

BRIEF PROJECT OVERVIEW

EATR: ENERGETICALLY AUTONOMOUS TACTICAL ROBOT

DARPA Contract W31P4Q-08-C-0292

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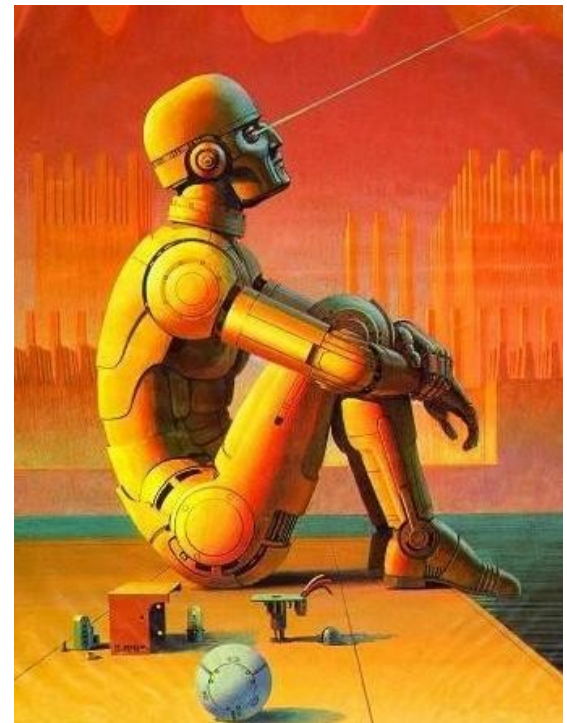
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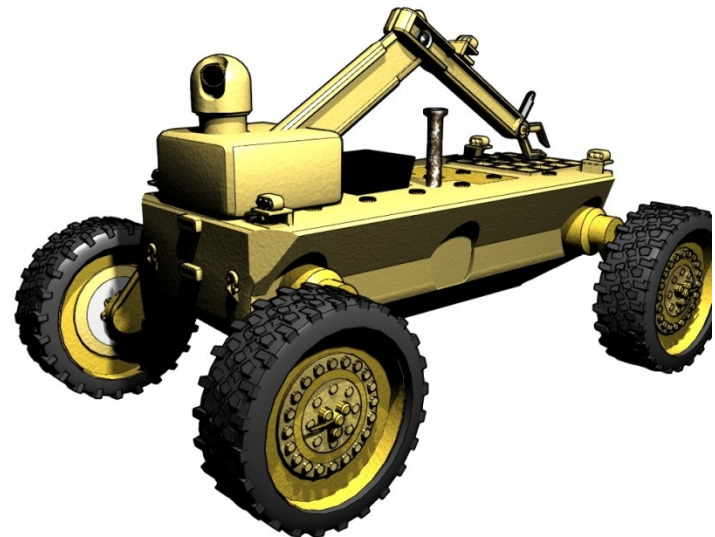
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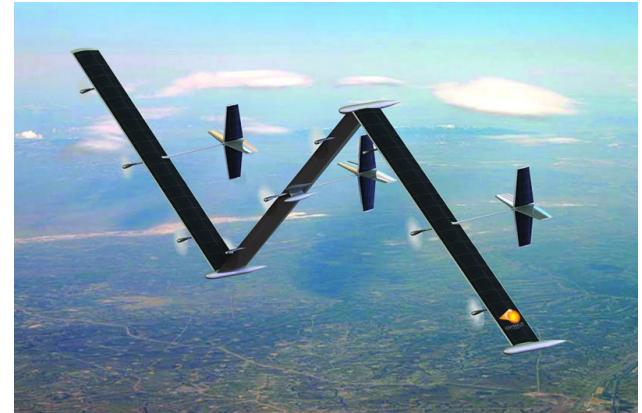
ENERGETICALLY AUTONOMOUS TACTICAL ROBOT (EATR)

- **Concept [patent pending]:** an autonomous robotic vehicle able to perform long-range, long-endurance missions indefinitely without the need for conventional refueling
- **Robotic vehicle forages:** biologically-inspired, organism-like behavior the equivalent of eating
 - **Can find, ingest, and extract energy from biomass in the environment (and other organically-based energy sources)**
 - **Can also use conventional fuels (heavy fuel, gasoline, kerosene, diesel, propane, coal) when available**



EATR: RATIONALE AND UTILITY

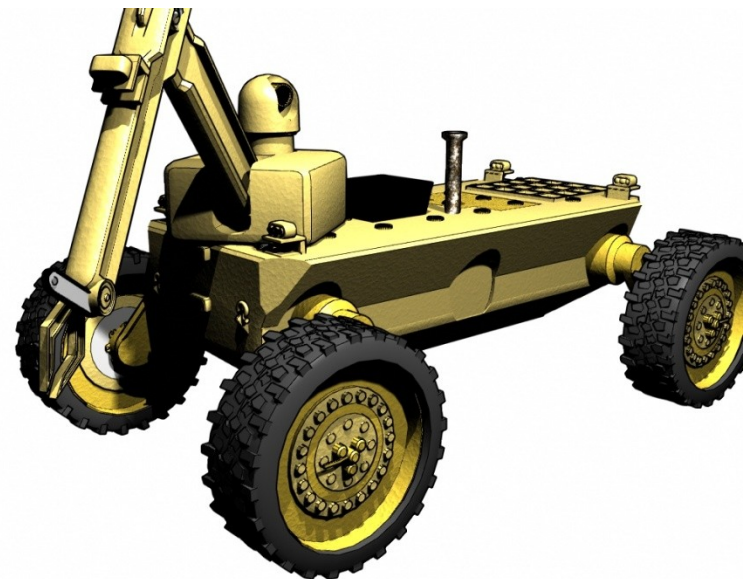
- A robotic vehicle's inherent advantage is the ability to engage in long-endurance, tedious, and hazardous tasks such as RSTA (Reconnaissance, Surveillance, and Target Acquisition) without fatigue or stress
 - Advantage is diminished by need to replenish fuel supply
- EATR provides:
 - Revolutionary increase in robotic ground vehicle endurance and range
 - Ability of robot to perform extended missions autonomously
 - Ability to occupy territory and perform missions with sensors or weapons indefinitely
- Long-range, long-endurance unmanned ground vehicles (UGVs) can complement the missions of long-range, long-endurance unmanned air vehicles (UAVs)



