King Saud University

College of Engineering

IE – 341: "Human Factors Engineering"

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Chapter 10. Human Control of Systems – Tracking (Part 1)

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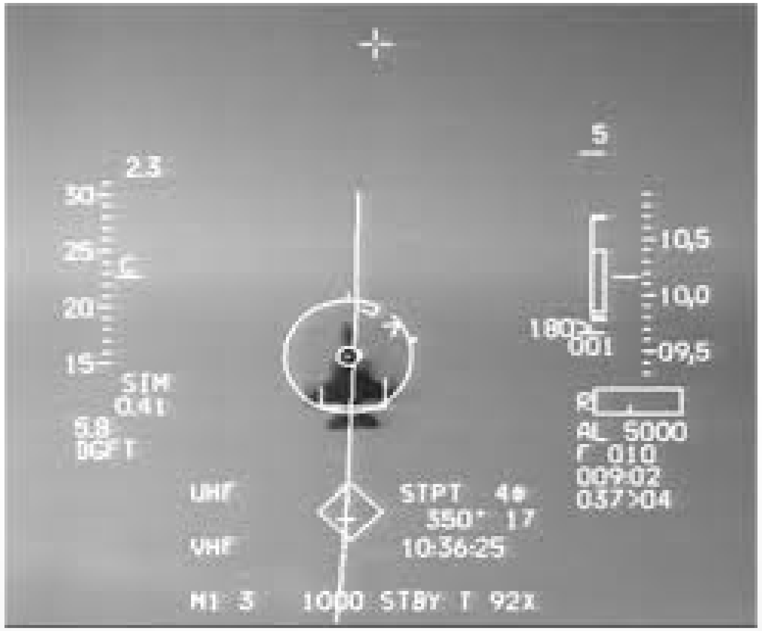

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Inputs and Outputs in Tracking

- What is tracking?
  - Involves continuous control of something
  - Examples: driving a vehicle, piloting a plane, tracing a line on a paper

- Requirements of Tracking
  - Make correct movements at right times
  - Task is paced by person doing it (e.g. when driving a car)
  - Task can be externally paced, i.e. person has no control on task rate (e.g. following a racehorse with binoculars)

- Topics to be covered here:
  - Some background on certain concepts in tracking
  - Some background on many variables involved with tracking performance

Cont. Inputs and Outputs in Tracking

- In tracking:
  - Input specifies desired output of system
  - Example: curves in road (*input*) specify desired path to be followed (*output*)

- Inputs
  - Types of input:
    - Constant(e.g. steering a ship to specified heading, flying a plane to an assigned altitude), or
    - Variable (e.g. following winding road, chasing a maneuvering butterfly with a net)
  - Received directly from environment
  - Sensed by:
    - People
    - Mechanical sensors (then presented on display as signals)
  - Other classification of input:
    - Signal sometimes called: *target* (or it really is a target)
    - Movement of signal called: *course*
    - Input signal can be described mathematically and shown graphically
    - These graphs can be used to characterize input

Cont. Inputs and Outputs in Tracking

- Input Patterns
  - Types of elementary patterns (input) that can be distinguished (next slide):
    - Sine input (characterized by a sine wave)
    - Step input:
      - Specifies discrete change in value
      - e.g. instruction from control tower for plane to change altitude
    - Ramp input:
      - Specifies constant rate of change of some variable
      - e.g. maintaining constant velocity (since $V = dS/dt$)

- Output
  - Frequently called the *controlled element*
  - Outputs are brought by:
    - Physical response with a control mechanism or
    - Transmission of some form of energy
  - Output is reflected by:
    - Indication on display, sometimes called follower or *cursor*, or:
    - Observed by outward behavior of system (e.g. movement of car)

