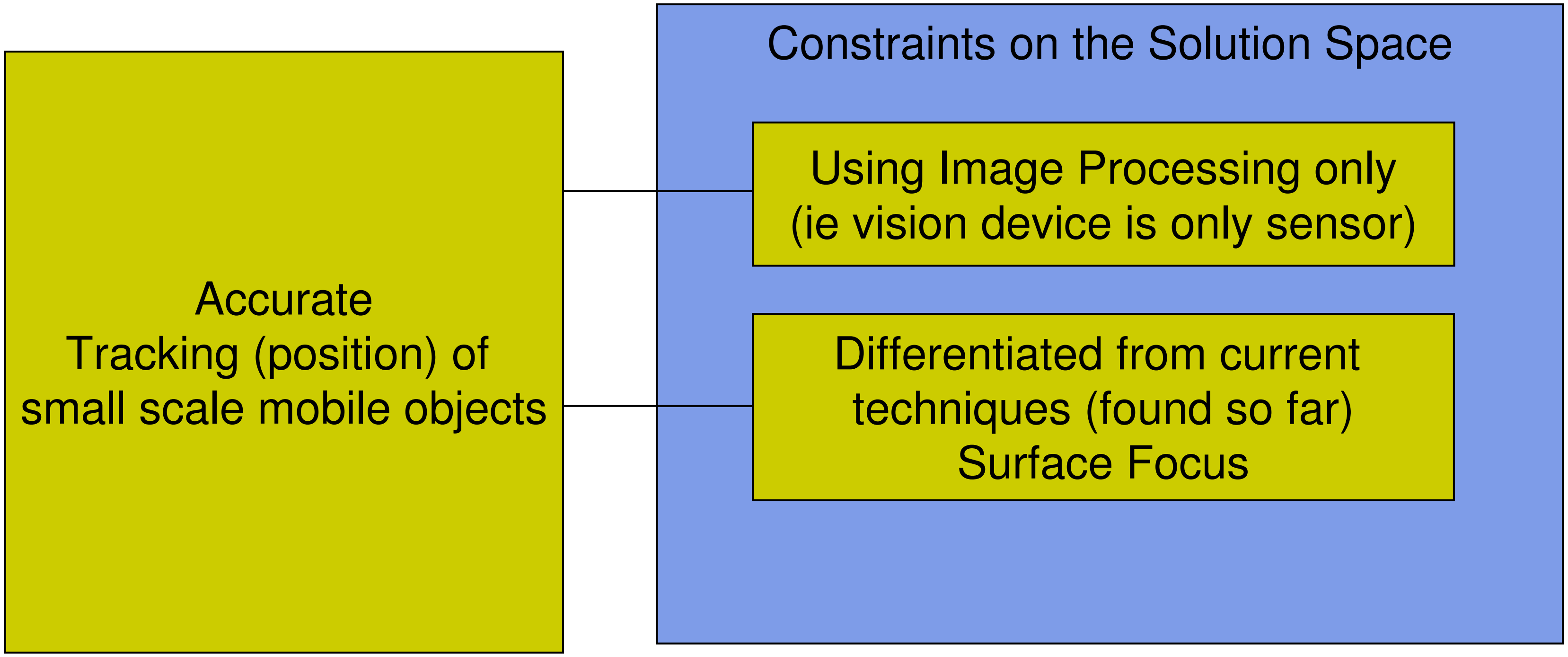
Towards Surface Image Based Vehicle Tracking

Discussion of the first passages in the maze towards a PhD

Agenda

- Problem Statement
- Image Processing Background
- Fixed image plane distance (FIPD) motion tracking
- Experimental Solution
- Results
- Conclusion
- Future Work

Global Problem Statement



A survey of hardware techniques

- I: Relative Position Measurements (also called Dead-reckoning)
  - Odometry
  - Inertial Navigation
- II: Absolute Position Measurements (Reference-based systems)
  - Magnetic Compasses
  - Active Beacons
  - Global Positioning Systems
  - Landmark Navigation
  - Model Matching

Borenstein et al, 1997

Some old pictures

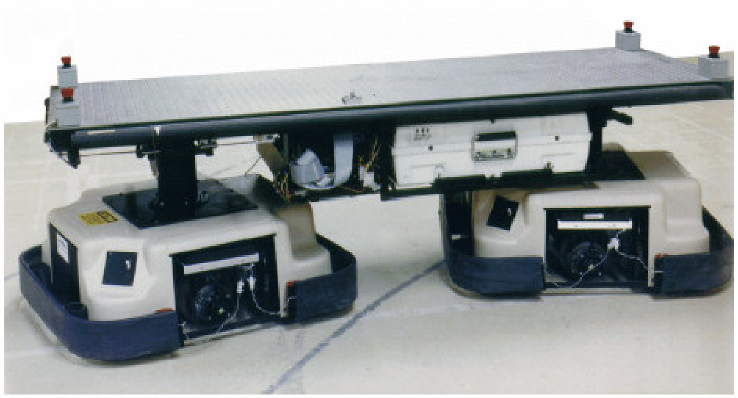
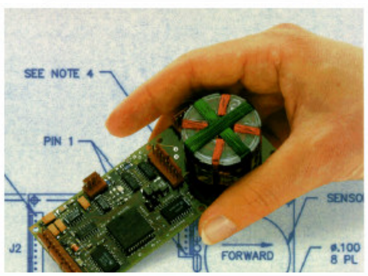


Figure 7: A single STROAB beams a vertically spread laser signal while rotating at 3,000 rpm. (Courtesy of MTI Research



