“A 20/20 Vision for Robotics in 2020”

• First cut ideas for the evolutionary development and systems insertion of revolutionary UGV robotics technology in 2015-2025

• In the context of the development of the Army’s Objective Force, but beyond the FCS initial deployment

• If not us, who? If not now, when?
Outline

• The target capabilities  **WHAT?**
• Why an **evolutionary** development of the FCS Objective Force is necessary  **WHY?**
• Some strategies for evolutionary development  **HOW?**
• Scoping the development job  **HOW MUCH WILL IT COST?**  **HOW LONG WILL IT TAKE?**
• Vehicle driving capabilities at human level
  - Heavily perception based
  - Do not require GPS, but exploit it when available
• Initial baseline: non-military on-road “chauffeur” capability
  - Capabilities prerequisite to tank driver training
  - Prevent explicit military mission-based requirements from “masking” implicit underlying required capabilities
    • “Anthropomimetic” behaviors
  - A very complicated task: strawman list in DoT Driver Task Descriptions
• Later step: build required military behaviors and TTPs on top of baseline capability
This volume is the first of a four-volume report dealing with the development of driver education objectives through an analysis of the driver's task. It contains a detailed description of the behaviors required of passenger car drivers, rated criticalities of these behaviors, and items of supporting information relating to driver performance and performance limits, enabling driver knowledges and skills, and behavior criticality. The task descriptions have been organized in terms of the situations giving rise to the behaviors; behaviors involved in controlling movement of the car without regard to specific situations; behaviors that must be performed continuously or periodically while driving, rather than in response to a specific situation; and those off-road behaviors that are performed before driving, to maintain the car in sound operating conditions, and in compliance with the legal regulations. Volume II, entitled Driver Education Task Analysis: Task Analysis Methods, provides a description of the manner in which the content of this volume was generated.
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21-23 Observes traffic ahead, both parked and moving vehicles, to include cycles possibly obscured by larger vehicles (see 31, Following and 36, Reacting to Traffic)
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21-25 Observes traffic from the side
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36-114 Watches for vehicle doors being opened or indications that vehicle occupants are about to exit on the roadway side

36-1141 Flashes headlight beams or sounds horn to provide warning

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41-112 Decelerates in sufficient time to avoid stopping in intersection or on crosswalk
41-12 Enters correct lane
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Why FCS Requires an Evolutionary Development Process

• Technical Context
  - Perception-based navigation technologies required to realize the full FCS vision will NOT be available before 2020
  - Moore’s Law evolution of processing performance
    • 10 to 100 fold increase by 2012, 1,000 to 10,000 fold by 2025
  - Continuing rapid progress in sensor technologies
    • New product generations appear every 12-18 months

• Programmatic Context
  - Must respond to emerging/evolving requirements
    • Will be continuously modulated until deployment
  - Must produce information to support April 2003 development decision
  - Must support the development of system to meet initial 2010-2012 deployment
    • Can’t afford to delay start until after April 2003 decision
  - Guidance from FCS SAG Report July 2000
From FCS SAG Report July 2000

• “The program office should define a clear and attractive strategy for continuing technologies that are important to FCS but which are not ready for 2003 date.
  - Robotics is a prime example”

• “Robotics has historically promised leap-forward goals, never succeeding although there are near-term payoffs. Step-wise goals will provide better management of expectations.”
Evolution of Autonomy: Over-Simplistic View

- Fully Autonomous
- Supervised
- Teleoperated

SYSTEM AUTONOMY LEVEL ACHIEVED

User Interface

Strategy: Evolutionary Elimination of Operator Intervention

- Perception
- Behavior
- Coordination
- Planning
- Estimation
- Signal Processing

Required Synchronous Operator Intervention

Supervisory Command Interface(s)

A slice through one execution of one autonomous function
Operator Intervention: Sample Execution Slice

1. Supervisor orders a coordinated group move
2. Planner generates individual move commands, sends them to vehicles. Vehicle planner is unable to generate waypoints for move, prompts Operator
3. Operator generates list of waypoints, inputs to vehicle
4. Vehicle encounters a major obstacle, asks Operator for assistance
5. Operator clicks on an image point on the obstacle, commands follow-wall-on-left behavior
6. While following wall of obstacle, vehicle sensors “lose” the wall. Controller asks Operator for assistance
7. Operator designates several image points as features to continue follow-wall-on-left navigation of wall
Evolution of Human-Robot Interfaces Achieves...

