SPACE STATION WILL HAVE REQUIREMENTS FOR CONDUCTING SUCH MANIPULATION/OBSERVATION ACTIVITIES AS CONSTRUCTION, MAINTENANCE, MANUFACTURING, EXPERIMENTS, RENDEZVOUS AND DOCKING, POINTING AND TRACKING, TARGET ACQUISITION/IDENTIFICATION, AND SOLAR SYSTEM OBSERVATIONS. INITIALLY, MOST OF THESE MANIPULATIONS/OBSERVATIONS WILL REQUIRE A MAN-IN-THE-LOOP WITH VIDEO DISPLAY, WHICH IN TURN WILL REQUIRE REAL-TIME PROCESSING OF DATA AND INFORMATION FOR VISUAL PRESENTATION WILL IMPROVE MAN'S OPERATIONAL CAPABILITIES. AS THE SPACE STATION MATURERS, SOME OF THESE OPERATIONS WILL BECOME NEARLY AUTONOMOUS WITH MAN MONITORING, WHICH WILL CREATE AN ADDITIONAL NEED FOR REAL-TIME PROCESSING AT DATA RATES EXCEEDING 100 MBITS/SEC. PROCESSING AT SUCH HIGH RATES WILL MOST LIKELY BE ACCOMPLISHED BY SPECIAL PURPOSE COMPUTING IMPLEMENTING COMPUTATIONALLY SIMPLE ALGORITHMS. CURRENT TECHNOLOGY PROJECTIONS INDICATE THE LACK OF AVAILABILITY OF SUCH SPECIAL PURPOSE COMPUTING IN THE EARLY 1990S, AND NASA NEEDS TO ACCELERATE THIS TECHNOLOGY FOR APPLICATION TO SPACE STATION. POTENTIAL FUNCTIONS FOR VIDEO IMAGE SPECIAL PURPOSE PROCESSING ARE BEING INVESTIGATED, SUCH AS SMOOTHING, ENHANCEMENT, RESTORATION AND FILTERING, DATA COMPRESSION, FEATURE EXTRACTION, OBJECT DETECTION AND IDENTIFICATION, PIXEL INTERPOLATION/EXTRAPOLATION, SPECTRAL ESTIMATION AND FACTORIZATION, AND VISION SYNTHESIS. ALSO, ARCHITECTURAL APPROACHES ARE BEING IDENTIFIED AND A CONCEPTUAL DESIGN GENERATED. COMPUTATIONALLY SIMPLE ALGORITHMS WILL BE RESEARCHED AND THEIR IMAGE/VISION EFFECTIVENESS DETERMINED. SUITABLE ALGORITHMS WILL BE IMPLEMENTED INTO AN OVERALL ARCHITECTURAL APPROACH THAT WILL PROVIDE IMAGE/VISION PROCESSING AT VIDEO RATES THAT ARE FLEXIBLE, SELECTABLE, AND PROGRAMMABLE.
SPACE STATION ACTIVITIES
NEEDING VIDEO

- CONSTRUCTION
- SATELLITE SERVICING
- RENDEZVOUS
- PROXIMITY OPERATIONS
- COMMUNICATION AND TRACKING
- INSPECTION
- MAINTENANCE
- PAYLOAD DELIVERY/RETRIEVAL
- EXPERIMENT MONITORING
- DATA MANAGEMENT
- TRAINING
EXAMPLE SPACE STATION APPLICATIONS
OF VIDEO IMAGE PROCESSING

RENEZVOUS

Target Identification
Target Tracking for Cross Range Velocity and Position Estimation
Point Target Detection

PROXIMITY OPERATIONS

Target Tracking for Target Orientation, Position and Velocity Estimation

DATA MANAGEMENT

Bandwidth Compression for Data Movement and Archiving

INSPECTION

Machine Vision Techniques for Verification of Space Station Structural Integrity and Detection and Classification of Defects

COMMUNICATION AND TRACKING

Bandwidth Compression for Downlink Transmission
Multi-Target Tracking for Area Traffic Control
Target Detection and Identification for Area Traffic Control

CONSTRUCTION

Verification of Construction Steps
VIDEO IMAGE PROCESSOR
506-58-13/N. D. MURRAY

OBJECTIVE

- Research and develop the real-time data and information processing of video image data for space station requirements.

APPROACH

- Investigate potential functions for video rate image/vision special purpose processing, identify architectural approach, and generate a conceptual design. Honeywell

- Research computationally simple algorithms and determine their image/vision effectiveness.

- Implement selected algorithms in special hardware designs and evaluate.

