LDART: A Large Scale Network of Embedded Systems for Laser Detection and Reciprocal Targeting

Authors: Jathan Manley, Robert DeMers, Jan Jelinek, Michael Rhodes, Jay Schwichtenberg, Vicraj Thomas, Brian VanVoorst, Phil Zumsteg

Honeywell Labs
3660 Technology Drive
Minneapolis, MN 55418

jathan.manley@honeywell.com

Areas: Networked Embedded Systems, Embedded Computing for Global Sensors and Information Dominance, Case Study Examples of High Performance Embedded Computing,

I. LDART Application and Concept of Operations

LDART (Laser Detection And Reciprocal Targeting) is a novel military application developed by Honeywell under the DARPA NEST program[1]. LDART provides battlefield situational awareness by detecting if a soldier or vehicle has been painted by a battlefield laser (target designator, range finder, etc.) and determines a precise position of the source (within ±0.06º). It can also be configured to reciprocally designate an enemy laser source or communicate a combat ID to a friendly laser system. LDART, in addition to providing situational aware capabilities, allows the asset to take evasive action and possibly take offensive action against the enemy.

LDART can be used in three configurations. 1. LDART interfaced with a situation awareness system such as an Objective Force Warrior helmet mounted display or a vehicle cockpit display—the warrior would be warned almost instantly that he has been targeted and, shortly thereafter, be informed of the direction of the laser source. 2. LDART with a slave computer controlled designator to reciprocally target an OPFOR laser source. 3. LDART with embedded VCSEL (Vertical Cavity Surface Emitting Laser) elements to reciprocally target an OPFOR laser or send a coded friend-or-foe signal.

II. LDART Technology

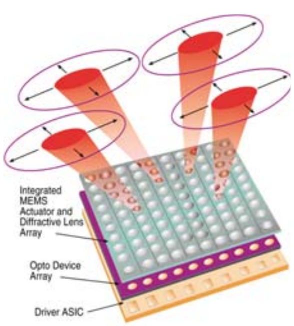


Figure 1: Micro Lens Array

It is envisioned that LDART will be deployed as a "patch" that can be placed on military assets. The LDART "patch" consists of a network of embedded systems that co-operatively recognize, locate, and respond to hostile or friendly lasers in the battlefield. LDART is based on a network of steer-able MEMS micro lenses, currently being developed by Honeywell under the DARPA STAB program, and is controlled by a computational and communications fabric.

An LDART "patch" consists of tens of thousands 1 mm^2 "cells" (See Figure 1). Each cell contains a single micro lens (0.1mm∅) that can be independently steered in 2-axes. Beneath each lens is a detector or emitter. Each cell also contains a small computational element that controls the lens, reads the detector or controls the emitter (See Figure 2). Each computational element is networked to its four nearest neighbors.

[1] This work is funded by the DARPA/IXO NEST program under contract number F33615-02-C-1175.

Report Documentation Page					*Form Approved OMB No. 0704-0188*

1. REPORT DATE **20 AUG 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **LDART: A Large Scale Network of Embedded Systems for Laser Detection and Reciprocal Targeting**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Honeywell Labs 3660 Technology Drive Minneapolis, MN 55418**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001694, HPEC-6-Vol 1 ESC-TR-2003-081; High Performance Embedded Computing (HPEC) Workshop (7th)., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**24**	

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

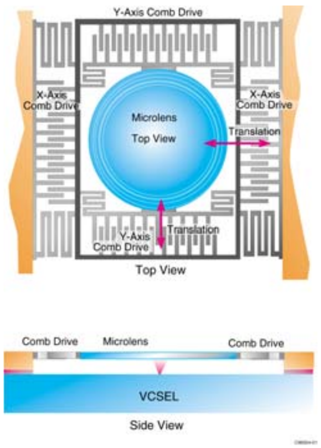


Figure 2: Micro Lens Details

Control of LDART is distributed among the computational elements. Each cell controls its own sensors and actuators, but many cells must cooperate to accurately locate incoming laser sources. During operation, nodes form dynamic groups that solve subtasks in the application: what nodes will track a target, what nodes should paint back and the handling of communications off "patch". Control must also tolerate faults in individual nodes should the "patch" become partially damaged.

Advantages of the LDART design include (1) The large numbers of MEMS sensors (10^5) allows a single patch to cover a wide total field of view, (2) The simultaneous use of a large number of sensors mitigates error in position measurements, and (3) The tight coupling of sensor and data processing and the ability to communicate with other sensor/processor pairs enables these sensors to cooperatively identify, locate and respond to hostile or friendly battlefield lasers quickly in a changing battlefield.

III. LDART Development

The LDART MEMS hardware is currently under development. In the meanwhile, development of the distributed control for LDART is taking place on a macro platform that is, whenever possible, a faithful representation of the future MEMS system. The macro system has many advantages ranging from cost (ability to use many COTS parts) to easing experimental complexity (viewing platform at work with the naked eye).

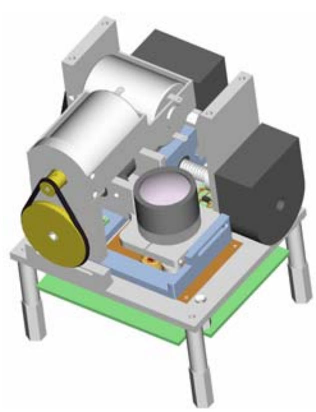


Figure 3: Macro Lens Assembly

The macro platform consists of a collection of 2-axis, lens translating stages, and an FPGA-based compute element. Each optical stage contains both a detector and an emitter so each stage can be used for either role in the macro system (See Figure 3). Despite the platforms larger size, there are still stringent mechanical requirements. In order to accurately find targets the lens positioning accuracy must be within 3µm; however, it is important to maintain high speed movement to enable target tracking.

The compute element consists of a single FPGA (Altera APEX 20KE) that hosts a small 32-bit microprocessor and additional custom logic for low-level controls and remote circuit interfaces. This platform has two major advantages. (1) A port of µClinux from Microtronix allowed the use of a standard Linux development environment. (2) The FPGA made implementing hardware and software extremely fast and flexible by allowing easy trade-offs between hardware and software implementations of low-level controls. For example, low-level stage positioning controls are implemented in hardware on the FPGA while the distributed control algorithms are implemented in software.

IV. Status

Currently, the macro platform is a 3×3 array of optical stages able to detect a simulated battlefield laser and target it back. As the experimental platform continues to grow it is expected that a target will be accurately tracked, simulating the designation of a moving asset. Transition to the MEMS-based platform should begin the fourth quarter of this year.

Overall, the prolific use of battlefield laser systems necessitates a system that can quickly sense and react to these threats. The LDART system provides this unique and needed capability in a small form factor that can protect both soldier and vehicle on the new battlefield.