LONG ENDURANCE UAVs

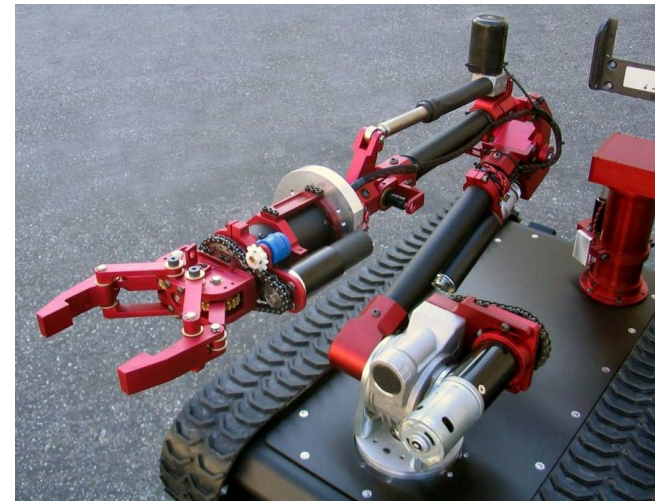
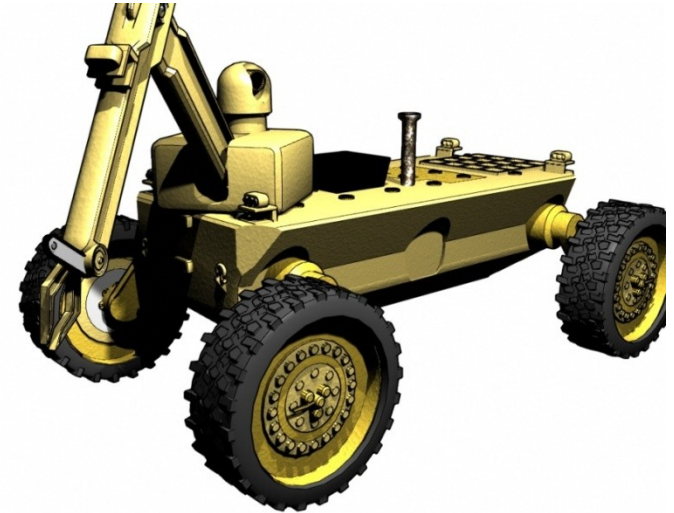
EATR PROJECT TECHNICAL OBJECTIVES

- Initial objective is to develop and demonstrate a proof-of-concept system
 - **Demonstration of a full operational prototype is the objective for a subsequent Phase III commercialization project**
- The project will demonstrate the ability of the EATR™ to:
 - **Identify suitable biomass sources of energy and distinguish those sources from unsuitable materials (e.g., wood, grass, or paper from rocks, metal, or glass)**
 - **Spatially locate and manipulate the sources of energy (e.g., cut or shred to size, grasp, lift, and ingest); and**
 - **Convert the biomass to sufficient electrical energy to power the EATR™ subsystems**

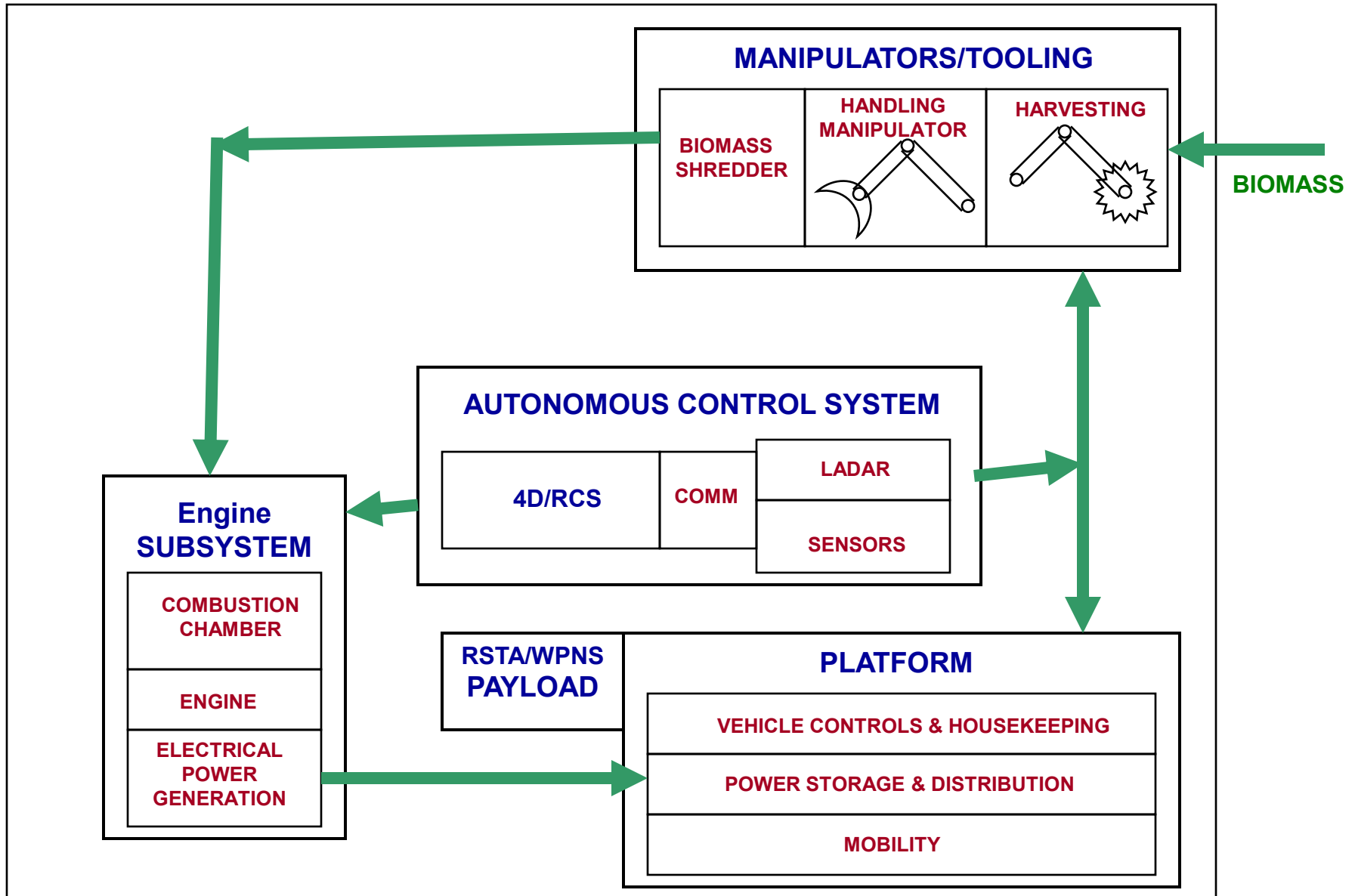


EATR: TECHNICAL APPROACH

- Four major subsystems:
 - **Robotic mobility platform:** mission mobility, EATR support subsystems (batteries, power conversion and conditioning), mission payload, and payload support subsystems
 - **Autonomous control system/sensors :** allow platform to find and recognize suitable energy sources and manipulate material with arms and end effectors
 - **Robotic arms and end effectors:** gather and manipulate combustible energy sources (prepared by shredder which will ingest and process “food” into combustion chamber)
 - **External combustion engine:** hybrid engine system (combustion chamber, power unit, and battery)