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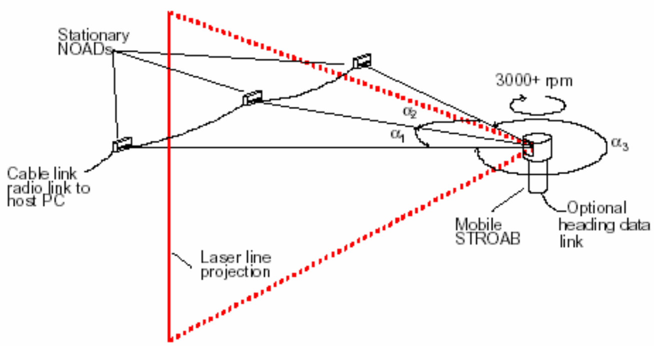
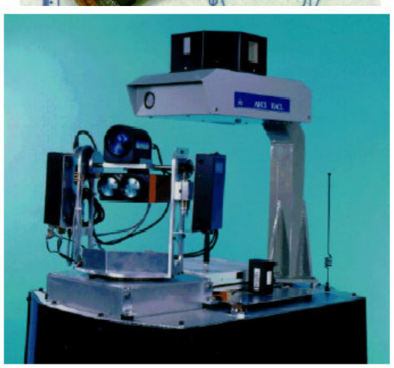


Figure 8: Stationary NOADs are located at known positions; at least two NOADs are networked and connected to a PC. (Courtesy of MTI Research, Inc.)



Borenstein et al, 1997

Comparison Table

System & Description	Features	Accuracy – Position [mm]	Accuracy – orientation [°]	Effective Range	Reference
Odometry on TRC LabMate, after UMBmark calibration. Wheel-encoder resolution: 0.012 mm linear travel per pulse		4×4 meters square path: smooth floor: 30 mm, 10 bumps: 500 mm	Smooth floor: 1-2°. With 10 bumps: 8°	Unlimited	[Borenstein and Feng, 1995]
CLAPPER and OmniMate: Dual-drive robot with internal correction of odometry. Made from two TRC LabMates, connected by compliant linkage. Uses 2 abs. rotary encoders, 1 linear encoder.		4×4 m square path: smooth floor: ~20 mm 10 bumps: ~40 mm	smooth floor: <1° 10 bumps: <1°	Unlimited	[Borenstein, 1995; 1996]
Complete inertial navigation system including ENV-O5S Gyrostar solid state rate gyro, START solid state gyro, triaxial linear accelerometer and 2 inclinometers		Position drift rate: 1-8 cm/s depending on frequency of acceleration change	Drift: 5-0.25°/s. After compensation drift 0.0125°/s	Unlimited	[Barshan and Durrant-Whyte, 1993; 1995]
Andrew Autogyro and Autogyro Navigator. Quoted minimum detectable rotation rate: ±0.02°/s. Actual minimum detectable rate limited by deadband after A/D conversion: 0.0625°/s. Cost: $1000		Not applicable	Drift: 0.005°/s	Unlimited	[ANDREW]
KVH Fluxgate Compass. Includes microprocessor-controlled fluxgate sensor subsystem. Cost <$700		Not applicable	Resolution: ±0.5° Accuracy: ±0.5° Repeatability: ±0.2°	Unlimited	[KVH]
CONAC™ (computerized opto-electronic navigation and control). Cost: $6,000.	Measures both angle and distance to target	Indoor ±1.3 mm outdoor ±5 mm	Indoor and outdoor ±0.05°	> 100 m	[McLeod, 1993]; [MTI]
Global Positioning Systems (GPS). Cost: $1,000 - $5,000.		order of 20 m during motion, order of centimeters when standing for minutes	Not applicable	Unlimited	Different vendors
Landmark Navigation		<5 cm	< 1 deg	~10 m	Different research projects
Model Matching (map-based positioning)		order of 1-10 cm	order of 1-3 deg	~10 m	Different research projects

Borenstein et al, 1997

Survey of all Image Processing techniques

- Still looking for a good one
- Seems like a worth while exercise - any volunteers?
- Existing techniques found
  - Some look at “off-board” object tracking in video (i.e. camera looking at scene and tracking objects in it)
  - Robot vision techniques process video of surrounding environment.
    - Beacons are found by segmentation, vertical edges, etc
    - Form of model matching/mapping

