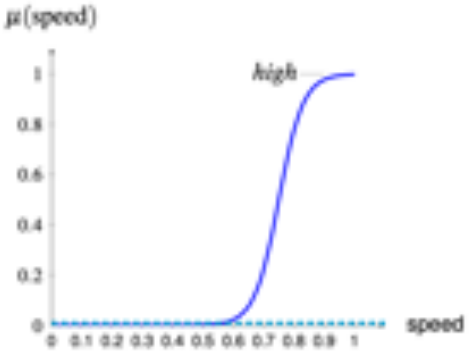






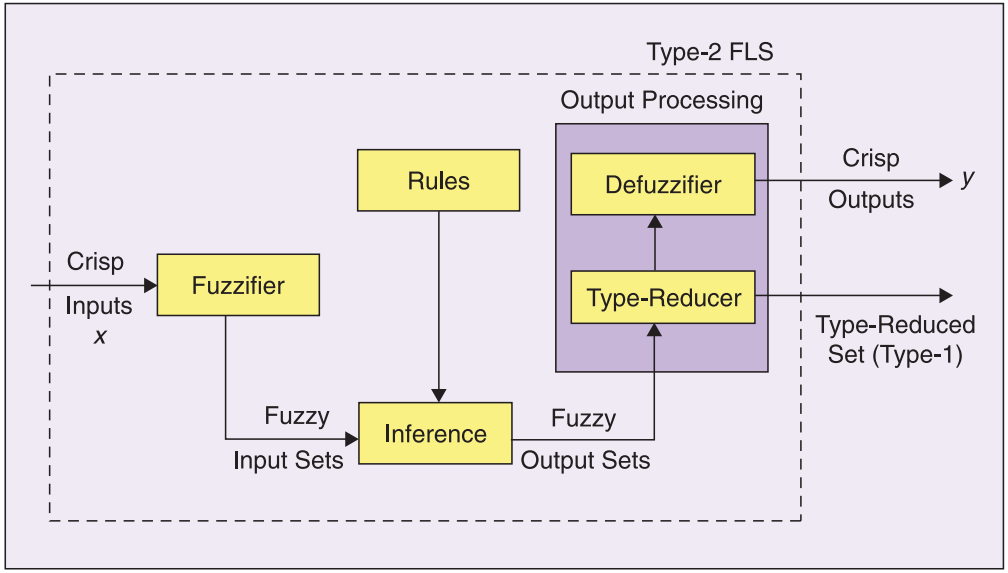


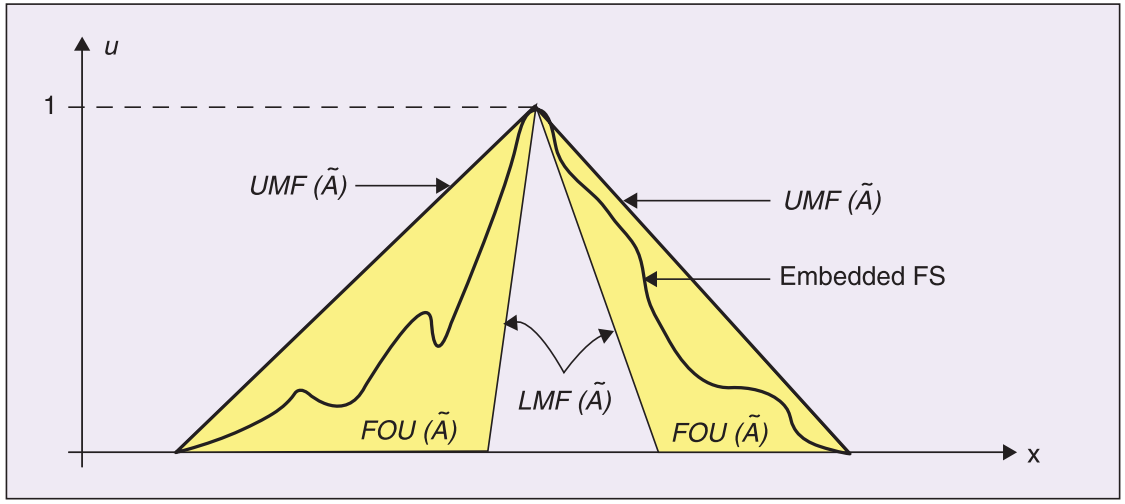




Speed should be a bit Low, more towards Steady but definitely not High

Type-2 Fuzzy Logic System





How do we know that the distance is exactly 3.5m?

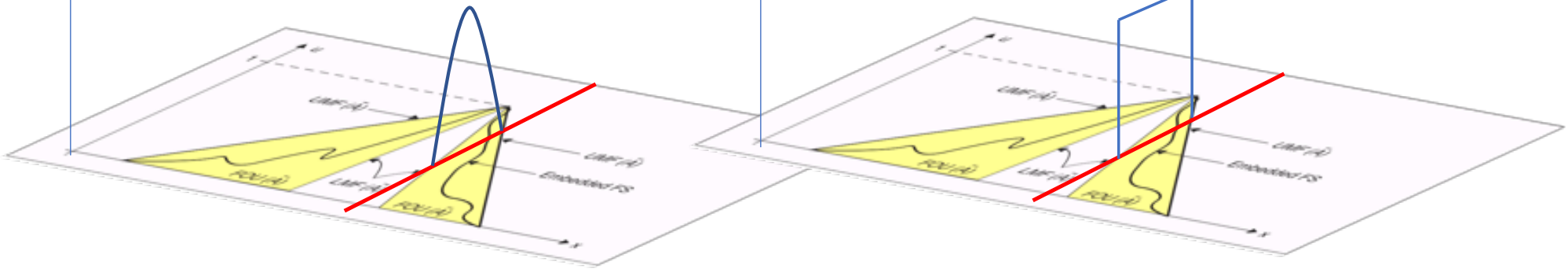
What about it is about 3.5m, say, 3.1m, 3.85m?

