Automatic PSO-Based Deformable Structures Markerless Tracking In Laparoscopic Cholecystectomy

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Outline

Context and motivation

Proposed Method

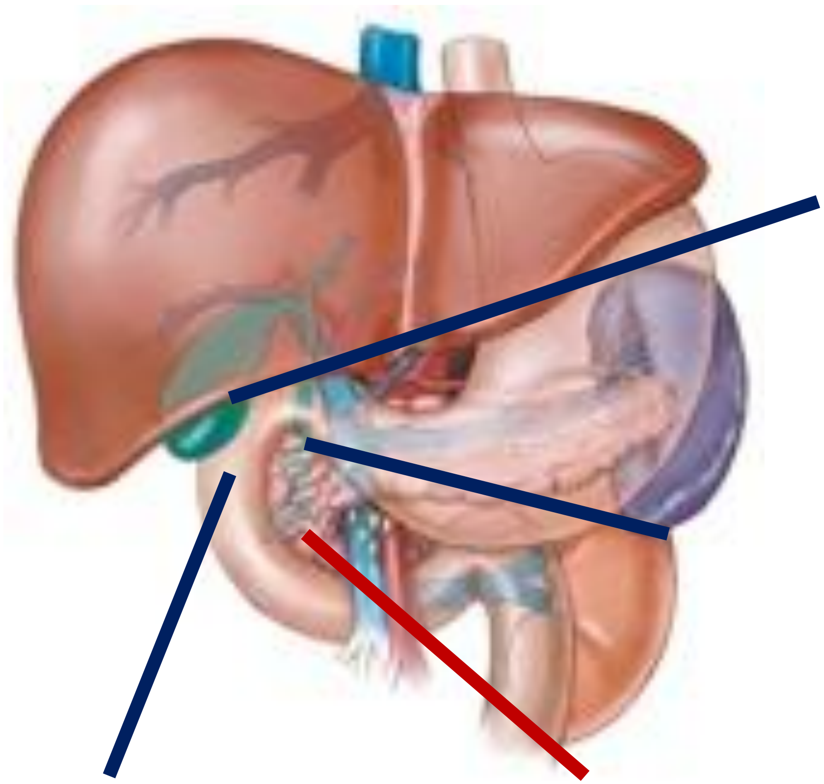
- Anatomical Color Model Segmentation
- PSO-Based Detection and tracking
- Modeling priori knowledge

Results and discussion

Problem Statement

Laparoscopic Cholecystectomy

- Monocular laparoscopic view with limited field of view,
- The laparosocopic view provides only images of the surface of organs,
- Vascular and cystic ducts (to be dissected) are occluded,



Motivation

Clinical

- **Bringing together**
  - preoperative medical information (MRI, CT-Scan, Echography…)→2D tomographic (grey level)
- **And**
  - Intra-interventional laparoscopic images → 2D projective images (RGB colors)
- ***To track anatomical structures (generally occluded)***

Motivation

Assumptions 1:

- There is no RGB colors in the preoperative medical images (CT-Scan, MRI, Echography…)

- Organs are not transparent in laparoscopic images (we can view only the surface of structures)

