Intelligent Systems Design

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# Intelligent Systems Design

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Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
Outline

Current state of the art

Near term prospects

Long term potential
4D/RCS Reference Model Architecture for Unmanned Vehicle Systems

Developed by NIST for ARL Demo III Program
Adopted by GDRS for FCS Autonomous Navigation System
Adopted by TARDEC for Vetronics Technology Integration

- Hierarchical structure of goals and commands
- Representation of the world at many levels
- Planning, replanning, and reacting at many levels
- Integration of many sensors stereo CCD & FLIR, LADAR, radar, inertial, acoustic, GPS, internal

Robotics Technology
TRL6
2002 - 2003
Perception establishes correspondence between internal world model and external real world

Behavior uses world model to generate action to achieve goals
Intelligent System Architecture

4D/RCS Reference Model

Battalion Formation
Platoon Formation
Section Formation
Objects of attention

OODA
OODA
OODA
OODA

Surfaces
Lines
Points

Attention
Communication
Locomotion

Subsystem
Primitives
Servo

OODA
OODA
OODA
OODA

0.5 second plans
Steering, velocity

0.05 second plans
Actuator output

Plans for next 24 hours
Plans for next 2 hours
Plans for next 10 minutes
Tasks relative to nearby objects

0.5 second plans
Subtask on object surface
Obstacle-free paths

Plans for next 50 seconds
Task to be done on objects of attention

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A 4D/RCS Computational Node

4D/RCS node

RCS Node

SENSORY PROCESSING

PERCEIVED OBJECTS & EVENTS

UPDATE

PREDICTED INPUT

OBSERVED INPUT

SENSORY INPUT

OPERATOR INTERFACE

VALUE JUDGMENT

STATE

PLAN RESULTS

PLAN EVALUATION

PLAN

To Higher and Lower Level
World Modeling

SITUATION EVALUATION

KNOWLEDGE DATABASE

SENSORY OUTPUT

COMMANDED TASK (GOAL)

COMMANDED ACTIONS (SUBGOALS)

SENSORY OUTPUT

STATUS

PEER INPUT OUTPUT

OBSERVED INPUT

PERCEIVED OBJECTS & EVENTS

UPDATE

PREDICTED INPUT

To Higher and Lower Level
World Modeling

SITUATION EVALUATION

KNOWLEDGE DATABASE

SENSORY OUTPUT

COMMANDED TASK (GOAL)

COMMANDED ACTIONS (SUBGOALS)

SENSORY OUTPUT

PEER INPUT OUTPUT
The 4D/RCS methodology promises the ability for manned-unmanned collaboration to perform tactical behavior.

Company level – 30 to 40 vehicles
Platoon level – 8 to 10 vehicles
Section level – 2 to 4 vehicles
Vehicle level – single vehicle
An Example Scenario

Scout section conducting a route reconnaissance

HMMWV reconnoitering the right flank encounters an unexpected water obstacle

Center HMMWV encounters a bridge

The two vehicle commanders report their findings to the section leader

The section leader then commands the manned vehicles to take up overwatch positions for near-side security

The section leader commands the UAV to look for a route around the water obstacle. UAV sends hi-resolution color images data back to the section leader for manual viewing, and/or by scanning the ground with a LADAR to assess the topography.

Once a potential by-pass to the marsh is located, the UAV is commanded to search the far side of the marsh and the region beyond the next terrain feature for evidence of enemy forces.

UGV is then commanded to proceed through the bypass and establish an overwatch position on the far side of the next terrain feature.

The UGV path can be automatically generated from the data returned from the UAV and approved by the section leader before being executed.

Once the UGV is set in position, the UAV continues scanning for enemy activity further along the route.

Manned elements perform manual reconnaissance of the marsh by-pass, and assess the load carrying capacity of the bridge.
Task Decomposition Tree

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Task Vocabulary at Each Echelon
## Condition – Action Rules for Each State

### Map Task Decisions to State-Tables

#### Conduct Recon to Control Vehicle

<table>
<thead>
<tr>
<th>Condition</th>
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<tr>
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<tr>
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<tr>
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<td>FallbackToStandoffPosition</td>
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<td>TacticallyAssessDefile</td>
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<tr>
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<tr>
<td>KeyDominatingTerrain</td>
<td>NewPlan</td>
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<tr>
<td>DangerAreaDetected</td>
<td>S1 DetermineWaterIsObstacleToMovementPlanObservationGoalPt</td>
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<tr>
<td>EnemyPresenceDetected</td>
<td>Surv.LookForBypass</td>
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<tr>
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<tr>
<td>EngagedEnemyContact</td>
<td>SetupMovementParams</td>
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<tr>
<td>AvenueOfApproachDetected</td>
<td>S1 WaterFeatureIsMovementObstacle</td>
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<tr>
<td>ManMadeObjectsDetected</td>
<td>S2 SetupWaterObstacleReport</td>
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<tr>
<td>BridgeDetected</td>
<td>S2 SetAtObstacleOverwatch</td>
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<tr>
<td>TunnelDetected</td>
<td>S2 SetAtObstacleOverwatchReport</td>
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### Vehicle TacticallyAssessWaterFeature

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### PLAN STATE-TABLE

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<th>Output Commands</th>
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<td>PLAN STATE-TABLE</td>
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Determine State - Transition Conditions
Identify Objects and Attributes
Determine Sensor Requirements

