Micropositioning mechatronics system based on FPGA architecture

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About us…

- Faculty of Engineering (riteh.uniri.hr) and Centre for Micro and Nano Sciences and Technologies (www.cmnzt.uniri.hr),



- Precision Engineering Laboratory (precenglab.riteh.uniri.hr):
  - People: Saša Zelenika, David Blažević, Ervin Kamenar
  - Main activities:
    - Ultra-high precision positioning systems and laser interferometric measurements,
    - Energy harvesting systems,
    - Stereomicroscope measurements,
    - Laser Doppler vibrometer measurements.

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- Experimental Set-Up
  - Actuator and feedback sensor
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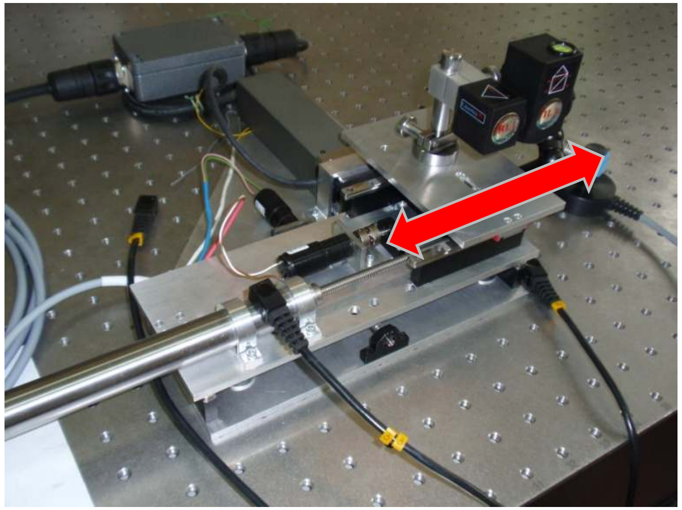
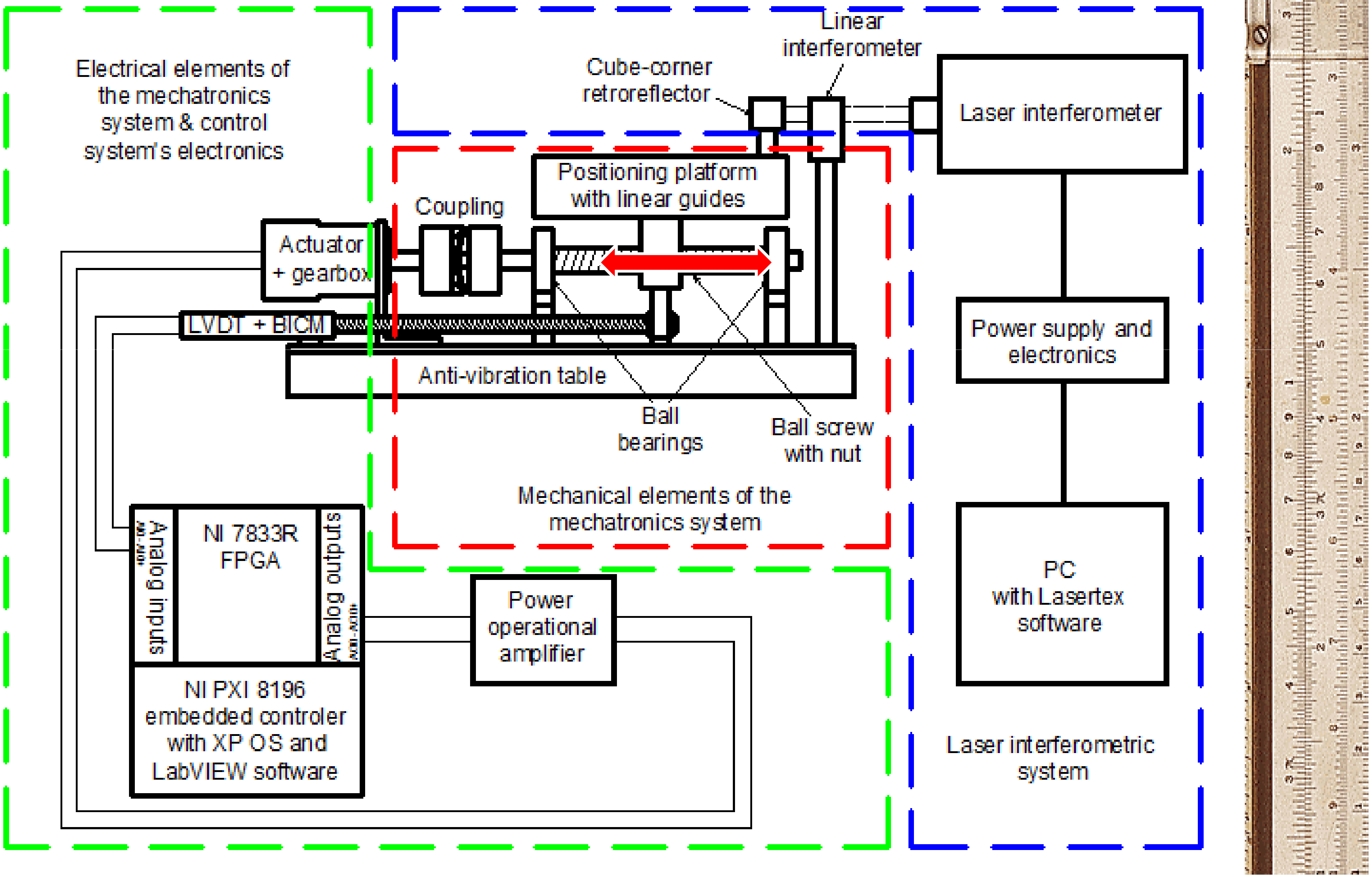
Introduction

