BIOMORPHIC EXPLORERS LEADING TOWARDS A ROBOTIC ECOLOGY

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BIOMORPHIC EXPLORERS

- COOPERATIVE BEHAVIORS OF VERSATILE MOBILE ENTITIES
  - INTERDEPENDENCE
  - EFFICIENT USE OF NATURAL AND EXISTING RESOURCES

- TO PROVIDE EXTENDED SURVIVAL AND USEFUL LIFE OF THE ROBOTS TOWARDS FULFILLMENT OF THE MISSION/APPLICATION
BIOMORPHIC EXPLORERS

- SMALL, DEDICATED, LOW-COST EXPLORERS THAT CAPTURE SOME OF THE KEY FEATURES OF BIOLOGICAL EXPLORERS
  - VERSATILE MOBILITY: aerial, surface, subsurface, and in fluids
  - ADAPTIVE, DISTRIBUTED OPERATION
  - BIOMORPHIC COOPERATIVE BEHAVIOR
- CONDUCTED WORKSHOP, AUG 19-20, 1998
  - SPONSORED BY NASA/JPL
  - VERY SUCCESSFUL; OVER 150 PARTICIPANTS
ADVANCED MOBILITY FOR BIOMORPHIC EXPLORERS

RECONFIGURABLE MOBILE UNITS
BIOMORPHIC EXPLORERS: SIZE BASED CLASSIFICATION

Volume Envelopes (cm³)

A

B

C

Basic Configurations

Modeled After

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Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Surface/Subsurface

Biomorphic Surface Systems

Biomorphic Subsurface Systems

Seed Wing
Honey Bee
Ant
Centipede
Soaring Bird
Humming Bird
Snake
Earthworm
Germinating Seed
Jelly Fish

Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class

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Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial

Seed Wing Flyer (60 g)
Ornithopter

Glider (75 g)
Powered Flyer

Surface/Subsurface

Biomorphic Surface Systems

Hexapod (1-2 kg)
Reconfigurable Legs/Feet

Artificial Earthworm

Biomorphic Subsurface Systems

Artificial Jelly Fish

Worm Robot (85 g)

Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses
Biomorphic Flight Systems: Vision

- Extended reach over all kinds of terrain
- Unique perspective for imaging and Spectral Signature
- Many flyers work in cooperation with larger aircraft, and balloons to enable new missions to reach currently inaccessible locations
BIOMORPHIC EXPLORERS

BIOMORPHIC FLIGHT SYSTEMS

a. Seed Wing Pod

TOTAL MASS: 57 g
PAYLOAD MASS: 48 g

b. Seed Wing Pod Flyer

TOTAL MASS: 57 g
PAYLOAD MASS: 32 g

c. Biomorphic Glider

TOTAL MASS: 57 g
PAYLOAD MASS: 6 g

d. Biomorphic Flyer

Biomorphic flight systems offer rapid mobility and extended reach. For comparison, the above illustrates for the same total mass of the system, the respective payload fractions in each case.
COOPERATIVE ORGANIZATION OF LANDER, ROVER, AND A VARIETY OF INEXPENSIVE BIOMORPHIC EXPLORERS WOULD ALLOW COMPREHENSIVE EXPLORATION AT LOWER COST WITH BROADER COVERAGE.
Insects operating cooperatively:

Ants’ elaborate communication method with pheromone trails

Honeybee’s recruitment dance with the sun as a celestial reference

Nakamura and Kurumatani, 1995
Kubo, 1996

Karl von Frisch, 1965
Wehner and Rossel, 1985
Barbara Shipman, 1997
BIOMORPHIC EXPLORERS

PAYOFF

BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE

- EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS
- MUCH BROADER COVERAGE OF EXPLORATION SITES
- EXPLORATION AT LOWER COST
BIOMORPHIC EXPLORERS

Biomorphic Glider Deployment Concept: Larger Glider Deploy/Local Relay

- Probe enters atmosphere
- Parachute deployed
- Heat shield released and antenna deployed (14 km)
- Larger Aircraft (Large Glider) released (13 km)
- Large Glider flies preset flight plan deploying the biomorphic gliders

Local relay collects and transmits data to orbiter

Gliders transmit data to local relay.

