Vision-Aided Position Control Method for Manufacturing Machines

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Outline

1. Introduction:
   a) CNC machines and position control
   b) Motivation
2. Kinematic model vs. direct position sensing
3. Dynamic target on LCD
4. Sub-pixel resolution method
5. Experimental results
6. Conclusions

1. Introduction

a) CNC machines and position control

Computer Numerical Control (CNC) machines have been widely used in the manufacturing sector because:

- they provide high production rates
- achieve basic accuracy requirement

Resolution and accuracy: depend on the type of sensors used for axis positioning, e.g. linear or rotary encoders, interferometers.

Drawback: geometric accuracy errors such as imperfect straightness of the axis guideways, non-squareness of their motion directions, and thermal variations are not compensated.

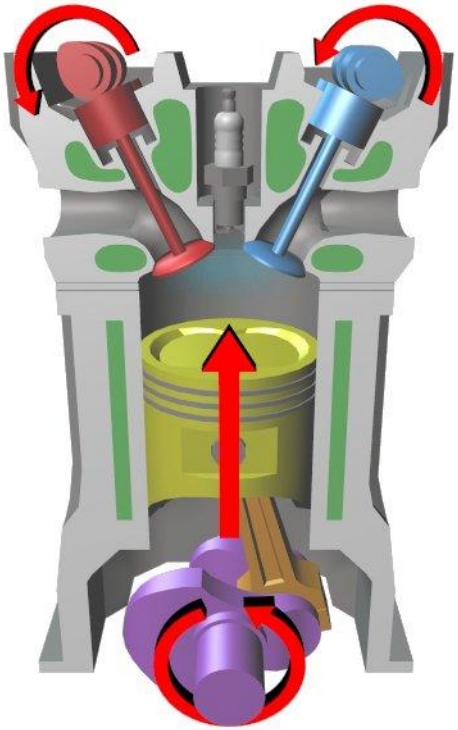
Goal: investigate a new class of spatial position measurement systems for CNC machines, where the sensing element (digital camera) observes an active target.

b) Motivation

Accurate part manufacturing plays a key role in the development of sustainable technologies.

Example:

- More efficient internal combustion (IC) engines. Minimize friction between individual parts in order to more efficiently transform chemical energy into mechanical energy.

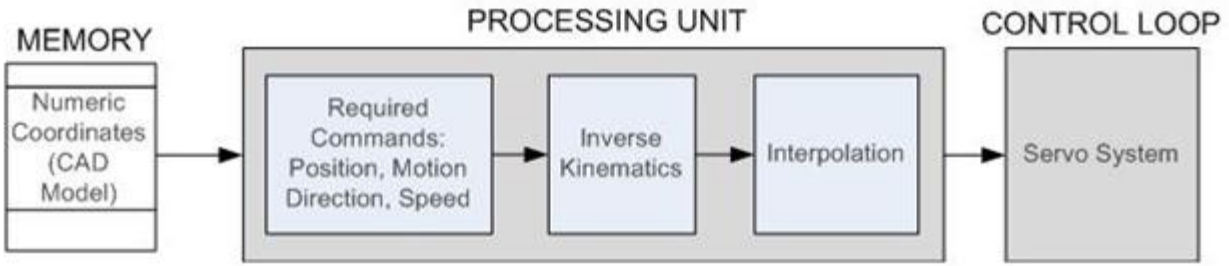


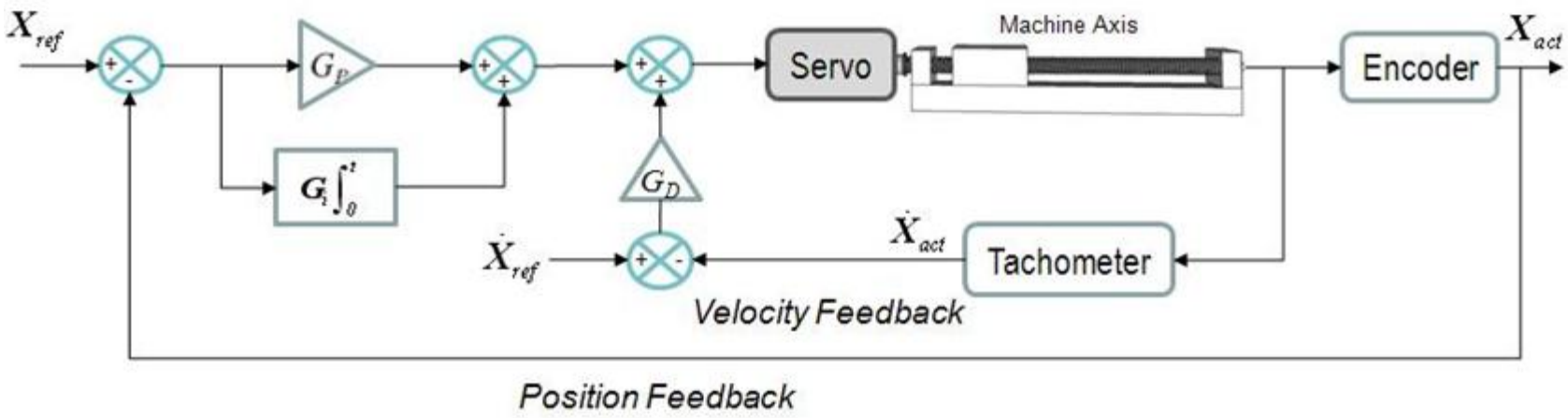
•Airbus: http://wallpapers.pixxp.com/14__A350_-_800_Airbus.htm
• IC engine image: physics.byu.edu
• Concept: www.audiusa.com/.../704x396_A_F09_002.jpg

