Using human-compatible reference values in design of cooperative dynamic human-machine systems

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What is a cooperative dynamic system?

- Cockpits and assistance in modern vehicles (aircraft, cars, vessels, trains etc.)
- Traffic and traffic management
- Industrial and office systems
- Robot and swarm control etc.

Common ground:
- 0..n human agents
- 0..n machine agents
- At least two cognitive agents
- Interaction (cooperation) between agents
How does system design work?

There are always forming and inhibiting constraints in system design:
- Existing designs
- Tight design processes
- Resource constraints
- How to not design?

System design needs also enabling and pushing paradigms:
- Design approaches
  - e.g. user centered design
- Metaphors
  - e.g. desktop-metaphor
- How to design?
Overview

- Theoretical background to the enabling and pushing 'tension approach'
- Using the tension approach in automotive domain
  - Operationalization of tensions in a top-down deductive process
  - Evaluation of tensions in a bottom-up inductive process
- Summary and Outlook
Technical perspective: common human-machine configuration in automotive

- At least **five closed control loops**
- No explicit controller and synchronization unit yet
  - **Suboptimal system stability and usability**
Psychological and Human Factors perspective: Lewin’s ‘Forces’ and Gibson’s ‘Affordances’

- **Lewin** describes motivational processes in the way where the human, being in a particular state, is experiencing ‘psychological forces’ toward another state.
- For example, being in the state ‘hungry’, we perform actions in order to get some food and to reach the state ‘full’.
- Lewin names the ‘inner’ psychological forces *tensions*.

- **Gibson** introduces *affordances* as an object quality opening ‘action opportunities’ interfering with the current human state.
- For example, if we are tired and see a chair, the object chair is affording, ‘pulling’ us to sit down.

- Both useful psychological concepts operate with terms being near to physical and technical terms like force and *tension*.
- Opportunity to model the behavior of humans and machines both on a higher level and on a common ground.
Tension as reference value in a system design

 Thesis: A cognitive system being in a particular state is controlled by multiple tensions directed toward actions leading to other system states

 Hypothesis: Humans are aimed to follow tensions toward actions leading to optimal states and machines can be designed to do so as well

 Definition for automotive domain:

 \[ \text{Tension}_{\text{ACTION}} = f(\text{State}_H, \text{State}_M, \text{State}_V, \text{State}_E, \text{Tension}_{\text{OPTIMAL}}) \]

 Tension_{\text{ACTION}} is a directed motivational value toward a particular action

 State_{H,M,V,E} are composed values

 State_H: human factors, current and preferred human actions and states
 State_M: current and preferred and alternative machine actions and states
 State_V: current and future vehicle states and vehicle dynamics
 State_E: environmental data like dangerousness of situation, traffic rules etc.
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 Tension\textsubscript{ACTION} can be separated in categories in order to control and synchronize correspondent behavior within the designed system

 e.g. longitudinal, lateral or automation level transition behavior

 Tension\textsubscript{OPTIMAL} is directed toward the optimal action and can be regarded as a reference tension within the system

 It is a reference for the human as well as for the machine behavior

 Tension\textsubscript{OPTIMAL} can be determined by a former design decision, e.g. using Yerkes-Dodson law, or arbitrated dynamically
Technical perspective: enhancement of the common human-machine configuration by a 'tension unit'

\[
\text{Tension}_{ACTION} = f(\text{State}_H, \text{State}_M, \text{State}_V, \text{State}_E, \text{Tension}_{OPTIMAL})
\]

- Additional 'tension unit' responsible for **control** and **synchronization** of the behavior of system parts in the integrative manner
- More **human-compatible** reference values for system control
- This can be realized technically by a **model predictive controller**
Connection of 'tension approach' to related concepts

- Onken: ‘danger model’ that contains a non-directional value named ‘time reserve’ describing a time slot for a possible action to avoid danger
- Rhede: ‘warning toolbox’ as situation criticality based warning and escalation approach in interaction design
- These and other related concepts (e.g. risk) are highly compatible to the tension approach, although they seem to provide rather descriptive scalar metrics
- We propose prospective directed and more solution oriented metrics to emphasize e.g. the direction toward certain possible actions to reach the same system state
- Tension approach can be seen as an integrative framework for design different kinds of cognitive systems instead of description of singular design methods and reference values in particular domains
Top-Down action tension operationalization in approach brake and/or evade driving scenario

\[ \bar{Tension}_{ACTION} = f(State_H, State_M, State_V, State_E, Tension_{OPTIMAL}) \]

- Using Time To Collision for description of State_V, State_E and Tension_{OPTIMAL}
- Synchronization borders, State_H and State_M derived from literature
Bottom-up action tension evaluation

- **Usability Study: Question**: whether the top-down identified tension areas also resemble subjectively need for action by an assistance system
- **6 naïve subjects** were confronted with situations being prototypical for different action tension areas and rated on a **semantic differential**
- **Observation**: Tension areas matched to the perception of the subjects
Example of interaction design using the 'tension approach'

How comprehensible was this interaction design?

Comprehensible

-3  -2  -1  0  +1  +2  +3

Comprehensible
Summary and Outlook

- Tension approach is an enabling and pushing **meta-level design concept** and based on the well-known **scientific concepts**
- It enables an **ontological and holistic** kind of system understanding and offers a useful **framework for design** of cognitive systems
- It allow a **domain independent dialog** between the professionals from different domains

- The important **constraint** of the approach is the finding of an appropriate **manner to operationalize the tensions**

- The tension approach can help in deriving user-compatible **software and hardware frameworks** that would use tensions as reference values within the designed system
- It is planned to research a **formal analytical** kind of cognitive system **design and analysis** using human-machine arbitration concept toward the human-machine interference concept
References


Yerkes, R.M. & Dodson, J.D. (1908): *The relation of strength of stimulus to rapidity of habit-formation*. Journal of Comparative Neurology and Psychology, 18, pp. 459-482
Thank You

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