BRIEF PROJECT OVERVIEW

EATR: ENERGETICALLY AUTONOMOUS TACTICAL ROBOT

DARPA Contract W31P4Q-08-C-0292

PURPOSE

The **purpose** of the **Energetically Autonomous Tactical Robot (EATR)** ™ project is to develop and demonstrate an **autonomous robotic platform** able to perform long-range, long-endurance missions without the need for manual or conventional re-fueling, which would otherwise preclude the ability of the robot to perform such missions. The system obtains its energy by **foraging** – engaging in biologically-inspired, organism-like, energy-harvesting behavior which is the equivalent of eating. It can **find, ingest, and extract energy** from **biomass** in the environment (and other organically-based energy sources), as well as use **conventional and alternative fuels** (such as gasoline, heavy fuel, kerosene, diesel, propane, coal, cooking oil, and solar) when suitable.

The **EATR ™ system** consists of **four main subsystems**: (1) an autonomous intelligent control system and sensors; (2) a manipulator system consisting of a robotic arm and end effectors; (3) a hybrid engine system consisting of a biomass combustion chamber, a Stirling (i.e., external combustion) engine, and a multi-cell rechargeable battery; and (4) a platform system consisting of a robotically-modified High Mobility Multi-Wheeled Vehicle (HMMWV). The initial **proof-of-concept demonstration,** a Phase II Small Business Innovation Research (SBIR) project sponsored by the Defense Advanced Research Projects Agency (DARPA), will focus on the ability of the EATR to recognize biomass sources of energy from non-energy materials, properly manipulate and ingest the biomass materials into the engine system, and generate electrical power to operate the various subsystems.

This demonstration project can lead to **three potential Phase III commercialization projects**: (1) the development of prototype and operational EATR™ systems for military and civil applications; (2) new civil and military applications for the 4D/RCS autonomous intelligent control system for robotic vehicles and ubiquitous intelligence; and (3) development of the Stirling engine system for civil and military automotive applications, whether for manned or unmanned vehicles.

BACKGROUND

Unmanned Air Vehicles (UAVs) are being developed to perform long-range, long-endurance missions (such as DARPA's Vulture Program to develop a UAV capable of remaining on-station uninterrupted for over five years to perform intelligence, surveillance, reconnaissance (ISR), and communication missions over an area of interest). Likewise, there is a **need for Unmanned Ground Vehicles** (UGVs) to perform **long-range, long-endurance missions** without manual or conventional refueling (however, unlike for UAVs, solar energy alone is insufficient for most UGV energy requirements).

A robotic vehicle's **inherent advantage** is its ability to engage in long-endurance, tedious, and hazardous tasks, such as Reconnaissance, Surveillance, and Target Acquisition (RSTA) under difficult conditions, without fatigue or stress. This advantage can be severely reduced by the need for the robotic platform to replenish its fuel supply. **Example long-range, long-endurance missions** for robotic ground vehicles include: RSTA missions in the mountains and caves of Afghanistan and Pakistan; search missions for nuclear facilities and underground bunkers in rogue nations; special operations and counter-insurgency; patrolling remote borders; homeland security; serving as nodes in distributed and remote command, control, communications, and intelligence (C3I) networks; and serving as remote, mobile sensor and target tracking platforms in ballistic missile defense systems. Either strategically or tactically, **long-range, long-endurance UGVs can work cooperatively with – and complement – long-range, long-endurance UAVs,** such as the **DARPA Vulture project** to develop a heavier-than-air craft that can keep a 1,000-pound payload aloft for five years.

TECHNICAL OBJECTIVES

The initial objective is to **develop and demonstrate a proof-of-concept system**. Demonstration of a full operational prototype is the objective for a Phase III commercialization project.

The project will **demonstrate** the ability of the EATR™ to: (1) **identify** suitable biomass sources of energy and distinguish those sources from unsuitable materials (e.g., wood, grass, or paper from rocks, metal, or glass); (2) spatially **locate and manipulate** the sources of energy (e.g., cut or shred to size, grasp, lift, and ingest); and (3) **convert** the biomass to sufficient electrical energy to power the EATR™ subsystems.

The EATR™ system has **four major subsystems**: a robotic mobility platform subsystem; an autonomous, intelligent control and sensor subsystem; a robotic arm and end effectors subsystem; and a hybrid external combustion (Stirling-cycle) engine subsystem.

Robotic Mobility Platform

The autonomous robotic mobility platform may consist of any suitable automotive vehicle, such as a robotically-modified High Mobility Multi-Wheeled Vehicle (HMMWV), or a purely robotic vehicle. The platform provides mobility for the mission and mission payload, and, for our proof-of-concept purposes, accommodation for the EATR™ subsystems.

The robotic mobility platform is **not** the focus of this project, nor is it essential for the EATR™ proof-of-concept demonstration. However, it will be included to provide a more **realistic system context** than a laboratory "breadboard" type demonstration of the

EATR™ subsystems. The vehicle may, in fact, be either an autonomous or telerobotic HMMWV, although its movement (including cross-country path planning and obstacle avoidance) will be an **optional** part of the proof-of-concept demonstration. The subsystems, for example, might be mounted on a trailer attached to the vehicle.

Autonomous Intelligent Control

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™. The 4D/RCS has been under development by the Intelligent Systems Division of the National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce, for more than three decades with an investment exceeding $125 million. The NIST 4D/RCS has been demonstrated successfully in various autonomous intelligent vehicles, and a variation of the 4D/RCS serves as the Autonomous Navigation System (ANS) mandated for all robotic vehicles in the Army's Future Combat System (an additional investment of $250 million). NIST is providing assistance in transferring the 4D/RCS technology for the EATR™.