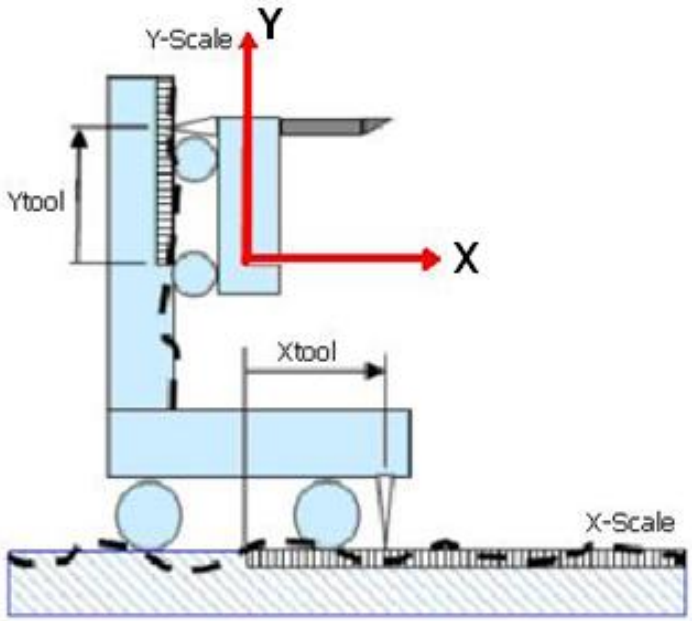
2. Kinematic Model vs. Direct Position Sensing

Common CNC machine:

Position based on kinematic model, i.e. error compensation is performed outside the control loop.