• “Mixed initiative” “Dynamic Autonomy” during ops
  - Supervisor tells robots what to do, based on tactical picture
    • Multiple Supervisor command levels
  - Operators separate from Supervisor ensure successful execution despite limitations of the system (Wizard of Oz)
    • Exploit perceptual capabilities of the Operator as required
  - Acknowledge that the system will always encounter limits to its autonomy
    • Build mechanisms into system architecture up front

• “Incremental Simulation” during development
  - Facilitate early exercise of system functionality in diverse environments
Strategy: Evolution of Use of Deictic Percept-Referenced Commands

- Sequence of Operator-input semantically-based Deictic commands
  - OP: Goto <click-on-image-point> Building
- Script including prompts for Operator-input non-semantic Deictic commands
  - SYS: (show image) “Click on Building for Goto”
  - OP: <click-on-image-point>
- Script including prompts for Operator-input OK or correction
  - SYS: (show image with building highlighted) “Goto this Building?”
  - SYS: display OK button and wait
  - OP: <click-on-OK> (or <click-on-alternate-image-point>)
- Script including prompts for Operator attention (and override)
  - SYS: (show image with building highlighted) “Goto this Building”
Percept-Referenced Navigation Commands

• Move Under <this> Vehicle
• Climb <how many> Flights Up <these> Stairs
• Climb <how many> Flights Down <these> Stairs
• Take <this> Elevator to the <number> Floor
• Cross <this> Street (and don’t get hit)
• Hide in <this> Vegetation
• Move Along <this> Wall (until...)
• Open <this> Door (and Enter... and Close)
• Move in <this> Direction (until...)
• Wait until... (humans are (not) present...)
• Move Under <this> Vehicle
• Climb <how many> Flights Up <these> Stairs
• Climb <how many> Flights Down <these> Stairs
• Take <this> Elevator to the <number> Floor
• Cross <this> Street (and don’t get hit)
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• Open <this> Door (and Enter... and Close)
• Move in <this> Direction (until...)
• Wait until... (humans are (not) present...)

DARPA
A Complex Command Behavior: Using an Elevator

• Take <this> elevator to the <number> Floor
  - No people present --> many people present
  - Single elevator --> double bank of elevators

• Issues
  - Manipulation: reach, strength, tactile/haptic feedback
  - Sensor viewpoint (e.g., be able to see indicators above door)
  - Perception: “understand” controls, indicators, auditory cues
  - Task planning, execution, monitoring: Press Up or Down? Get into this elevator? Press which floor button? Get off here?

• A “good” challenge
  - A useful real world human task with a good blend of complexity and structure, an easy tasking paradigm, and ease of testing
Perception of Relevant Environmental Features

• Enable robots to “perceive” many of the relevant environmental features that a human would use for navigation and mapping
  - Develop perception operators for relevant features/entities in a robot’s environment
    • Replace existing placeholders in current research
  - Develop library of representations and abstractions to address the specific needs of FCS robotic navigation
  - Enable development of a family of robust perception-based navigational competencies
Environmental Features in a Spectrum of FCS Environments

• Off-Road: Obstacle detection and avoidance
  – Rock, grass, bush, tree, hole, slope, ditch, water, terrain traversability

• Open Highway: Road following
  – Pavement, lane, shoulder, intersection, ramp, obstacle, vegetation, other vehicle, pedestrian, signboard

• Urban Streets: City driving
  – Other vehicle, complex intersection, building, pedestrian

• Close Quarters: Maneuver around buildings
  – Road, parking lot, sidewalk, vehicle, person, animal, building, wall, door, fence, gate, grass, tree, bush, signboard

• (Indoors)

• OTHER PEOPLE – Drivers, pedestrians – Friends, neutrals, enemy
• Sign Reader (SR) function employs the vehicle’s sensor suite to detect, track, and “parse” any textual or graphic signboards in its environment

