Visual Object Recognition and Tracking System

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The Problem

- Using only vision, how does one track a moving object?
- Can this be modeled?
- Can this be implemented?

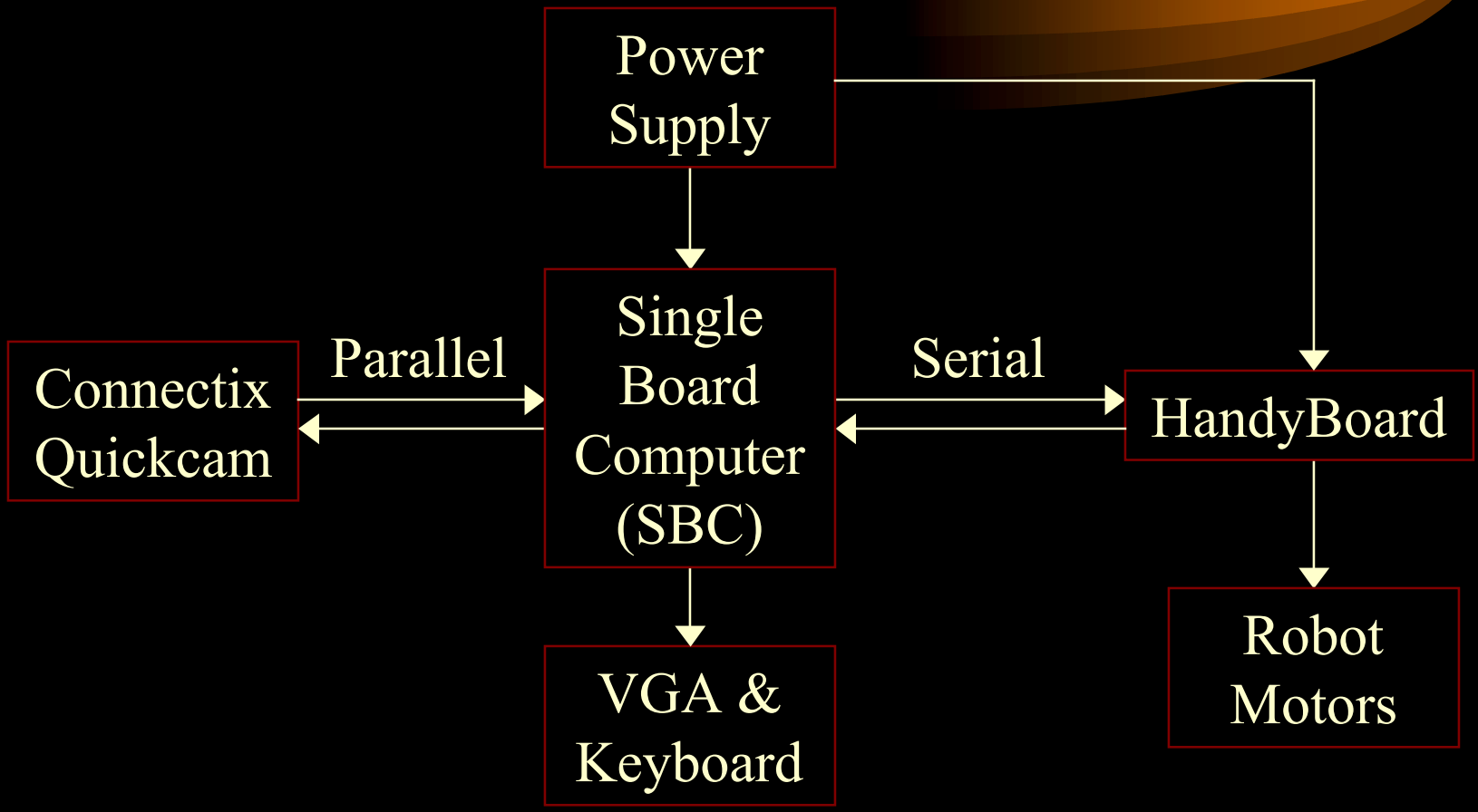
Project Objectives

- Develop an object tracking algorithm
- Recommend suitable hardware platform
  - Price
  - Size
  - Performance
- Build a demonstration robot

Current Research

- Is Template Matching Obsolete?
- Feature tracking
- MIT Cheap Vision Machine Project
- ASSET-2 Project

System Components

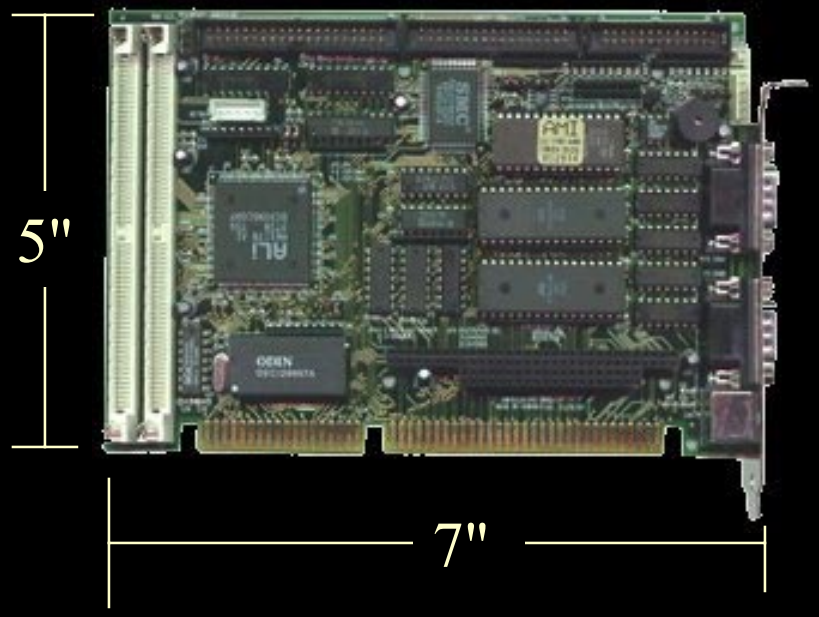


Connectix Color Quickcam

- Max Resolution
  640x480
- Operating Resolution
  80x30
- Color Depth: 24-bit
  RGB
- Field of view
  - 21° horizontal view
  - 18 inches to 12 feet