LDART

A Large Scale Network of Embedded Systems for Laser Detection and Reciprocal Targeting

Jathan Manley, Robert DeMers, Jan Jelinek, Michael Rhodes, Jay Schwichtenberg, Vicraj Thomas, Brian VanVoorst, Phil Zumsteg

This work is funded by the DARPA/IXO NEST program under contract number F33615-02-C-1175

Points of Contact

- Honeywell
  - Vic Thomas (vic.thomas@honeywell.com)
  - Jathan Manley (jathan.manley@honeywell.com)
- DARPA
  - Dr. Vijay Raghavan, Program Manager (IXO)

Outline

- LDART Application and Concept of Operations
- LDART Technology – MEMS Implementation
- LDART Development Efforts – A Macro Platform
- Current Status

LDART: Laser Detection & Reciprocal Targeting

- A lightweight, easy-to-deploy technology for improved battlefield situation awareness
- Implemented as a "patch" attached to a soldier or vehicle
- Combines capabilities provided by multiple systems into one small package
  - Detect if soldier/vehicle has been painted by laser
  - Accurate location of source of laser (new capability)
  - Friend-or-foe identification
  - Reciprocal targeting (new capability)
- Functions are easily separable
- Can interface with existing systems
  - Situation awareness systems
    - e.g., Objective Force Warrior displays and vehicle cockpit display systems
  - Target designators

DARPA Honeywell

LDART: Laser Detection Capabilities

- Detect when soldier/vehicle has been painted by laser
  - Range finder
  - Target designator
  - Beam rider
  - Spotting Beam
  - Battlefield illuminator
- Can identify direction of laser source
  - Within ? 0.06 degrees (?1m for source at 1km)
- Can estimate distance of laser source
  - Accuracy depends of distance of source and size of patch
  - 1m^2 patch can estimate distance of target at 1km within ?30m
  - Greater accuracy for closer sources
- Continues to track direction and distance of source even as source and target move relative to each other

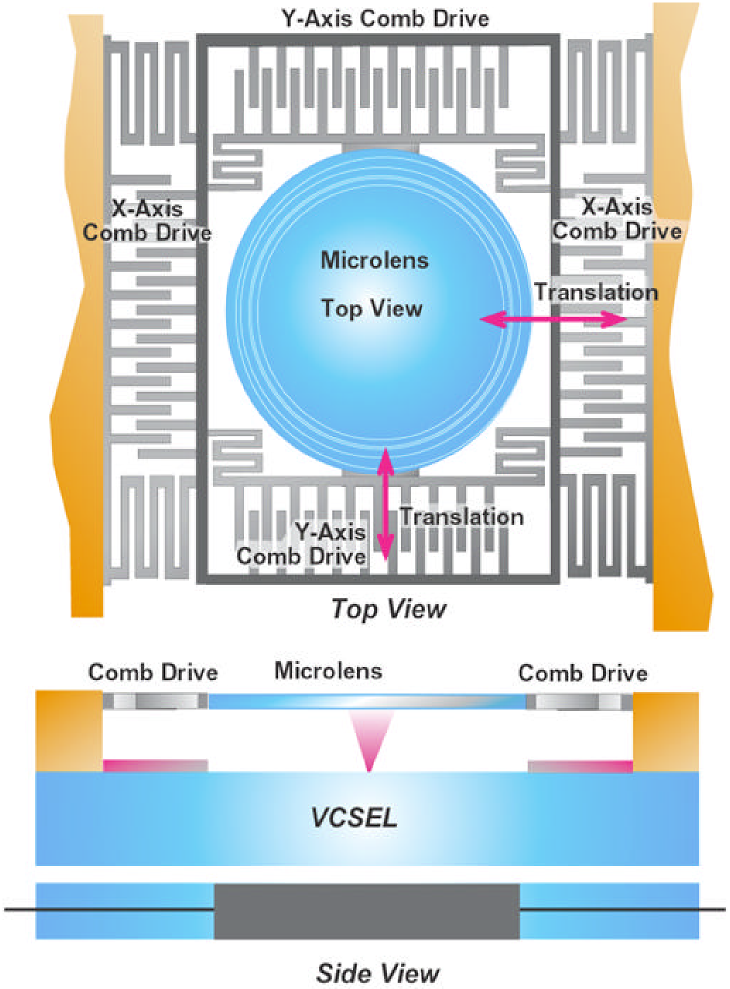
Target Designator

Range Finder

DARPA Honeywell

LDART: Hardware Technology

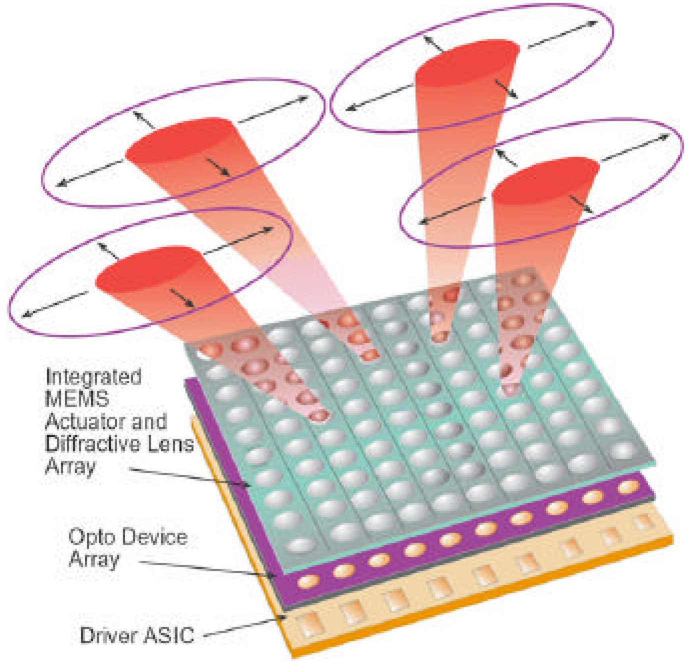
- Hardware based on MEMS technology being developed by Honeywell
  - Sponsored by the DARPA/MTO STAB program
- The LDART "fabric" consists of a large number of cells
  - Cell size: 1 mm^2 (~40,000 cells in 8inX8in area)
- Each cell consists of
  - A micro-lens (0.1mm diameter)
  - Drives to move lens in x and y directions
  - Detector or laser under the lens at its optical axis
  - Compute element to control cell
  - Communication links to neighboring cells