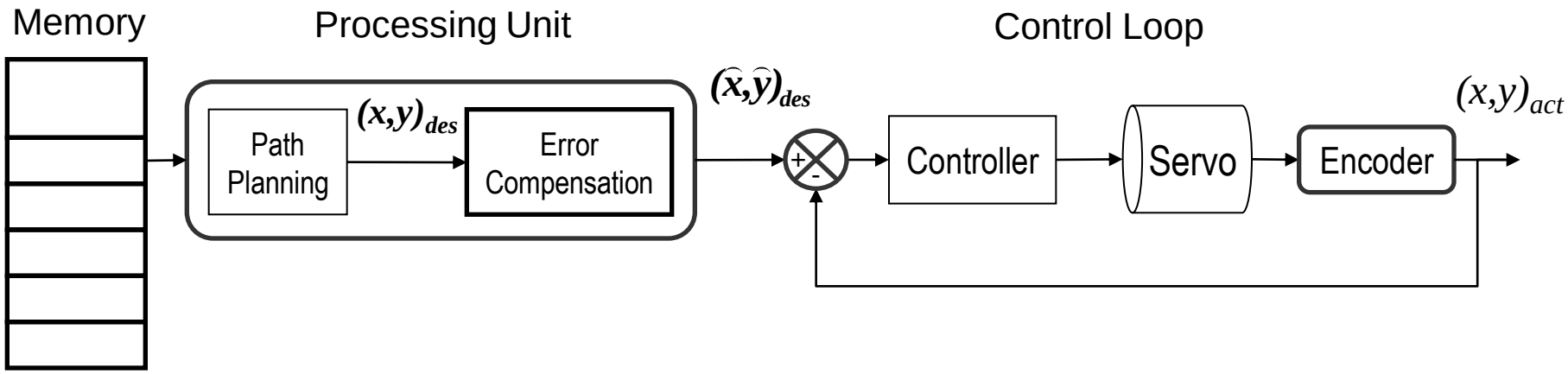




Setpoint

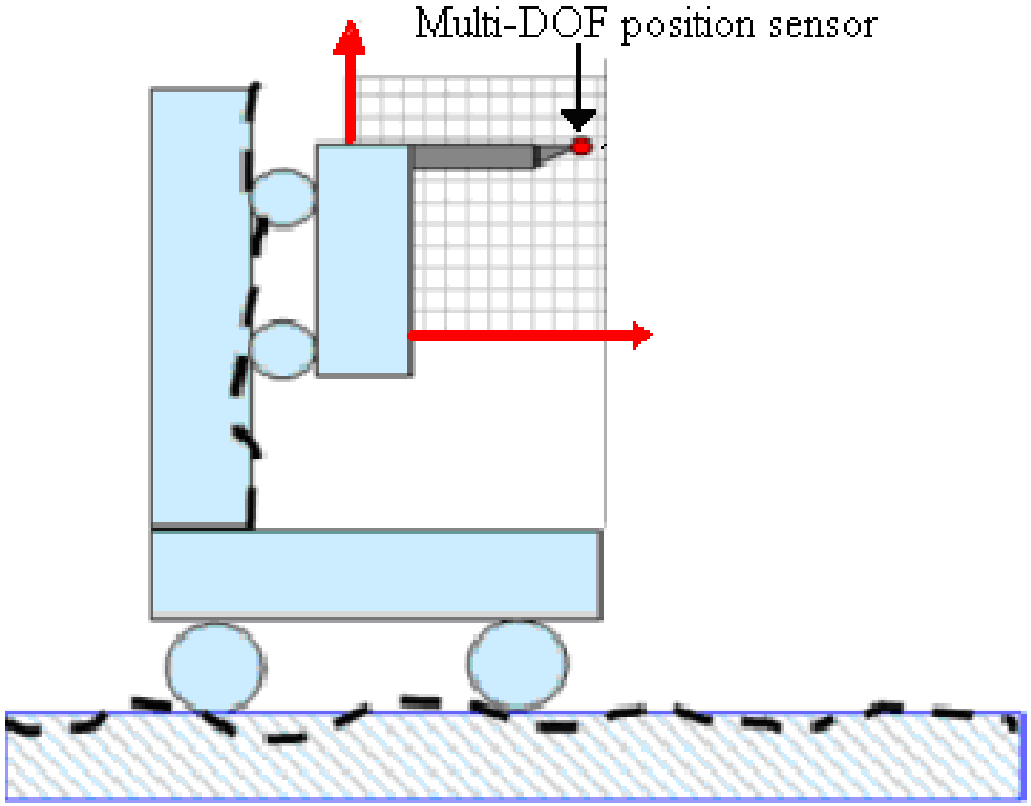
$$\hat{x}(t) = x_{des}(t) + \Delta x_{err}(t)$$