Single Board Computer (SBC)

- 40 MHz 386sx
  - Familiar PC architecture
  - DOS Compiler and Debugger
- Keyboard, VGA, serial, & parallel interfaces
- 1 Mbyte Flash Disk

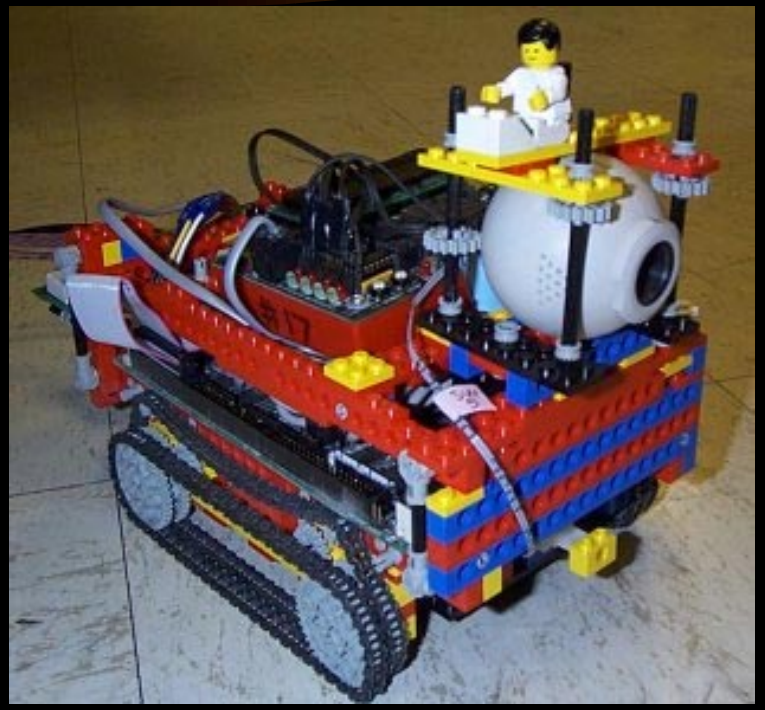


HandyBoard

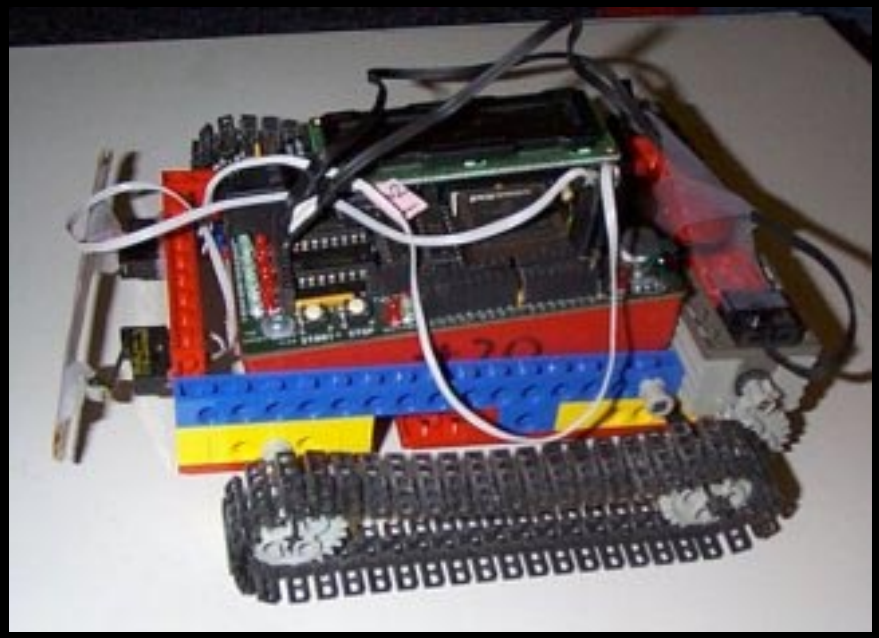
- Motorola 68HC11
- Serial interface
- I/O and Motor Ports

Mobile Robot

- Constructed of LEGOs
- Extended power connector
- Wheels vs. Treads
- Mounting location of Quickcam
  - ~4 inches off ground
  - Angled slightly downward