Top and Side View of a Single Cell

LDART: Hardware Technology

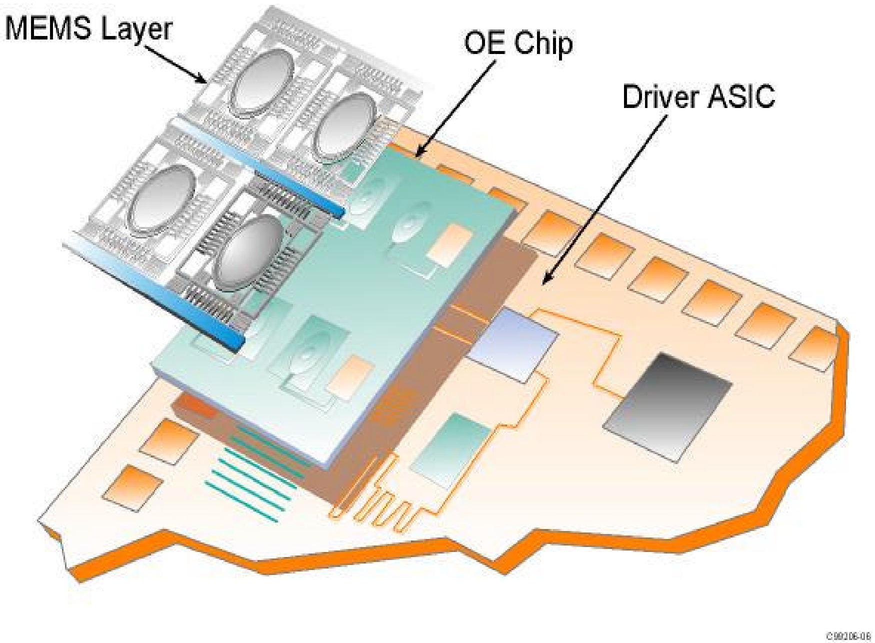
- Incoming laser beam can be steered onto detector by moving lens
  - Lens position used to determine incident angle of beam
  - Lens positioning accuracy: 0.0005mm
- Outgoing (paintback) laser beam can be steered by moving lens



LDART "Fabric" with Large Number of Cells

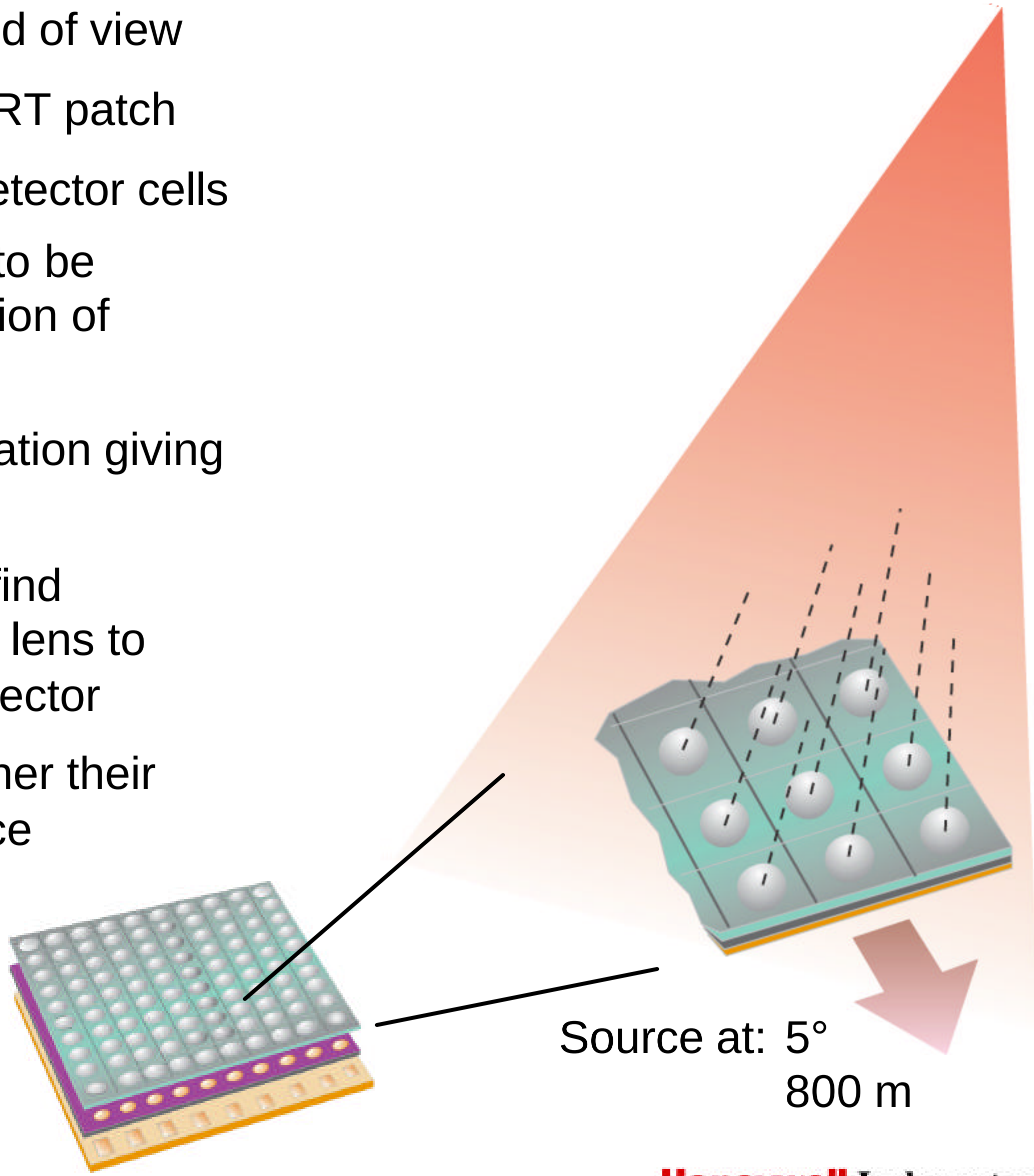
MEMS Details

- Lens/sensor/actuator assembly
  - Size: <1 sq. mm
- Lens
  - Diameter: ~0.1 mm
  - Travel: ~0.05 mm in X & Y
  - Resolution: ~0.0005 mm (0.5 µm)
  - Speed: 5-10 KHz
  - Focal length: 0.12/0.32 mm
  - Refractive index: 3.4