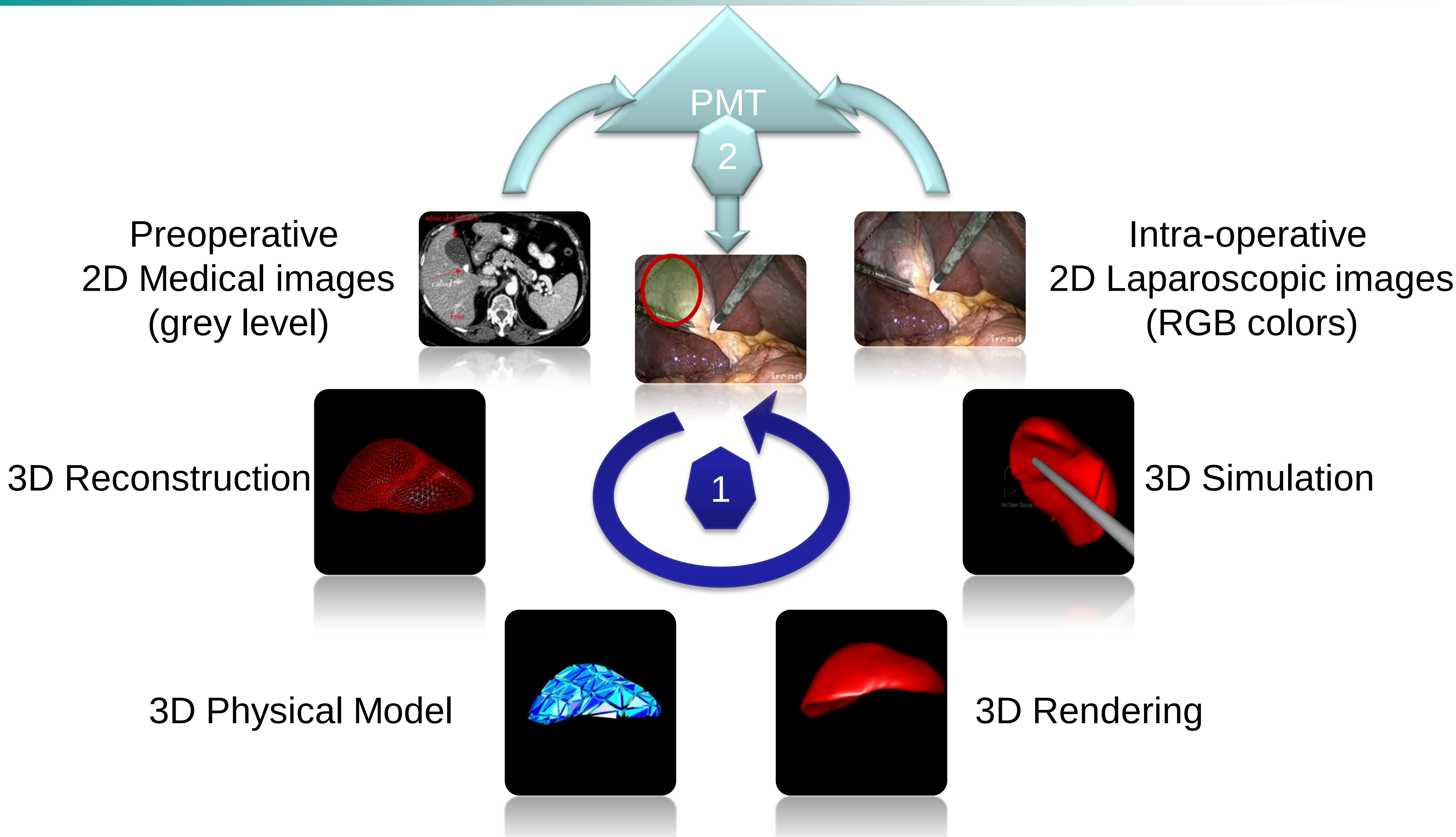
- →What are the common elements that will enable the combination of tomographic images (grey level) and projective laparoscopic images (RGB images) in different color spaces ?

Motivation

Assumptions 2:

- European school standard laparoscopic cholecystectomy intervention protocol
- Gold standard topology of anatomical structures (one gallbladder)
- The laparoscopic camera is calibrated (Distortions are corrected)

Context


PMT
2
Preoperative
2D Medical images
(grey level)
Intra-operative
2D Laparoscopic images
(RGB colors)
3D Reconstruction
1
3D Simulation
3D Physical Model
3D Rendering

Methods

Pixel-based Organs Detection

- The histogram count is converted to a discrete probability density
- An anatomical color model is a **dictionary** of RGB triples **sorted** according to their probabilities
- Segmentation of each pixel according to its rank in the color model

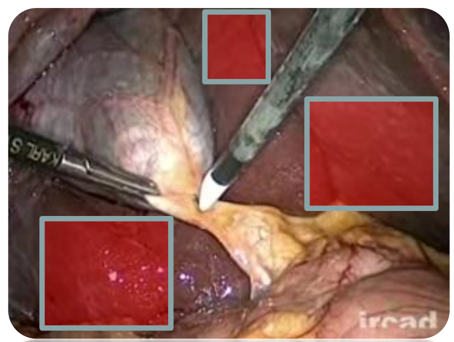
Methods

How to build the Anatomical color model ?