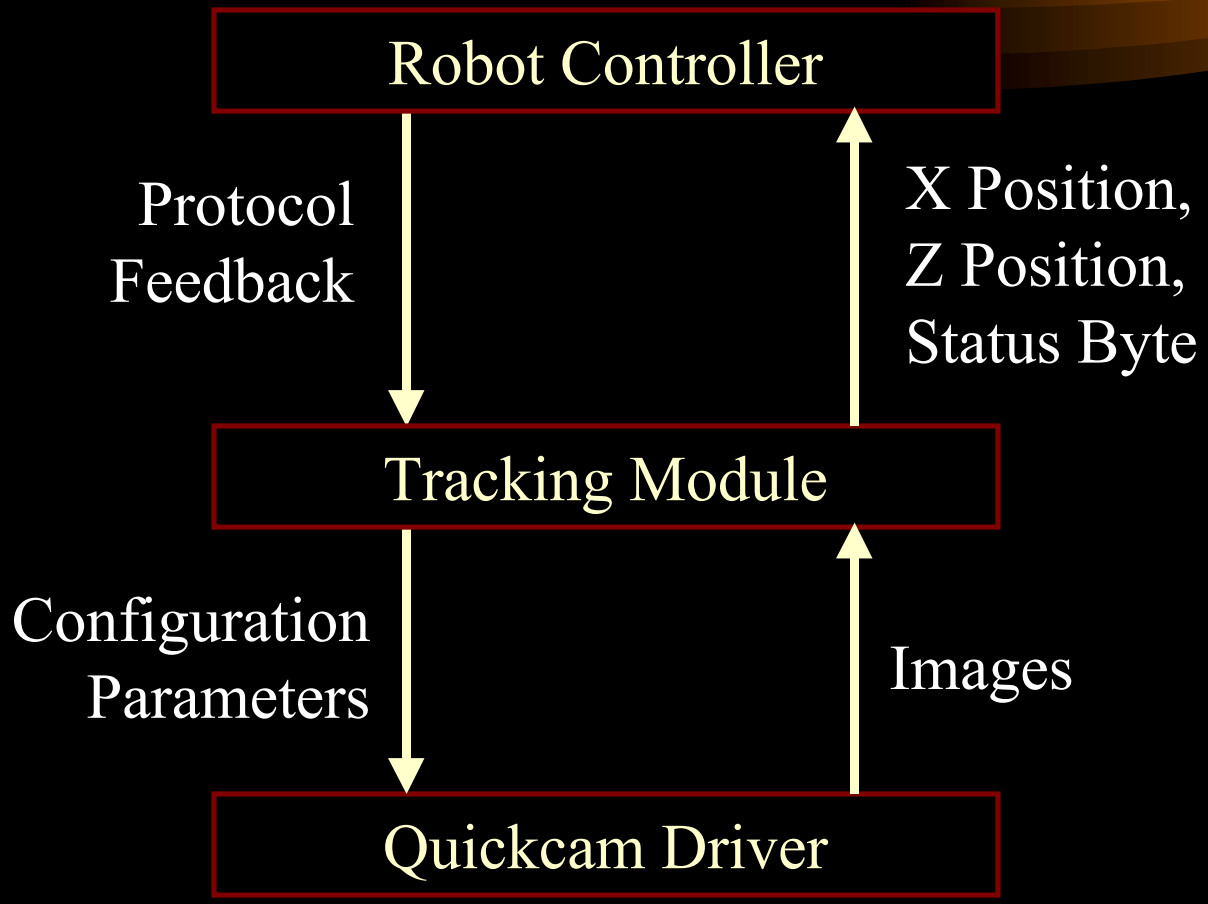
Drone Robot



Software Design

- Software Modules
  - Quickcam Driver
    - Runtime configurable
    - Simple C interface
  - Tracking Code
  - Robot Controller

Software Design



Visual Tracking

- Optical Flow
  - Continuous to Discrete
  - Local Motion
  - Global Motion
- Algorithms
  - Motion Detection
  - Object Recognition

Algorithm Selection

Neural Networks

+ Accurate
+ Insensitive to noise
- Must be trained
- Grow for color images
- Requires floating point