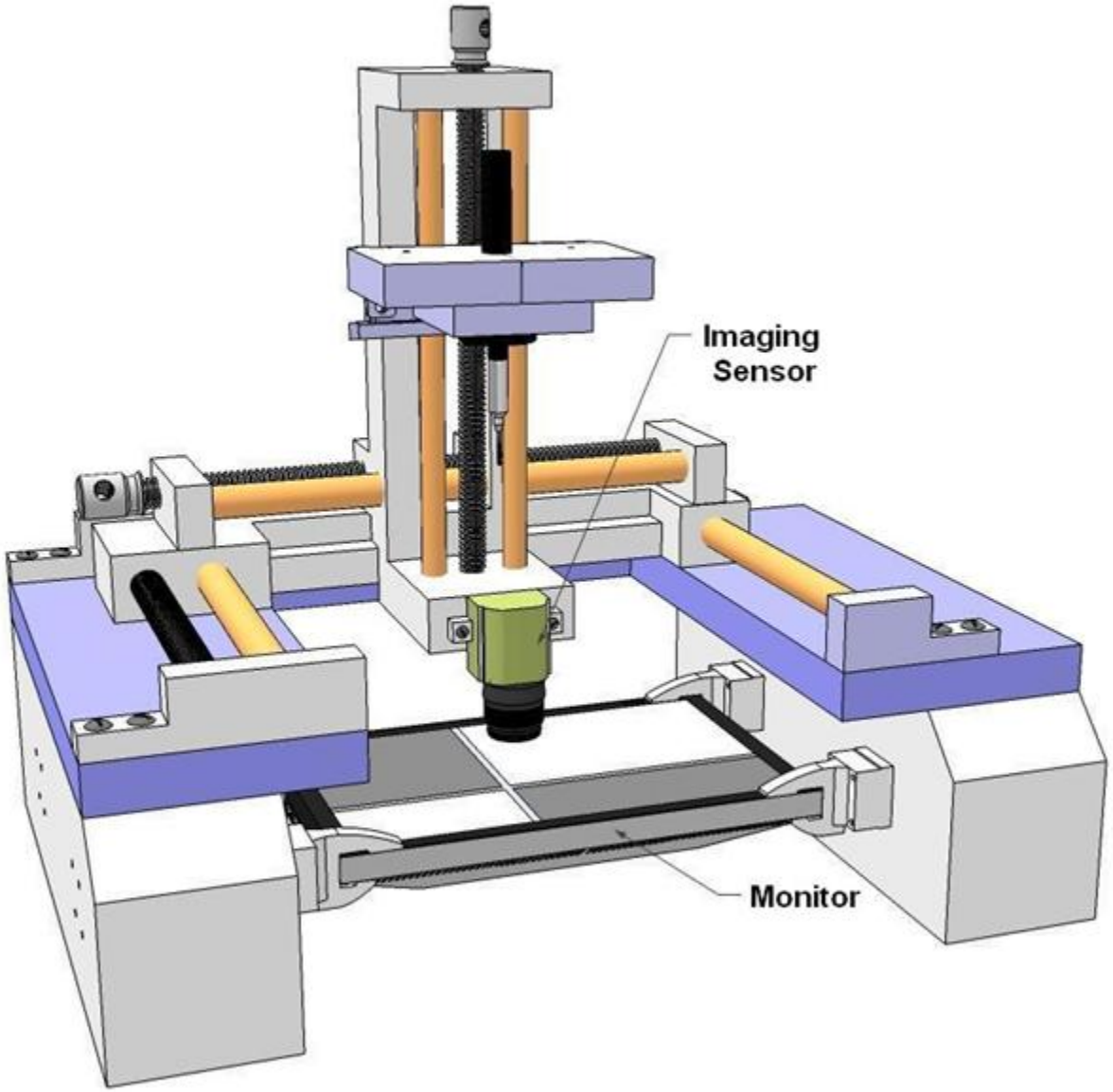
$$\hat{y}(t) = y_{des}(t) + \Delta y_{err}(t)$$



Direct Position Sensing: 2D Absolute Positioning

- A vision feedback system is implemented to directly sense the tool position.
- The position of the tool is not measured indirectly through rotary or linear encoders, but it is measured directly with respect to the target.





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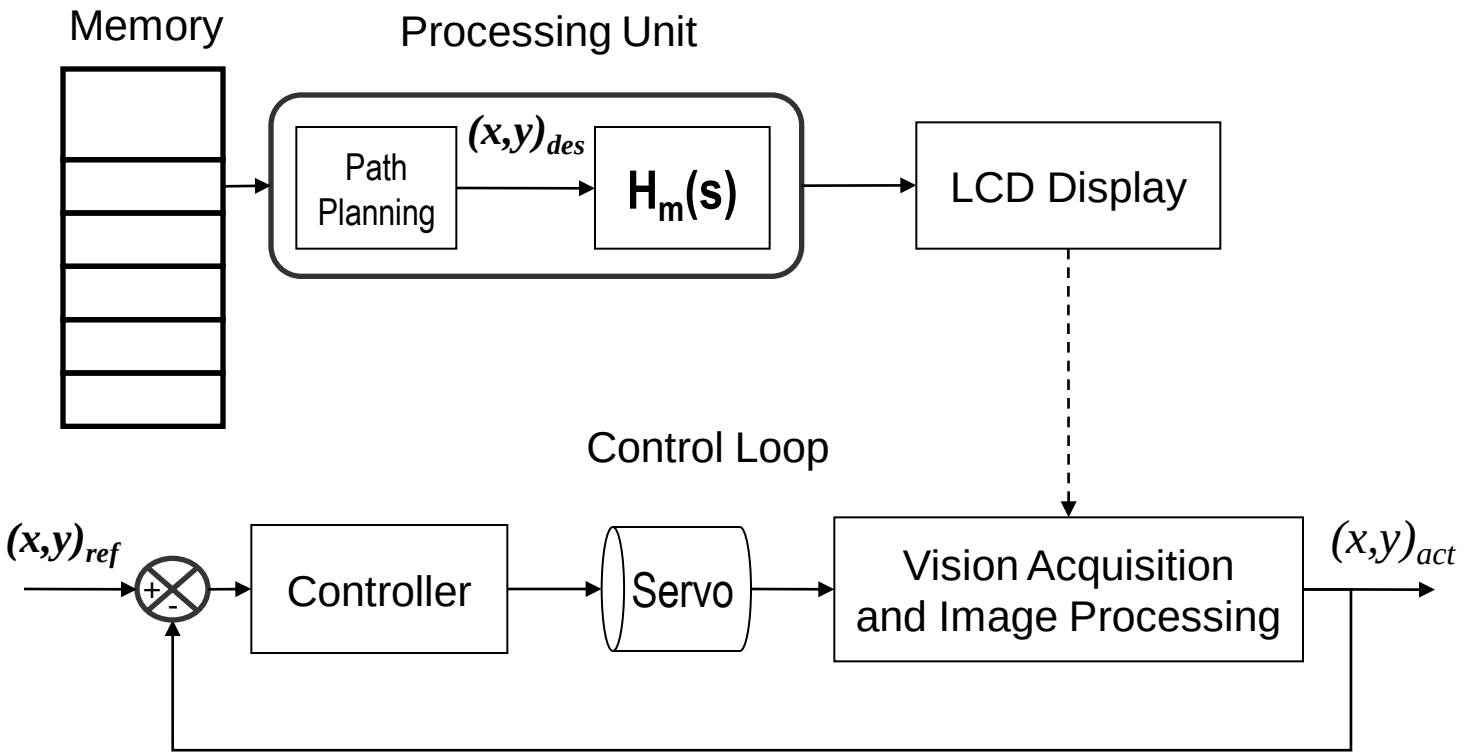
- Correcting action previously performed by the processing unit is no longer conducted outside the control loop.
- Commands are given by arbitrarily moving or modulating the dynamic object and thereby creating a position error between the target and a fixed reference in the camera plane.