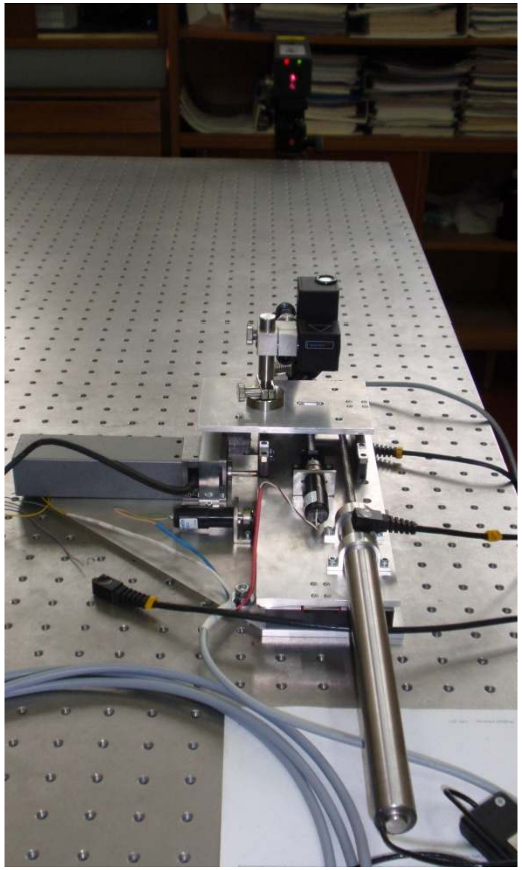
- Precision positioning systems are often used for manipulation of small structures,
- Other micropositioning applications:
  - Positioning of optical devices
  - Handling and assembly of microsystems
  - Focusing mechanism for telescopes
  - Micro and Nano manipulation
  - Semiconductor industry
  - MEMS devices
  - …