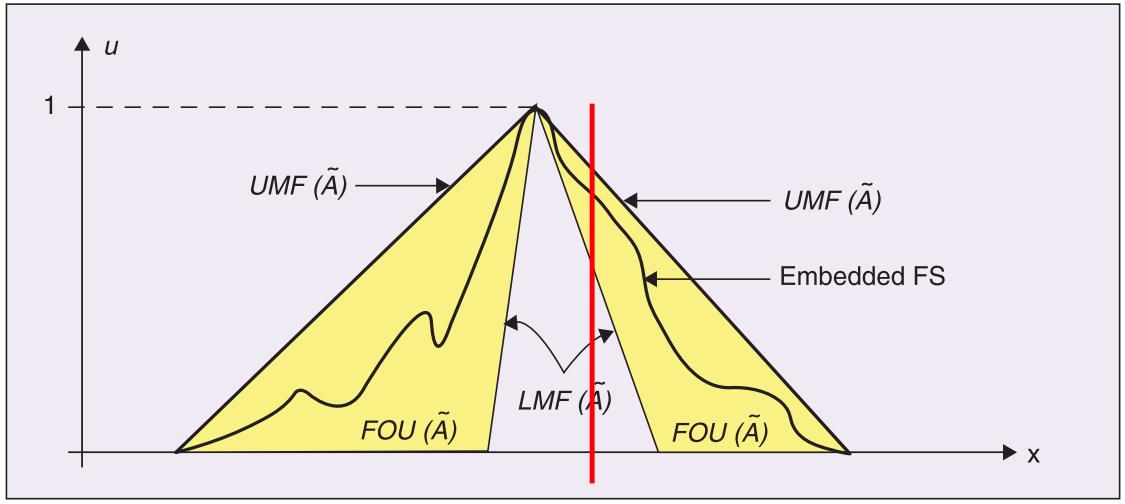
Source: Mendel, Jerry M. "Type-2 fuzzy sets and systems: an overview." IEEE computational intelligence magazine 2, no. 1 (2007): 20-29.