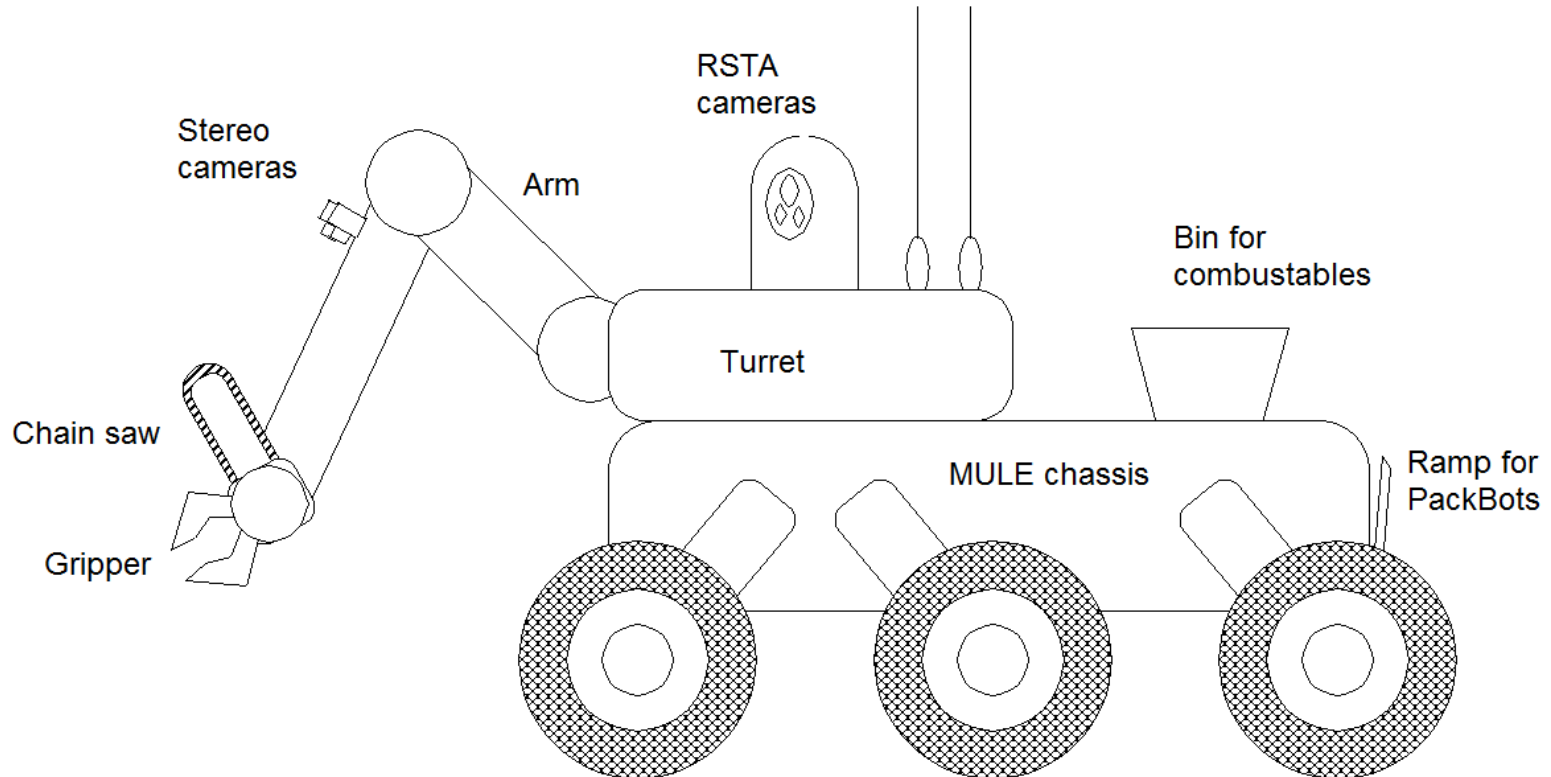


EXAMPLE EATR ARCHITECTURE



EXAMPLE EATR PLATFORM

- The autonomous robotic mobility platform is not essential to the EATR™ proof-of-concept demonstration – but it is required for the commercialization phase
 - Provides mobility for the mission and mission payload



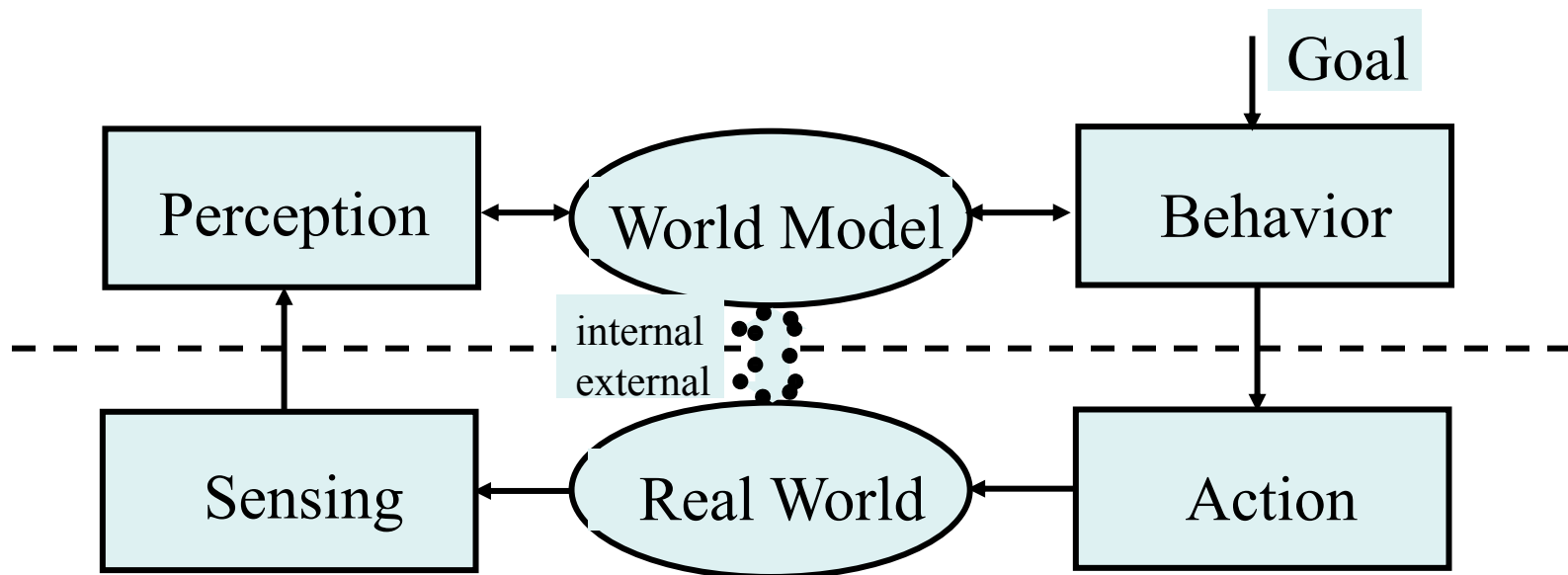
EXAMPLE EATR PLATFORM

- The **experimental prototype** platform for the commercialization phase may consist of any suitable automotive vehicle, such as a purely robotic vehicle, a robotically-modified High Mobility Multi-Wheeled Vehicle (HMMWV), or a robotically-modified all-electric truck