Organ #1

R	G	B	Pr
88	64	48	0.02
168	116	104	0.01
192	132	120	0.005

Reference image

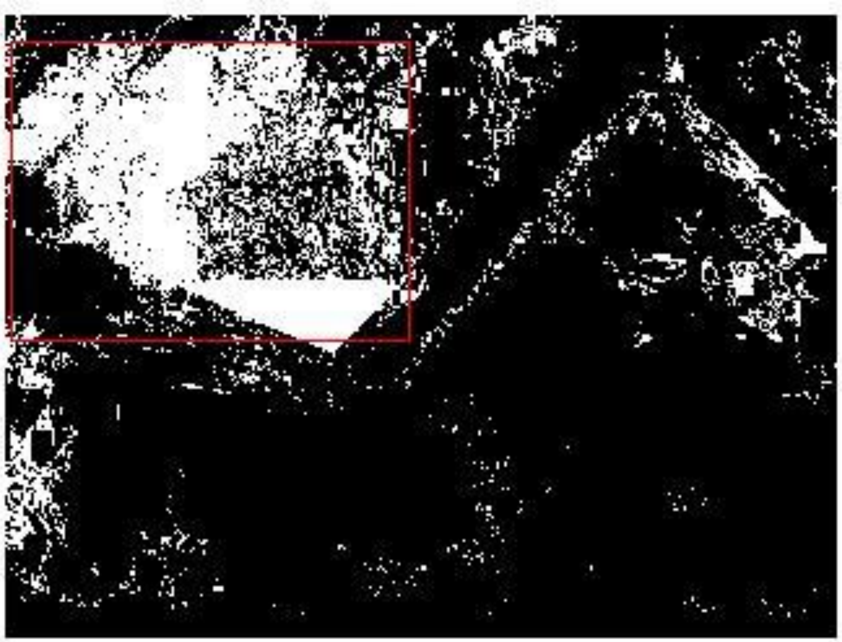


Organ #2

R	G	B	Pr
200	68	56	0.03
188	148	64	0.01
52	45	41	0.01

Methods

Detection of the gallbladder



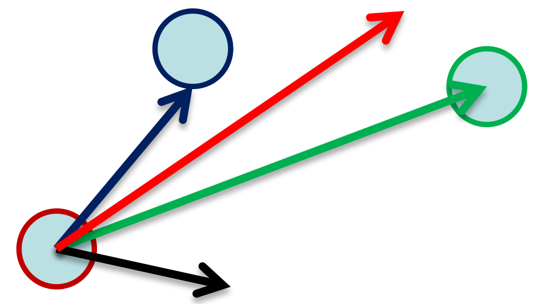
Methods

Particles Swarm Optimization

- Particles Swarm Optimization (PSO) introduced by Kennedy and Eberhart in 1995
- Global search strategy based on the social evolution simulation of a set of particles based on the rules of Newtonian physic

Methods

Standard PSO



- The particle is at the position :
  - $X = [x_1 \quad x_2 \quad \dots \quad x_N]$
- With the velocity :
  - $V = [v_1 \quad v_2 \quad \cdots \quad v_N]$
- Then, the new position is determined by :

$$V_{t+1} = f_{inertia} V_t + f_{cognitive}(X^* - V_t) + f_{social}(\hat{X} - V_t)$$

$$X_{t+1} = X_t + V_{t+1}$$

Methods

PSO Application

- Organs tracking is converted to a PSO optimization problem
- Each particle models an elementary geometric building structure:
  - A disk : the center and the radius → X = [x y r]
  - A square : the upper-left corner and the side length → X = [x y l]
  - A rectangle : two opposite vertices → X = [x1 y1 x2 y2]
  - …
- The process stops if there is no changes in the value of the fitness function or the global best particle position
- The global best particle determines the position of the targeted organ (the gallbladder)