Type-2 Fuzzy Logic System

(General) Type-2 Fuzzy Set

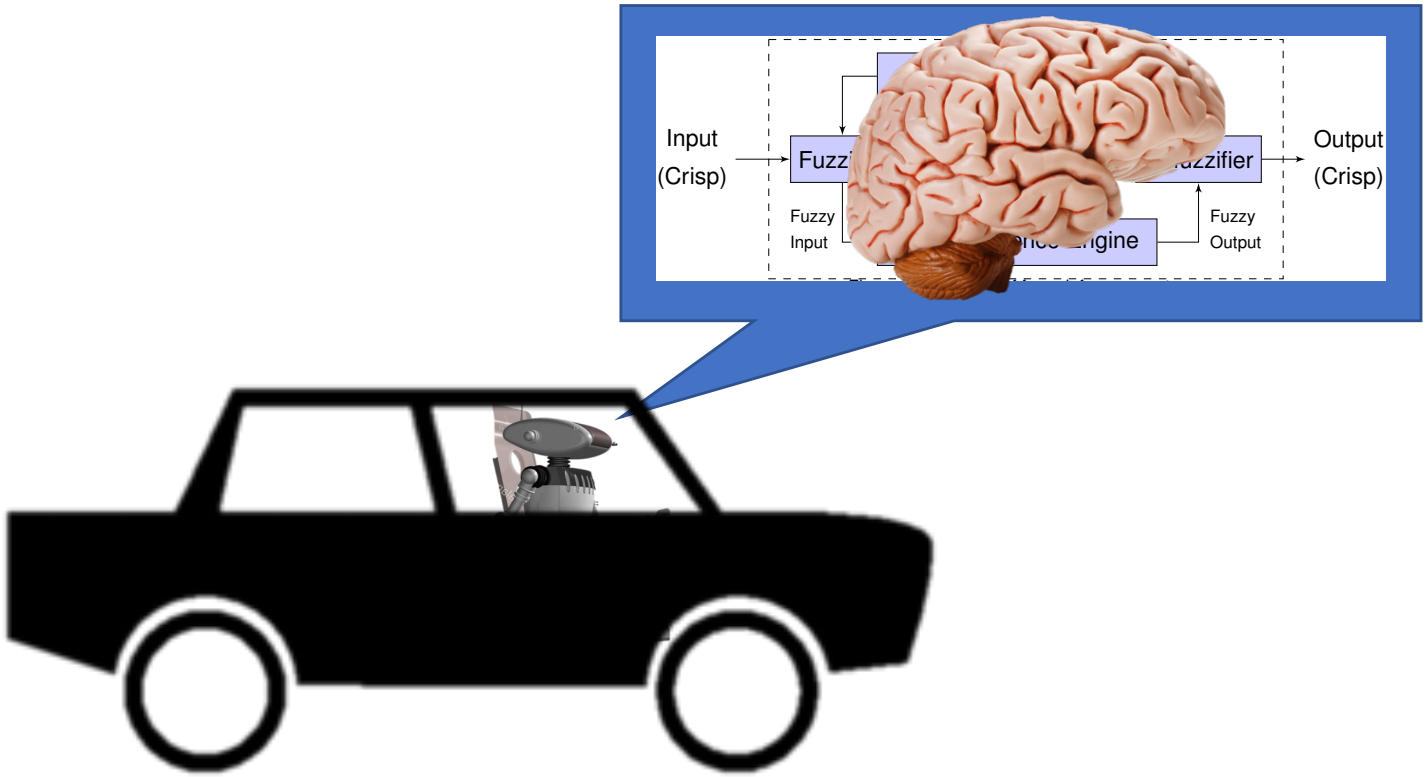
Interval Type-2 Fuzzy Set





- Type-2 fuzzy sets can capture the uncertainties
  - Measurement
  - Linguistic terms
  - System parameters
- Type-2 fuzzy logic system is equivalent to an infinity number of type-1 fuzzy logic system
  - Enhance expressing capability

Source: Mendel, Jerry M. "Type-2 fuzzy sets and systems: an overview." IEEE computational intelligence magazine 2, no. 1 (2007): 20-29.

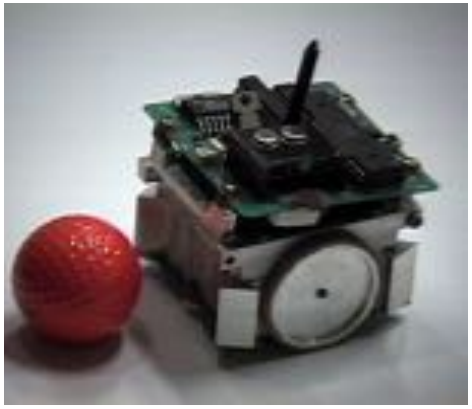


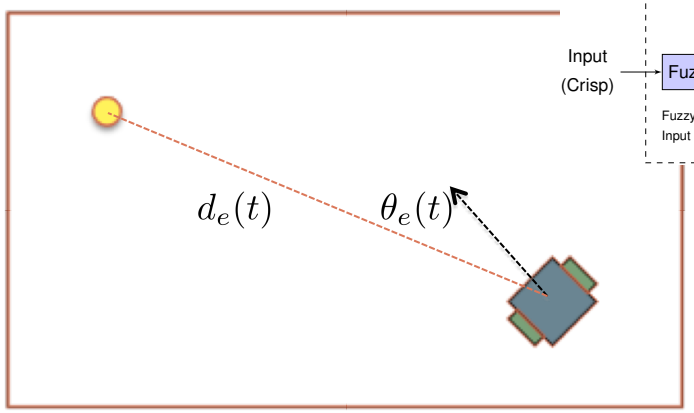
Fuzzy Rule-Based Applications

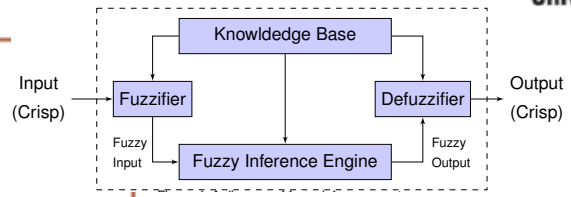
- Mobile Robots
- Robot Soccer
- Drug Administration

Source: Images from Internet or speaker's paper

Control of Mobile Robots







Rule 1: IF *Error Distance* is *Small* AND *Error Angle* is *Small*
THEN *Translational Force* is *Small*, *Rotational Force* is *Small*

.
.
.

Rule *k*: IF *Error Distance* is *Medium* AND *Error Angle* is *Medium*
THEN *Translational Force* is *Medium*, *Rotational Force* is *Medium*

.
.
.

Rule *n*: IF *Error Distance* is *Large* AND *Error Angle* is *Large*
THEN *Translational Force* is *Large*, *Rotational Force* is *Large*

