# Computational Intelligence
# Lecture 9: Fuzzy Control I

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# Comparing Fuzzy Control with Conventional Control

- Similarities:
  - They must address the same issues that are common to any control problem, e.g., stability and performance.
  - The mathematical tools used to analyze the designed control systems are similar, because they are studying the same issues (stability, convergence, etc.) for the same kind of systems.
- Difference
  - In conventional control mathematical model of the process and controllers are available. In fuzzy control, the controllers are designed using rules based on heuristics and human expertise
    - Advanced fuzzy controllers may use both heuristics and mathematical models

# Fuzzy Control

- Fuzzy control is classified into
  - Nonadaptive Fuzzy Control
    - the structure and parameters of the fuzzy controller are fixed
  - Adaptive Fuzzy Control
    - The structure or/and parameters of the fuzzy controller change during realtime operation.
- Nonadaptive fuzzy control is simpler than adaptive fuzzy control
- Nonadaptive fuzzy control requires more knowledge of the process model or heuristic rules.
- Adaptive requires less information and may perform better at the cost of more complexity.

# Assumption is Fuzzy Control Design

- The plant is observable and controllable: state, input, and output variables are usually available for observation and measurement or computation.
- There exists a body of knowledge comprised of a set of linguistic rules, engineering common sense, intuition, or a set of inputoutput measurements data from which rules can be extracted
- A solution exists.
- The control engineer is looking for a good enough solution, not necessarily the optimum one.
- The controller will be designed within an acceptable range of precision.

## The Trial-and-Error Approach

- By using experience-based knowledge (e.g., an operating manual) and by asking the domain 'experts to answer a carefully organized questionnaire, IF-THEN rules are provided and fuzzy controllers are constructed
- Then the fuzzy controllers are tested in the real system and if the performance is not satisfactory, the rules are fine-tuned or redesigned in a number of trial-and-error cycles until the desired performance is achieved.

# The Trial-and-Error Approach

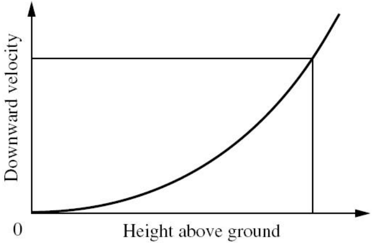
1. Analyze the real system to choose state and control variables and outputs.
   - The state variables:
     - characterize the key features of the system
   - The control variables (inputs of the plant):
     - influence the states of the system.
     - are the outputs of the fuzzy controller.
2. Partition the universe of discourse or the interval spanned by each variable into a number of fuzzy subsets, assigning each a linguistic label
   - Assign or determine a membership function for each fuzzy subset.
   - You may require to choose appropriate scaling factors for the input and output variables in order to normalize the variables to the $[0, 1]$ or the $[-1, 1]$ interval.

## The Trial-and-Error Approach

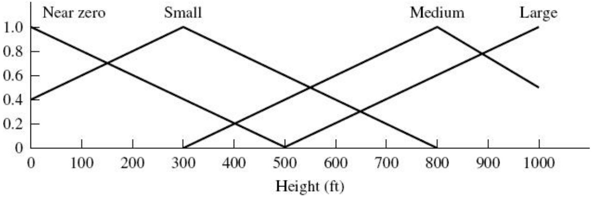
3. Derive IF-THEN rules that relate the state variables with the control variables
   - The rules are defined using
     - An introspective verbalization of human expertise like operating manual
     - the information obtained from a filled carefully organized questionnaire
4. Design the fuzzy system and test the closed-loop system with this fuzzy system as the controller
   - If the performance is not satisfactory, fine-tune or redesign the fuzzy controller by trial and error
   - repeat the procedure until achieving the desired performance

# Example:AIRCRAFT LANDING CONTROL

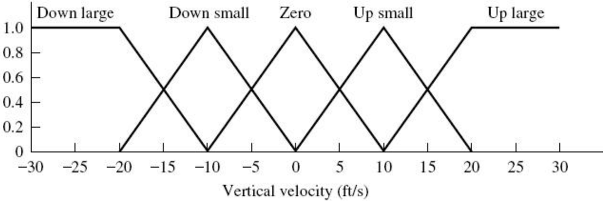
- The desired profile is shown in Fig.
- The downward velocity is proportional to the square of the height.
  - At higher altitudes, a large downward velocity is desired.
  - As the height (altitude) diminishes, the desired downward velocity gets smaller and smaller.
  - In the limit, as the height tends to be zero, the downward velocity also goes to zero.
- The states:
  - $h$:height above ground
  - $v$: vertical velocity of the aircraft
- The control signal
  - $f$: force



- Mass $m$ moving with velocity $v$ has momentum $p = mv$.
- If a force $f$ is applied over a time interval $\Delta t \rightsquigarrow \Delta v = f\Delta t/m$
- $\Delta t = 1.0(s)$ and $m = 1.0lb \rightsquigarrow \Delta v = f$
- $\therefore v_{i+1} = v_i + f_i, \quad h_{i+1} = h_i + v_i\Delta t$
  - $v_{i+1}$: new velocity, $v_i$: old velocity
  - $h_{i+1}$ new height, $h_i$ old height