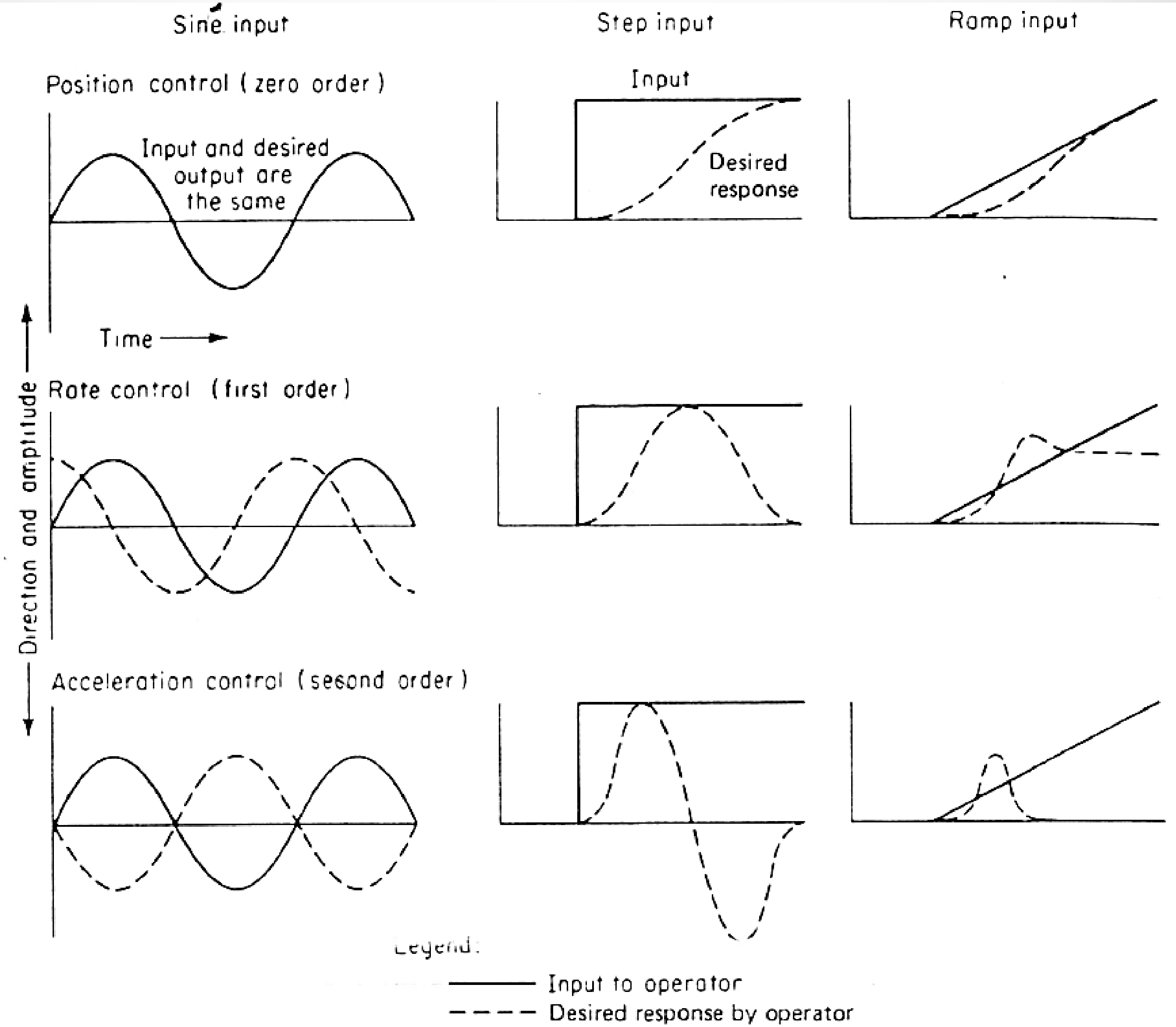


FIGURE 10-11.
Tracking responses to sine, step, and ramp inputs which would be conducive to satisfactory tracking with position, rate, and acceleration control. The desired response, however, is not often achieved to perfection, and actual responses typically show variation from the ideal. In a positioning response to a step input, for example, a person usually overshoots and then hunts for the exact adjustment by overshooting in both directions, the magnitude diminishing until arriving at the correct adjustment.

Pursuit & Compensatory Displays in Tracking

- Types of tracking displays (see next slide):
  - Pursuit display
  - Compensatory display
- Displays are shown as:
  - 1-D: relative movement of 2 elements: represented by single value (top fig.)
  - 2-D: relative movement in 2-D (e.g. chasing a moving aircraft) (bottom fig.)