- P Controller

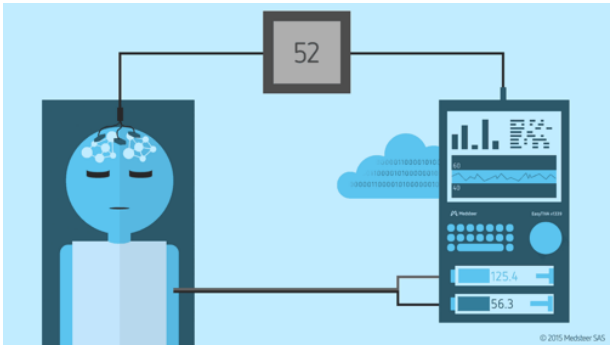
- Fuzzy P Controller

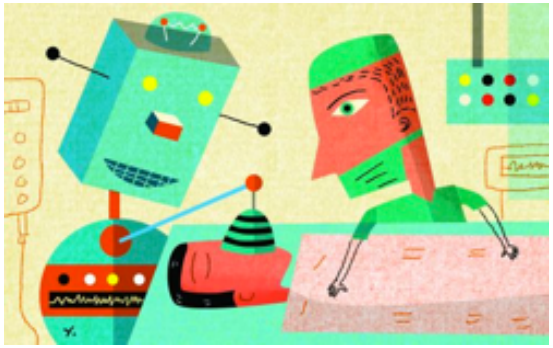
Robot Soccer

Obstacle avoidance

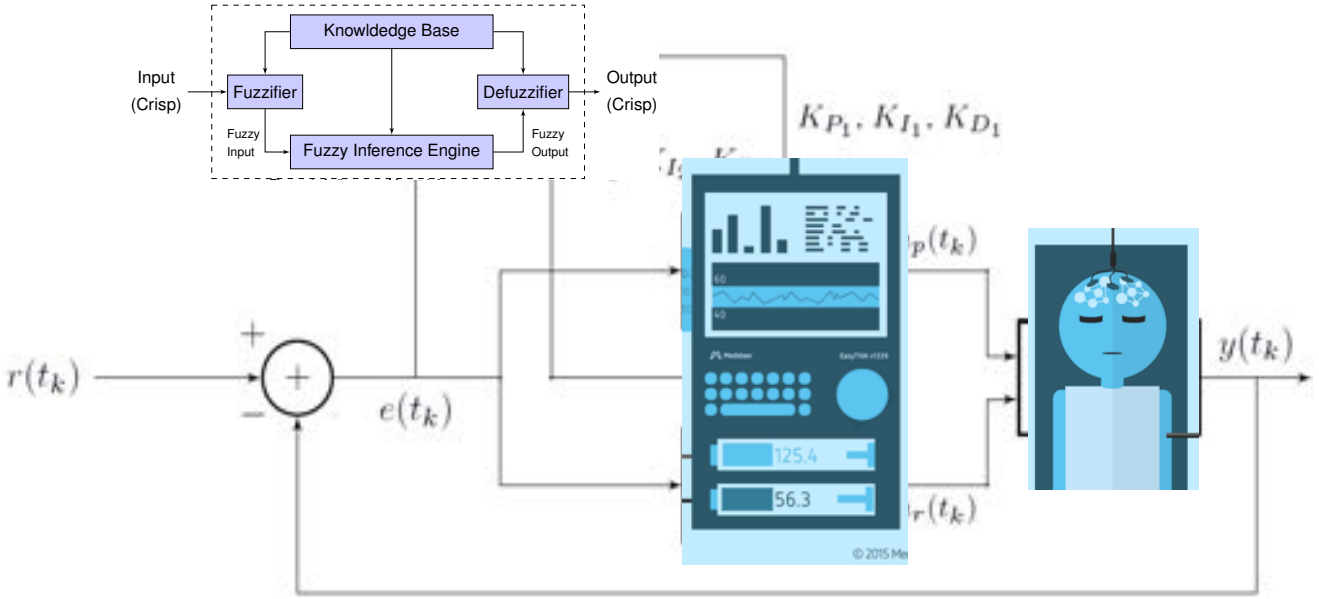
Game strategy

Drug Administration of Aesthesia





Source: Figures from Internet; Araujo, H., Xiao, B., Liu, C., Zhao, Y. and Lam, H.K., 2014. Design of type-1 and interval type-2 fuzzy PID control for anesthesia using genetic algorithms. *Journal of Intelligent Learning Systems and Applications*, *6*(02), p.70.



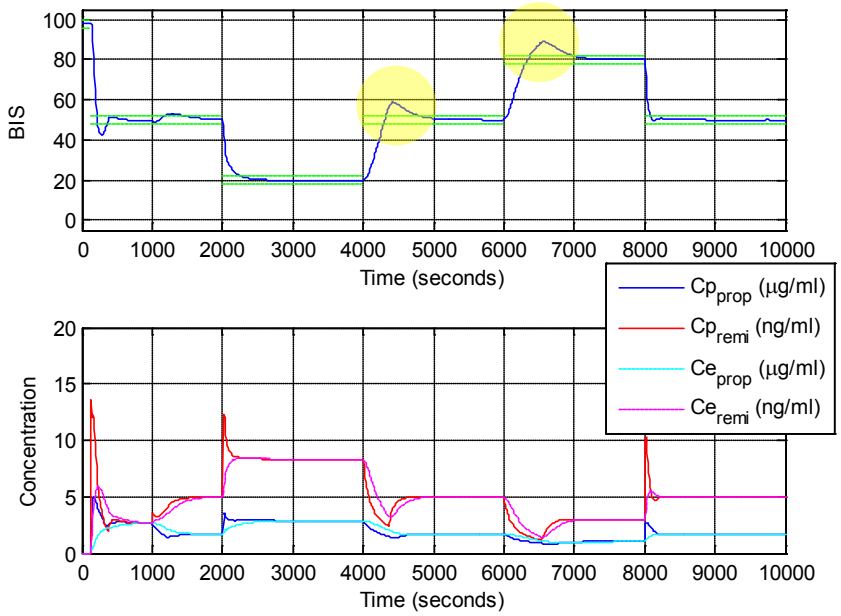


Figure 20. BIS and drug concentration for testing profile by two PID controllers.