- Using results of proceeding efforts, implement an overall architectural design that will provide image/vision processing at video rates that are flexible, selectable and programmable.
VIDEO SOURCES

• CAMERAS

INTERNAL
- MODULE CAMERAS
- EXPERIMENT MONITORING

EXTERNAL
- MRMS
- DOCKING PORTS
- LOCAL AREA TRAFFIC MONITORING
- SERVICING FACILITY
- ON MMUS
- OMV/OTV
- FREE FLIERS

• VIDEO STORAGE DEVICES

• UPLINK VIDEO
INTERCONNECTION NETWORK

C C C C V I P V I P ...

C C C C C

STORAGE

TO/FROM GROUND

VIDEO DISTRIBUTION
VIDEO IMAGE PROCESSING IN SPACE STATION

- REAL TIME, 100 MBPS
ALGORITHMS

* PROCESSING
  REMOVAL OF NOISE
  HISTOGRAM
  THRESHOLDING

* ANALYSIS
  STRUCTURAL
  EDGES
  VERTICES
  REGIONS
  STATISTICAL
  DENSITY FUNCTION
  MOMENTS
  CO-OCCURENCE
  MATRICES

* RECOGNITION
  OBJECTS
  TEXTURES

* UNDERSTANDING
  SCENE DESCRIPTION
  SPATIAL RELATIONSHIP
  MOTION PARAMETERS
NATURE OF PROCESSING

IMAGE:
ORDERED SETS OF NUMBERS

IMAGE FEATURES:
SYMBOLS ASSOCIATED WITH NUMERICAL VALUES
A: 37, 28
B: 20, 73

OBJECTS:
INTERRELATED SYMBOLS (GRAPH)

SCENE:
SEMANTIC NETS
FUNCTIONAL ANALYSIS

GOAL: FUNCTIONAL DECOMPOSITION OF SPACE STATION TASKS AND DETERMINATION OF COMPUTATIONAL REQUIREMENTS

FEATURES:

- OPERATION THROUGHPUT
- DATA THROUGHPUT
- POTENTIAL PARALLELISM
- DATA DEPENDENT BEHAVIOR
- WORD SIZE REQUIREMENTS
- OPERATION DENSITY, (OPS/PIXEL OR OPS/FEATURE)
- IMPLICATIONS FOR
  - PROCESSING SUPPORT
  - COMMUNICATION REQUIREMENTS
  - CONTROL STRATEGIES
IMAGE ANALYSIS COMPUTATIONAL MODEL
PARALLEL TASKS MAY BE FORMULATED BY EXPLOITING PARALLELISM IN THE TRANSFORMATIONS OR DATA STRUCTURES

TRANSFORMATIONS MAY BE CLASSIFIED AS

- IMAGE TO IMAGE (PREPROCESSING)
- IMAGE TO DATA STRUCTURE (DATA REDUCTION)
- DATA STRUCTURE TO DATA STRUCTURE (HIGH LEVEL)
### Image-to-Image Functions

<table>
<thead>
<tr>
<th>EXAMPLE</th>
<th>MOPS</th>
<th>DATA ACCESS PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>DETECTOR COMPENSATION</td>
<td>8-9</td>
<td>FIXED, HIGHLY PARALLEL</td>
</tr>
<tr>
<td>THRESHOLDING</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>FILTERING</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>CORRELATION</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>EDGE DETECTION</td>
<td>400-800</td>
<td></td>
</tr>
<tr>
<td>ENHANCEMENT</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>CHANGE DETECTION</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
IMAGE-TO-IMAGE FUNCTIONS (CONTINUED)

- DATA DEPENDENCIES - VERY LOW
- WORD SIZE REQUIREMENTS - PIXEL RESOLUTION
- OPERATION DENSITY - $10^{-2}$ OPS/PIXEL
- PROCESSING SUPPORT - SIMPLE ARITHMETIC OPERATIONS
- COMMUNICATION - FIXED, PREDETERMINED
- CONTROL STRATEGIES - SYNCHRONOUS, SIMD
# Image-to-Data Structure Functions