The control subsystem will also include the **sensors** needed for the demonstration (e.g., optical, ladar, infrared, and acoustic). While the NIST 4D/RCS architecture is capable of autonomous vehicle mobility, it will be used in this project 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; and control the operation of the **hybrid Stirling engine** to provide suitable power for the required functions.

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 **several types of intelligence** (where *intelligence* is the ability to make an *appropriate* choice or decision):

(1) **Reactive intelligence** based on an autonomic **sense-act** modality which is the ability of the system to make an appropriate choice in response to an immediate environmental stimulus (i.e., a threat or opportunity). **Example:** the vehicle moves toward a vegetation sensed by optical image processing.

(2) **Deliberative intelligence**, which includes **prediction** and **learning,** which is based on world models, memory, planning, and task decomposition, and includes the ability to make appropriate choices for events that have not yet occurred but which are based on prior events. **Example:** the vehicle moves downhill in a dry area to search for wetter terrain which would increase the probability of finding biomass for energy.

(3) **Creative intelligence**, which is based on learning and the ability to cognitively **model and simulate** and it is the ability to make appropriate choices about events which have **not yet been experienced.** **Example:** from a chance encounter with a dumpster, the vehicle learns that such entities are repositories of paper, cardboard, and other combustible materials, and develops tactics to exploit them as energy-rich sources of fuel.

Robotic Arm and End Effector

The **robotic arm and end effector** will be attached to the robotic mobility platform, either directly or affixed to a platform towed behind the HMMWV. 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

The source of power for EATR™ is a hybrid external combustion (i.e., Stirling) engine. The **Stirling engine** will be integrated with a **biomass combustion chamber** to provide heat energy for the Stirling cycle. The Stirling engine will then provide electric current for a rechargeable **battery pack**, which will power the sensors, processors and controls, and the robotic arm/end effector. (The battery compensates for the inability of the Stirling engine to provide instantaneous power). For our proof-of-concept demonstration, the Stirling engine will not provide mobility power for the vehicle.

The Stirling engine is very **quiet, reliable, efficient, and fuel-flexible** compared with the internal combustion engine, but its specific power is relatively low, especially for automotive applications. A hybrid system allows the battery to provide immediate and sufficient power to the vehicle (as with a hybrid automobile with an internal combustion engine), as well as serving as an energy storage system for autonomous foraging robots.

COMMERCIALIZATION

Our vision is that this demonstration project will lead to **three potential Phase III commercialization projects**: (1) the development of prototype and operational EATR™ systems for military and civil applications; (2) new civil and military applications for the autonomous intelligent control system; and (3) development of the Stirling engine system for civil and military automotive applications, whether for manned or unmanned vehicles.

EATR™

In Phase III, EATR™ will be commercialized for **long-range, long-endurance military missions**, but it also has **civil applications** as well – wherever vehicles must function in wilderness areas for extended periods of time, such as for forestry, exploration, natural resource monitoring, fire protection, and border patrol. Agriculture, for example, is a particularly promising application, where energy-intensive vehicles such as tractors and harvesters could glean their energy directly from waste biomass in the field.

AUTONOMOUS INTELLIGENT CONTROL: 4D/RCS

The Phase III commercialization of the 4D/RCS autonomous intelligent control system promises to be the **most significant** opportunity. In addition to its potential for achieving a high level of performance – and ultimately cognition – in various kinds of robots, it will serve as the basis for ubiquitous intelligence: the ability to insert intelligence into entities and facilities of all kinds. With sensors and voice interaction, we will be able to converse with our walls without having lost our sanity.

The 4D/RCS can serve as the basis as a decision tool for managing **complex systems of systems**, whether for the **military** (as for the Future Combat System (FCS) where it could provide an overarching decision framework for ground and air robotic and manned platforms, or **civil applications** such as for traffic control or management of large organizations. In a corporation, for example, historical and real-time data can flow into the system concerning sales, competition, investors, geopolitics, environmental conditions, etc. (instead of data from sensors for robotic control) and the processed data can flow through the world model and task decomposition modules to provide suggested courses of action to decision makers (or be allowed to act autonomously for some decisions). Large interactive displays can show the system's real-time interaction embodying the corporation's classic SWOT analysis: Strengths, Opportunities, Weaknesses, and Threats.

HYBRID STERLING ENGINE

Once every generation since the dawn of the automotive age in 1900, the Stirling engine has been examined for potential use in cars and trucks. It has always been discarded for various reasons – a major failure has been its inability to provide sufficient instantaneous power for acceleration. However, **hybrid car technology** is now readily available for internal combustion engines, so the battery pack can be used to power cars and trucks where the external combustion engine is used to charge the batteries instead of the internal combustion engine. There are other problems (such as size and weight) to be overcome, but for over a century the internal combustion engine has had billions of dollars invested in achieving its level of performance while the external combustion engine has languished.

Given that the Stirling engine can be designed to be **extremely fuel flexible and efficient**, there are many prospective **commercialization opportunities** with **civil automotive applications** for the Stirling engine, although a focused R&D program is needed to reduce its size and increase its efficiency. In an era of energy uncertainties, it would allow vehicles to be **highly adaptive** in their sources of fuel, including conventional and unconventional fuel (e.g., gasoline, diesel, heavy fuel, kerosene, propane, biomass, paper and cardboard, used cooking oil, and solar). An automotive Stirling engine would be **quiet** and **environmentally friendly**.