Template Matching

+ Scalable
+ No training
+ Computationally simple
- Sensitive to noise

Correlation Matrix

Template

1	1	1
1	1	1
1	1	1

Image

1	1	1	0	0
1	0	1	0	1
1	1	1	0	0
0	0	0	0	0
0	1	0	0	1

Correlation Matrix

Correlation Matrix

Correlation Matrix

Template

1	1	1
1	1	1
1	1	1

Image

1	1	1	0	0
1	0	1	0	1
1	1	1	0	0
0	0	0	0	0
0	1	0	0	1

Correlation Matrix

1	4

Correlation Matrix

Template

1	1	1
1	1	1
1	1	1

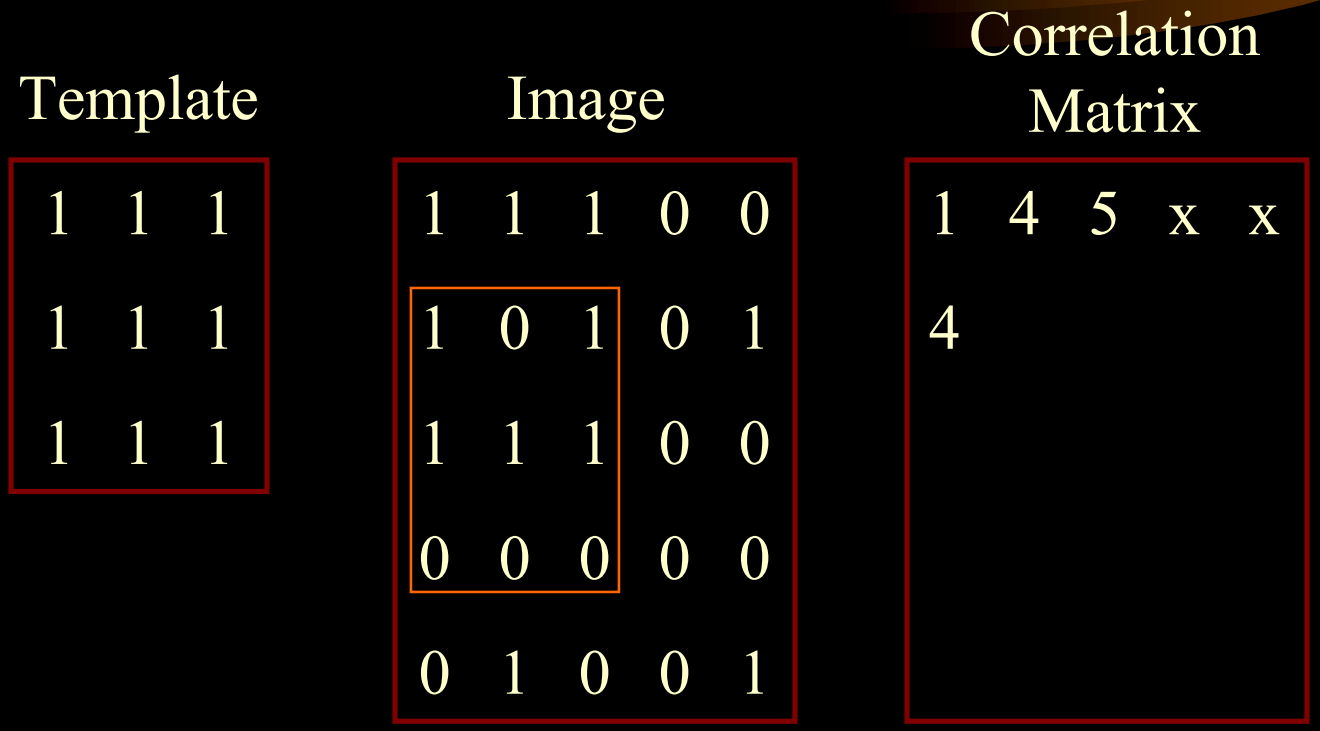
Image

1	1	1	0	0