Testbed:

Control Loop:

User Interface

PID Controller on FPGA

Position Feedback

Real-time Vision System

Y position

X position

Servo Motors

Motion

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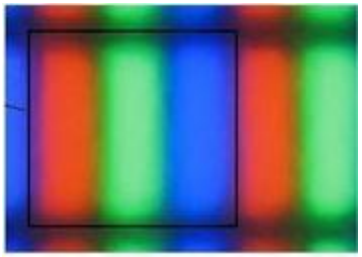
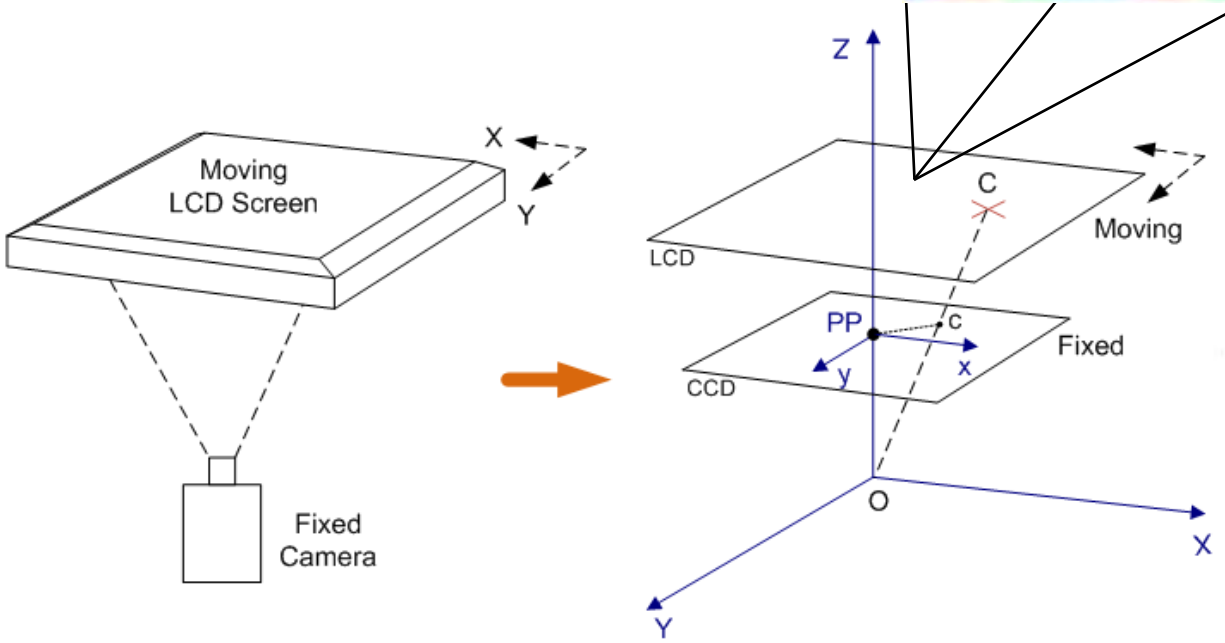
3. Dynamic Target on LCD