LARGER GLIDER

COM PORT 1
COM PORT 2
JAVELIN

LANDER ROVER
Surface measurements

Biomorphic Gliders perform in-flight measurements (42 km to surface)

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Biomorphic Glider Deployment Concept: Balloon Deploy/Dual Relay

- Balloon probe transmits data to orbiter.
- Gliders released as balloon drifts downwind.
- Gliders transmit data to balloon probe.
- Glider in-flight measurements
- Glider surface observations

Winds Aloft

COM PORT 2

COM PORT 1 LANDER ROVER

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BIOMORPHIC EXPLORERS

Biomorphic Explorer: Conceptual Design

BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL
ALGORITHMS

μSENSORS

RECONFIGURABILITY
ADVANCED MOBILITY
μNAVIGATION

μCOMMUNICATION
TEMPERATURE CONTROL
μSTRUCTURE
μCOMPUTING
μPOWER

GLIDER BASELINE DESIGN CHARACTERISTICS

• MASS: 75 g
• PAYLOAD FRACTION: 60 %
• GLIDE RATIO, L/D ~ 5.8
• LARGE RANGE OF AERIAL MOBILITY:
  ~ 50 km to 100 km
• LEVERAGE FROM MAV TECHNOLOGY

• VOLUME: 300 cm³
• ACTIVE FLIGHT CONTROL
• SOLAR NAVIGATION
• SOARING FLIGHT IN RISING CURRENTS
• COOPERATIVE MISSION: 32 GLIDERS
• COVERAGE AREA: ~ 100 km x 100 km

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BIOMORPHIC EXPLORERS

Biomorphic Gliders

- Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.
  - small mass (100 g - 500 g)
  - low radar cross section
  - larger numbers for given payload due to low mass
  - amenable to cooperative behaviors
  - missions use potential energy: deploy from existing craft at high altitude
  - Captures features of soaring birds, utilizing rising currents in the environment
  - Adaptive Behavior
  - Self Repair features
**Vulture**

For vultures and many other large birds, flying involves little effort. They hold their wings out and rise high into the sky by soaring — circling upward on columns of rising warm air called thermals. At the top of one thermal, they glide gently down in search of the next.

* Bird Photo by R.W. Scott and G. J. Scott
Biomorphic Glider Deployment/Telecommunication Concept

Probe enters atmosphere
Parachute deployed

Relay to Earth

Heat shield and gliders released (12-14 km).

In flight measurements (12 km to surface)

Gliders transmit data to local relay using self-organized, self-routing network, which changes dynamically during the flight and after landing, to communicate optimally the information to the local relay

LANDER ROVER

COM PORT 1

JAVELIN

COM PORT 2

Surface measurements
Applications

- Distributed Aerial Measurements
  - Ephemeral Phenomena
  - Extended Duration using Soaring

- Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents)

- Close-up Imaging, Site Selection
  - Meteorological Events: storm watch
  - Reconnaissance
  - Biological Chemical Warfare
  - Search and Rescue etc
  - Surveillance
  - Jamming
BIOMORPHIC EXPLORERS

Demonstrated optical correlator can be miniaturized to fit in a small interceptor

**OPTICAL CORRELATOR SCHEMATIC**

- Diode Laser
- Input SLM
- Lens
- Beam Splitters
- Fourier Transform
- Filter SLM (Reflective)
- CCD Detector

**BMDO FUNDED CAMCORDER-SIZED GRAYSCALE OPTICAL CORRELATOR**

JPL - 1998

**MATCH-BOX SIZED OPTICAL CORRELATOR TO BE DELIVERED FOR DOD AND NASA APPLICATIONS**

*Optical correlator provide wide-area search and track at the speed of light independent of sensor resolutions*

**JPL'S OPTICAL CORRELATOR SETUP INSIDE THE VIGILANTE INSTRUMENT TRAILER DURING TEST AT MOJAVE (NOV. 1998)**

**VIGILANTE sensor platform and trailer**

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BIOMORPHIC EXPLORERS

Background for 3-Dimensional Artificial Neural Network (3DANN)

10 gm, 5 cc, 2 W
On-chip IR detector
1 trillion 8-bit multiplies/sec
270 million template matches/sec
Compute power greater than fast supercomputer

3D Artificial Neural Network (3DANN)

AI neural network chip design enables the 3DANN technology that delivers unprecedented processing speed for ATR.
BIOMORPHIC EXPLORERS

SUMMARY & ROADMAP

Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost

BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL ALGORITHMS

μSENSORS

μCOMMUNICATION
TEMPERATURE CONTROL
μSTRUCTURE
μCOMPUTING
μNAVIGATION
μPOWER
ADVANCED MOBILITY

* Bird Photo by R.W. Scott and G. J. Scott

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