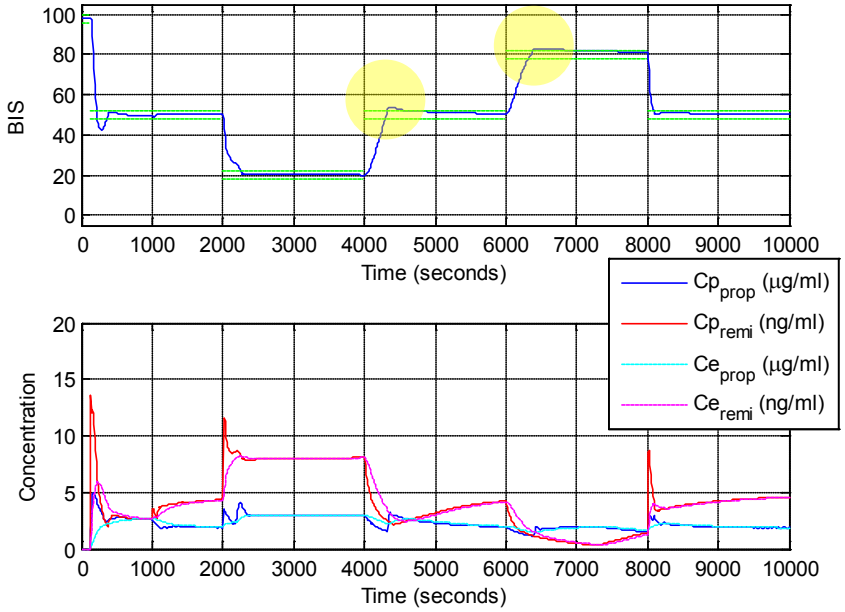
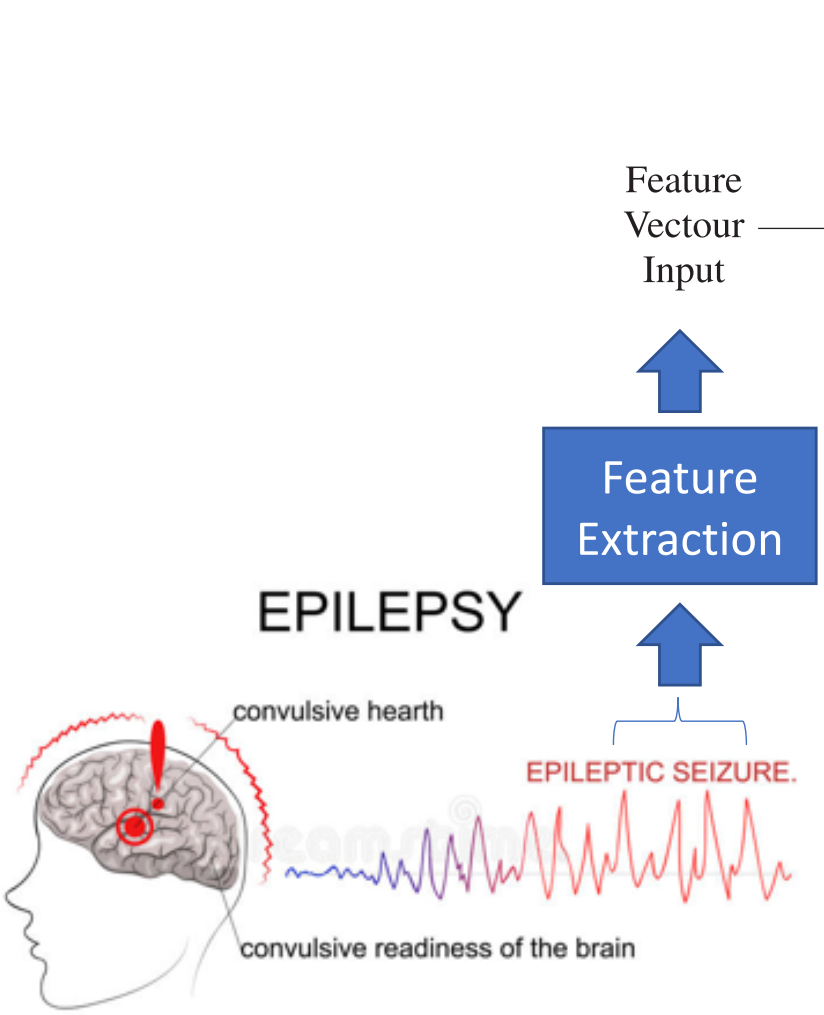
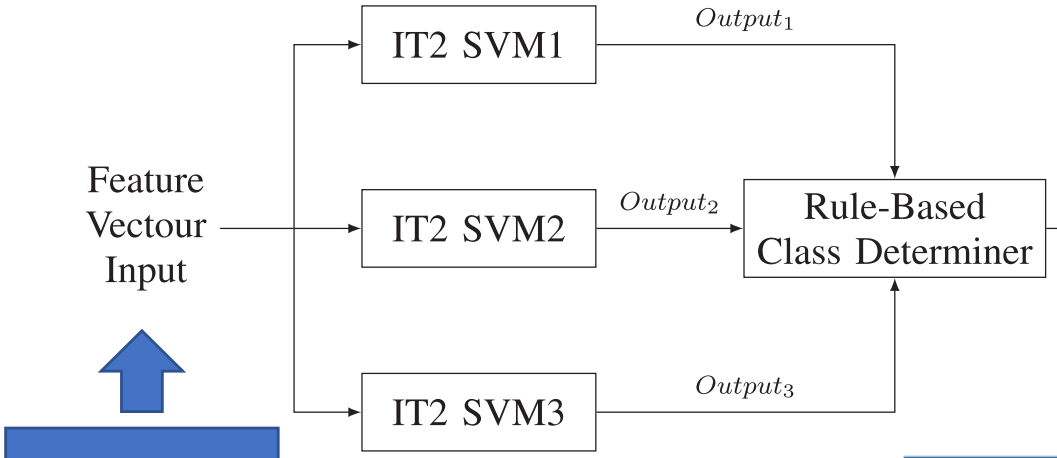


Figure 22. BIS and drug concentration for testing profile by two IT2 fuzzy PID controllers.