1	0	1	0	1
1	1	1	0	0
0	0	0	0	0
0	1	0	0	1

Correlation Matrix

1	4	5

Correlation Matrix



Correlation Matrix

Template

1	1	1
1	1	1
1	1	1

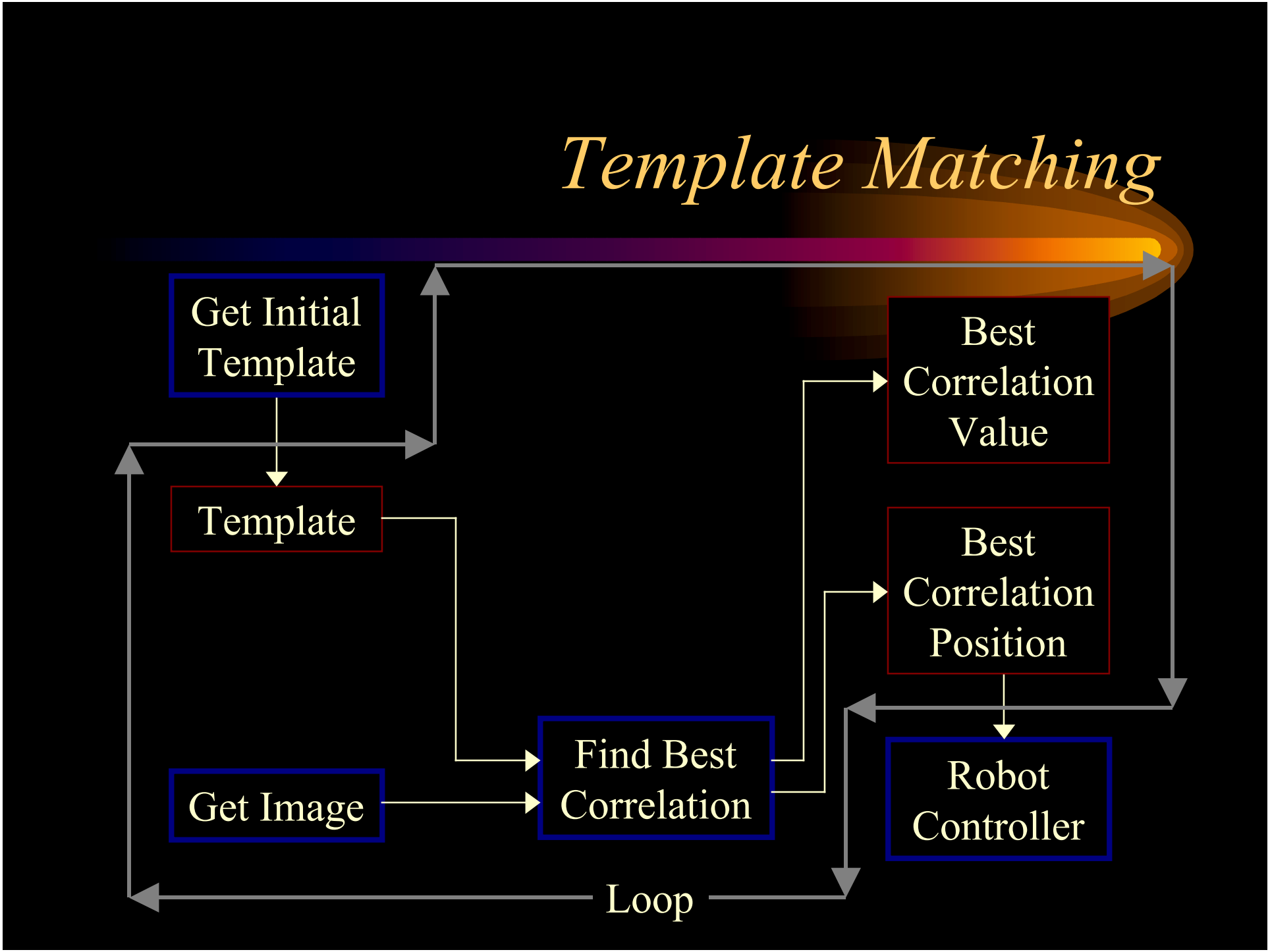
Image

1	1	1	0	0
1	0	1	0	1
1	1	1	0	0
0	0	0	0	0
0	1	0	0	1

Correlation Matrix

1	4	5	x	x
4	4	6	x	x
5	6	7	x	x
x	x	x	x	x
x	x	x	x	x

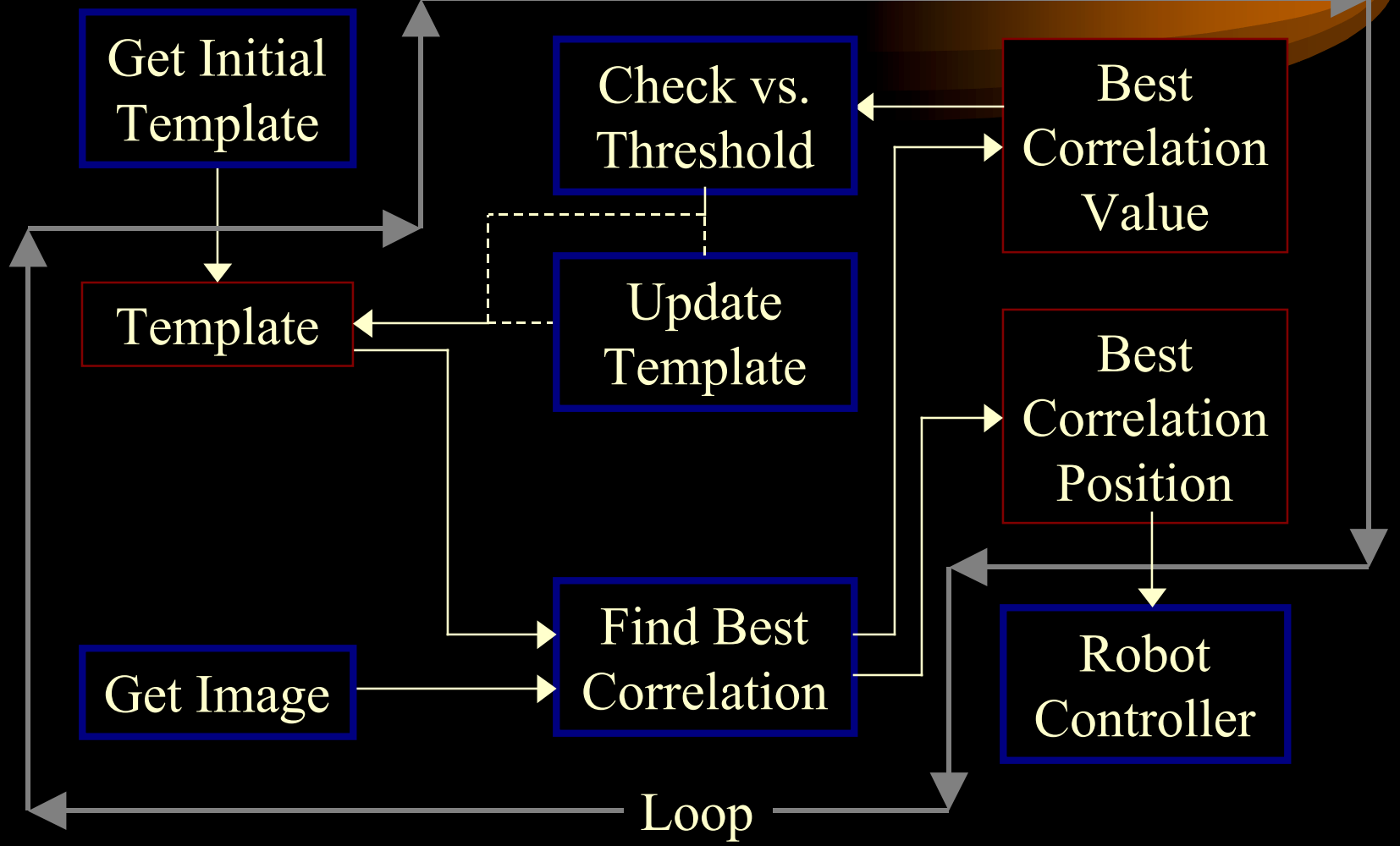
Template Matching



Limitations

- Sensitive to:
  - Lighting
  - Target orientation
  - Target Size
  - Image Noise