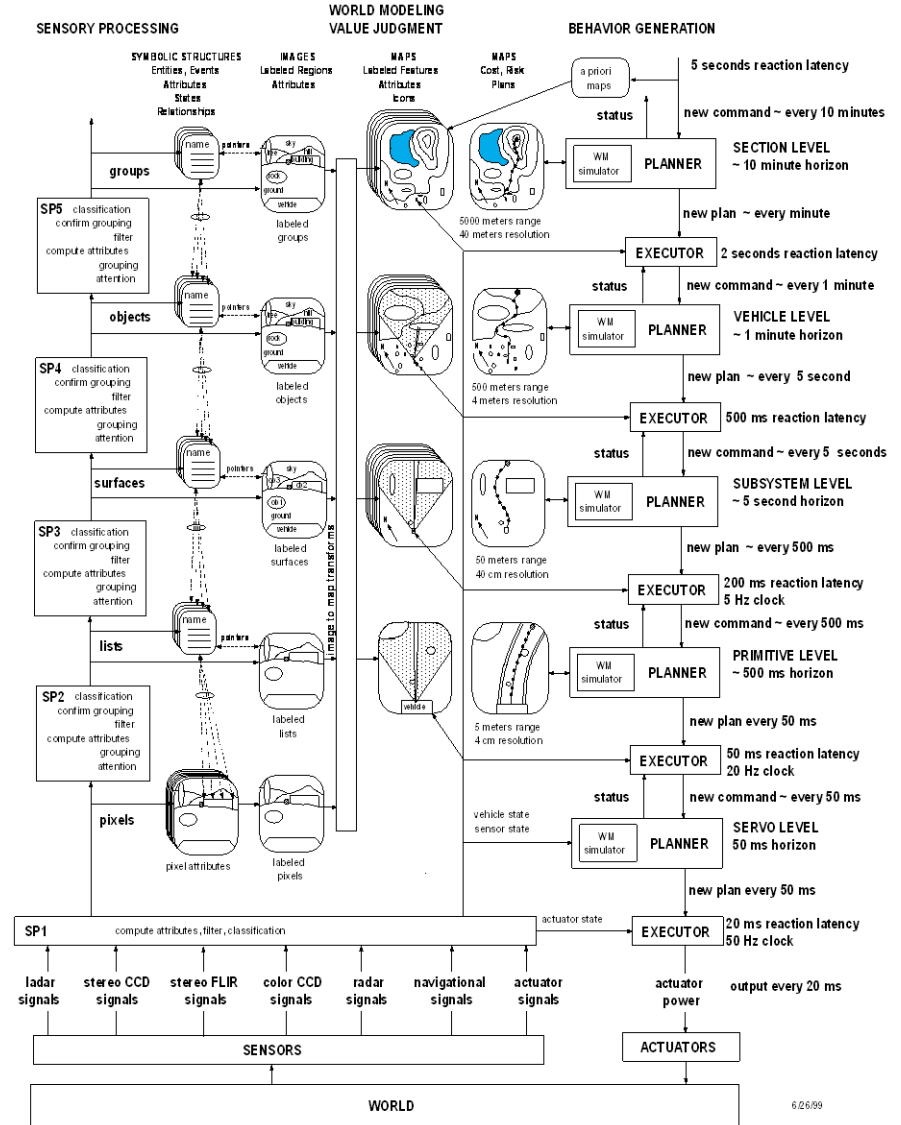
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- The autonomous intelligent control subsystem will consist of the 4D/RCS (three dimensions of space, one dimension of time, Real-time Control System) architecture, with new software modules which we will create for the EATR™
 - Under development for more than three decades, with an investment exceeding \$125 million, by the Intelligent Systems Division (ISD) of the National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce
 - Demonstrated successfully in various autonomous intelligent vehicles, and a variation of the 4D/RCS, with \$250 million in developmental funding, serves as the Autonomous Navigation System (ANS) mandated for all robotic vehicles in the Army's Future Combat System (FCS)
 - NIST is assisting in the transfer of the 4D/RCS for the EATR™ project



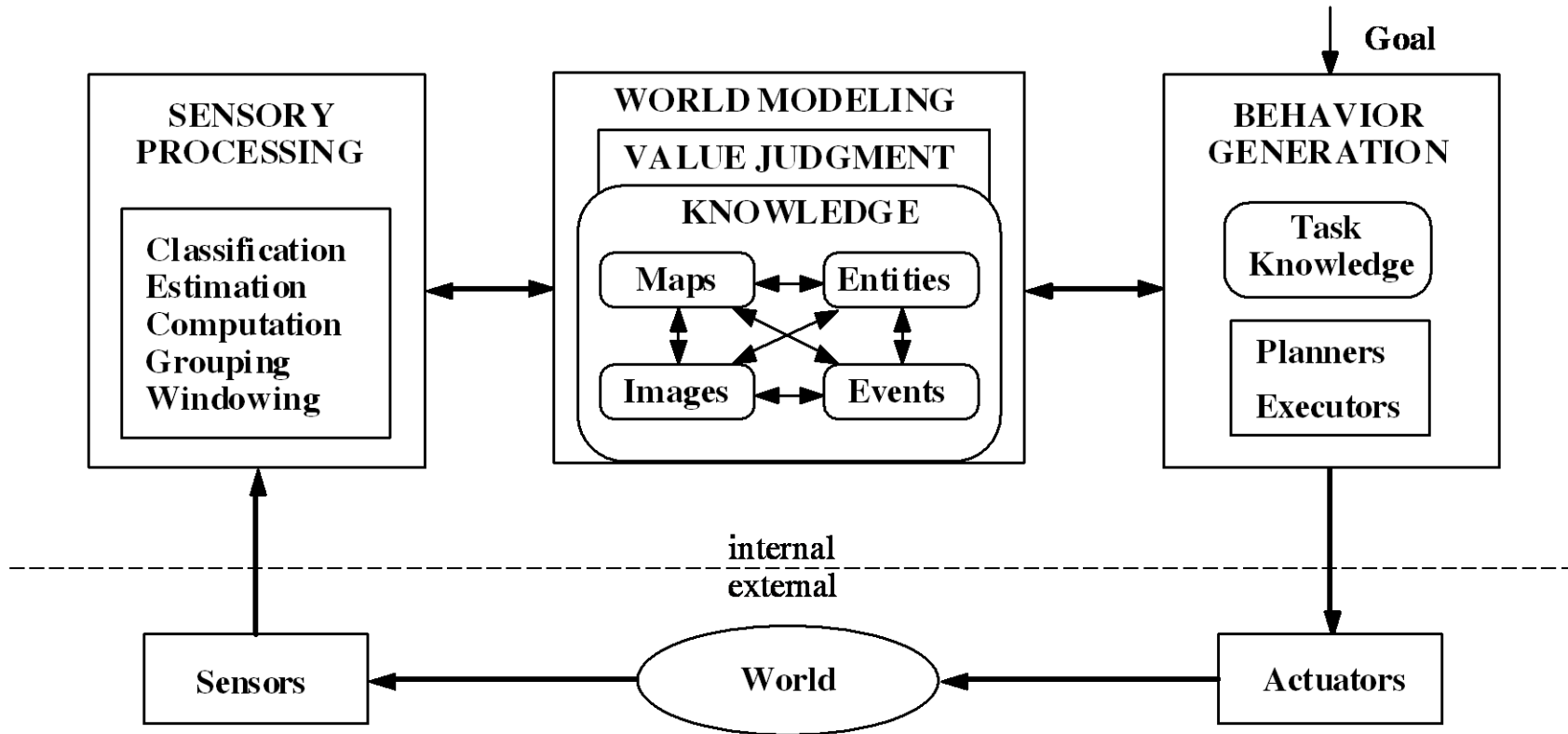
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- The control subsystem will also include the sensors needed for the demonstration (e.g., optical, ladar, infrared, and acoustic)
 - **NIST 4D/RCS architecture will provide EATR prototype with autonomous vehicle mobility & allow EATR proof-of-concept to:**
 - Control the movement and operation of the sensors, process sensor data to provide situational awareness such that the EATR™ is able to identify and locate suitable biomass for energy production
 - Control the movement and operation of the robotic arm and end effector to manipulate the biomass and ingest it into the combustion chamber
 - Control the operation of the hybrid external combustion engine to provide suitable power for the required functions