Sensor resolution is determined based on pinhole camera model



90x magnification of one LCD pixel



$$\mathrm{Res}_{CCD} = \frac{f}{Z}\mathrm{Res}_{LCD}$$

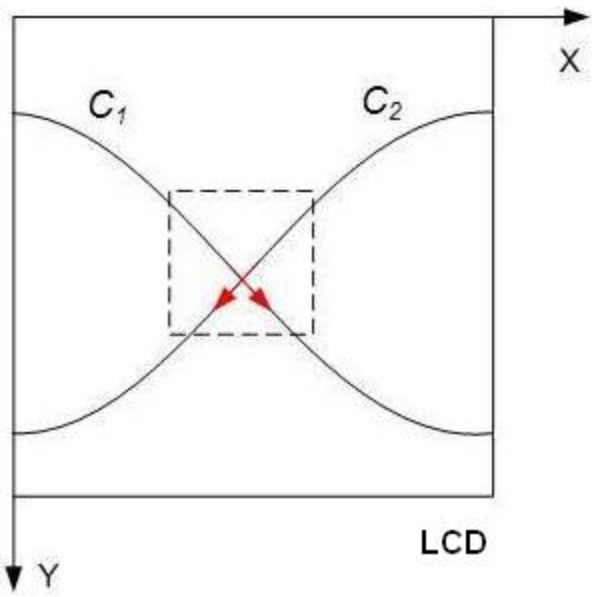
$$\mathrm{Res}_{LCD} = \left|\Delta X_C\right|$$

4. Sub-pixel Resolution Method

1. **Coarse point location:** the sets S_1 and S_2 are identified.

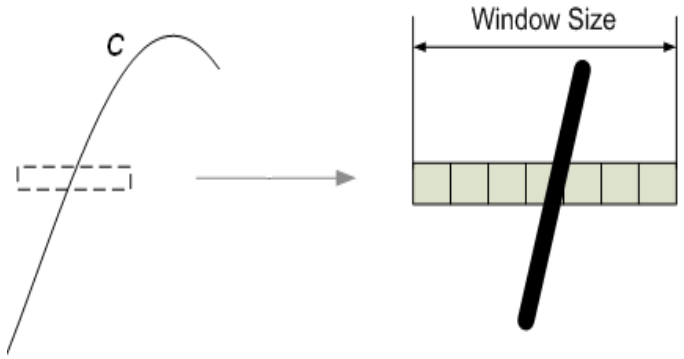
$$S_1 = \quad x_1, y_1 \ , \ x_2, y_2 \ , \ldots, \ x_m, y_m$$

$$S_2 = \quad \hat{x}_1, \hat{y}_1 \ , \ \hat{x}_2, \hat{y}_2 \ , \ldots, \ \hat{x}_n, \hat{y}_n$$



2. **Fine location:**

$$X_{C,j} = \frac{\sum_{i=0}^{m} x_i I \ \ x_i, j}{\sum_{i=0}^{m} I \ \ x_i, j}$$



The new coordinates are stored in the new sets S_{C1} and S_{C2}.

$$S_{C1} = \boldsymbol{X_C} \quad \boldsymbol{Y}$$

$$S_{C2} = \left[\hat{\boldsymbol{X}}_{\boldsymbol{C}} \quad \hat{\boldsymbol{Y}} \right]$$

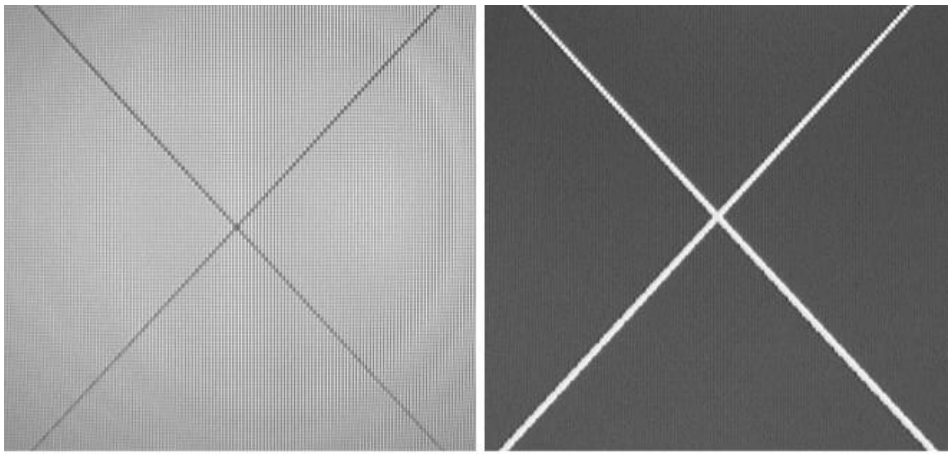
3. **Best fit line:** fromS_{C1} and S_{C2}, two best fit curves, C_1 and C_2, are determined using a least-squares approximation. The intersection of the curves is calculated analytically.