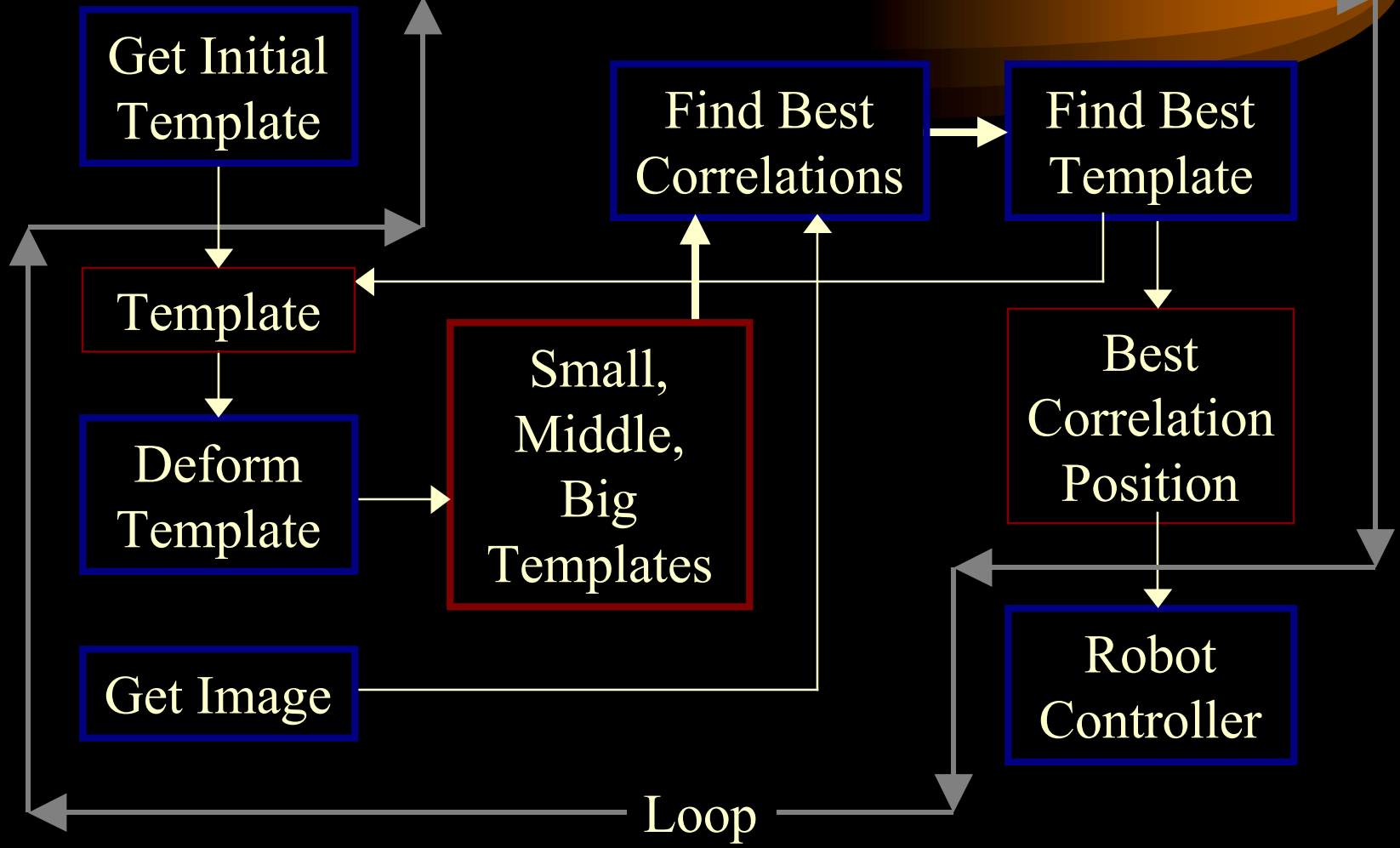
Dynamic Template Matching



Dynamic Template Matching

- Benefits
  - Less sensitivity to changes in:
    - lighting
    - noise
    - orientation
  - No additional processing overhead
- Limitations
  - Sensitivity to changes in target size
  - Constant aspect ratio
  - Reliance on frame rate
  - Template Drifting

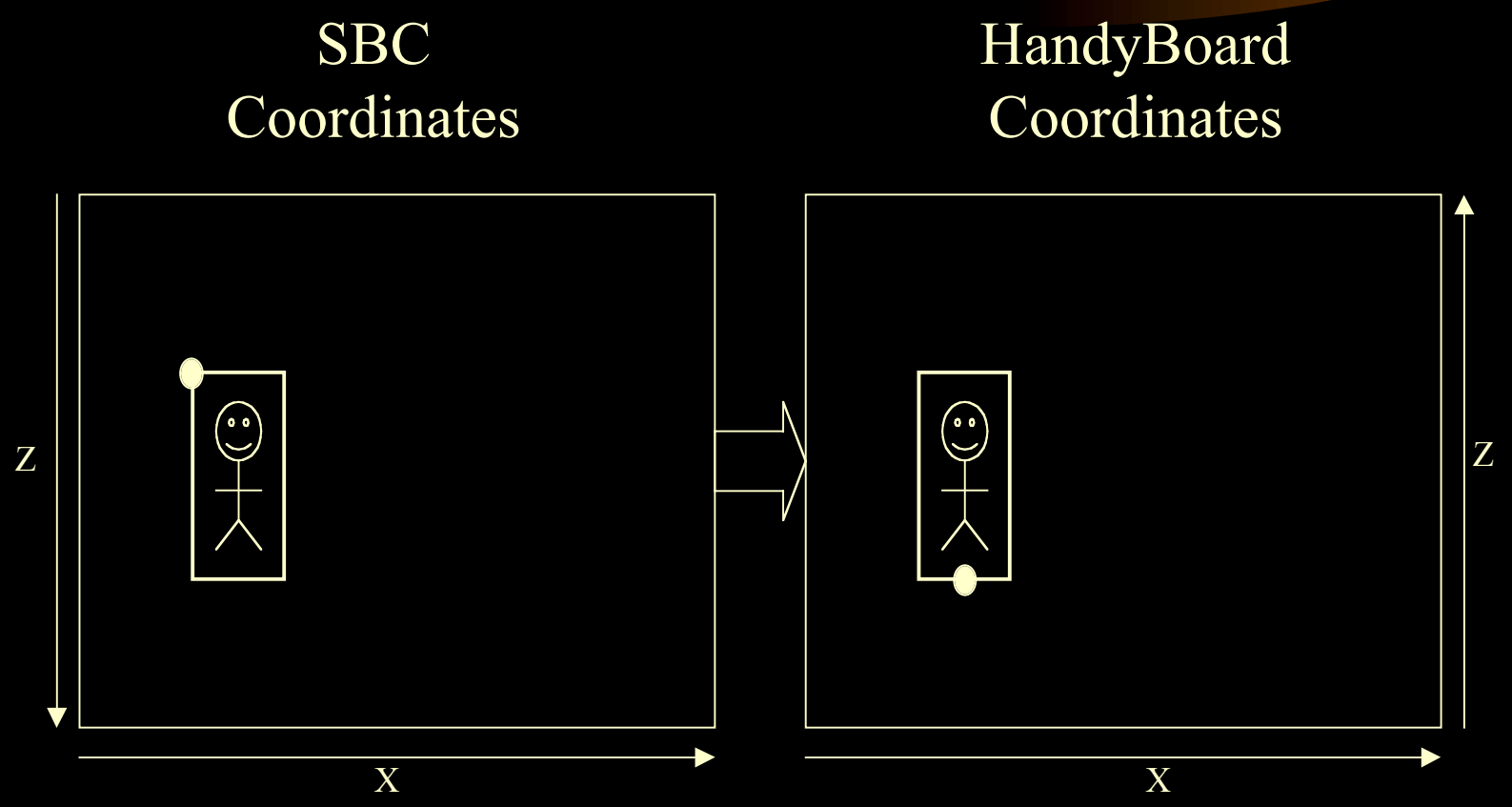
Dynamic Template Matching With Deformations



Dynamic Template Matching With Deformations

- Benefits
  - Less sensitivity to changes in size
  - Adaptability to other deformations
- Limitations
  - “Infinite Shrinkage” effect
  - Constant aspect ratio
  - Processor overhead
  - Reliance on frame rate