Source: Araujo, H., Xiao, B., Liu, C., Zhao, Y. and Lam, H.K., 2014. Design of type-1 and interval type-2 fuzzy PID control for anesthesia using genetic algorithms. *Journal of Intelligent Learning Systems and Applications*, *6*(02), p.70.

Classification of Epilepsy Seizure Phases





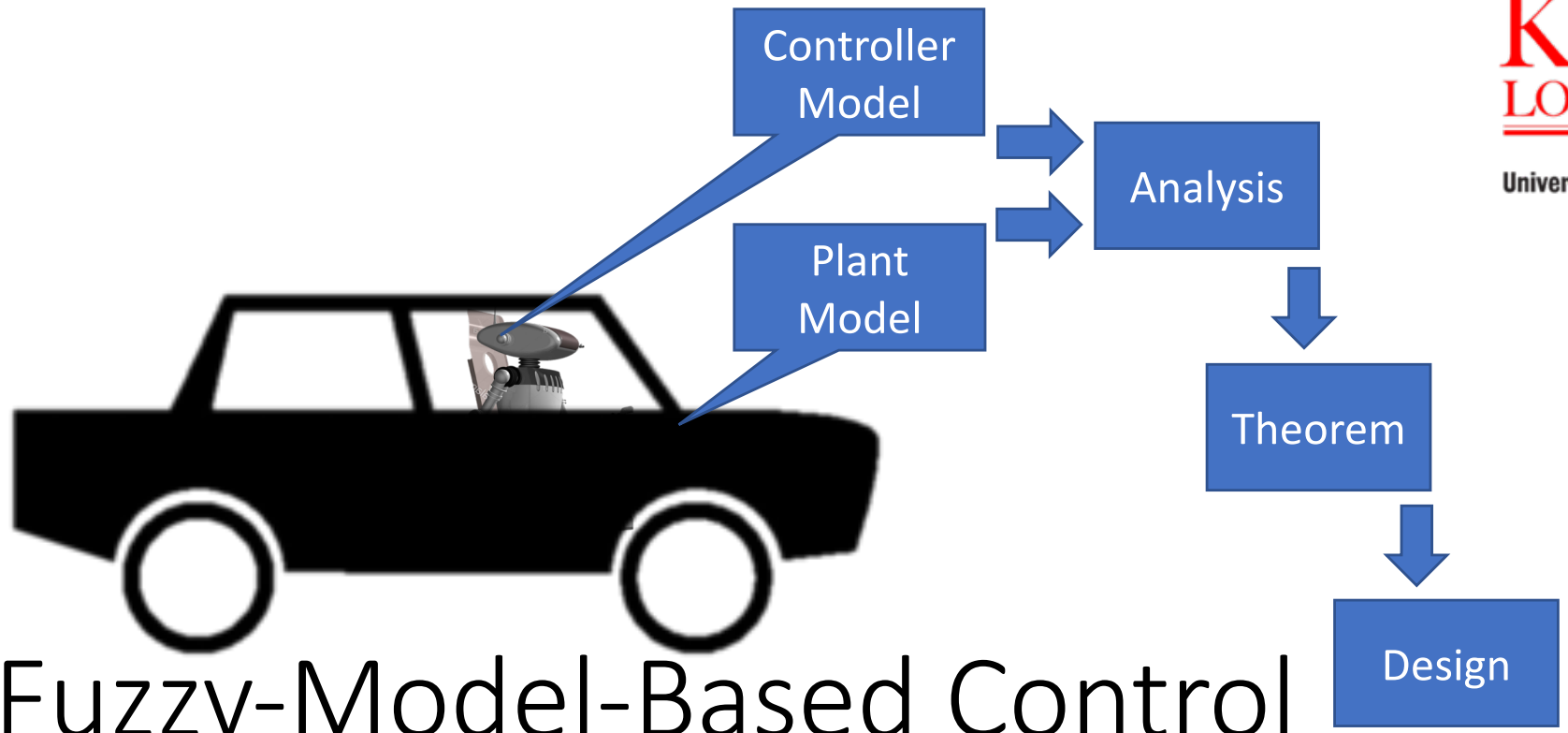
3 Classes

- Non-seizure
- Pre-seizure
- Seizure

Classifier	Classification Average
1	87.7800
2	71.1100
3	56.6667
4	77.7778

Summary of testing samples classification performance for EEG signal with original dataset. Classifier 1: FSVM classifier, classifier 2: traditional SVM classifier, classifier 3: k-Nearest Neighbor classifier, 4: naive Bayes classifier.

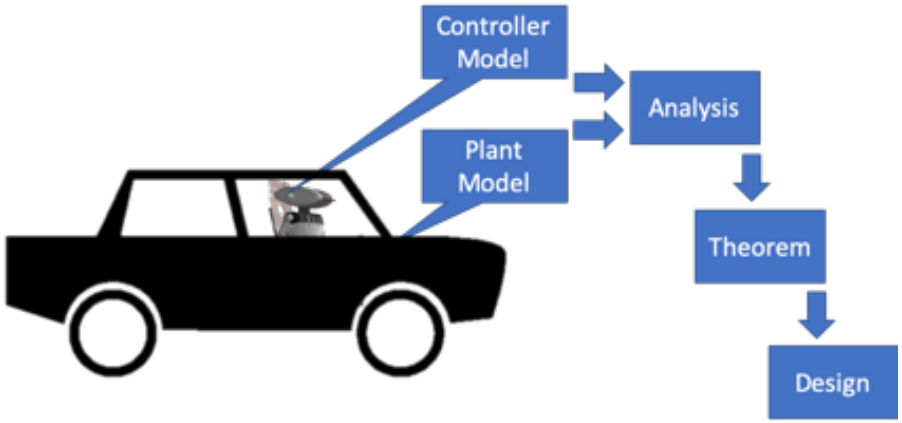
Sources: Image from Internet; Ekong, U., Lam, H.K., Xiao, B., Ouyang, G., Liu, H., Chan, K.Y. and Ling, S.H., 2016. Classification of epilepsy seizure phase using interval type-2 fuzzy support vector machines. *Neurocomputing*, *199*, pp.66-76.