Image Processing Background

- Motion from 2D images
- Block Match Algorithm

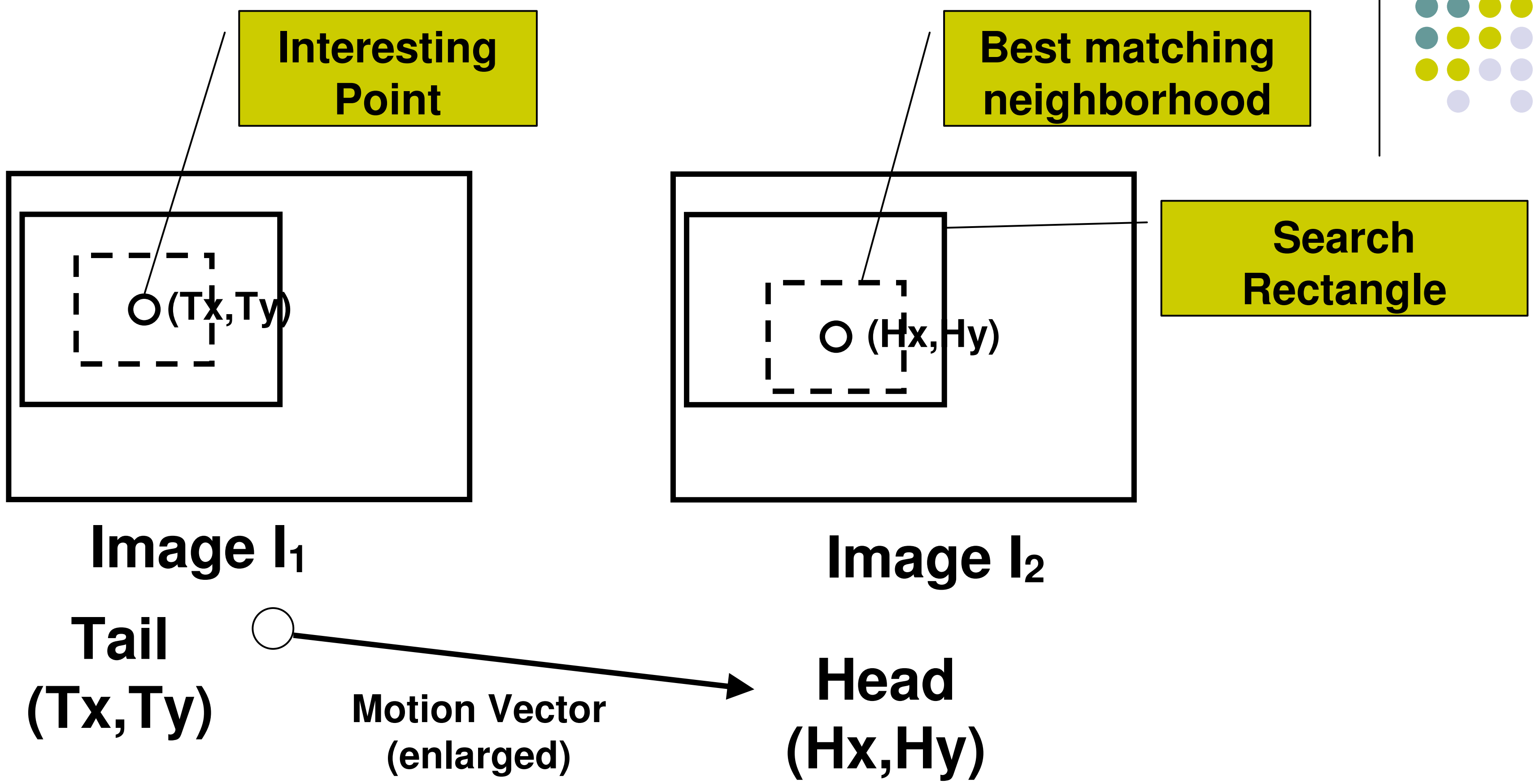
Motion from 2D images

- Motion vectors
  - **Motion field**: 2D array of 2D vectors representing motion of 3D scene points. A vector in the motion field has one of the following two meanings:
    - The tail represents the position of an imaged 3D point at time t and the head represents the position of the corresponding 3D point at time $t + \Delta t$
    - The vector represents an instantaneous velocity at time t
  - **Image flow** is the motion field computed under the assumption that image intensity near corresponding points is relatively constant

Computing Motion Vectors

- Interest Points, eg
  - Centroids of moving regions of segmented image
  - Corner points found from an edge operator
- Interest Operator
  - Thresholded intensity variance through a point P
  - Using texture – variance in an entire n x n neighborhood
- To find motion vectors: Given interesting points $\{P_j\}$ in I_1 at time t, corresponding points must be identified in I_2 at time $t + \Delta$.

Computing Motion Vectors



For each interesing point (T_x,T_y) in I_1 a rectangular region of Image I_2 is searched for the best match to a small neighborhood of (T_x,T_y) . If the match is good, then it becomes the head (H_x,H_y) of a motion vector

Computing Motion Vectors

- Cross-Correlation
  - Cross-Correlation of image F[x,y] and mask H[x,y] is defined as

$$G[x,y] = F[x,y] \otimes H[x,y]$$

$$= \sum_{i=-w/2}^{w/2} \sum_{j=-h/2}^{h/2} F[x+i,y+j]H[i,j]$$

where w and h represents the width and height of the mask

  - The minimum value for G in the search rectangle discussed above gives the best match.

Block Match Algorithm

- Each frame divided into fixed size macro blocks (MB)
- In MPEG and H.263 each MB is 16X16 pixels
- The search region (SR) is rectangular region larger than the macro blocks.
- For a SR formed by displacing the MB by +- 15 pixels, a full search (FSA) of the SR to find the best matching block gives $(15x2+1)^2 = 961$ search points (SP).
- Matching per SP is done using the sum of absolute differences (SAD)

$$SAD[x,y] = \sum_{i=-0}^{M-1} \sum_{j=0}^{N-1} | I_1[x+i,y+j] - I_2[i,j] |$$

Optimised BMA

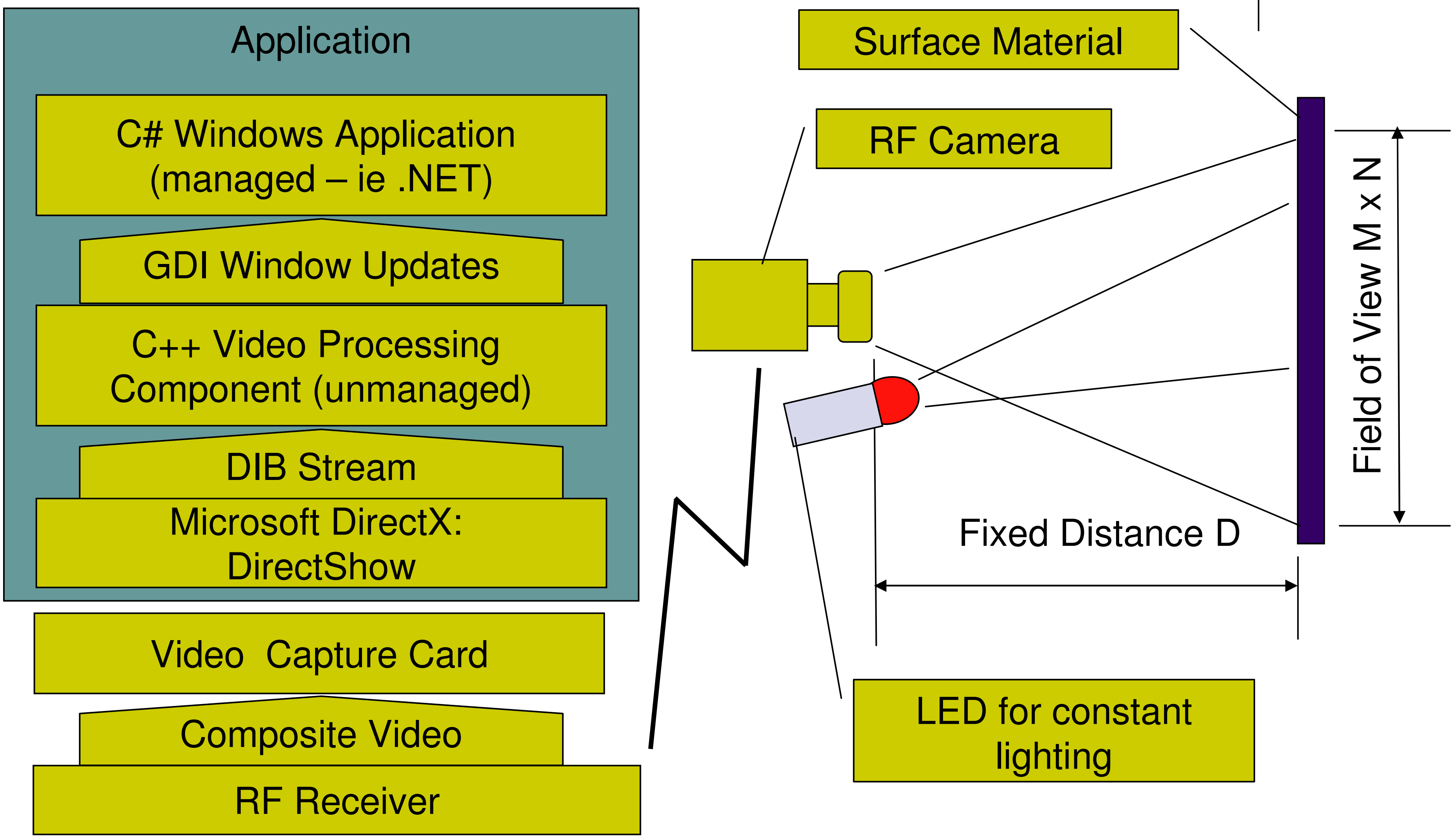
- Using SAD, the amount of RISC-like computations per 16x16 MB for FSA (961 SPs) is:
  $(2 \times 15 + 1)^2 (2 \times 16^2 - 1) = 491071$