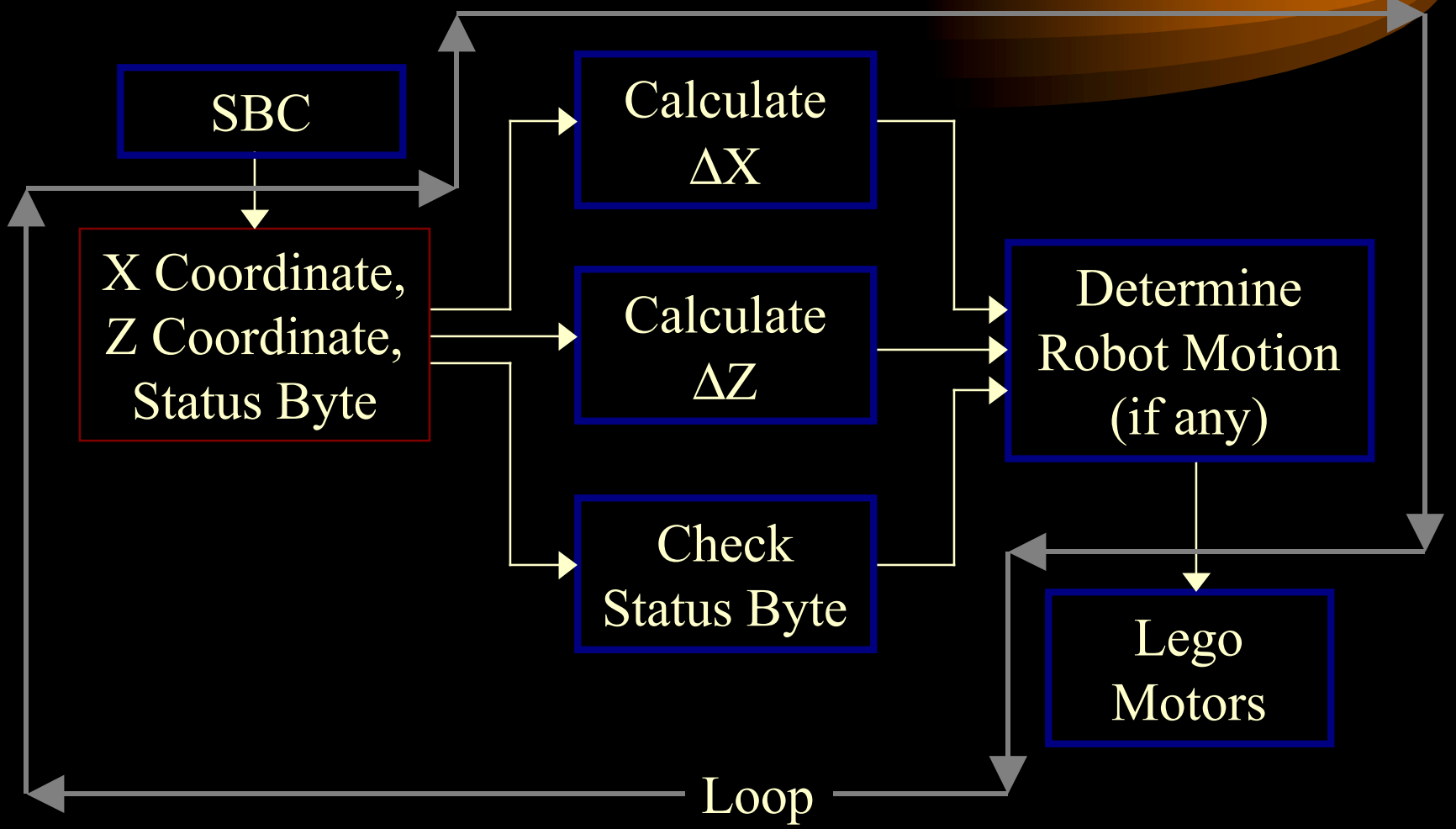
Coordinate Systems



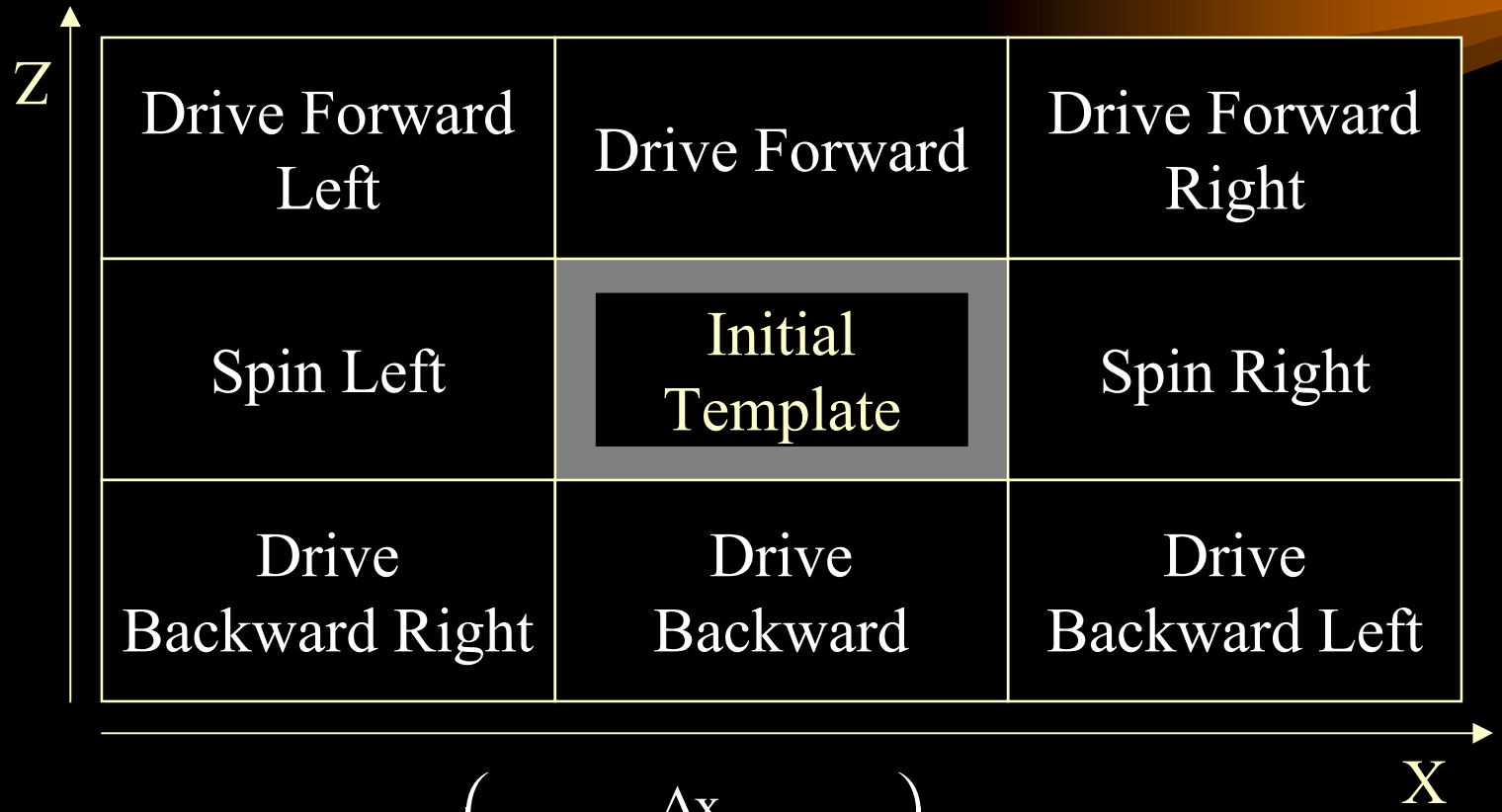
Robot Controller

- Modular design
- Constant distance behavior

Robot Controller



Robot Motion



$$\text{Spin Time} = \left(\frac{\Delta x}{(\text{Frame Width} / 2)} \right) * \text{Max. Spin Time}$$

Results

- Subjective Evaluation
  - Maintain constant distance
  - React to lateral motion
  - Follow a wandering target
- Objective Evaluation
  - Frames Per Second (fps)

Accuracy vs. Frame Rate

- 80x30 24-bit color images (↑ fps, ↓ acc.)
- Closed environment (↑ acc.)
- Disablement of deformations (↑ fps, ↓ acc.)
- Localized template searches (↑ fps, ↓ acc.)
- Disabling video output (↑ fps)
- Overexposure (↑ acc.)
- Modified template correlation (↑ fps, ↓ acc.)

Modified Template Correlation

Template

1	x	1
x	x	x
1	x	1

MatchResolution = 2

Image

1	1	1	1	0
0	1	1	1	0
0	1	1	1	0
0	1	0	0	0
0	1	0	0	1

Correlation Matrix

SearchMatchProb = 0.5

Modified Template Correlation

Template

1	x	1
x	x	x
1	x	1

MatchResolution = 2

Image

1	1	1	1	0
0	1	1	1	0
1	1	1	1	0
0	1	0	0	0
0	1	0	0	1

Correlation Matrix

0

SearchMatchProb = 0.5

Modified Template Correlation

Template

1	x	1
x	x	x
1	x	1

MatchResolution = 2

Image

1	1	1	1	0
0	1	1	1	0
1	1	1	1	0
0	1	0	0	0
0	1	0	0	1

Correlation Matrix

0	x

SearchMatchProb = 0.5

Modified Template Correlation

Template

1	x	1
x	x	x
1	x	1

MatchResolution = 2

Image

1	1	1	1	0
0	1	1	1	0
1	1	1	1	0
0	1	0	0	0
0	1	0	0	1