• SR provides vehicle controller with each sign’s relative position, orientation, shape, size, color(s), text, and sign-type/sign-ID, if the sign matches an entry in its sign library (e.g., street sign, highway/STOP sign, commercial/McDonalds sign)

• Vehicle controller can then reason about the sign and its environmental context, and execute an appropriate behavior

• SR is highly relevant to indoor as well as outdoor navigation (e.g., hotel room numbers)
• Output of SR provides a well-defined perceptual-level input to autonomous planning resources
  - Precise, concise representation, meaningful to human operator

• Implementation of SR requires
  - Characterization of sensor inputs required by SR algorithms
  - SR algorithms development
  - World knowledge about signboards and how they are situated

• Using SR output for autonomous planning requires
  - World knowledge about signboards, how they are situated, and what they “mean”
  - Ability to perform sophisticated reasoning about the world, and the rich world knowledge resources necessary to support this reasoning, in order to execute the tactics, techniques and procedures required to perform our assigned task
Strategy: Methodical Exploitation of Path-Referenced Behaviors

• The class of Path-referenced Behaviors
  - Leader-follower
  - Route replay
  - Retrotraverse
  - “Go back to <this> previous location” (path annotation)
  - Subtle sensitivities: sensor calibration, POV, lighting, etc
• Support tasking in terms of mission events
• Evolve from GPS-Based to Perception-Based
• System level capabilities, require stored data
  - Representation is key -- what level of abstraction?
  - Maximum leverage of limited perception capabilities
• Classic “what do you mean you can’t...” stuff
Path-Referenced Data

• Data items associated with the distance traveled along the path include:
  - Perceived location of features relative to path, classification, identification (includes obstacles and not-obstacles)
  - Absolute (compass) and relative (steering angle) path direction
  - Absolute (GPS) and relative (to other features) location
  - Terrain slope, side slope, surface characteristics, relative suggested speed of advance
  - Annotations derived from maps or input by operator (e.g., names, images, links)
Strategy: Implement High-level Mission-oriented Autonomous Tasks

- Multiple coordinated robots, or single
- Mapping and monitoring building interiors
- Adaptive maintenance of communications connectivity
- Maintaining sensor/weapon coverage (e.g., self-healing minefield)
- Search (e.g., minefield breaching, demining, UXO disposal)
- Civilian: Agriculture (e.g., plowing, seeding, chemical dispensing, harvesting)
- ...

Summary: Strategies for Evolutionary Development

• Operator “behind the curtain”
• Percept-referenced commands
  – Separate perception of the referent from implementation of the behavior
• Path-referenced commands
  – Grounded in representations and abstractions
• Mission-oriented behaviors (one or more robots)

• Can we identify other “crutches” to facilitate the development process?
• How best to exploit learning techniques?
Approaches to Scoping the Development Job

- How can we determine how DIFFICULT the driving task is?
  - ALV plus 15 years of Moore’s Law
- How can we determine how BIG the development job is?
  - “Prairie Fire” metaphor
  - Driving Task Descriptions plus lessons from TMR
- If we had a dozen “son-of-UGCV” vehicles, complete with year 2012 computers and sensors, how long would it take for us to write the baseline driver software?
- How can we make a compelling case for the resources that will be required?
  - (an order of magnitude increase in robotics funding?)
We've been at this a while...

DOD Targets 3 Projects For AI, Supercomputer Uses

By Chappell Brown

BOSTON — Lynn Conway, assistant director of strategic computing for the Department of Defense, outlined a broad-based program here last week to apply artificial intelligence and supercomputer technology to military systems.

Congress has approved $50 million in funding in fiscal 1984 for an initial project that targets development of three military artificial intelligence systems by technology and applications "communities," Conway said.

Projects Described

Conway, speaking at a VLSI conference at the Massachusetts Institute of Technology, said the systems to be developed initially include an autonomous land vehicle, a personalized adviser for jet pilots and an aircraft battle-management system.