Methods

The fitness function

$$F_{Intra} = \beta|1 - H| + (1 - \beta)|1 - D|$$

With,

$$\beta \in [0,1] : a\ regulating\ factor$$

$H = \frac{\alpha}{\overline{\overline{I_x}}}$, the a priori knowledge term

$D = \frac{\overline{\overline{I_x}}}{x_S}$, the density of the particle term

Methods

The a priori knowledge factor

$$H = \frac{\alpha}{\overline{\overline{\overline{I}}}_x}$$

With,

α is the estimated size of the targeted organ using a priori knowledge

1. The human physician estimation,

2. Intersection of (ACM) segmentation and region of interest (ROI)

   $\alpha = f_{ROI}(f_{ACM}(I_{laparoscopic}, S_i))$

3. Preoperative tomographic images (CT-Scan, MRI,…)

Methods

Determining (α) from tomographic images

$$\alpha = \frac{\delta_{gal}}{K.\omega} + \varepsilon$$

where,

δ_{gal} is the area of the surface casing (outermost covering) of the targeted organ (the gallbladder)

K : indicates the visible part of the gallbladder $K \in [2,5]$

(K=2 → the half of the surface area is visible)

ω : the area of elementary surface projected into a pixel

ε : the residual term (approximation of deformations)

- $\varepsilon<0$: surfaces perpendicular to image plane,
- $\varepsilon>0$: dilatation of the gallbaladder after abdominal cavity establishment
- $\varepsilon=0$: the deformation is so small to be ignored

Methods

Determining (ω)

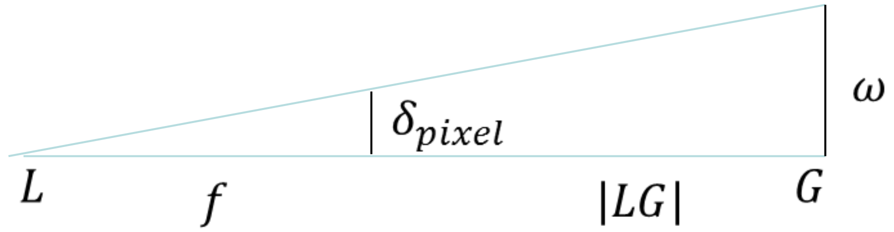
$$\omega = |LG| \frac{\delta_{pixel}}{f}$$

with,

δ_{pixel} is the area of laparoscopic camera square pixel

$|LG|$: the distance between the laparoscopic optical center (L) and the gallbladder surface (G)

f: the focal length of the laparoscopic camera



Methods

Determining α

$\alpha = \tau \frac{f}{2.\rho^2.|LG|}$ (after replacing the value of ω)

with,

τ : the count of the polygons modeling the surface of the gallbladder

ρ2 : the area of the square pixel

K=2 : the half of the gallbladder surface is visible

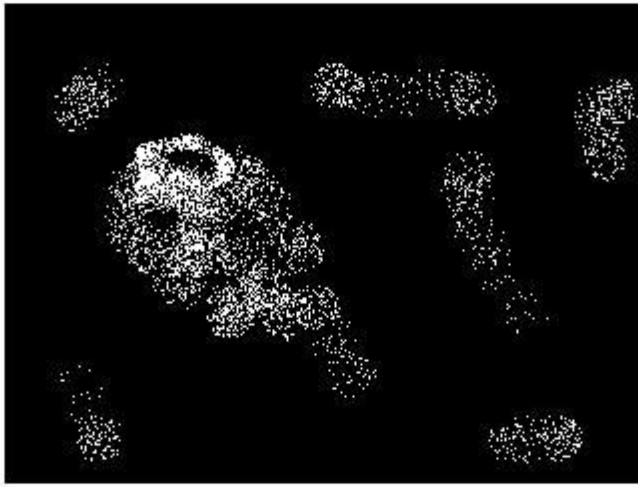
If the preoperative images are with millimeter resolution, we have :