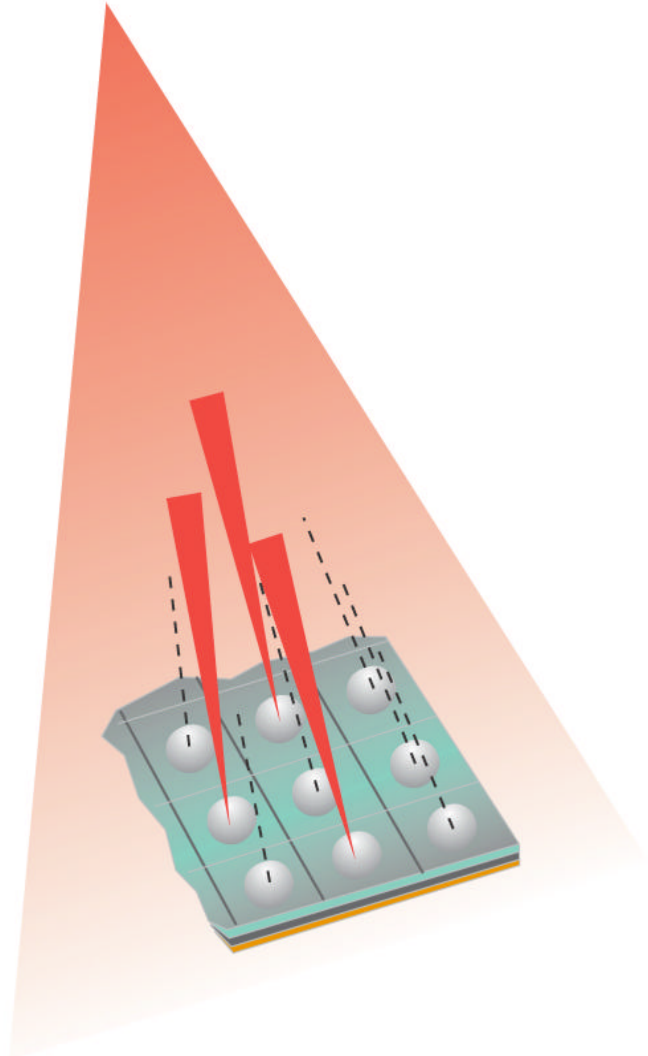
LDART: Laser Detection Overview

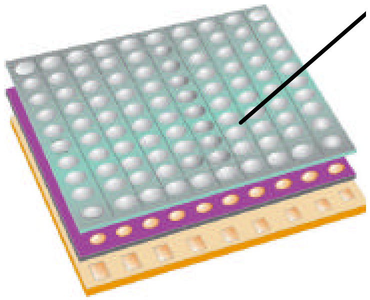
- Cells oriented to cover entire field of view
- Light from laser illuminates LDART patch
- Illumination detected by some detector cells
  - Cells whose lens happened to be pointing in the general direction of source
- Cells inform neighbors of illumination giving general direction of source
- Each cell independently tries to find direction of source by moving its lens to maximize energy seen by its detector
- Cells communicate with each other their estimate of the direction of source
- Cells estimate distance to source using triangulation



LDART: Reciprocal Targeting Overview

- After laser source is detected, set of cells is selected to do paintback
- Cells coordinate to determine code to be pulsed during paintback
- Cells paint back in a coordinated fashion
- Cells track target as it moves relative to LDART



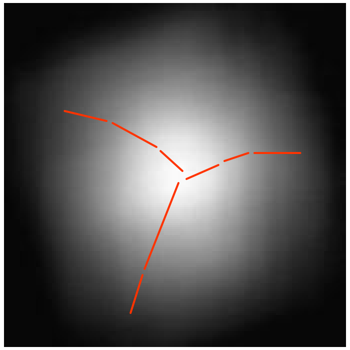


LDART: Features

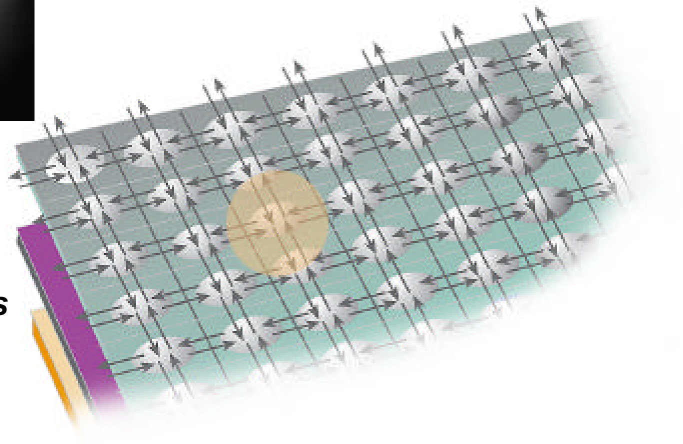
- Light weight
  - 8in X 8in patch: approx. 90 grams for MEMS hardware + approx. 250 grams for packaging
- Low power
  - Idle state (all lenses holding position): ?5mW for 8in X 8in patch
  - If all lenses are moving (unlikely): ? 5W for 8in X 8in patch
  - Paintback energy: ? 5mW per laser
- Accurate
  - Can locate source at 1km within ±1m (tangential) and ±30m (radial)
- Low cost
  - Estimate few hundred dollars for each patch
- Easy to deploy
  - Attached as patch of soldier/vehicle/asset
  - One system performs multiple functions

LDART: Software Technology

- LDART control distributed over the tens of thousands of cells
- Cells collect their own observations and use data from other cells
- Advantages of distributed control
  - Much greater accuracy as errors are averaged
  - Greater fault tolerance
- Cells collaborate by exchanging data
  - Their own data on energies detected, location computed, etc.
  - By passing on data from other cells
- Each cell creates a table of observations from which it calculates where to move
  - For finding a moving laser
  - For painting back its own laser



Paths taken to find strongest energy. Each node takes four samples to compute a vector towards center.



Information Exchanged Between Nodes

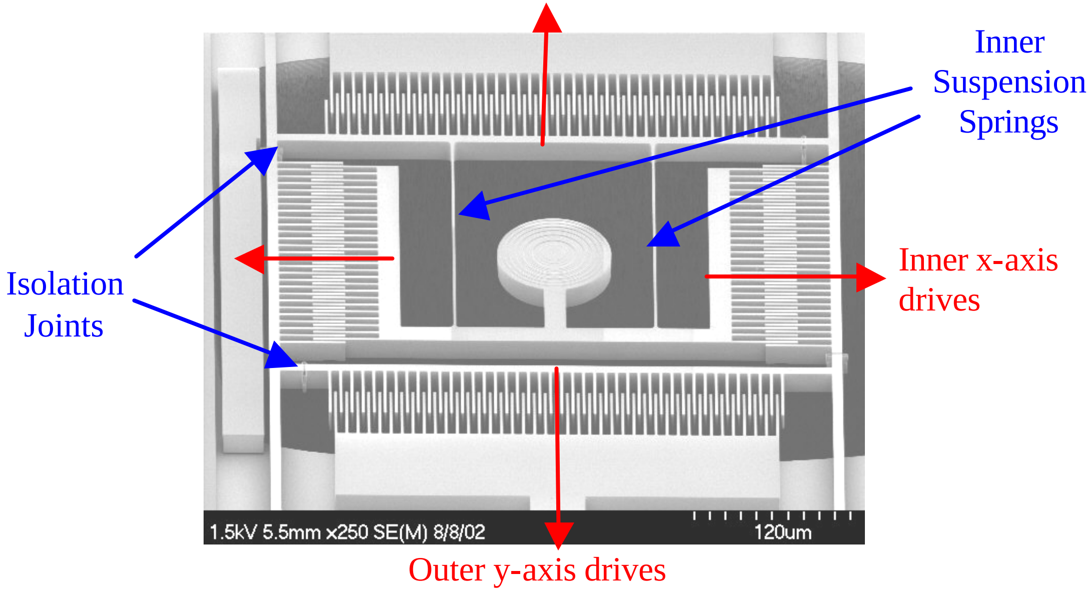
Table of Observations

Node	Energy Seen	Location	When
425	1020	45.367 º 121.24 M	12:00 01.0035
431	1044	45.380 º 121.25 M	12:00 01.0102
418	989	45.388 º 121.24 M	12:00 01.0199
• • •	• • •	• • •	• • •

