# Research
# in
# Progress

## ROBOTICS AT STANFORD

## HISTORY

The Robotics Project (the 'Hand-Eye Project') evolved within the Stanford Artificial Intelligence Laboratory under the guidance of John McCarthy, Les Earnest, Jerry Feldman, and Tom Binford.  Major efforts have been undertaken to isolate and solve fundamental problems in computer vision, manipulation, and autonomous vehicles. Generalised cones were introduced for modelling the geometry of 3-dimensional objects, and programs were constructed which learned structural descriptions of objects from laser-ranging data ('structured light')  Stereo vision and texture have been examined.  Several generations of robot programming languages have resulted in AL, an intermediate-level language for commanding manipulation. A computer-controlled roving vehicle ('the cart') detected obstacles (using 9-eyed stereo) and planned paths to avoid them.

## PROJECTS

### Edges

Several group members are investigating generalisations of convolution and lateral inhibition for the detection of edges in digital imagery.  Effective techniques for linking edges are being sought.

### Stereo

Research into edge-based stereo vision attempts to exploit line-to-line coherence within a picture and the use of multiple resolutions of scan-lines between pictures.  A goal is to use high-level object models for guidance and output

### Geometric modelling

ACRONYM is a Computer-Aided Design system based on generalised cones and targeted to represent objects for visual recognition and for simulation and planning of assembly tasks.  Generic object classes can be represented, as well as tolerance information for industrial parts.  A language has been developed for expressing constraints among the parameters of object models.

### High-level vision

We use ACRONYM for 3-D interpretation of aerial photographs and industrial scenes.  Edges are linked into ribbons (2-D generalised cones) and the ribbons are used to index into the data base of object models.  ACRONYM predicts the generic appearance of objects and their quasi-invariant observables (those features and relations among features visible over a wide range of viewing angles).  Partial matches between observed 2-D features and predicted appearance are used to produce more completely specified 3-D interpretations.

### Stand-alone AL system

The arms are programmed in AL (Assembly Language), an intermediate-level robot programming language.  We

are developing a stand-alone AL system for export (PASCAL running under RSX-11).

## Force sensing and control

Hardware issues include developing novel force sensing instrumentation, including fingers capable of measuring location and direction of applied forces and a highly articulated three-finger hand capable of sensing intra-finger forces as well as externally applied forces. Investigations of low-level force control systems and high-level force strategy descriptors are of current interest. While AL now provides reasonable constructs for force and stiffness control, we are seeking improved position and force control language constructs for traditional manipulators and advanced hand mechanisms.

## Simulation

The SIMULATOR displays a computer animation of ACRONYM arm and object models in the course of an AL program. This permits off-line debugging of robot programs without endangering personnel or equipment. Rudimentary collision detection is implemented. SIMULATOR is being used in the design of the hardware and control language for a 3-fingered hand.

## High-level languages for robots

Current languages for manipulation talk about motions of the arms rather than about relative motions between parts to be assembled. One direction of research here is the analysis of actual programmed assemblies to identify operations which are candidates to be primitives in a high-level language for robots. What knowledge about robot capabilities and limitations is used by the human expert in laying out a robot assembly? What information must be represented in the object models? What must the system know about physics and geometry? We are investigating ways of linking with current AI research programs in planning, knowledge representation, and expert systems.

# FACILITIES

The basis for our computing is a DEC PDP-10 (KL processor) running WAITS, a cooperative operating system developed by the Stanford Artificial Intelligence Laboratory. A DataDisc system supports 36 video channels which can be viewed by any of 60 raster terminals distributed throughout Margaret Jacks Hall at Stanford. A recently acquired Grinnell display system (36 bit planes, each 512x512 pixels) will displace the Datadisc for black-and-white and color graphics for the Robotics Project. Vision input is coming from two GE TN-2500 solid-state cameras and will use the Grinnell for image memory. Three TI-990 computers will serve as dedicated vision processors.

There are currently four manipulators in our laboratory: two Scheinman Stanford arms (one with force wrist) and two Unimation PUMA-500 arms. These are supported by a DEC PDP-11/45 and PDP-11/60. A Vision Module from Machine Intelligence Corp is integrated into the AL manipulation system. A vise and electric screwdriver are under computer-control for assembly.

We expect to interface all the computers to the CS Department's ETHERNET.

**Group Members**
Ordered alphabetically by PPN at SAIL
CS = Computer Science
EE = Electrical Engineering
IE = Industrial Engineering
ME = Mechanical Engineering
NOTE: The notation '(xyz)' after a name refers to that person's electronic mail address at SAIL The ARPANET address for that person is thus xyz@SU-AI
Alan Miller (AAM), CS Student: cart, graphics
Ron Goldman (ARG), CS Student: stand-alone AL system
Barry Soroka (BIS), Research Associate: simulation.
Casey Cox (CEC), EE Student: force sensing and control
Craig Rublee (CR), CS Student, graphics
David Lower (DLO), CS Student: matching image features to visual predictions
Harlyn Baker (HHB), Visiting Student: stereo
John Craig (JJC), EE Student: force sensing and control
Ken Salisbury (JKS), ME Student: force sensing and control.
Jim Maples (JM), EE Student: sensors and instrumentation for robots
Ken Clarkson (KLC), CS Student: mathematics of imaging
Marianne Siroker (MAS), Secretary: coordination and project management
Mike Lowry (ML), CS Student: edge detection
Shahid Mujitaba (MSM), IE Student: analysis of manipulator programs
Pat MacVicar-Whelan (MVW), Visitor: edge detection
Peter Blicher (PB), Visiting Student: edge detection.
Dave Arnold (RDA), CS Student: stereo
Rod Brooks (ROD), CS Student: ACRONYM
Rick Vistnes (RV), CS Student: robot programming languages
Sid Liebes (SL), Senior Research Associate: stereo.
Tom Binford (TOB), Senior Research Associate: project direction, edges

**Collaborations**
Bob Cannon, Aeronautics & Astronautics, Stnaford: control of flexible manipulators.
Larry Leifer, Mechanical Engineering, Stanford: design and control of prosthetic devices
David Luckham, Electrical Engineering, Stanford: distributed computing
Bernard Roth, Mechanical Engineering, Stanford kinematics of manipulators; parts mating
Carl Ruoff, Jet Propulsion Laboratory: design of advanced end-effectors for manipulation.
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