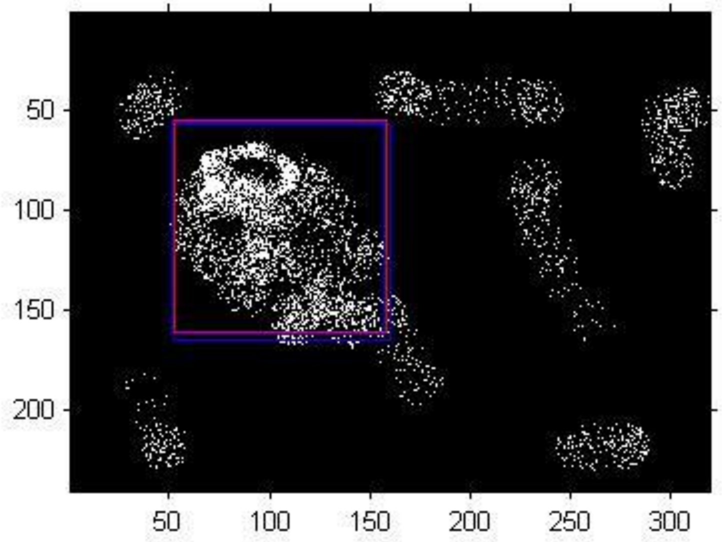
$\tau = \sum_{i=1}^{n} \gamma_i = 2n\pi \sum_{i=1}^{n} r_i$ (if the contour is approximated by a circle) then