- To reduce the computational effort, non-exhaustive search methods have been developed
  - Three Step Search (TSS) (33 SPs)
  - Modified Motion Estimation Algorithm (MMEA) (25 SPs)
  - Independent Orthogonal Search Algorithm (IOSA) (17 SPs)

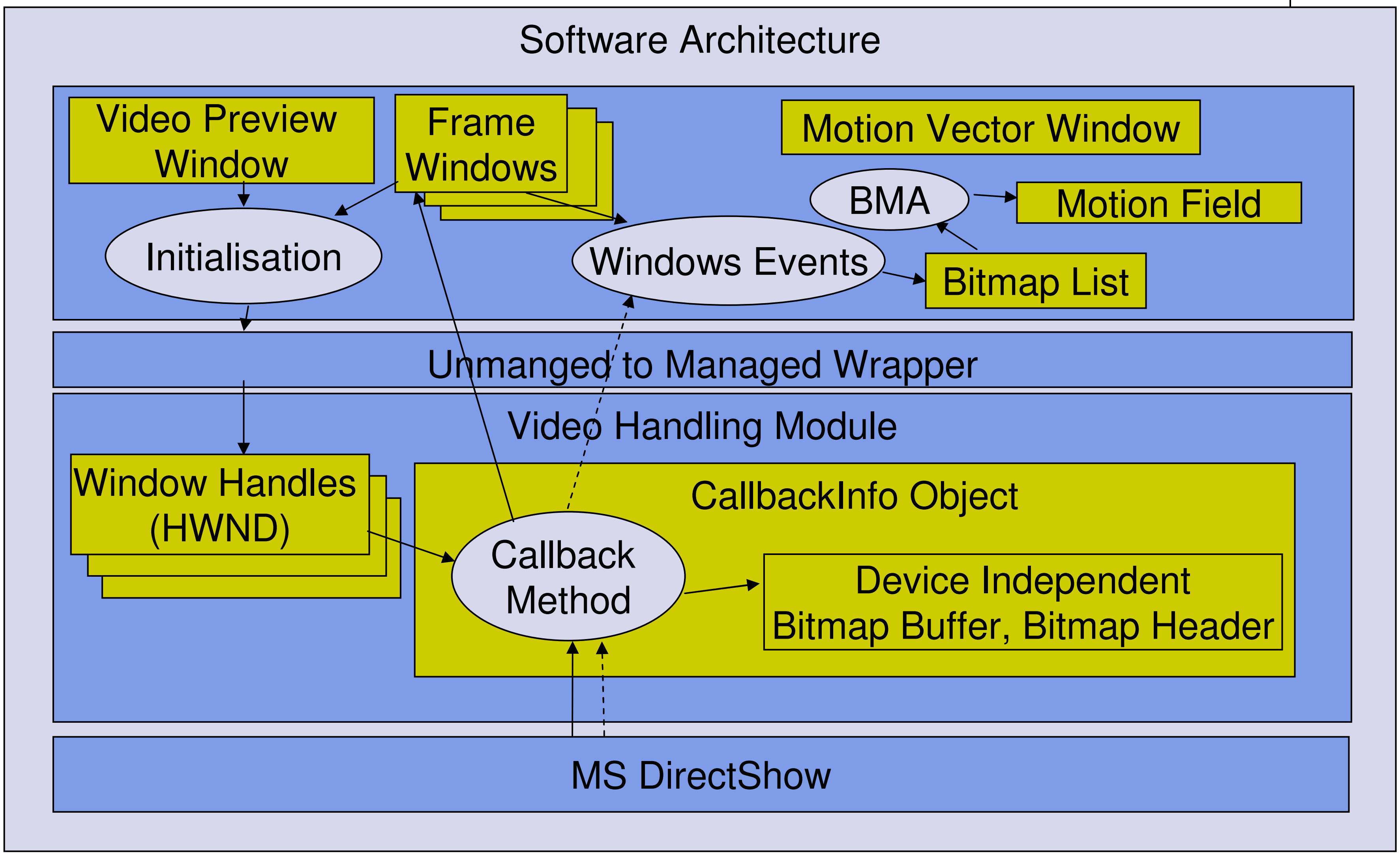
Fixed image plane distance (FIPD) motion tracking