Correlation Matrix

0	x	2

SearchMatchProb = 0.5

Modified Template Correlation

Template

1	x	1
x	x	x
1	x	1

MatchResolution = 2

Image

1	1	1	1	0
0	1	1	1	0
1	1	1	1	0
0	1	0	0	0
0	1	0	0	1

Correlation Matrix

0	x	2	x	x
x				

SearchMatchProb = 0.5

Modified Template Correlation

Template

1	x	1
x	x	x
1	x	1

MatchResolution = 2

Image

1	1	1	1	0
0	1	1	1	0
1	1	1	1	0
0	1	0	0	0
0	1	0	0	1

Correlation Matrix

0	x	2	x	x
x	1	3	x	x
2	x	x	x	x
x	x	x	x	x
x	x	x	x	x

SearchMatchProb = 0.5

Results

Match Resolution	SearchMatchProb	Size Deformations	Video	Image Resolution	Tracking Accuracy	FPS
1	**1**	**Off**	**Off**	**80x30**	**Good**	**~0.8**
2	**1**	**Off**	**Off**	**80x30**	**Good**	**~2**
2	**0.5**	**Off**	**Off**	**80x30**	**Fair**	**~3.5**
4	**0.5**	**Off**	**Off**	**80x30**	**Poor**	**~4.5**

Processor: 40 MHz 386

Template Size: 10x4

Lost Template

- When is object lost?
- Confusion caused by:
  - Low resolution
  - Monocular vision
- Lost template threshold

Conclusion

- Identified hardware platform
  - Quickcam / 386 SBC
  - Reusable
  - Total cost: $170
- Developed algorithm
  - Scalable
  - Adaptable
- Built Demonstration Robot

Applications

- Automated vehicles
  - Smart cars
  - Convoys
- Security cameras

Recommendations

- Use of motion detecting algorithm
- Complete autonomy
- Selective Zoom
- Feature tracking using mini-templates
- Use of preprocessing segmentation

Acknowledgments

- Special thanks to
  - Dr. Richard Drushel
  - Dr. Francis Merat