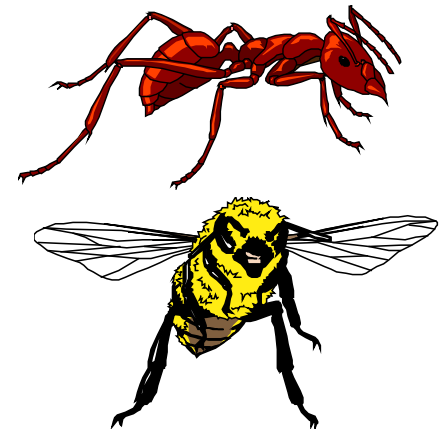
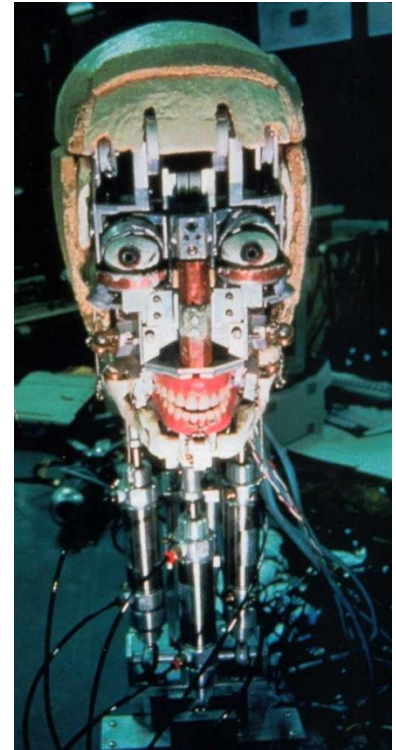
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- The 4D/RCS is a framework in which sensors, sensor processing, databases, computer models, and machine controls may be linked and operated such that the system behaves as if it were intelligent
- It can provide a system with functional intelligence (where *intelligence* is the ability to make an *appropriate* choice or decision)



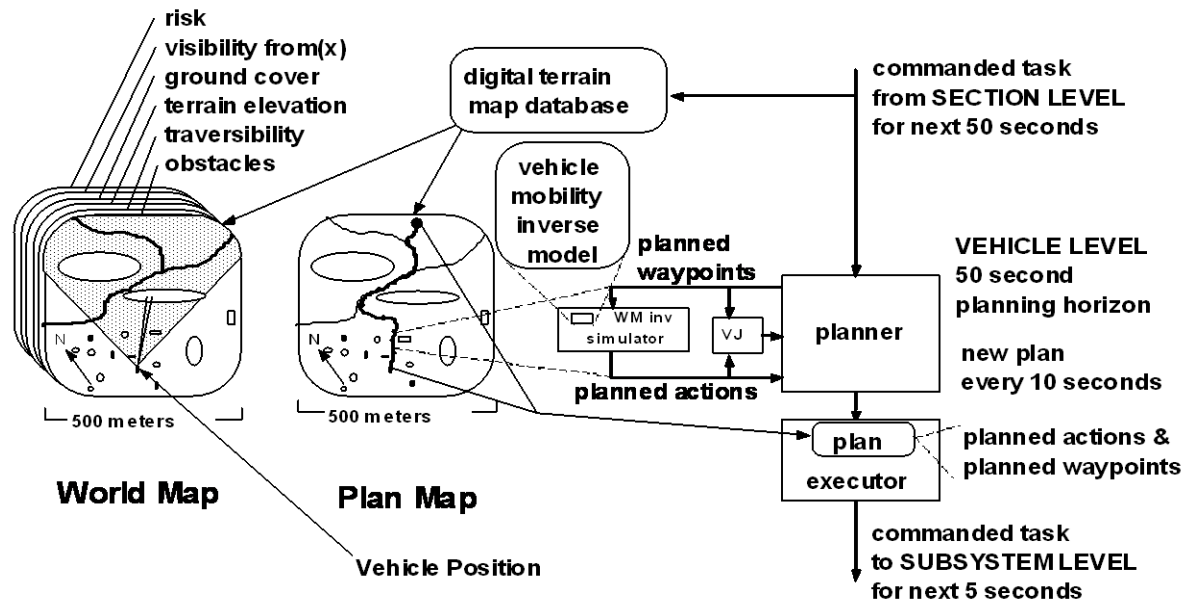
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- The 4D/RCS is a domain-independent approach to goal-directed, sensory-interactive, adaptable behavior, integrating high-level cognitive reasoning with low-level perception and feedback control in a modular, well-structured, and theoretically grounded methodology
 - It can be used to achieve full or supervised intelligent autonomy of individual platforms, as well as an overarching framework for control of systems of systems (e.g., incorporating unmanned and manned air, ground, sea surface, and undersea platforms, as well as serving as a decision tool for system of systems human controllers)