$$E = \min_{K_i} \left| \boldsymbol{Y}\text{-}\boldsymbol{C_1} \right|^2, \; i \in \; 0, p \; , \boldsymbol{Y} \in S_{C1}$$

5. Experimental Results

- Experiments are conducted using BMP images. Moreover, the target is represented by the intersection of two diagonal lines.

- **Fixed-Target**
  - Identification of optimal target format
  - Considering an 8-bit display, two types of formats are tested



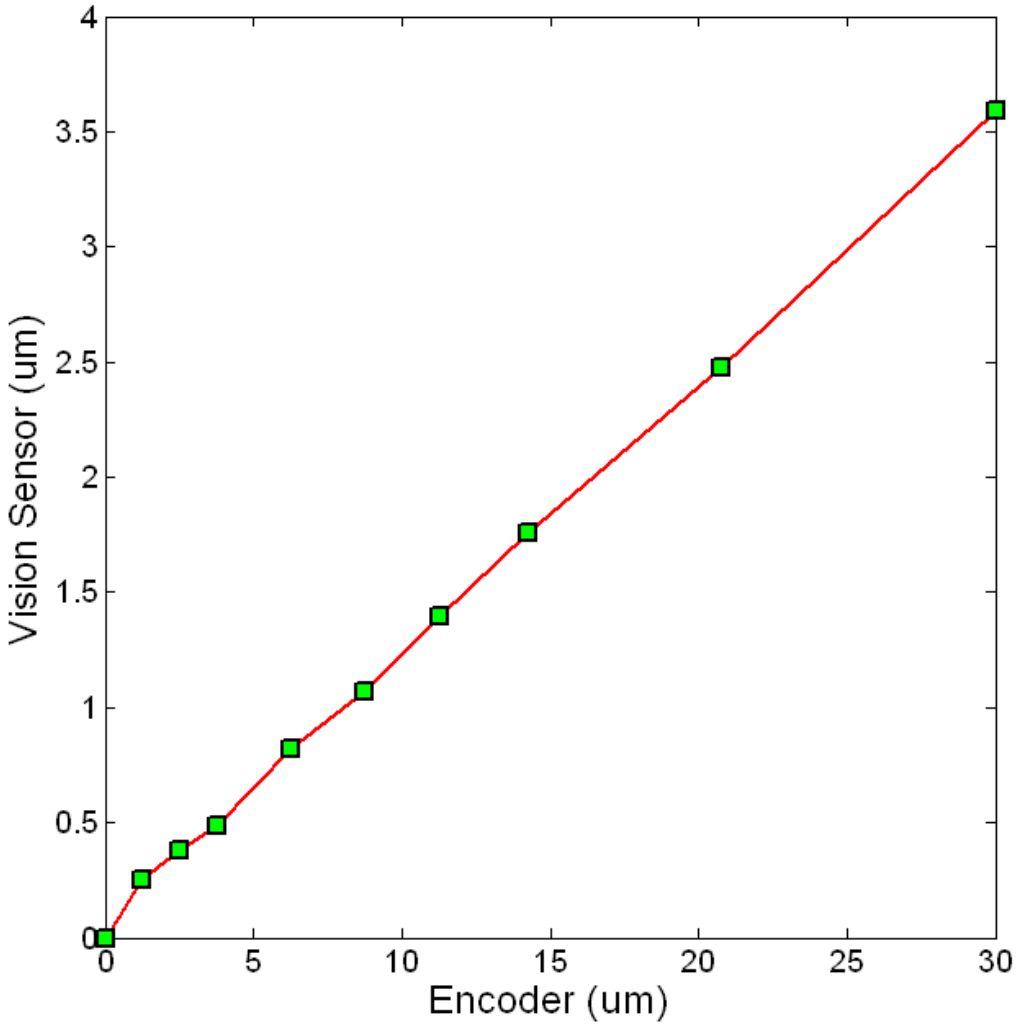
(A) (B)