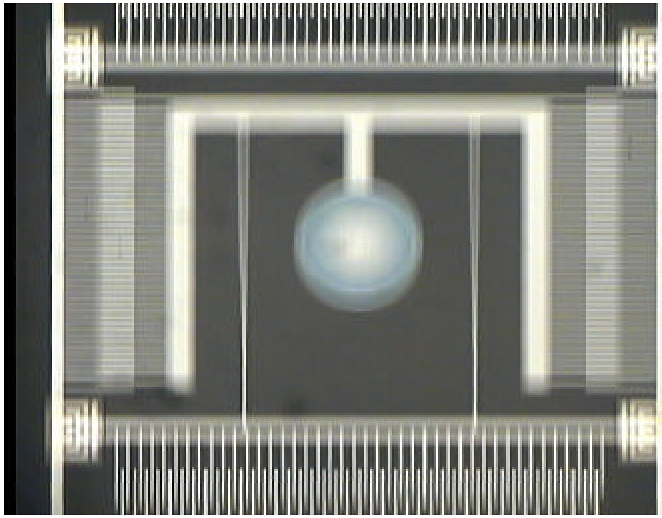
DARPA Honeywell

LDART Technology Status: Hardware

- MEMS hardware currently under development
- 2nd round of prototypes of the micro-lens array being fabricated and tested

