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 real-time processing of data and information for visual display, which in turn will require man’s operational capability to be autonomous with man monitoring, which will create an additional need for real-time autonomous 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 processing and filtering, data compression, feature extraction, object detection and identification, pixel interpolation/extrapolation, spectral estimation and factorization, and vision synthesis. Also, architecturally simple algorithms are being identified and a conceptual design generated. Computationally simple algorithms will be researched and implemented into an overall architectural approach that will provide image/vision processing at video rates that are flexible, selectable, and programmable.
IMAGE/VISION PROCESSOR

- AUGMENT MAN'S REMOTE WORK CAPABILITIES
- REVIEW AND EDIT OBSERVATIONS
SPACE STATION EVOLUTION

~1990

MANIPULATIONS
- CONSTRUCTION
- MAINTENANCE
- MANUFACTURING
- EXPERIMENTS
- RENDEZVOUS AND DOCKING

~2010

OBSERVATIONS
- EARTH/SOLAR SYSTEM/DEEP SPACE
- MANUFACTURING
- EXPERIMENTS
- POINTING AND TRACKING
- TARGET ACQUISITION/IDENTIFICATION

MAN IN THE LOOP
NEAR AUTONOMOUS
MAN MONITORS
<table>
<thead>
<tr>
<th>Example Space Station Image Processing</th>
<th>Target Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example Space Station Image Processing</td>
<td>Target Tracking for Cross Range Velocity and Position Estimation</td>
</tr>
<tr>
<td>PROXIMITY OPERATIONS</td>
<td>Target Tracking for Target Orientation, Position and Velocity Estimation</td>
</tr>
<tr>
<td>DATA MANAGEMENT</td>
<td>Bandwidth Compression for Data Movement and Archiving</td>
</tr>
<tr>
<td>INSPECTION</td>
<td>Machine Vision Techniques for Verification of Space Station Structural Integrity and Detection and Classification of Defects</td>
</tr>
<tr>
<td>COMMUNICATION AND TRACKING</td>
<td>Bandwidth Compression for Downlink Transmission</td>
</tr>
<tr>
<td>CONSTRUCTION</td>
<td>Target Detection and Identification for Area Traffic Control</td>
</tr>
<tr>
<td>VERIFICATION OF CONSTRUCTION STEPS</td>
<td>Target Detection and Identification for Area Traffic Control</td>
</tr>
</tbody>
</table>
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
    - ON MMUS
    - ON OV/TV
    - FREE FLIERS

- VIDEO STORAGE DEVICES

- UPLINK VIDEO
VIDEO DISTRIBUTION

INTERCONNECTION NETWORK

VIP

MPAC

STORAGE

TO/FROM GROUND
ALGORITHMS

- PROCESSING
  - REMOVAL OF NOISE
  - HISTOGRAM
  - THRESHOLDING

- ANALYSIS
  - STRUCTURAL
    - EDGES
    - VERTICES
    - REGIONS
  - STATISTICAL
    - DENSITY FUNCTION
    - MOMENTS
    - CO-OCCURRENCE
    - 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 : 28, 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

CLASS 1
(ENHANCEMENT)

IMAGES

CLASS 2
(EXTRACTION)

IMAGES

CLASS 3
(EVALUATION)

IMAGES

COMMANDS

(FEATURES)

DATA STRUCTURES

RESULTS

DATA STRUCTURES

LOW-LEVEL
IMAGE PROCESSING

HIGH-LEVEL
IMAGE UNDERSTANDING
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>
<tr>
<td>Function</td>
<td>Requirement</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------</td>
<td></td>
</tr>
<tr>
<td>DATA DEPENDENCIES</td>
<td>VERY LOW</td>
<td></td>
</tr>
<tr>
<td>WORD SIZE REQUIREMENTS</td>
<td>PIXEL RESOLUTION</td>
<td></td>
</tr>
<tr>
<td>OPERATION DENSITY</td>
<td>10-10^2 OPS/PIXEL</td>
<td></td>
</tr>
<tr>
<td>PROCESSING SUPPORT</td>
<td>SIMPLE ARITHMETIC OPERATIONS</td>
<td></td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>FIXED, PREDETERMINED</td>
<td></td>
</tr>
<tr>
<td>CONTROL STRATEGIES</td>
<td>SYNCHRONOUS, SIMD</td>
<td></td>
</tr>
<tr>
<td>EXAMPLES</td>
<td>MOPS</td>
<td>DATA ACCESS PATTERN</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------</td>
<td>---------------------</td>
</tr>
<tr>
<td>REGION GROWING</td>
<td>20-30</td>
<td>CONSTRAINED</td>
</tr>
<tr>
<td></td>
<td>(EMPirical)</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>Feature</td>
<td>Description</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>$10^{-3}$ ops/feature</td>
<td></td>
</tr>
<tr>
<td>PROCESSING SUPPORT</td>
<td>Arithmetic, some logical, limited floating point</td>
<td></td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>Can be structured in a manner that can be determined</td>
<td></td>
</tr>
<tr>
<td>CONTROL STRATEGIES</td>
<td>Inclined toward MIMD</td>
<td></td>
</tr>
<tr>
<td>EXAMPLES</td>
<td>MOPS</td>
<td>DATE ACCESS PATTERN</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>MATCHING DESCRIPTIONS</strong></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><strong>MATCHING FEATURE VECTORS</strong></td>
<td>1-2</td>
<td>FIXED</td>
</tr>
<tr>
<td><strong>3-D STRUCTURE</strong></td>
<td>?</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td><strong>INFERENACE RULE EVALUATION</strong></td>
<td>?</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td><strong>POSITION ESTIMATION, TRACKING</strong></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>IMAGE TO IMAGE</th>
<th>IMAGE TO DATA STRUCTURE</th>
<th>DATA STRUCTURE TO DATA STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA DEPENDENCIES</td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>ACCURACY</td>
<td>PIXEL RESOLUTION</td>
<td>16 BITS</td>
</tr>
<tr>
<td>OPERATION DENSITY</td>
<td>10-10^2 OPS/PIXEL</td>
<td>10-10^3 OPS/FEATURE</td>
</tr>
<tr>
<td>DATA THROUGHPUT</td>
<td>8-500 MOPS</td>
<td>10-300 MOPS</td>
</tr>
<tr>
<td>PROCESSING REQUIRED</td>
<td>ARITHMETIC, SIMPLE</td>
<td>ARITHMETIC, LOGICAL</td>
</tr>
<tr>
<td>CONTROL</td>
<td>SYNCHRONOUS (SIMD)</td>
<td>TOWARD SIMD</td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>FIXED</td>
<td>CAN BE STRUCTURED AND PREDETERMINED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASYNCHRONOUS, SIMD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DYNAMIC AND VARIABLE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32-64 BITS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10^4-10^6 OPS/FEATURE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-5 MOPS, MLIPS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLOATING POINT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SYMBOLIC NON-NUMERIC</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

- **$10^3 - 10^5$ Bits/sec.**
  - Objects
  - Matching
  - Understanding

- **$10^3 - 10^5$ MLIPS**
  - Symbolic Operations
  - Inference

- **Operation Density**
  - $10^2 - 10^3$ Ops/Feature

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