$$Contrast = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \cdot 100\%$$

	Black Target	White Target
Contrast	65.36%	84.67%

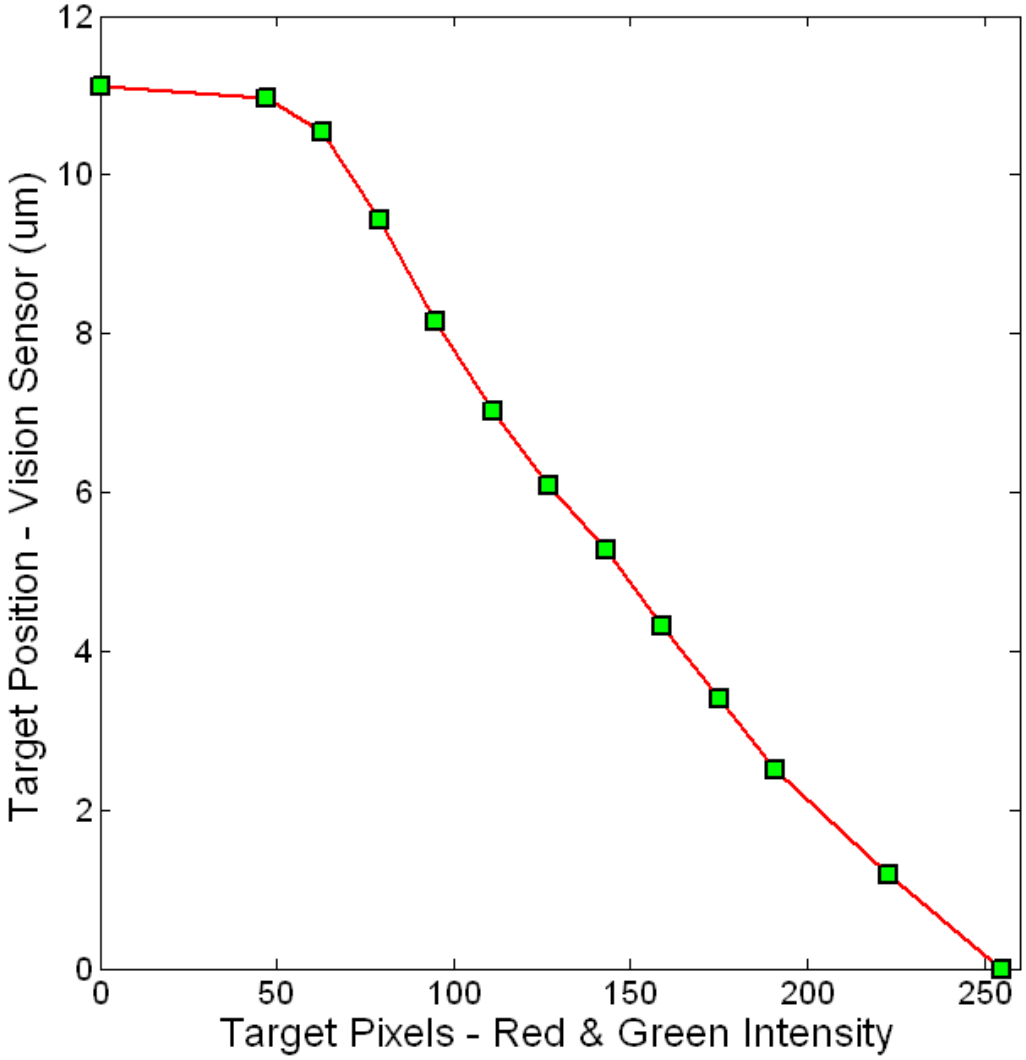
Displacement detection

- Horizontal displacement recorded using a rotary encoder is compared with the same displacement as capture by the camera.
- For each data point a 20 images sample is collected and the final value is obtained by averaging the sample.



Displacement command through LCD-camera configuration

- Change in the target location as a function of the intensity change on the red and green stripes of the pixels on the target.
- In this case a minimum displacement change of 0.8894 µm is detected through the camera, with a standard deviation of 0.0403 µm.



6. Conclusions

- Direct multi-DOF position control using a dynamic target (image) and an image acquisition process is possible.
- Displacements as small as 2.5μm can be detected by collecting and processing samples of at least 20 images.
- Best target configuration: white target over black background.

- 5-axis machine: www.breton.it/.../BRETON/web_files/16903.jpg
- IC engine block: www.autofiends.com/.../2009/02/matsuura2.jpg
- X35: upload.wikimedia.org/.../20080822184819!X-35.jpg

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QUESTIONS ?