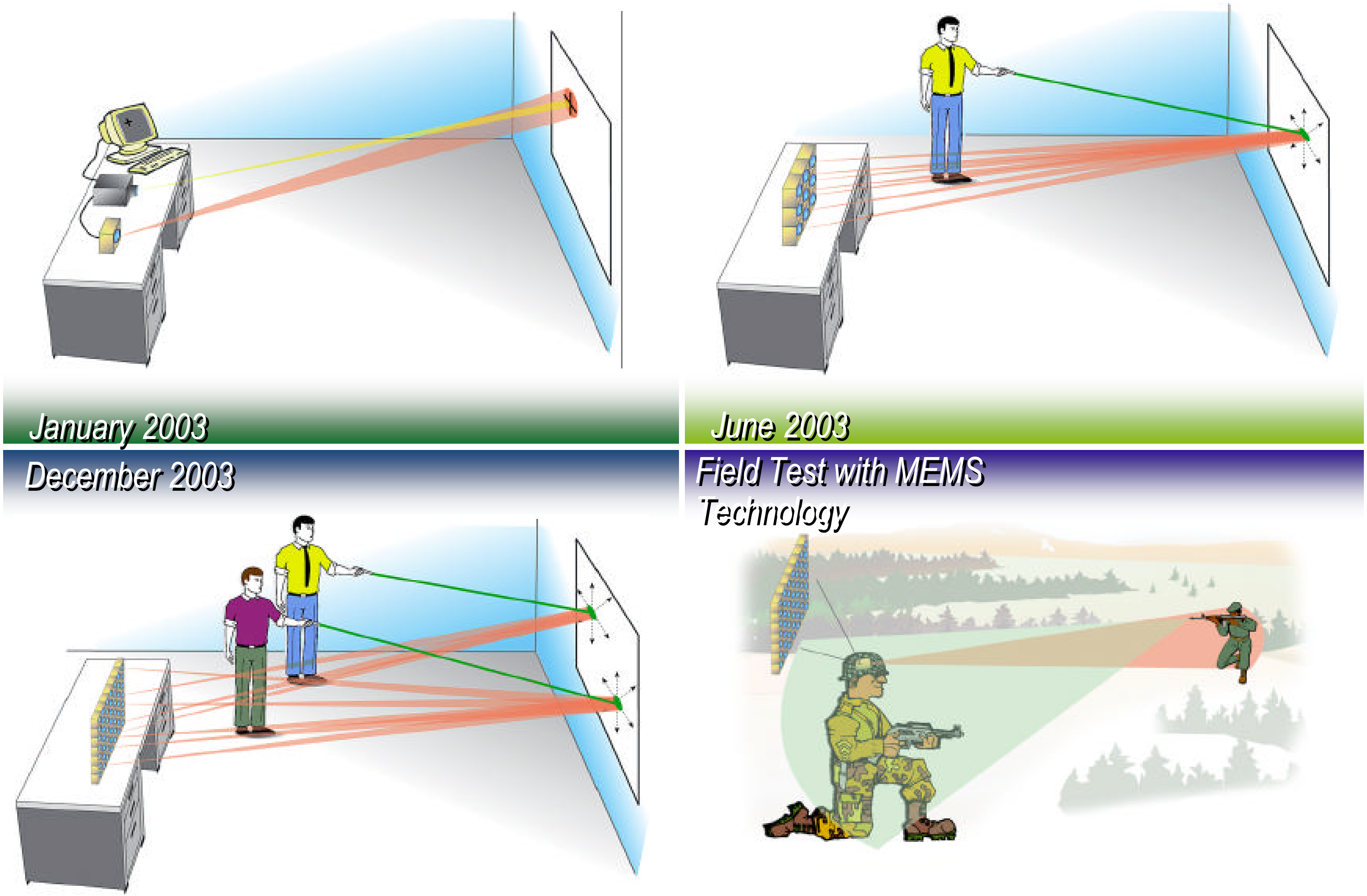


Microactuator structure



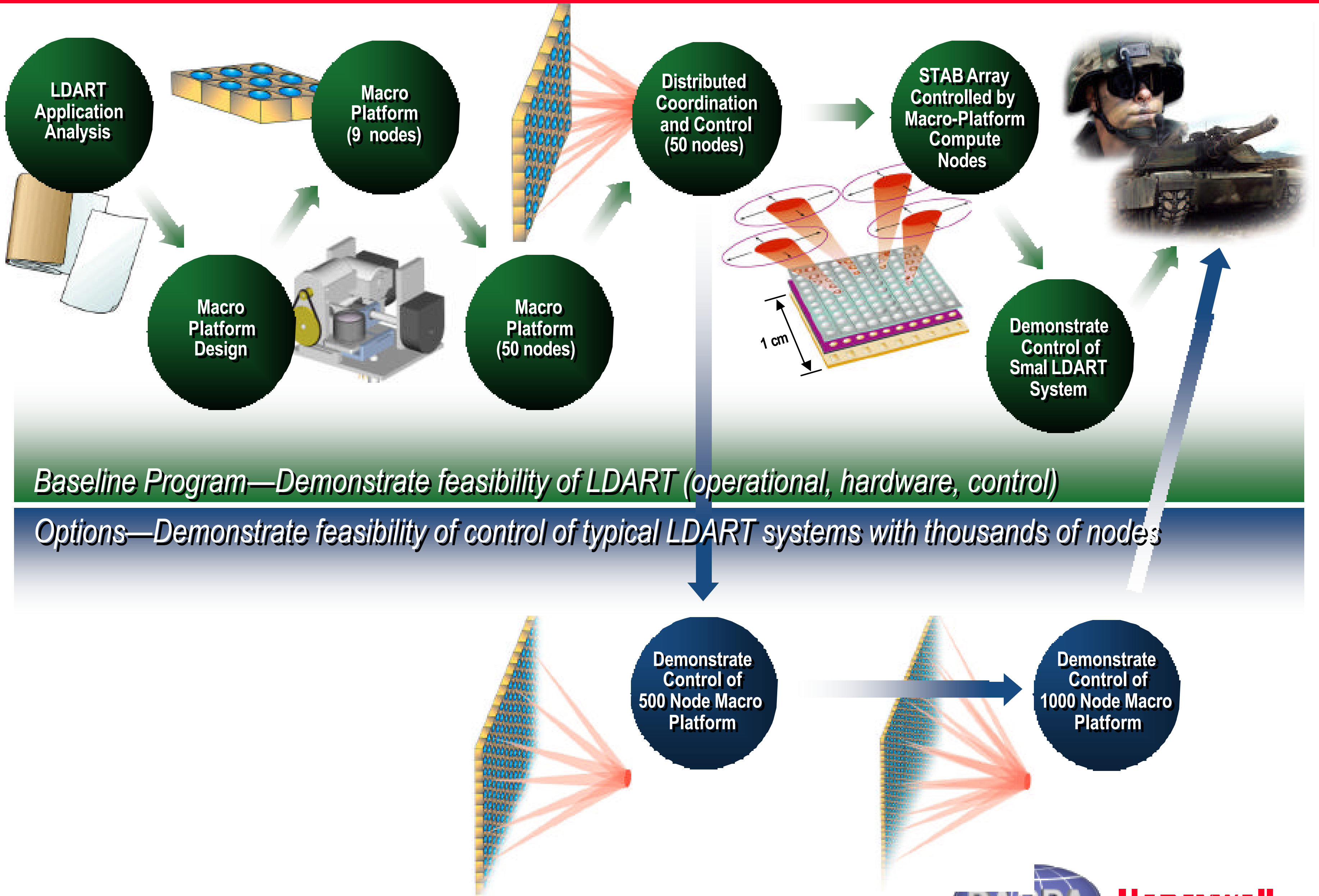
Microlens driven in resonance simultaneously in x and y-axes.