$$\alpha = \frac{n\pi f}{\rho^2.|LG|} \sum_{i=1}^{n} r_i$$

Experiments & Results

Synthetic images

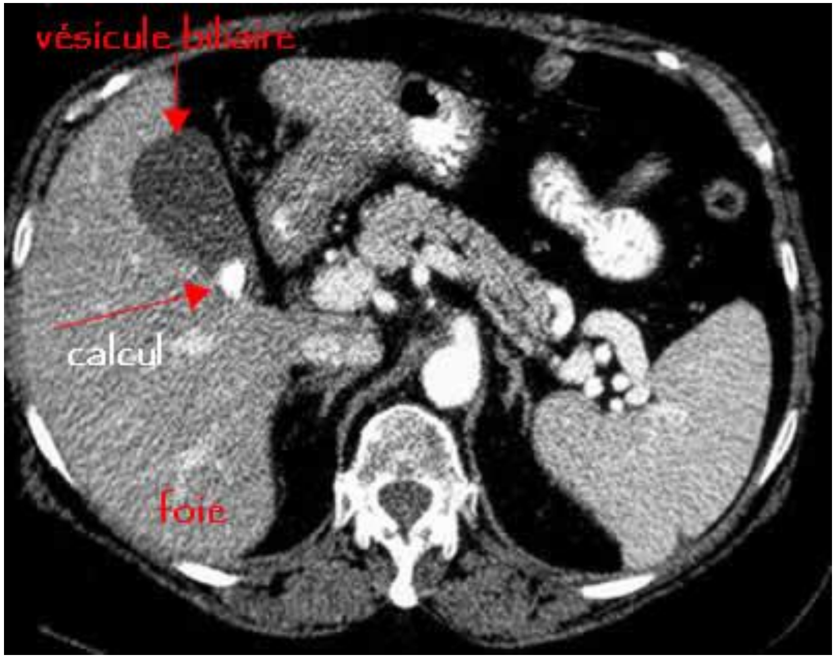


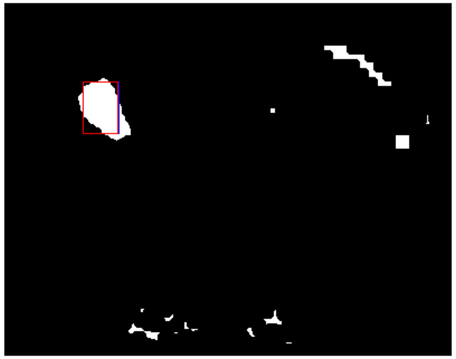


Experiments & Results

HAIS'10

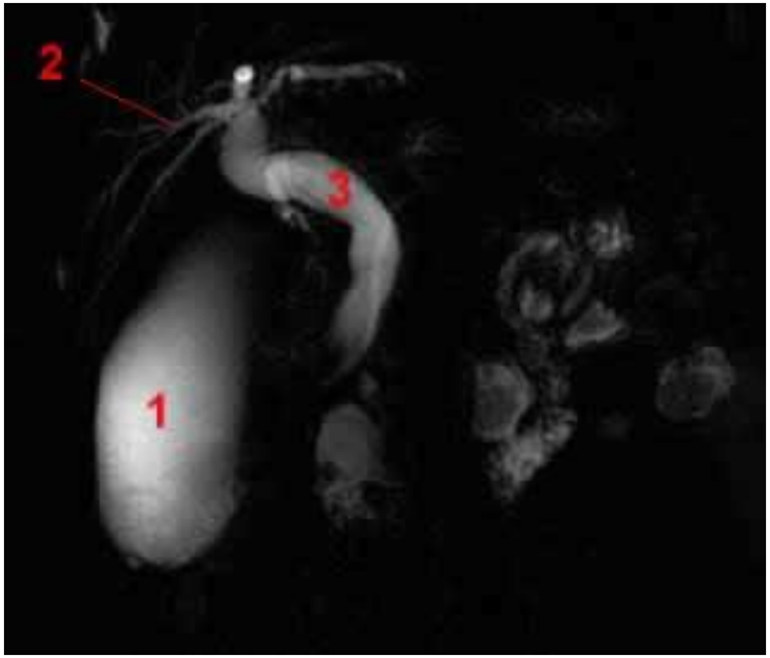
CT-Scan images

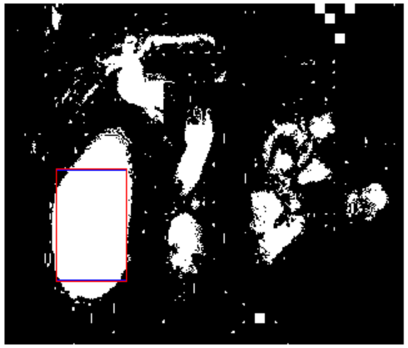




Experiments & Results

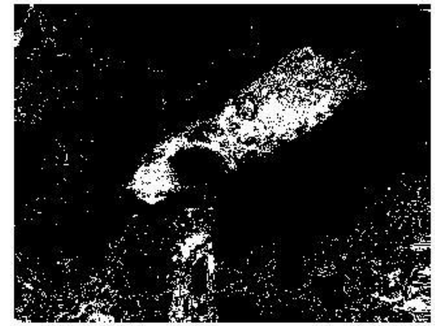
MRI images

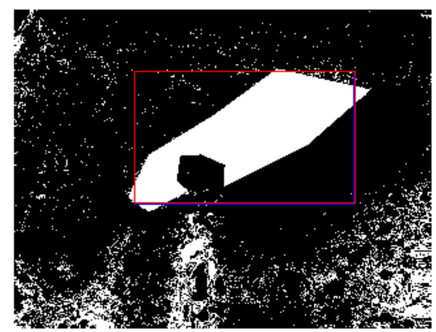




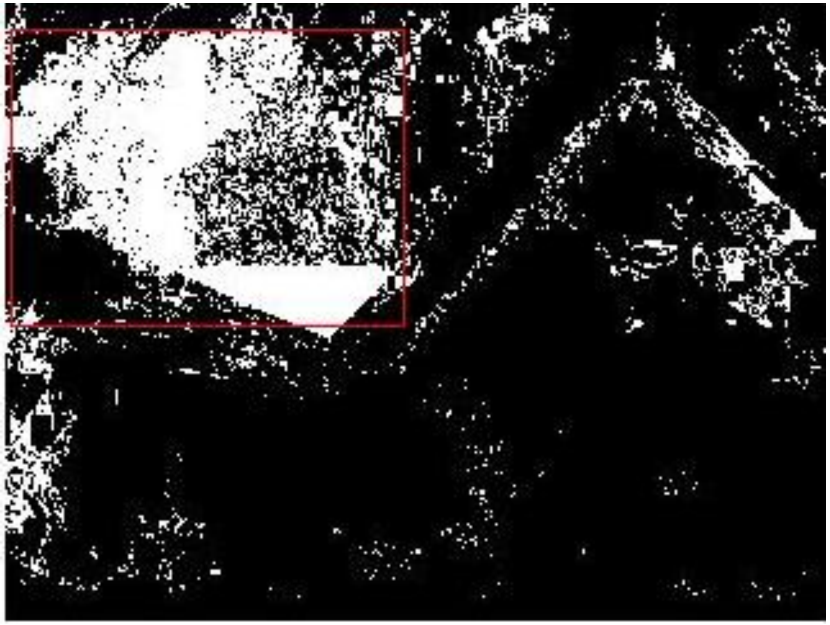
Experiments & Results

CT-Scan images

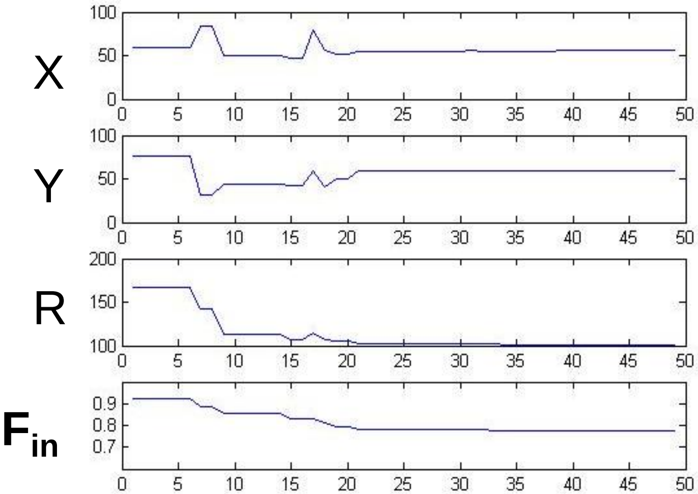




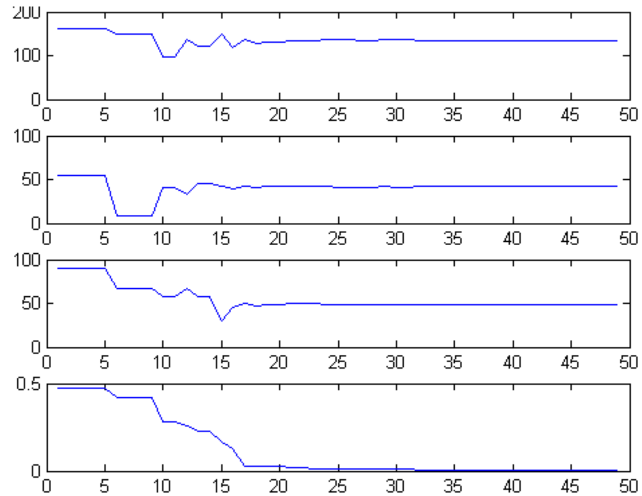