Although Conway did not go into details about each project, in the past the Defense Department has said that the military would like a land vehicle that could roam a battlefield and detect enemy troops or equipment. The jet pilot's "adviser" will be an expert system giving instantaneous advice to jet pilots during flight, and a computerized battle management system would coordinate attacks from an aircraft carrier.

Military Applications

Conway said development of these systems would provide the basis for a "strategic computing" program that would develop technology of "unprecedented capabilities."

The program will focus on military applications that require machine intelligence and will draw on recent advances in computer vision, speech, and expert system technology.

Military applications are a branch of artificial intelligence research that use databases derived from the experience of human experts to draw inferences in novel situations.

Conway used an incident in the Falklands war as an example, illustrating the use of this kind of system in a battle.

Falklands Incident Cited

British ships were using a computer-controlled radar system as a defense against Argentine aircraft. Although the system was highly advanced, the Argentine pilots found a ploy that would confuse the system—they would fly in a tight pattern, appearing as a single object to the radar, and then quickly disperse.

This unexpected maneuver confounded the computer-controlled system. The experts needed to reprogram the system were all back in Britain.

What was required was an instantaneous expert at the scene, or, even better, a system that was more adaptable to novel situations, Conway said.

There are three broad technological goals of the strategic computing program: to provide the United States with a broad-based machine intelligence capability, demonstrate applications important to defense and provide technological spinoffs.

A fundamental theme of the project will be the interaction of advanced areas of research. For example, advanced VLSI architectures need to be combined with the kind of software and systems work being undertaken by artificial intelligence researchers. At this time, research groups such as these are not coordinated, Conway pointed out.

Applications 'Pull'

In Conway's view, specific applications—such as developing an autonomous land vehicle—imply the kind of cooperation; she spoke of applications providing the "pull" needed to create machine intelligence.

Although DARPA (Defense Advanced Research Projects Agency) will manage the project, approximately 10 "computer technology communities" will be created to develop the required technology and another five to 10 "applications communities" will work on implementation. Each community will involve 100 professionals from private, academic and government areas.

A high degree of interactivity will be crucial to the project, and networks and interactive workstations will be heavily used. Conway used the phrase "an online window into activities."

Although the need for secrecy on defense projects might work against this open communications network, Conway replied that only the specific applications communities would be operating under classified information restrictions. The basic technology development program would be open.


Japanese Reveal VLSI Thrusts

By Chappell Brown

which are still laboratory curios (announcement of DARPA ALV program, January 1984)

Apple: Mac Won't Repeat Lisa Mistake

(announcement of DARPA ALV program, January 1984)
Autonomous Land Vehicle (ALV)
A Lesson from ALV?

• Autonomous Land Vehicle began in 1984, with goals that arguably have not yet been realized 15 years later
  - Not from want of trying: Demo II, Demo III, others
  - 15 years of Moore’s Law progress: factor of 100 to 1000

• If we were that far off in assessing the difficulties of the problem in 1984, what makes us think that we are any smarter today?
A Prairie Fire
Progress of Robotic Technology Programs
“Prairie Fire” Metaphor

TMR
1997-2002

“Backpackable” Robots

Stair Climbing

Interior Mapping

ALV
1984-1988

Unmanned Ground Vehicles

Demo II
1990-1996

Driving on Road

Rocks In Grass

Open Wire Fences

Negative Obstacles

Big Positive Obstacles

Demo III
1998-2001

“Backpackable” Robots

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Stair Climbing

Interior Mapping

TMR
1997-2002

“Backpackable” Robots
How Big Is the Whole Job?

What are the hazards we haven’t hit yet?
Should’t we “start more fires”?
Increased Resources
Hasten Capabilities

(What does this chart really look like?)
Summary

• Non-military on-road autonomous driving capability
  - Necessary for FCS (but not sufficient)
  - Rich “anthropomimetic” capability
  - Identifiable subgoals (sightseer, parker)

• Strategies for evolutionary development
  - Operator “behind the curtain”
  - Percept-referenced commands
    • Separate perception of the referent from implementation of the behavior
  - Path-referenced commands
    • Grounded in representations and abstractions
  - Mission-oriented behaviors (one or more robots)

• Scoping the development job
  - How difficult, how many lines of code?
  - How much will it cost, how long will it take?