From Research to Product



DARPA Honeywell

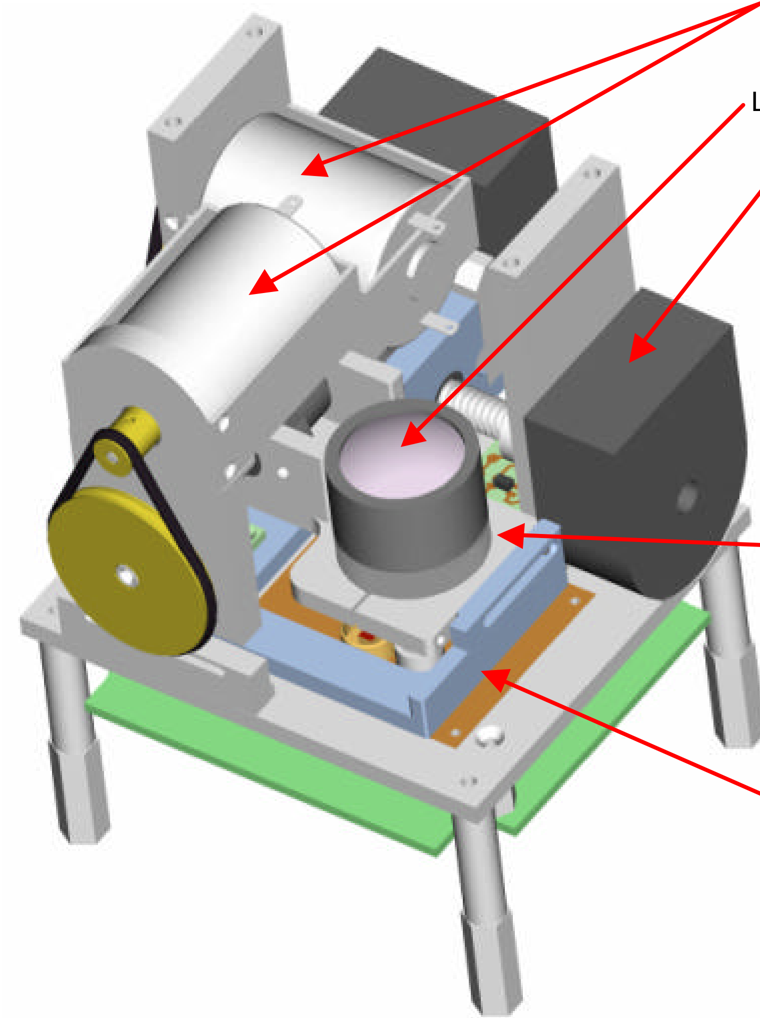
From Research to Product



DARPA Honeywell

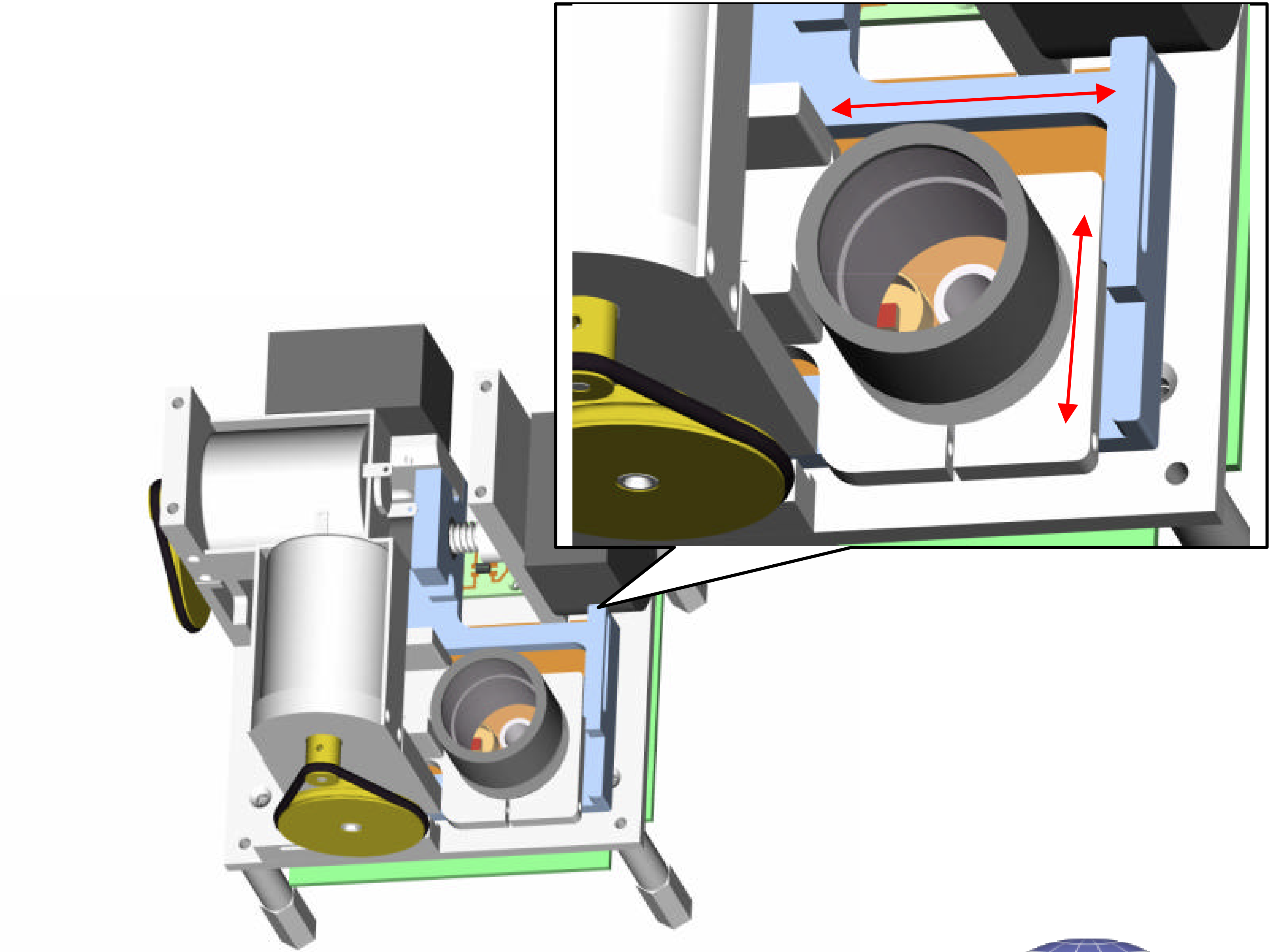
Macro Platform: X-Y Lens Stage

- The NEST optical stage employs a 2-axis stage to move a lens above an emitter (laser diode) and a detector (photo-diode).
- The Y-Stage is mounted on top of the X-Stage.
- Each stage is controlled independently by an inexpensive DC motor that drives a lead-screw. Each stage is translated as its lead-screw turns.
- Position feedback is accomplished by optical rotary encoders on the opposite end of the lead screw.