Fuzzy-Model-Based Control Applications

- Inverted Pendulum
- Blot-Tightening Application
- Continuum Manipulator

Source: Images from Internet or speaker's papers



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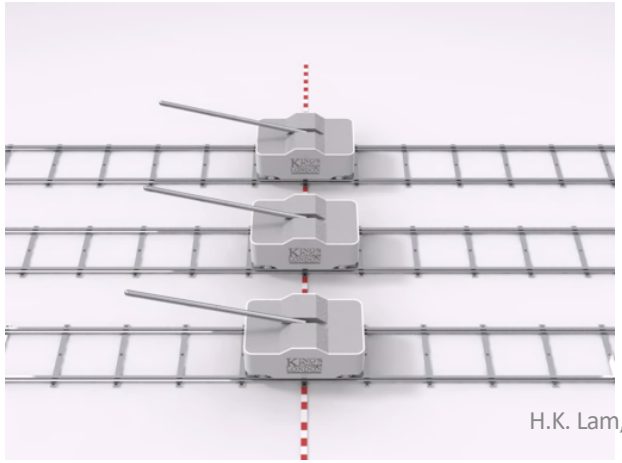
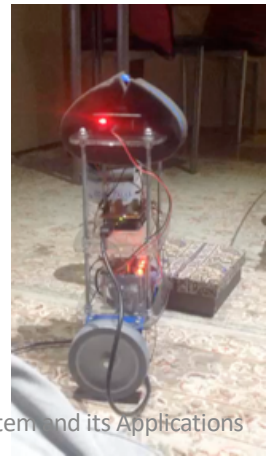
- **Contributions**
  - Initiate an **IT2 fuzzy model and modelling method** subject to fuzzy model based control point of view
  - Propose **an IT2 fuzzy controller**
  - Underpin a **systematic analysis method** for IT2 fuzzy-model-based control systems
  - Develop a **novel membership-function-dependent analysis** for IT2 fuzzy-model-based control systems

- **Seminal Papers**
  - Lam, Hak-Keung, and Lakmal D. Seneviratne. "Stability analysis of interval type-2 fuzzy-model-based control systems." *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 38.3 (2008): 617-628.
  - Lam, Hak-Keung, et al. "Control design for interval type-2 fuzzy systems under imperfect premise matching." IEEE Transactions on Industrial Electronics 61.2 (2013): 956-968.

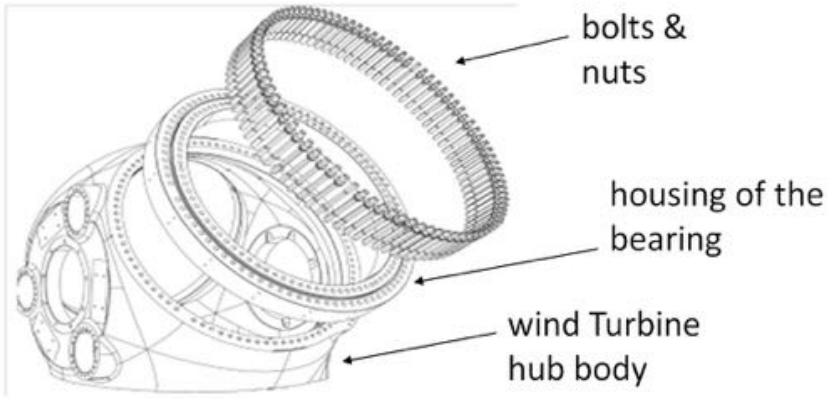
- **Impact**
  - Create a **new sub-filed of research** on IT2 fuzzy-model-based control systems
  - Provide **theoretical support** for research of this field