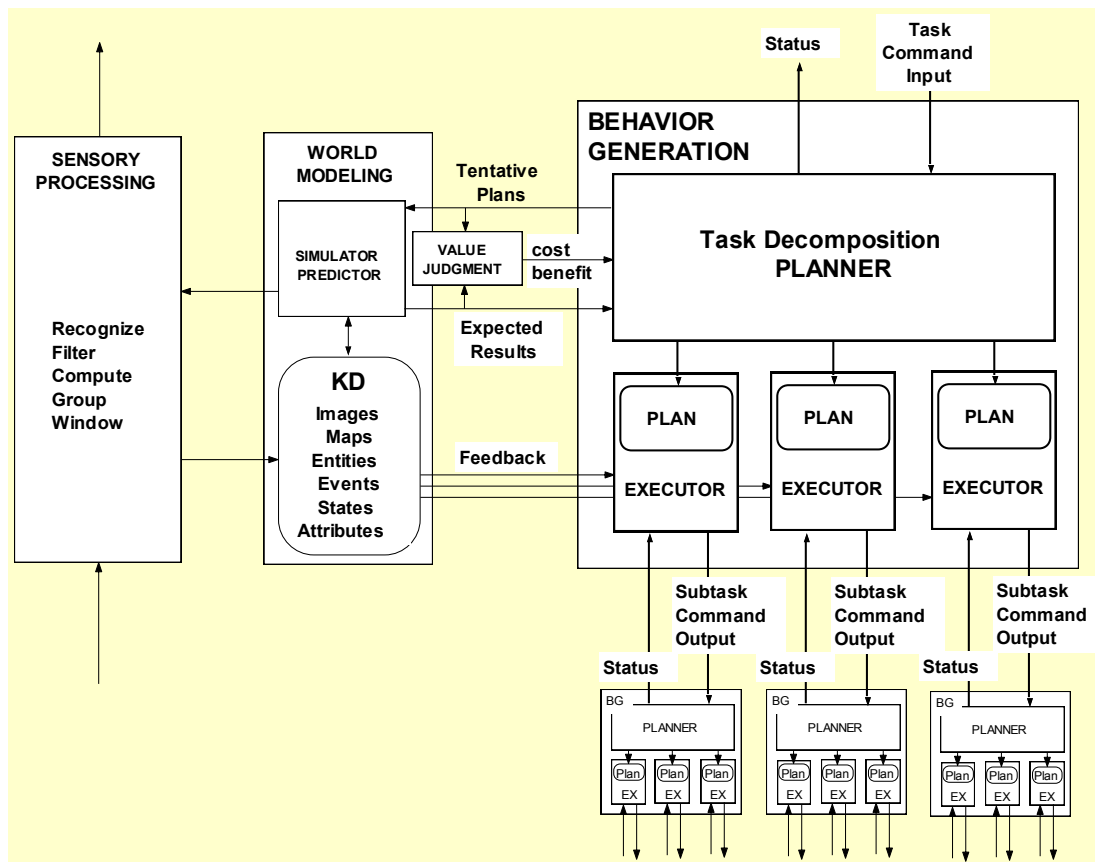
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- The 4D/RCS architecture is particularly well suited to support adaptability and flexibility in an unstructured, dynamic, tactical environment
 - It has situational awareness, and it can perform as a deliberative or reactive control system, depending on the situation
- The 4D/RCS is modular and hierarchically structured with multiple sensory feedback loops closed at every level
 - This permits rapid response to changes in the environment within the context of high-level goals and objectives



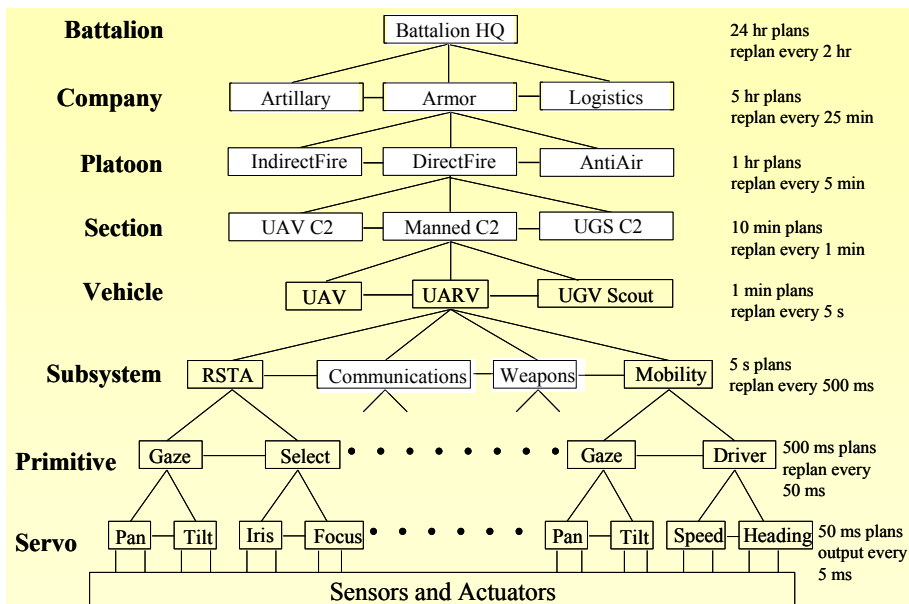
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- At the lowest (Servo) level, the 4D/RCS closes actuator feedback control loops within milliseconds
- At successively higher levels, the 4D/RCS architecture responds to more complex situations with both reactive behaviors and real-time re-planning



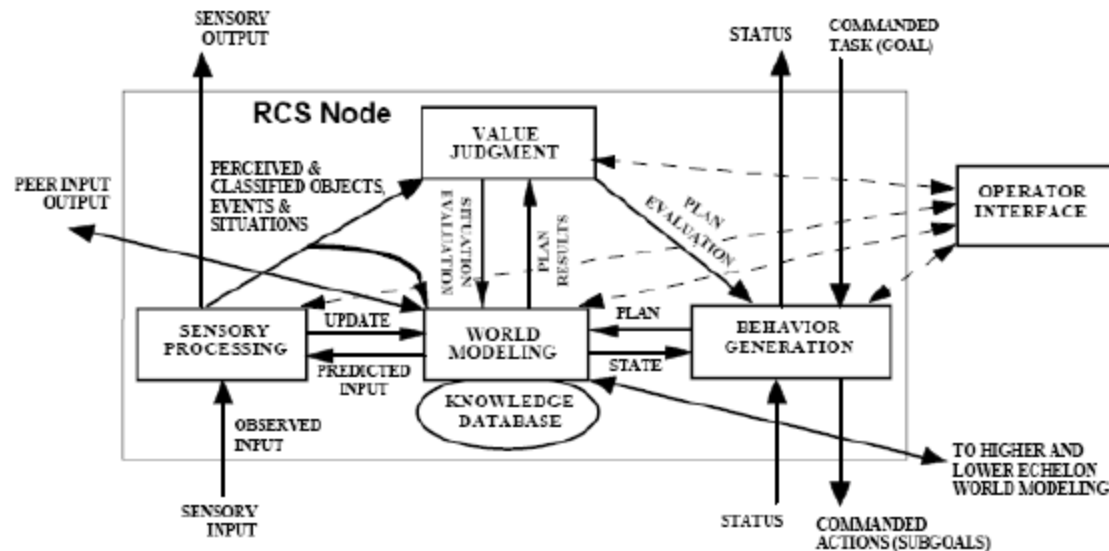
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- For example, at the second (Primitive) level, the 4D/RCS reacts to inertial accelerations and potentially catastrophic movements within hundredths of a second
- **At the third (Subsystem) level, the 4D/RCS reacts within tenths of a second to perceived objects, obstacles, and threats in the environment**
- At the fourth (Vehicle) level, the 4D/RCS reacts quickly and appropriately to perceived situations in its immediate environment, such as aiming and firing weapons, taking cover, or maneuvering to optimize visibility to a target
- **At the fifth (Section) level, the 4D/RCS collaborates with other vehicles to maintain tactical formation or to conduct coordinated actions**
- At the sixth (System of Systems) level, which has not yet been implemented, the 4D/RCS serves as an overarching intelligent control and decision system for (all or part of) a manifold of distributed unmanned and manned platforms, unattended sensors and weapons, and control centers



AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- At each level the 4D/RCS combines perceived information from sensors with a priori knowledge in the context of operational orders, changing priorities, and rules of engagement provided by a human commander
- At each level, plans are constantly recomputed and reevaluated at a range and resolution in space and time that is appropriate to the duties and responsibilities assigned to that level
- At each level, reactive behaviors are integrated with real-time planning to enable sensor data to modify and revise plans in real-time so that behavior is appropriate to overall goals in a dynamic and uncertain environment
 - This enables reactive behavior that is both rapid and sophisticated



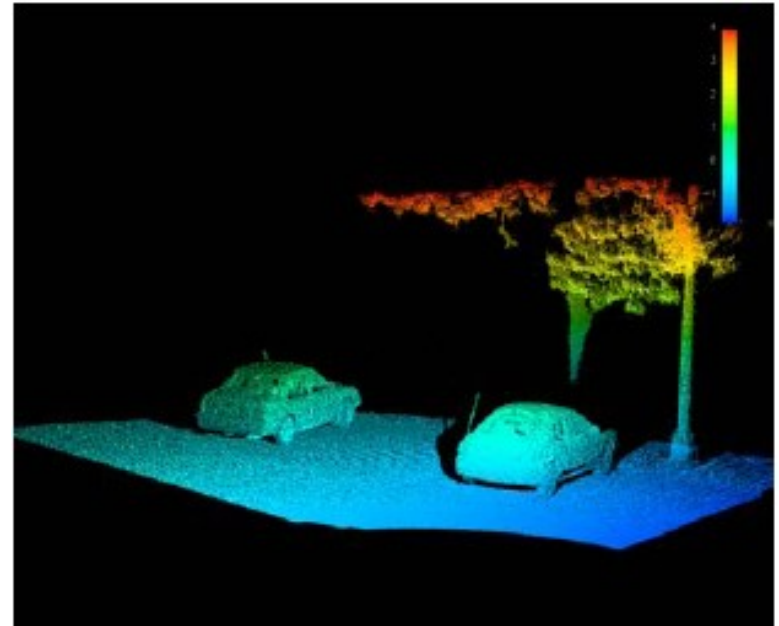
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- At the section level and above, the 4D/RCS supports collaboration between multiple heterogeneous manned and unmanned vehicles (including combinations of air, sea, and ground vehicles) in coordinated tactical behaviors
- **The 4D/RCS also permits dynamic reconfiguration of the chain of command, so that vehicles can be reassigned and operational units can be reconfigured on the fly as required to respond to tactical situations**



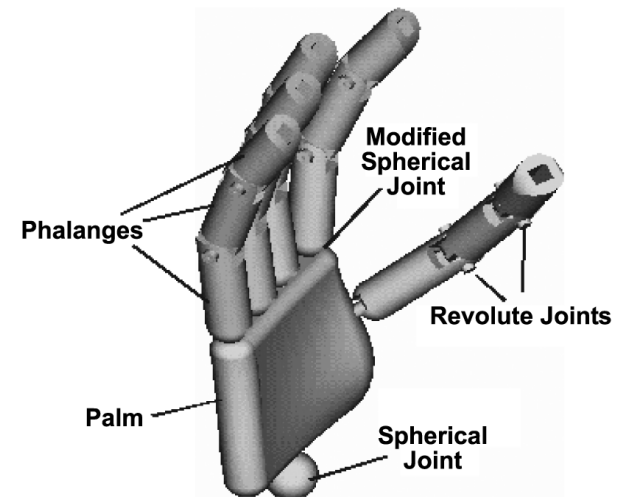
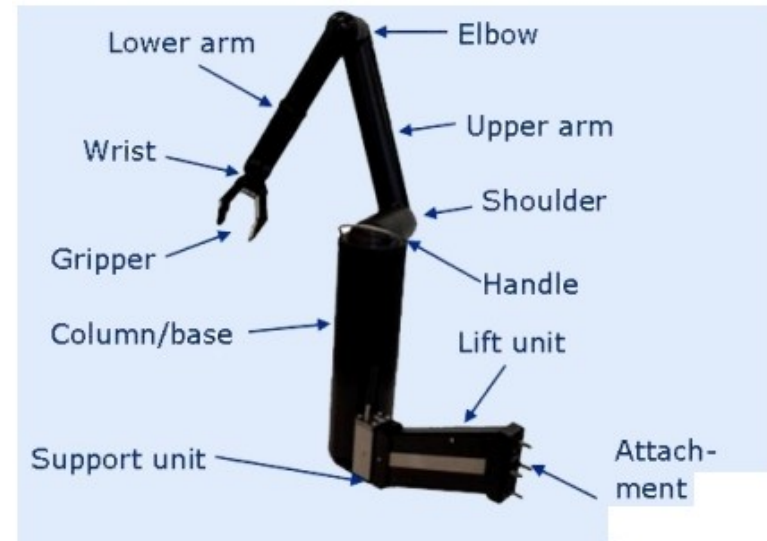
AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

- The 4D/RCS methodology maintains a layered partitioning of tasks with levels of abstraction, sensing, task responsibility, execution authority, and knowledge representation
 - Each layer encapsulates the problem domain at one level of abstraction so all aspects of the task at this one layer can be analyzed and understood
- The 4D/RCS architecture to be readily adapted to new tactical situations
 - The modular nature of the 4D/RCS enables modules to incorporate new rules from an instructor or employ learning techniques



ROBOTIC ARM AND END EFFECTOR

- Robotic arm and end effector will be attached to the robotic mobility platform, either directly or affixed to a platform towed behind the vehicle
 - It will have sufficient degrees-of-freedom, extend sufficiently from the platform, and have a sufficient payload to reach and lift appropriate materials in its vicinity
 - The end effector will consist of a multi-fingered (e.g., three-fingered or two-thumb, one-finger) hand with sufficient degrees-of-freedom to grasp and operate a cutting tool (e.g., a circular saw) to demonstrate an ability to prepare biomass for ingestion, and to grasp and manipulate biomass for ingestion