- Pursuit display:
  - Target and cursor (i.e. controlled element) move
  - Each indicator shows its own location in space
  - Task of the operator: align moving cursor with moving target
- Compensatory display:
  - One of the two indicators moves (controlled element); other is fixed (target)
  - Task of the operator: get the moving cursor to align with the target

Cont. Pursuit & Compensatory Displays

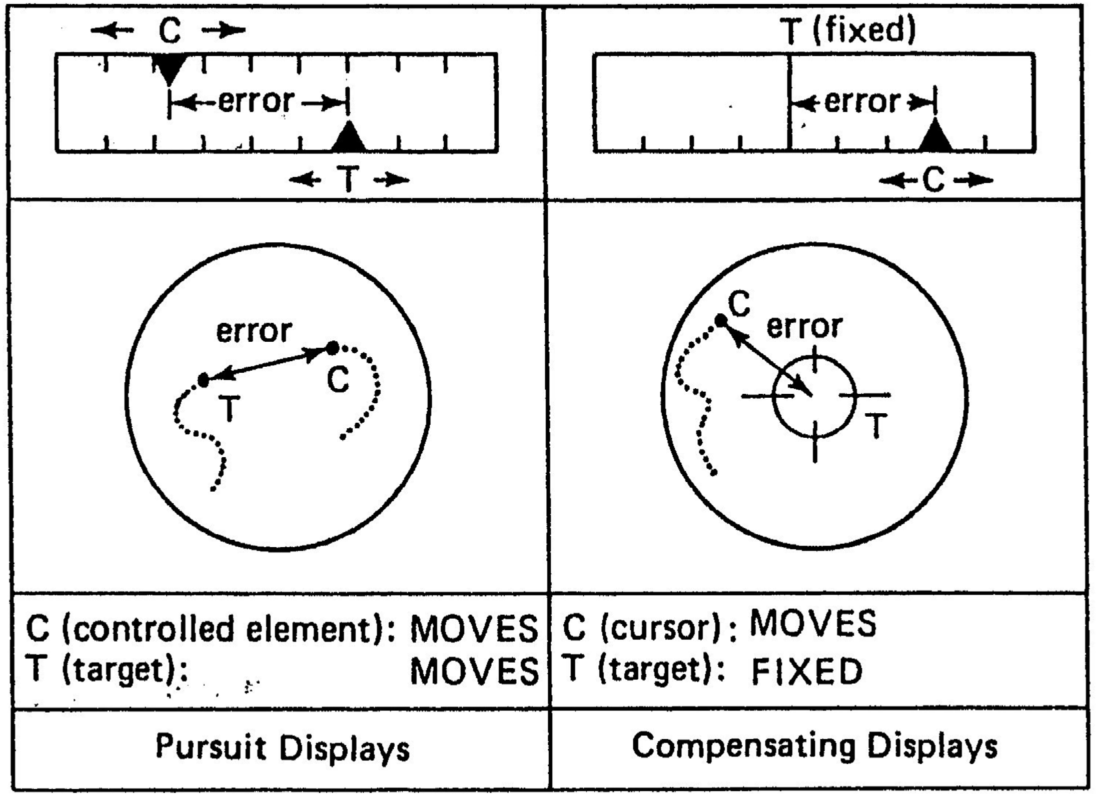


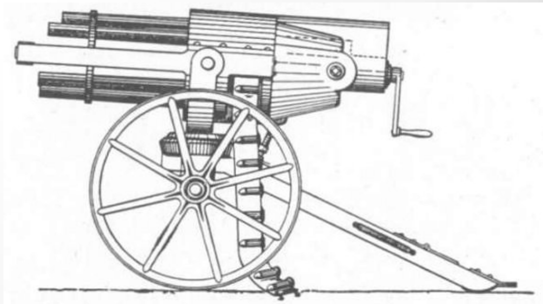
FIGURE 10-12.
Illustrations of compensatory and pursuit-tracking displays. A compensatory tracking display shows only the *difference* (error) between the target *T* and the controlled element *C*. A pursuit display shows the location (or other value represented) of both the target and the controlled element.

Pursuit & Compensatory Displays in Tracking

- Error control:
  - When indicators superimposed: controlled element is "on target"
  - Difference represents: error, which should be minimized/eliminated
  - Error in pursuit display:
    - Operator can determine if error is due to target or controlled element
    - Operator can see target independent of any movement
  - Error in compensatory display:
    - Only absolute error/difference between target and controlled element
    - If error increases, display does not show what has moved (i.e. target, or controlled element, or both)
    - Advantage of compensatory display: saves space on instrument panel since no need to show entire range of possible values of 2 elements