Laparoscopic images



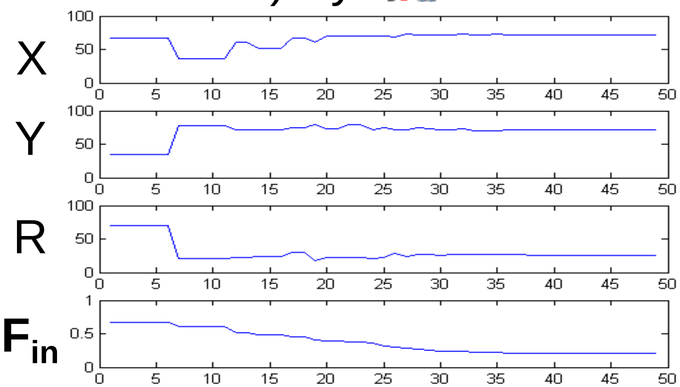
Experiments & Results



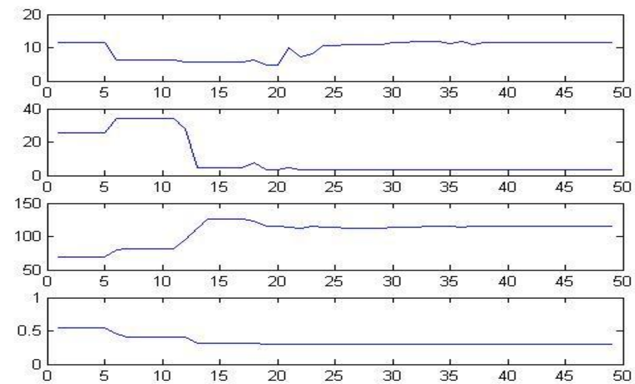
a) Synthetic



c) MRI



b) CT-SCan



b) Laparoscopic

Conclusion

- A new pixel based anatomical color model detection of digestive organs

- Markerless tracking of targeted organ (the gallbladder) in different modalities using PSO

- Direct use of geometric information from preoperative tomographic images for automatic tracking in laparoscopic cholecystectomy images without need of 3D reconstruction and rendering

Thank you for your attention !