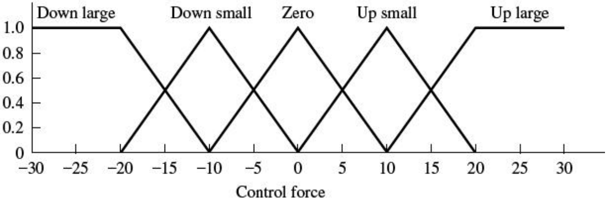
Near zero
Small
Medium
Large
1.0
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
1000
Height (ft)

Down large
Down small
Zero
Up small
Up large
1.0
0.8
0.6
0.4
0.2
0
−30
−25
−20
−15
−10
−5
0
5
10
15
20
25
30
Vertical velocity (ft/s)

Membership values for control force

| | Output force | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **−30** | **−25** | **−20** | **−15** | **−10** | **−5** | **0** | **5** | **10** | **15** | **20** | **25** | **30** |
| Up large (UL) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 1 | 1 | 1 |
| Up small (US) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 1 | 0.5 | 0 | 0 | 0 |
| Zero (Z) | 0 | 0 | 0 | 0 | 0 | 0.5 | 1 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| Down small (DS) | 0 | 0 | 0 | 0.5 | 1 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Down large (DL) | 1 | 1 | 1 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

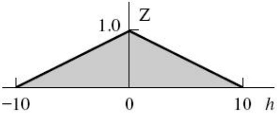


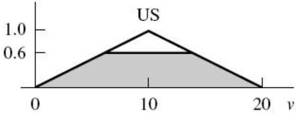
- The rules are summarized in the table

| | Velocity | | | | |
|---|---|---|---|---|---|
| **Height** | **DL** | **DS** | **Zero** | **US** | **UL** |
| L | Z | DS | DL | DL | DL |
| M | US | Z | DS | DL | DL |
| S | UL | US | Z | DS | DL |
| NZ | UL | UL | Z | DS | DS |

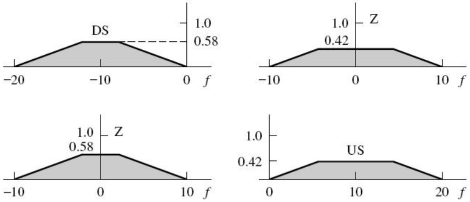
- Let us use
  - singleton fuzzifier,
  - min inf. eng.
  - centroid defuzzifier

- Initial height, $h_0 : 1000 ft$; Initial velocity, $v_0 : -20 ft/s$
- $h = 1$ for $L$ and 0.6 for $M$
- $v = 1$ for $DL$
- $\therefore$
  $L(1.0)$ AND $DL(1.0) \Rightarrow Z$
  $M(0.6)$ AND $DL(1.0) \Rightarrow US$
- Using defuzzifier: $f_0 = 5.8 lb$

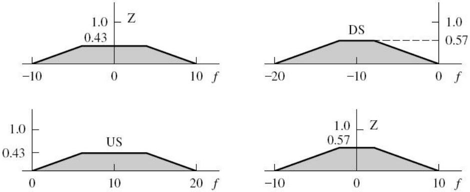


- $h_1 = h_0 + v_0 = 980ft;$
- $v_1 = v_0 + f_0 = -14.2ft/s$
- $h_1 = 0.96$ for $L$ and $0.64$ for $M$
- $v_1 = 0.58$ for $DS$ and $0.42$ for $DL$
- $\therefore$
  $L(0.96)$ AND $DS(0.58) \Rightarrow DS$
  $L(0.96)$ AND $DL(0.42) \Rightarrow Z$
  $M(0.64)$ AND $DS(0.58) \Rightarrow Z$
  $M(0.64)$ AND $DL(0.42) \Rightarrow US$
- Using defuzzifier: $f_1 = -0.5lb$



- $h_2 = h_1 + v_1 = 965.8ft;$
- $v_2 = v_1 + f_1 = -14.7ft/s$
- $h = 0.93$ for $L$ and $0.67$ for $M$
- $v = 0.57$ for $DS$ and $0.43$ for $DL$
- $\therefore$
  $L(0.93)$ AND $DL(0.43) \Rightarrow Z$
  $L(0.93)$ AND $DS(0.57) \Rightarrow DS$
  $M(0.67)$ AND $DL(0.43) \Rightarrow US$
  $M(0.67)$ AND $DS(0.57) \Rightarrow Z$
- Using defuzzifier: $f_2 = -0.4lb$



Summary of four-cycle simulation results

| | Cycle 0 | Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 |
|---|---|---|---|---|---|
| Height, ft | 1000.0 | 980.0 | 965.8 | 951.1 | 936.0 |
| Velocity, ft/s | −20 | −14.2 | −14.7 | −15.1 | −14.8 |
| Control force | 5.8 | −0.5 | −0.4 | 0.3 | |