- Coming back to the objective: Surface image motion tracking
- Fixing the distance from surface plane to image sensor plane makes it possible to transduce image motion vectors to physical distance travelled by the object that the sensor has been attached to.
- Related to dead reckoning techniques to track robot motion in the class of odometry

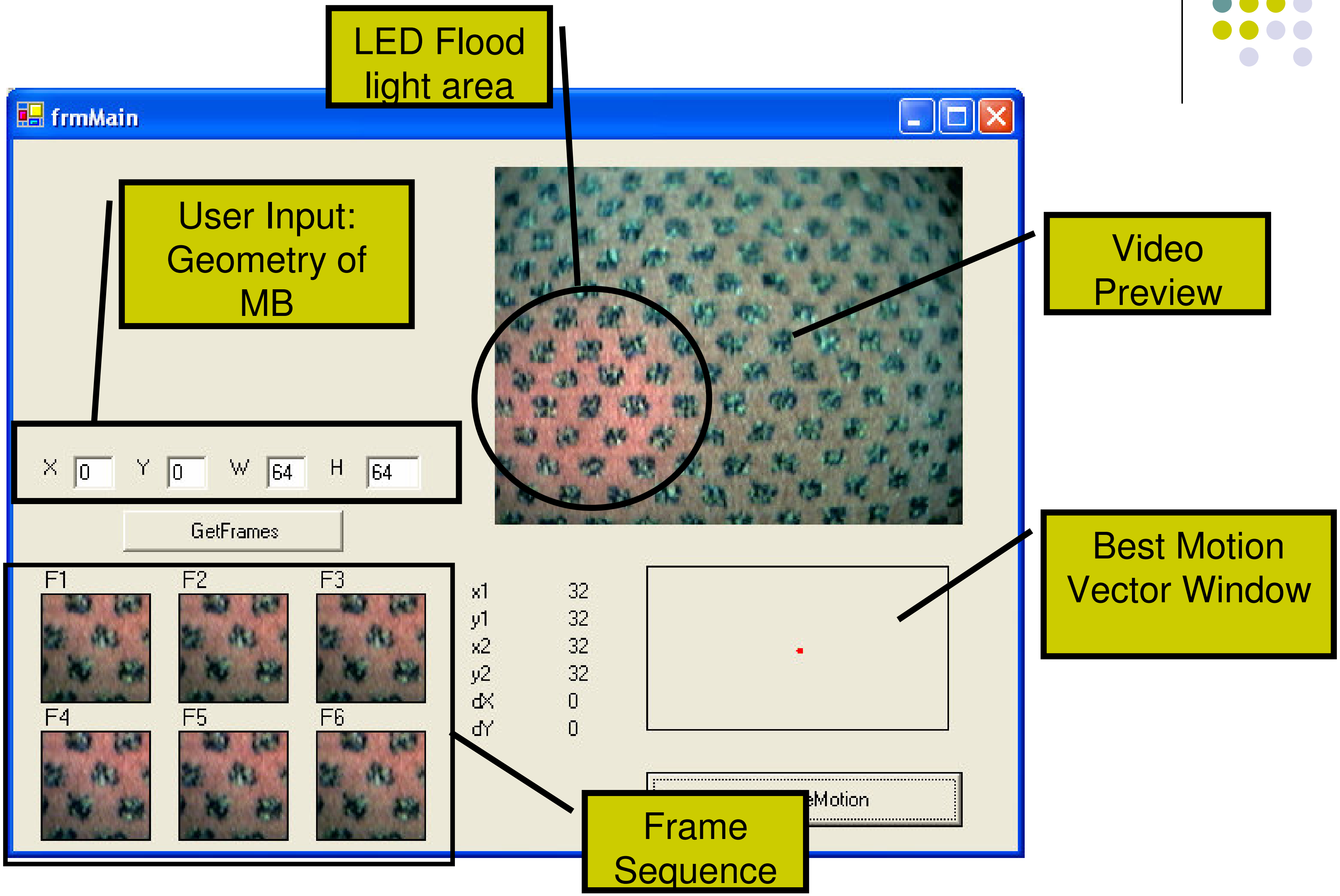
Experimental Solution