<table>
<thead>
<tr>
<th>EXAMPLES</th>
<th>MOPS</th>
<th>DATA ACCESS PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGION GROWING</td>
<td>20-30</td>
<td>CONSTRAINED</td>
</tr>
<tr>
<td>(EMPIRICAL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LINE AND SHAPE DETECTION</td>
<td>200-300</td>
<td>FIXED</td>
</tr>
<tr>
<td>(HOUGH TRANSFORM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENCODING VIA</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>- QUAD TREES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- RECTANGLE CODES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATISTICS</td>
<td>30</td>
<td>PREDETERMINED</td>
</tr>
<tr>
<td>Function</td>
<td>Value</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------------------------</td>
<td></td>
</tr>
<tr>
<td>DATA DEPENDENCIES</td>
<td>TENDS TO BE HIGH</td>
<td></td>
</tr>
<tr>
<td>WORD SIZE REQUIREMENTS</td>
<td>16 BITS</td>
<td></td>
</tr>
<tr>
<td>OPERATION DENSITY</td>
<td>10-10^3 OPS/FEATURE</td>
<td></td>
</tr>
<tr>
<td>PROCESSING SUPPORT</td>
<td>ARITHMETIC, SOME LOGICAL, LIMITED</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FLOATING POINT</td>
<td></td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>CAN BE STRUCTURED IN A MANNER</td>
<td></td>
</tr>
<tr>
<td></td>
<td>THAT CAN BE PREDETERMINED</td>
<td></td>
</tr>
<tr>
<td>CONTROL STRATEGIES</td>
<td>INCLINED TOWARD MIMD</td>
<td></td>
</tr>
</tbody>
</table>
# Data Structure-to-Data Structure Functions

<table>
<thead>
<tr>
<th>Examples</th>
<th>MOPS</th>
<th>Date Access Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matching Descriptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Graphs</td>
<td>1-3</td>
<td>Predetermined</td>
</tr>
<tr>
<td>- Contours</td>
<td>20-30</td>
<td>Predetermined</td>
</tr>
<tr>
<td>Matching Feature Vectors</td>
<td>1-2</td>
<td>Fixed</td>
</tr>
<tr>
<td>3-D Structure</td>
<td>?</td>
<td>Unknown</td>
</tr>
<tr>
<td>Inference Rule Evaluation</td>
<td>?</td>
<td>Unknown</td>
</tr>
<tr>
<td>Position Estimation, Tracking</td>
<td>?</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
DATA STRUCTURE-TO-DATA STRUCTURE
FUNCTIONS (CONTINUED)

- DATA DEPENDENCIES - VERY HIGH
- WORD SIZE REQUIREMENTS - 32-64 BITS
- OPERATION DENSITY - $10^4$-$10^6$ OPS/FEATURE
- PROCESSING SUPPORT - SYMBOLIC OPERATIONS, DATA
MANIPULATION, NON-NUMERIC OPERATIONS
- COMMUNICATION - DYNAMIC, VARIABLE
- CONTROL STRATEGIES - MIMD
## Functional Analysis Summary

<table>
<thead>
<tr>
<th></th>
<th>Image to Image</th>
<th>Data Structure to Data Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Dependencies</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>Pixel resolution</td>
<td>32-64 bits</td>
</tr>
<tr>
<td><strong>Operation Density</strong></td>
<td>$10^{-2}$ ops/px</td>
<td>$10^4-10^6$ ops/feature</td>
</tr>
<tr>
<td><strong>Data Throughput</strong></td>
<td>8-500 MOPS</td>
<td>1-5 MOPS, MLIPS</td>
</tr>
<tr>
<td><strong>Processing Required</strong></td>
<td>Arithmetic, Simple</td>
<td>Floating point</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Symbolic non-numeric</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Synchronous (SIMD)</td>
<td>Toward MIMD</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>Fixed</td>
<td>Can be structured and predetermined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dynamic and variable</td>
</tr>
</tbody>
</table>
FUNCTIONAL ANALYSIS SUMMARY
(CONTINUED)

- MIX OF COMPUTATIONS AND CONTROL STRATEGIES
- INCREASING NON-DETERMINISTIC BEHAVIOR
- SHIFT IN POTENTIAL PARALLELISM FROM DATA TO ALGORITHMS
- PERHAPS CONFLICTING ARCHITECTURAL SOLUTIONS?
- ROLE OF COLOR NEEDS TO BE DETERMINED
- IMPACT OF DYNAMIC AND STATIC NATURE OF DATA STRUCTURES TO BE EVALUATED
Computational Characteristics

$10^8 - 10^9$ Bits/sec.

- Enhancement
- Edge Detection
- Vertices
- Filtering
- Histogram
- Statistics

Objects

Matching

Understanding

Arithmetic Operation (MOPS)

- Pixel and Window Operations
- Constructing Descriptions
- Searching
- Matching
- Inference

Operation Density

$10^4 - 10^6$ Ops/Feature

$10^3 - 10^5$ Bits/sec.

$\approx 10 - 10^3$ Features/sec.
CONCURRENT PROCESSING ARCHITECTURES

- SPECIAL-PURPOSE PROCESSORS
- WORD-SEQUENTIAL PROCESSORS
- ASSOCIATIVE PROCESSORS
- ARRAY PROCESSORS
- PIPELINE PROCESSORS
- RECONFIGURABLE PROCESSORS
- MULTIPROCESSORS
- DATA FLOW PROCESSORS
- OBJECT-ORIENTED PROCESSORS
- INFERENCE PROCESSORS