Control of Inverted Pendulum

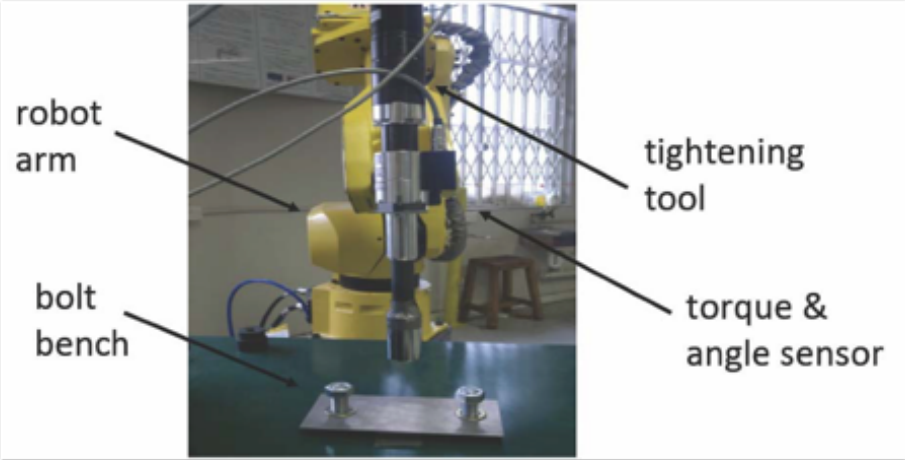


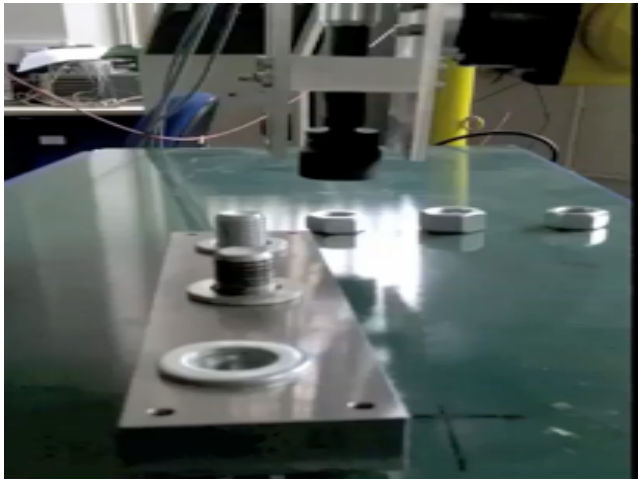


Blot-Tightening for Wind Turbine Assembly



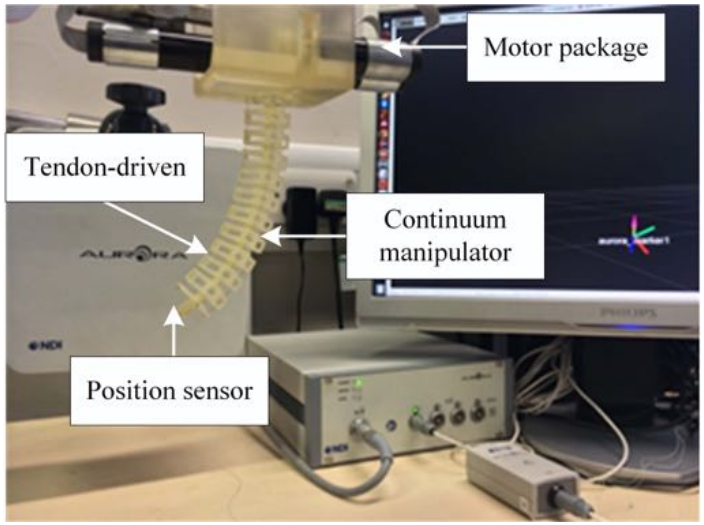
- Wind Turbine Hub Bearing Assembly:
- Bolt tightening

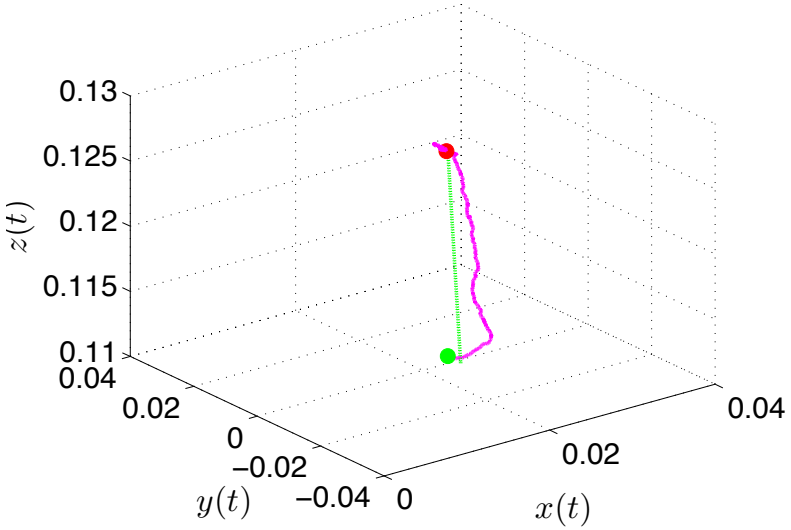




H.K. Lam, Hongyi Li, C. Deters, H. Wurdemann, E. Secco and K. Althoefer, "Control design for interval Type-2 fuzzy systems under imperfect premise matching," *IEEE Trans. Industrial Electronics*, vol. 61, no. 2, pp. 956-968, Feb. 2014.

Tracking Control of Continuum Manipulator





Peng Qi, Chuang Liu, Ahmad Ataka Awwalur Rizqi, H.K. Lam and Kaspar Althoefer, "Kinematic control of continuum manipulators using a fuzzy-model-based approach," *IEEE Trans. on Industrial Electronics*, vol. 63, no. 8, pp. 5022 -5035, Aug. 2016

Conclusion

- **Fuzzy logic system and its working principle**
  - Type-1 fuzzy sets
  - Type-2 fuzzy sets
  - Interval type-2 fuzzy sets
- **Interval/general type-2 fuzzy sets**
  - Capture uncertainties
  - Enhance expressing capability
- **Applications**
  - Fuzzy rule-based applications
    - Complex actions described by expert knowledge in linguistic form
    - Control of mobile robots
    - Playing robot soccer game
    - Classification of epilepsy seizure phases
    - Automatic control of aesthesia by drug administration
  - Fuzzy-model-based applications
    - Well supported by mathematics
    - Blot-tightening for wind turbine assembly
    - Tracking control of continuum manipulator