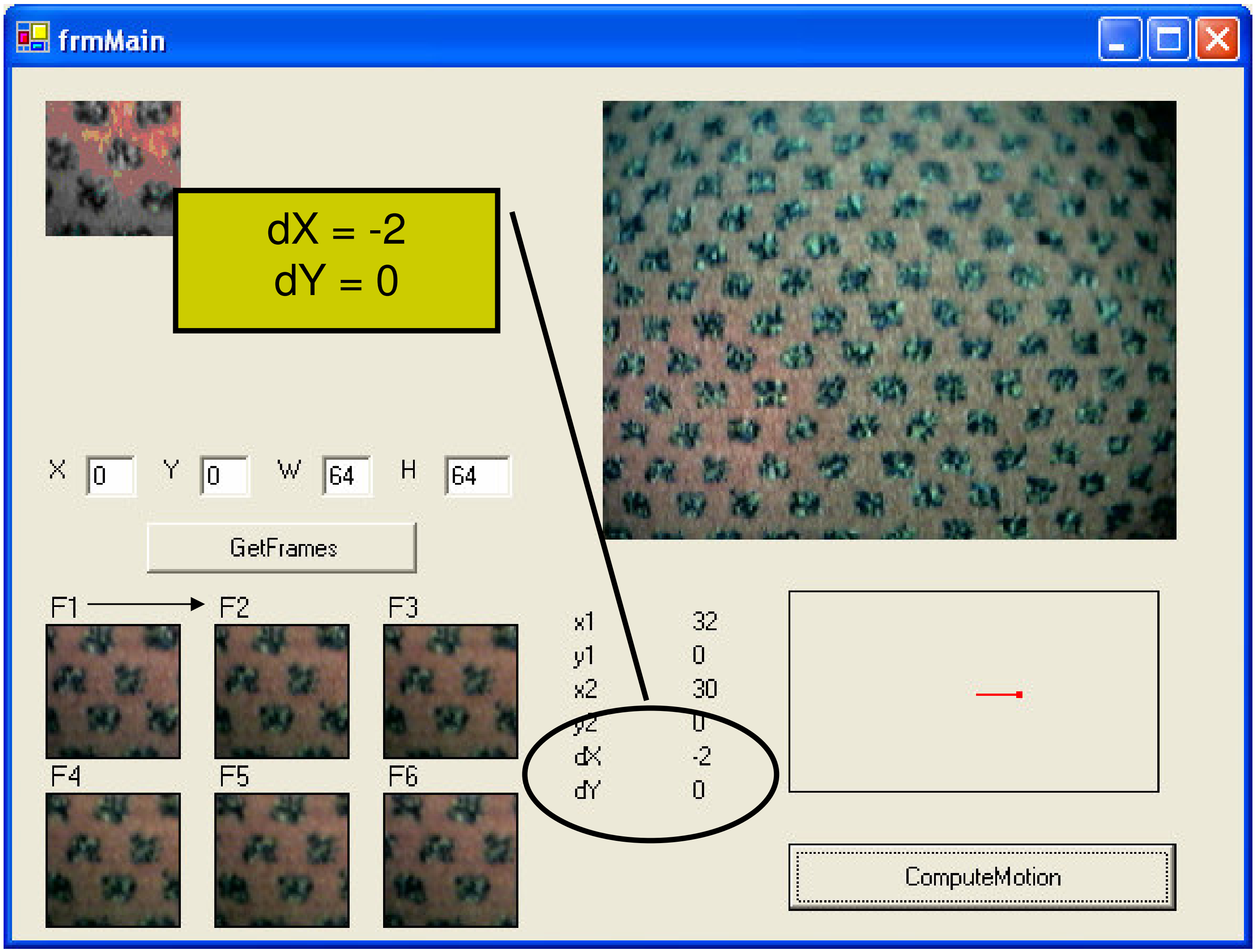
Experimental Solution



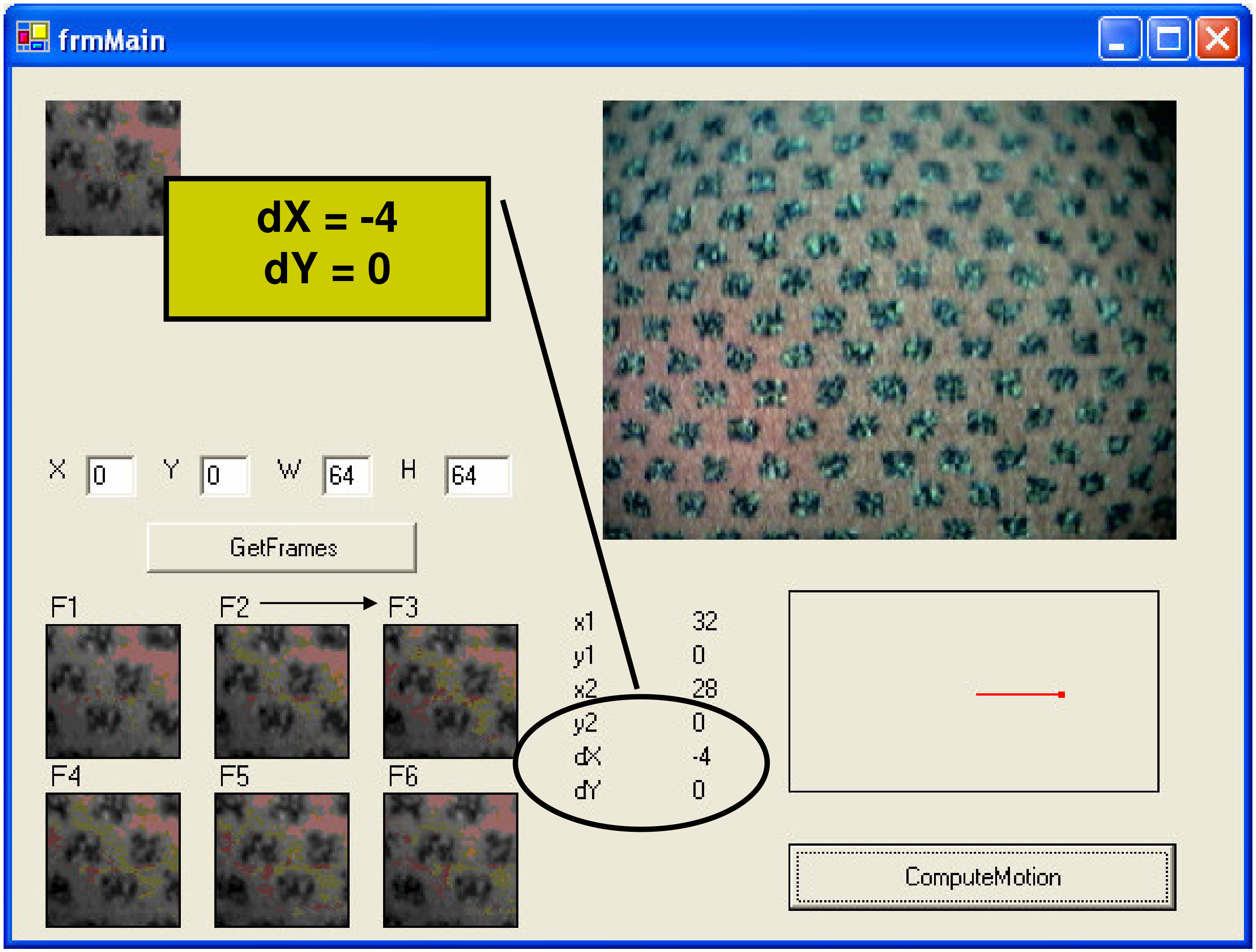
Application Output



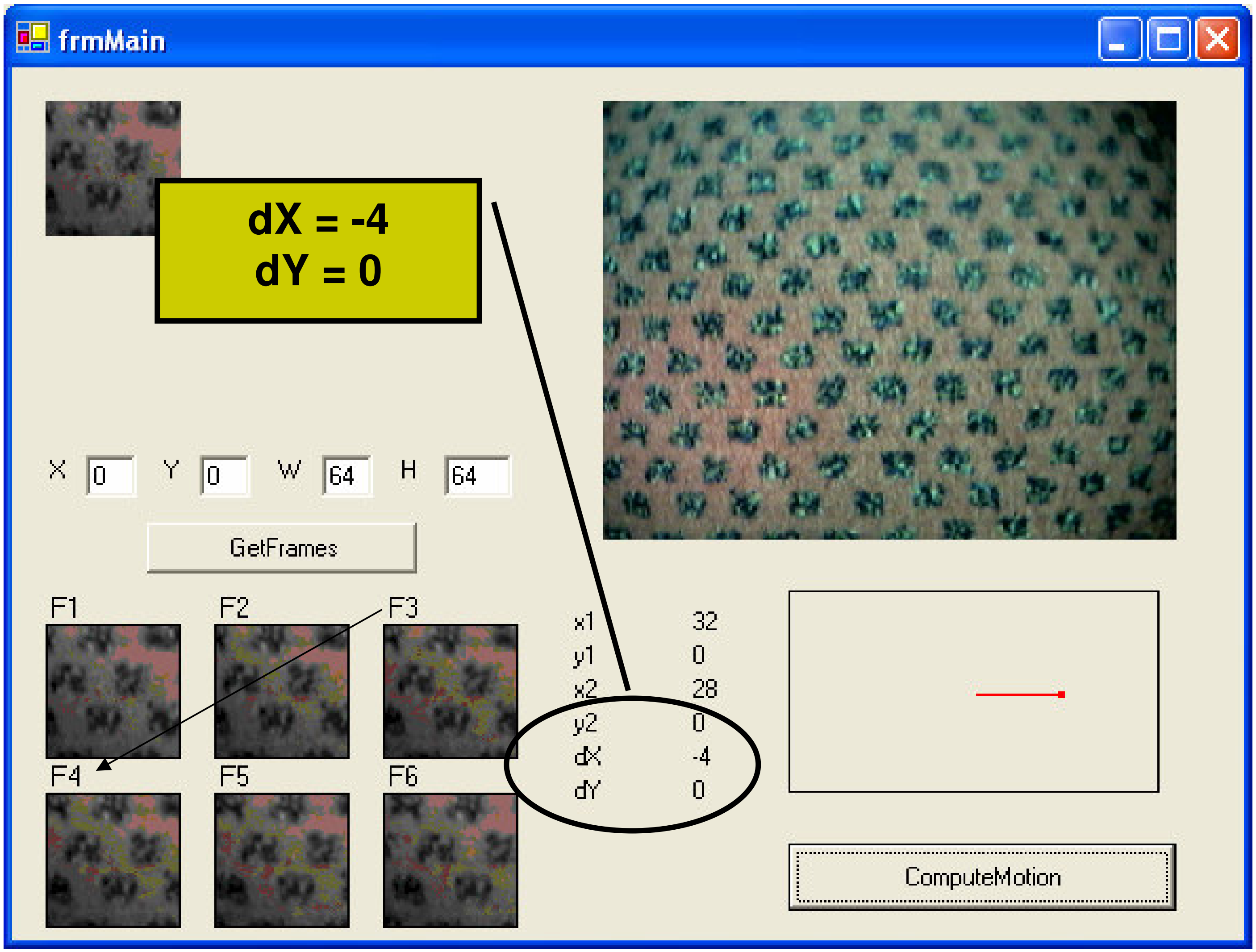
Results: F1 –> F2



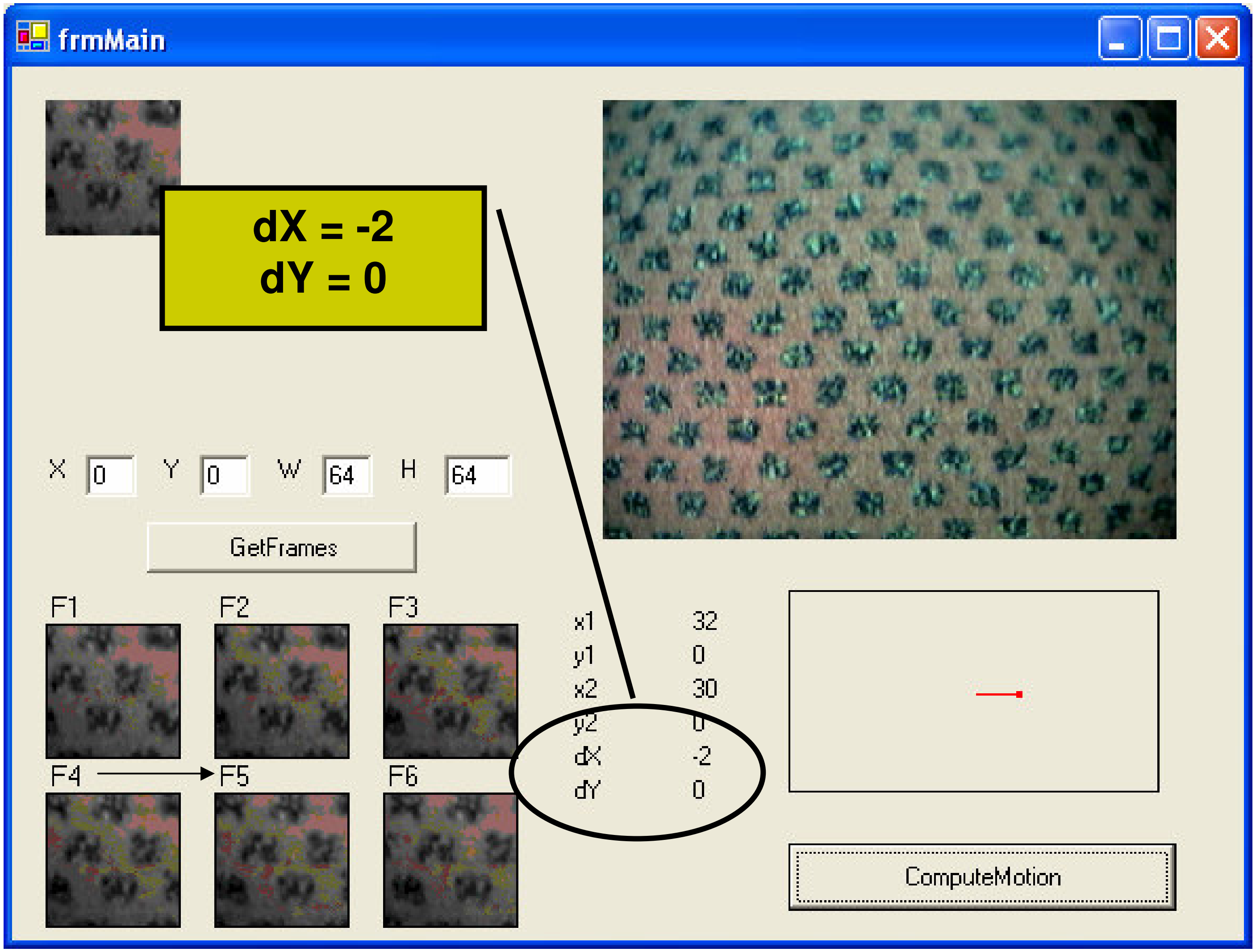
Results: F2 –> F3



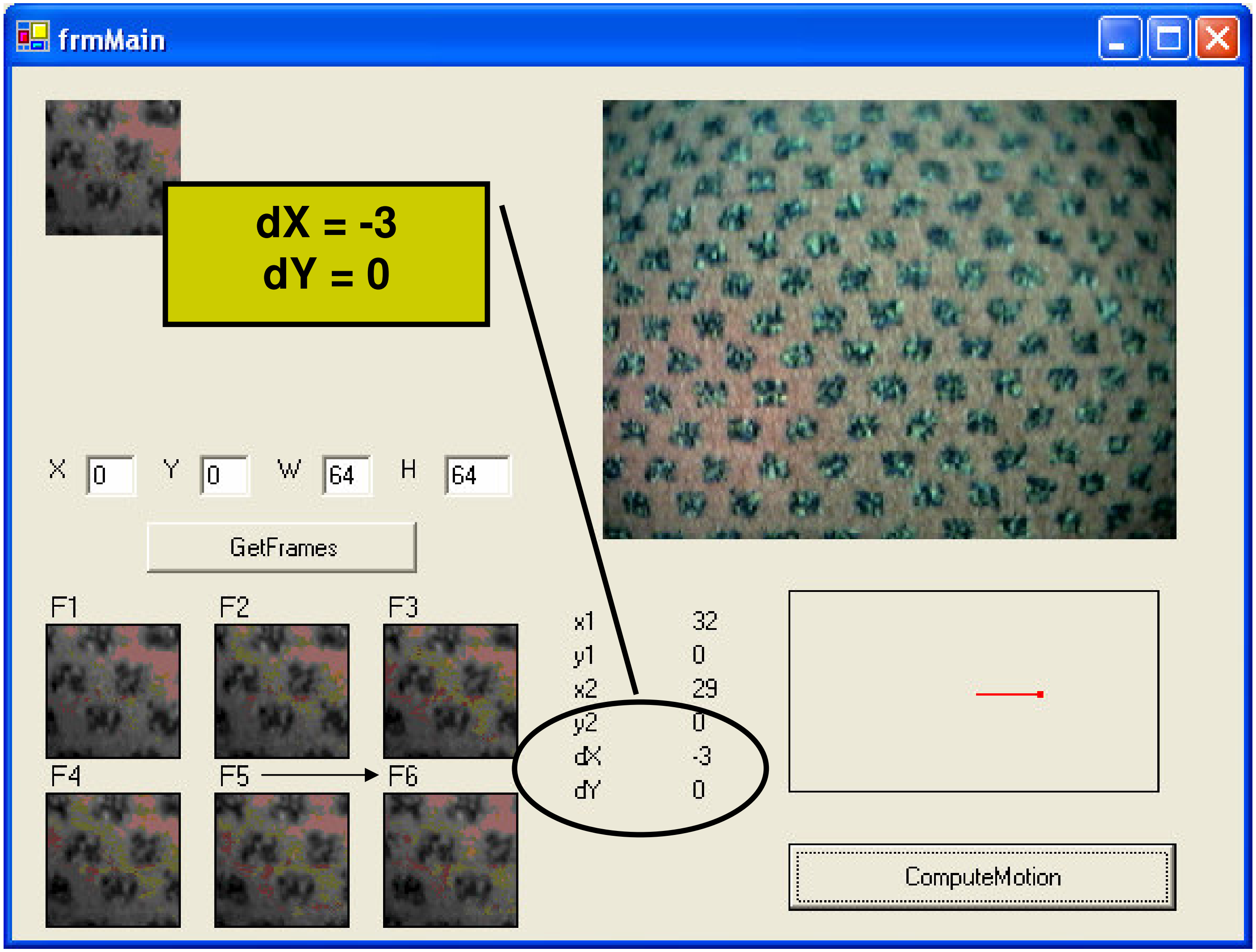
Results: F3 –> F4



Results: F4 –> F5



Results: F5 –> F6



Conclusion

- Coarse tracking of motion working
- Highly optimised BMA not as critical as for image compression, VLSI chips
  - Increase in accuracy
- Theoretical basis of accuracy can be derived from geometry.
  - Function of resolution of imaging device and D (distance from object plane)

Further work

- Completing the survey of techniques
- Further displacement accuracy analysis (theoretical basis)
- Combination of segmented image regions and motion analysis and beacon recognition
  - This will enable the unbounded error drift attributable to dead reckoning to be reduced by resets at previously discovered surface beacons
  - Study of different surface image characteristics and its influence on the design of techniques.
- Map discovery (using surface beacons)
- Comparison of the surface based technique with current panoramic image analysis of eg vertical edges.