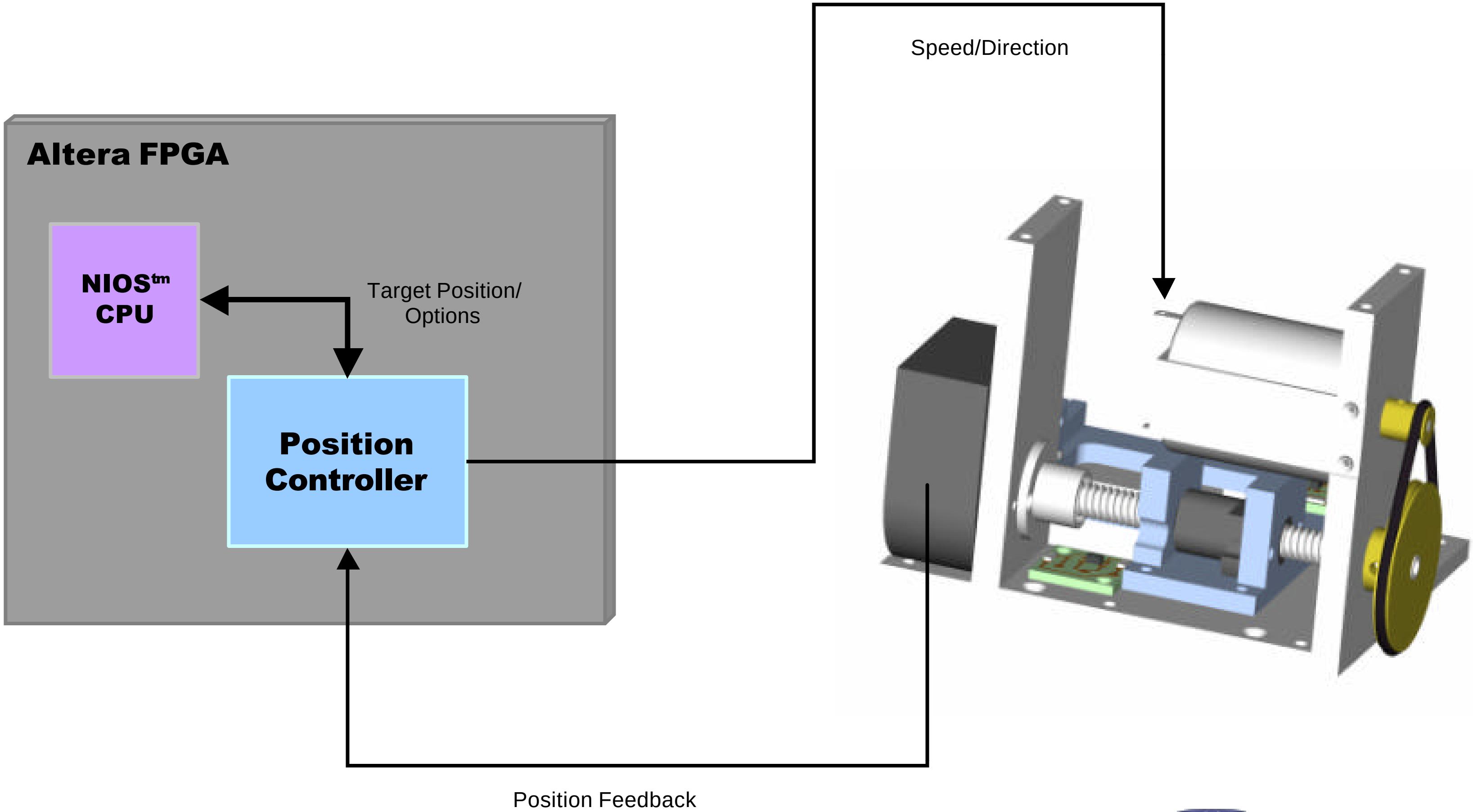
DARPA Honeywell

Macro Platform -- A closer look



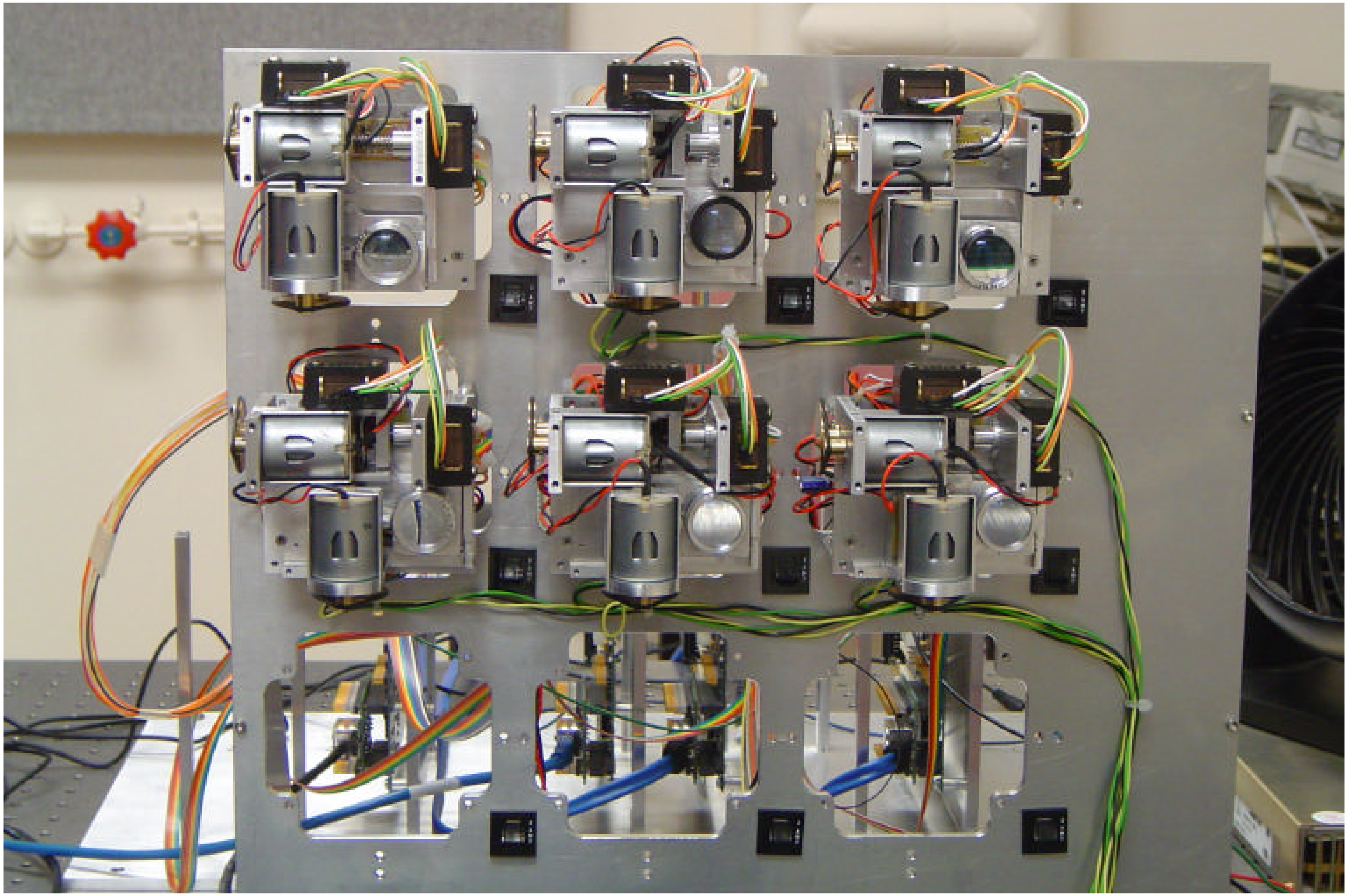
Position Control

- **Each axis has a complete control circuit that looks like the following:**



DARPA Honeywell

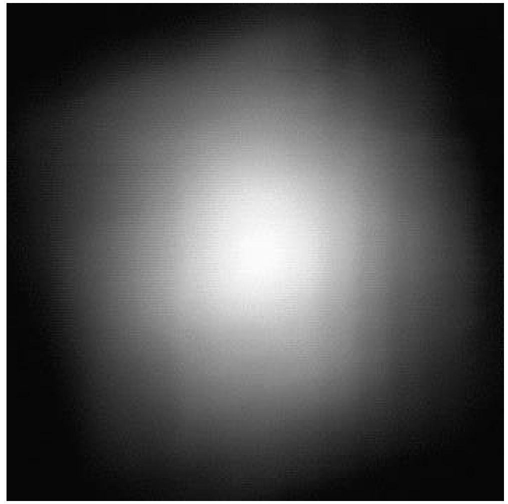
Macro Platform

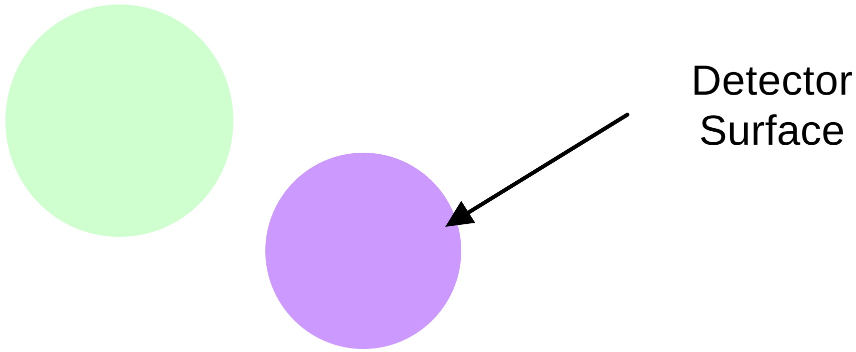


Compute Element

- Altera/NIOS 32-bit CPU (Rev. 2.1), CPU core in Altera 20K200E FPGA
- Running μCLinux
- Hill Climb is performed by taking samples from four points and computing the gradient.
- When all four points have equal intenisty then we have found the top of the hill

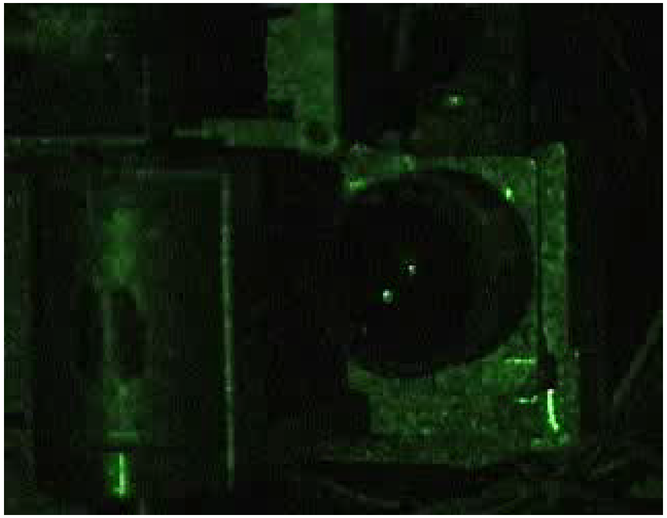
Image formed by scanning the lens and reading intensity





LDART Technology Status: Macro Platform

- Distributed control software being developed in parallel with MEMS hardware
- Control being developed and tested using a "macro-platform"
  - Macro-scale representation of MEMS platform
  - Designed to be a faithful representation of MEMS platform
    - lens positioning accuracy: 0.03175 mm
    - positioning speed: 128.8 mm/sec
    - detector sensitivity: ? 6 nW



Movie clip of macro cell locating laser source

DARPA Honeywell

Summary

Abstract *Presentation* *Back to Agenda* *Next Abstract*

- MEMS-based laser detection and reciprocal targeting (LDART) shows promise in speed, accuracy, weight, and power consumption
- Macro platform has allowed first proof of concept in the development of LDART
- Plan moving forward will test MEMS design in the field at Fort Benning