Control Order of Systems

- Control order:
  - It is the hierarchy of control relationships between:
    - movement of control, and
    - output it controls
  - Objective of tracking task:
    - control system so that output corresponds to input as closely as possible
- Position (Zero-Order) tracking tasks:
  - Movement of control device controls position directly
  - e.g. moving a spotlight to keep it on an actor on a stage
  - e.g. following movement of athlete with a camera
- Rate (Velocity or First-Order) control tasks:
  - Operator movement controls rate at which output is being changed
  - e.g. accelerator (i.e. gas pedal) of car which controls speed (dS/dt) $\Rightarrow$ also S
  - e.g. operation of machine gun that is controlled by hand cranks



Control Order of Systems

- Acceleration (second-order) control:
  - Acceleration: rate of change in rate of movement
  - e.g. steering wheel of car
    - angle at which wheel is turned controls angle of front wheels
    - ⇒ this determines rate at which car turns
    - i.e. rotation of steering wheel accelerates car towards turning direction (i.e. angular acceleration)
- Higher order control:
  - i.e. third- or fourth-order control
  - e.g. third-order control involves:
    - direct control of rate of change in acceleration (aka "jerk")
    - which then controls rate (i.e. velocity)
    - which finally controls position of whatever is controlled
  - e.g. control of a large ship
    - Considered 3-rd or even 4^{th} order control since involves many variables:
    - Person steering and actual movement, position, mass of ship
  - Continuous control can be described as chain-reaction effects:
    - i.e. change in position ⇒ changes velocity (rate) ⇒ changes acceleration, etc.

Control Responses with Various Control Orders

- Operator Control:
  - Expected to make control responses
  - This brings about desired operation of system (that is implied by input)
  - e.g. road to be followed, or flight path of plane

- Effect of control order on tracking performance
  - Absence of help to operator ⇒ makes control harder, esp. with higher-order
  - e.g. appropriate response for ramp, step, and sine inputs with: position, rate, and acceleration control systems (Figure 10-11)
  - Dotted line: is response over time needed for satisfactory tracking of input
  - With higher order of control ⇒ # of controlled movements operator needs to make in response to single change in input ↑
    - ⇒ People do well in 0-order and 1st order control systems
    - But performance ↓ with 2nd order control system
    - Tracking error ↑ from 40 to 100%

Control Responses with Various Control Orders

- Example of deterioration of control
  - Consider step input: (middle column in Figure 10-11)
  - Target: jumps forward, then stops
  - Responses: made by joystick
  - 0-order control:
    - Simply move stick forward to proper distance and hold
  - 1-st order (rate) control:
    - Move stick forward to give certain velocity to controlled element
    - As controlled element approaches position of target ⇒ return stick to null position before overshooting target position
  - 2nd order control:
    - More complicated procedure here
    - Control is first moved forward ⇒ this gives acc. to controlled element
    - Stick must then be brought to null position (i.e. 0 acc. or const. vel.)
    - Stick must then be moved in opposite direction (i.e. deceleration or slowing down control) ⇒ this avoids overshooting target
    - Finally, return stick to null position ⇒ this avoids stopping and going to other direction
    - Note, this is all to move controlled element forward and stopping it!
    - Thus, performance here clearly deteriorates

Human Limitations in Tracking Tasks

- Humans:
  - Not very good at tracking tasks
  - Especially with higher-order control parameters (see last slide)
- *Wickens* (1984): limitations affecting tracking:
  1. Processing time
  2. Bandwidth
  3. Anticipation

1. Processing time
   - People don't process information instantaneously
   - ⇒ there is time delay bet. target change and start of responses to track it
   - Magnitude of time delay is dependent on order of controlled system:
     - 0 and 1st-order: $150 - 300\, ms$
     - 2nd order: $400 - 500\, ms$
   - Delays are harmful to tracking performance since:
     - Operator is always chasing target, and
     - Operator is always behind (unless help is provided to operator)

Human Limitations in Tracking Tasks

2. Bandwidth:

- This is upper limit of freq. with which corrective decisions can be made
- It is the max. freq. of random input that can be successfully tracked
- Typical values:
  - $0.5 - 1.0\ Hz$ (normally)
  - Note, since 2 corrections/cycle required $\Rightarrow 1.0\ Hz \rightarrow 2\ corrections/s$
  - People can predict courses as high as $2 - 3\ Hz$

3. Anticipation:

- Often operators track targets using time lagged/sluggish systems
- e.g. ships or planes
- $\Rightarrow$ operator must:
  a) Anticipate future errors based on present conditions
  b) Then make control responses that may reduce anticipated future error
- Problem: people are not good at anticipating future outputs (esp. with slow systems) due to limitations of working memory
- Note, this is true even with experienced operators