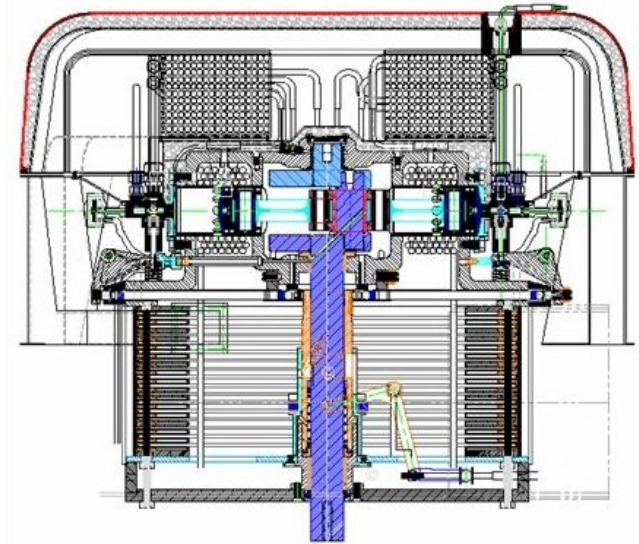
HYBRID EXTERNAL COMBUSTION ENGINE

- Source of power for EATR™: new hybrid external combustion engine system from Cyclone Power Technology Inc.
 - Integrated with a biomass combustion chamber to provide heat energy for the engine (EATR can also carry supplemental fuel, such as propane)
 - Engine will provide electric current for a rechargeable battery pack, which will power the sensors, processors and controls, and the robotic arm/end effector (battery ensures continuous energy output despite intermittent biomass energy intake)
 - Engine will not provide mobility power for vehicle for proof-of-concept, but will for EATR prototype
- Hybrid external combustion engine is very quiet, reliable, efficient, and fuel-flexible compared with the internal combustion engine



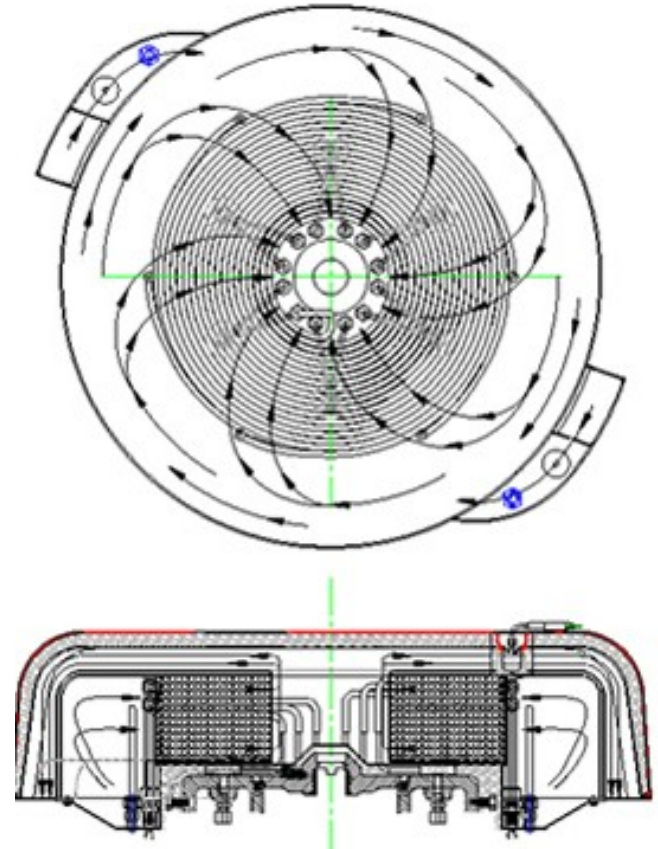
HYBRID EXTERNAL COMBUSTION ENGINE

- Unlike internal combustion engines, the Cyclone engine uses an external combustion chamber to heat a separate working fluid (de-ionized water) which expands to create mechanical energy by moving pistons or a turbine (i.e., Rankine cycle steam engine)
- **Combustion is external so engine can run on any fuel (solid, liquid, or gaseous)**
 - Biomass, agricultural waste, coal, municipal trash, kerosene, ethanol, diesel, gasoline, heavy fuel, chicken fat, palm oil, cottonseed oil, algae oil, hydrogen, propane, etc. – individually or in combination
- **A 100 Hp vehicle engine has been developed**



HYBRID EXTERNAL COMBUSTION ENGINE

- Cyclone engine is environmentally friendly because combustion is continuous and more easily regulated for temperature, oxidizers, and fuel amount
 - Lower combustion temperatures and pressures create less toxic and exotic exhaust gases
 - Uniquely configured combustion chamber creates a rotating flow that facilitates complete air and fuel mixing, and complete combustion, so there are virtually no emissions
 - Less heat released (hundreds of degrees lower than internal combustion exhaust)
 - Does not need: catalytic converter, radiator, transmission, oil pump or lubricating oil (water lubricated)
 - Decreased engine size and weight, increased efficiency and reliability



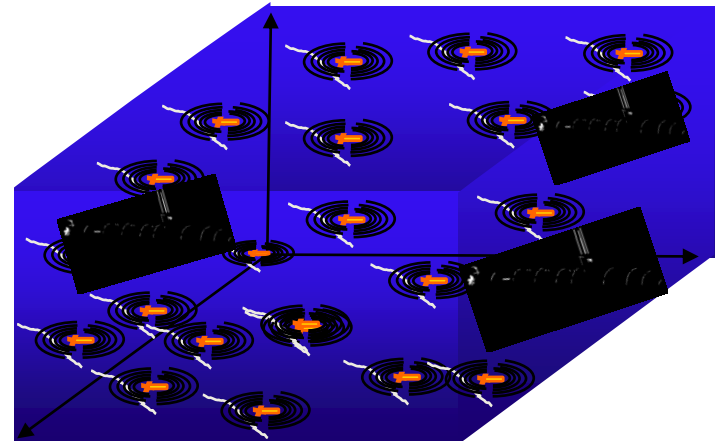
EATR: EXAMPLE ENERGY BUDGET

- **Example: 1kW recharges batteries for 1 hour (1kWh)**
 - **About 3-12 lbs of dry vegetation (wood or plants) produces 1kWh**
 - **This power translates to 2-8 miles driving or more than 80 hours of standby, or 6-75 hours of mission operations (depending on power draw and duty cycle) before needing to forage, process and generate/store power again**
- **About 150 lbs of vegetation could provide sufficient energy for 100 miles of driving**



EATR: COMMERCIALIZATION OPPORTUNITY

- Commercialization of the EATR is focused on:
 - Developing a prototype EATR for military applications and civil applications including agriculture, forestry, and homeland security
 - Evolving the NIST 4D/RCS autonomous intelligent control system for a wide variety of applications, including:
 - Unmanned air, ground, and water vehicles; robotic swarms and cognitive collectives; driverless cars; distributed intelligence; ubiquitous intelligence and intelligent infrastructures; control of complex systems of systems; decision tools for decision makers



EATR: COMMERCIALIZATION OPPORTUNITY

- We are able to fast-track the Phase III commercialization (for military and civil applications) of our technology because DARPA will match dollar-for-dollar additional funding from companies or other government agencies
 - Therefore, we are interested in teaming with organizations (government or industry) which will invest in the project in exchange for sharing in the intellectual property and commercialization of our transformational technology



EATR: COMMERCIALIZATION OPPORTUNITY

- There are currently a dozen scientists and engineers working on the EATR project
- **The University of Maryland Intelligent Systems Laboratory, the Center for Technology and Systems Management, is our subcontractor**
- **Elbit Systems of America signed on as our first Teaming Partner**
- **We have plans for five Teaming Partners during the Phase III Commercialization**



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Technology for Intelligent Decisions