**STEP 6**

Determine Sensor Processing Requirements and Resolutions

- Objects
- Features and Attributes
- Segmented Groupings

**SENSORY PROCESSING**

- Color Cameras
- LADAR
- Radar
- Stereo
- FLIR
- Nav

**STEP 5**

Identify Objects and Their Relevant Attributes

**STEP 4**

Determine Antecedent World States

**WORLD MODEL KNOWLEDGE**

- Swamp Detected
- Bog Detected
- Marsh Detected
- Mostly Trees, Some Bushes
- Extensive Water Surface Visible
- Slow Moving Water
- Covered Land
- Significant Traction Slip
- Major Ground Deformation
- Stagnant Water
- Organic Material on Water Surface
- Indeterminant Ground Level
- Mosses, Evergreens, and Brush
- Significant Traction Slip
- Water Covered Land
- Submerged Vegetation
- Water Depth To Six Feet
- Traction Slip
- Flowing Water
- Narrow Width Indeterminant
- Non Vegetated Water
- Flooding
- Flooded Earth Embankments
- Large Surface Area
- Organic Material
- Large Area Without Grass
- Bounded by Swamp
- Flowing Water
- Significant Width Indeterminant
- Vegetated Water
- Flooding
- Flooded Earth Embankments
- Water Sheen on Ground Surface
- Rotted With Standing Water
- Little To No Vegetation
- Significant Traction Slip
- Significant Ground Deformation

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Software Methodology

This is a tedious process.

There are many tasks in the command library at each level.

There are many parameters for each task.

There are many objects that must be recognized.

There are many situations that must be understood.

But, the numbers are not infinite. They are, in fact, quite modest. (One of the advantages of hierarchies.)
RCS Software Development for Autonomous On-Road Driving

Estimated numbers:

~ 200 tasks
~ 100 parameters
~ 1000 transition conditions
~ 10,000 objects or events

Other skills may require similar numbers
Cognitive reasoning capabilities, planning, and control will enable useful tactical behaviors on the battlefield within a decade.

The remaining tall pole in the tent is perception.

Intelligent machines cannot achieve human levels of performance until machine vision systems can perform as well as human vision.
Sensor technology is well developed – Color, FLIR, Night Vision, and LADAR

What is lacking is the ability to perceive and understand situations and relationships

Machine vision remains far inferior to human capabilities in scene understanding and situation assessment
Long term potential

A solution may lie in Reverse Engineering the Brain

Cited as a Grand Challenge by National Academy of Engineering

Subject of a Decade of the Mind Conference at Sandia National Labs
Jan 13 –15, 2009
http://www.dom4.org/

Recent progress in neuroscience & intelligent systems engineering makes this a promising approach
Reverse Engineering the Brain

Brain imaging is revealing many of the functional operations in the brain

Neural modeling is explaining many of the computational processes in the brain

Computers are approaching the computational power of the brain

Details of the functionality and connectivity within and between areas in the brain are emerging
Circuit diagram of visual system in brain

12 layers
32 areas
Each area is an array of Cortical Computational Units (CCUs)
Functional diagram of CCU arrays in V1-V5

**Where**
- Space
- High speed
- Motion

**What**
- Objects
- High resolution
- Color
Long term potential

Detailed circuitry and functionality of CCU arrays in visual cortex are being understood

About 1 million CCUs in human brain
About 200,000 CCUs in visual cortex
About 10,000 neurons in each CCU
Connectivity within and between CCUs are being mapped
Inputs and outputs are being discovered
A Theoretical Model of a CCU

Cortical Computational Unit at location \((u, v)\) in level \((i)\) at time \((t)\)

CCU frame

library of procedures

set of processors

cortical hypercolumn

thalamus

Drivers (data)

attributes
- range
- shape
- size
- texture
state
- orientation
- velocity
- trace
- predicted behavior
pointers
- belongs-to
- is-a-member-of
relationships

Modulators (addresses)

where \(j =\) slot index in CCUframe

CCU Outputs

windowing, segmentation, grouping, computing group attributes & state, filtering, classification, setting and breaking relationships

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CCU Grouping Hierarchy

Pointers link symbols to pixels & vice versa

Provide symbol grounding

Pointers reset every saccade $\sim 150$ ms
Long term potential

- Functional modeling of the human brain at the level of Cortical Computational Units (CCUs) appears within the capacity of current supercomputers.

- Human level performance in perception, situation awareness, reasoning, planning, and behavior may be feasible on desktop-class machines within two decades.
Summary

Mid term solution to building intelligent robots lies in the 4D/RCS reference model

1. Bridges the gap between Artificial Intelligence (AI) and modern control theory

2. Well documented and tested in a number of applications

3. Mature with many software development tools
Summary

Long term solution to building robots with human level performance may lie in Reverse Engineering the Brain

1. Neurosciences and brain imaging enable visualization of brain activity during perception, thinking, planning, and acting

2. Testable models of computation and representation in the brain are emerging

3. Functional modeling of the human brain seems within the capacity of supercomputers today & desktop computers within two decades
We are at a tipping point
Analogous to where nuclear physics was in 1908

• **Fundamental processes are understood in principle**
  - Perception
  - World modeling
  - Reasoning
  - Planning
  - Control
  - Brain structure and function
  - Cognitive & control architectures
  - Computational equivalence
  - Language
  - Learning & memory

• **Technology is emerging to conduct definitive experiments**

• **Significant military and economic applications will develop early in the century**
Impact on Military Strength

Intelligent weapons systems will:
- outperform manned systems
- cost less to train
- cost less to maintain readiness
- keep soldiers out of harm’s way

Intelligent weapons will revolutionize warfare
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