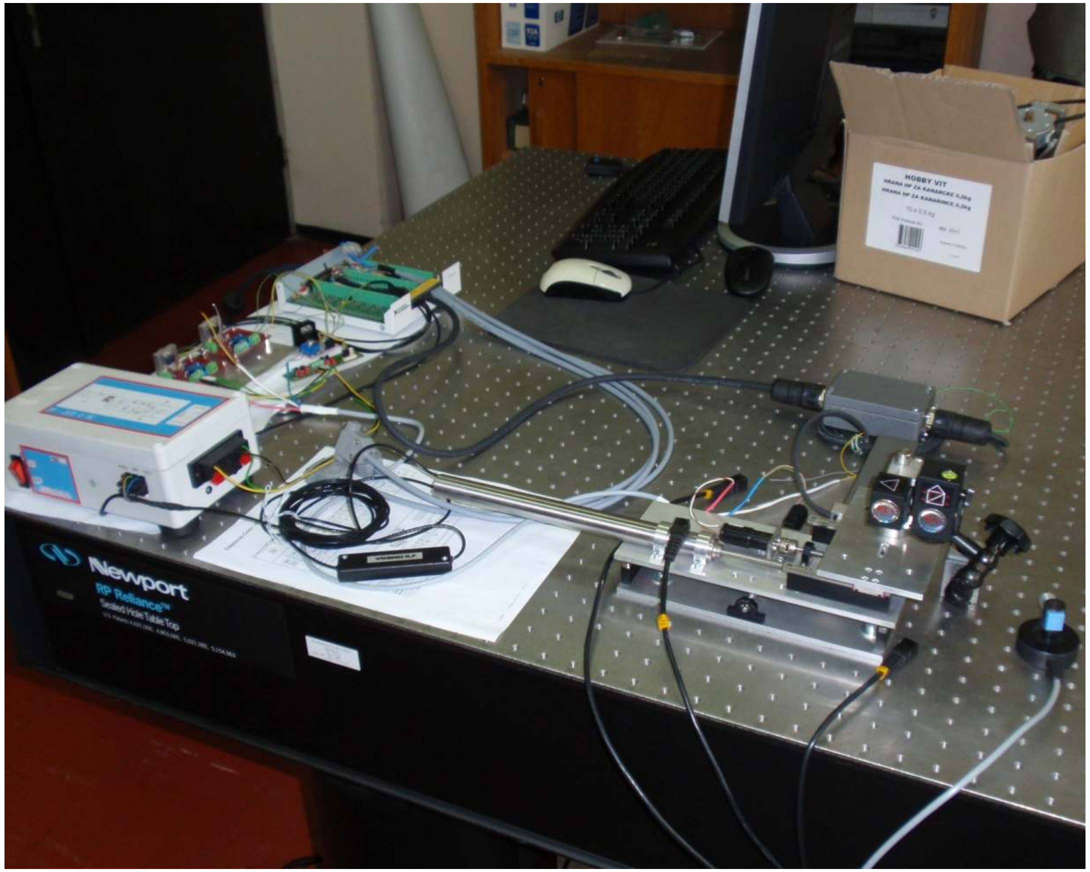


Experimental Set-Up (1/2)



Experimental Set-Up (2/2)





Actuator and feedback sensor (1/2)

- System is driven by DC actuator
- A Linear Variable Differential Transformer (LVDT) is used as a feedback sensor:
  - **Static element:** central primary winding excited with an AC excitation voltage, located between two symmetrical secondary windings
  - **Moving element:** cylindrical core made of a Ni-Fe alloy, mechanically connected to the moving stage
  - An AC voltage with an amplitude proportional to the movement on the secondary windings is generated
  - AC voltage is conditioned by the Boxed Inline Conditioning Module (BCIM)

Actuator and feedback sensor (2/2)

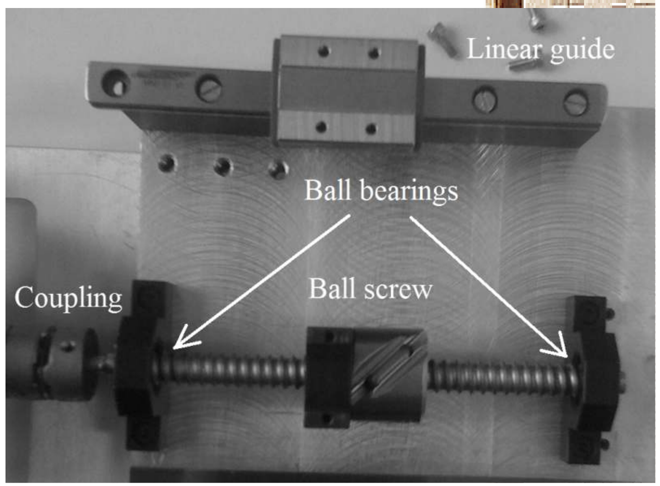
Element	Type	Manufacturer	Parameters
Actuator	M 1724 006 SR DC	Faulhaber	U_N = 6 V, n_0 = 8600 rpm, Ø= 17 L = 24 mm
Planetary gearhead (integrated with the actuator)	15A series	Faulhaber	L_g = 17.7 mm i = 19:1
Feedback sensor	LD610-50	Omega	Measuring range: ± 50 mm (100 mm) Output voltage (after BCIM conditioning): -10V to +10V

Mechanical elements (1/2)

- Miniature ball screw is used to obtain linear displacement
- Ball screw is supported by Miniature ball bearings,
- The motor and the ball screw are linked by using a miniature coupling
- Sliding of movable part is obtained using profiled miniature guideways





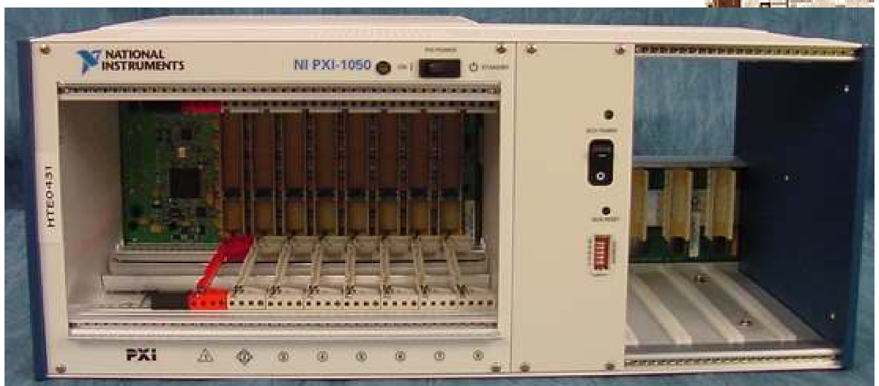


Mechanical elements (2/2)

Element	Type	Manufacturer	Parameters
Ball screw	SHS6X2R	SKF	d_0 = 6 mm p = 2 mm B = 50 mm h_p = 94%
Ball bearings	618/4	SKF	d = 4 mm D = 9 mm b = 2.5 mm
Coupling	MCGS13-3-3	Misumi	D_C = 16 mm inner diameters $d_1 = d_2$ = 3 mm l_C = 13 mm
Linear guideways	MINIRAIL MN7	Schneeberger	fixed part dimensions: $l_f/w_f/h_f$ = 85 /7/4.5 moving part dimensions: $l_m/w_m/h_m$ = 24.6/ 17/6.5 mm

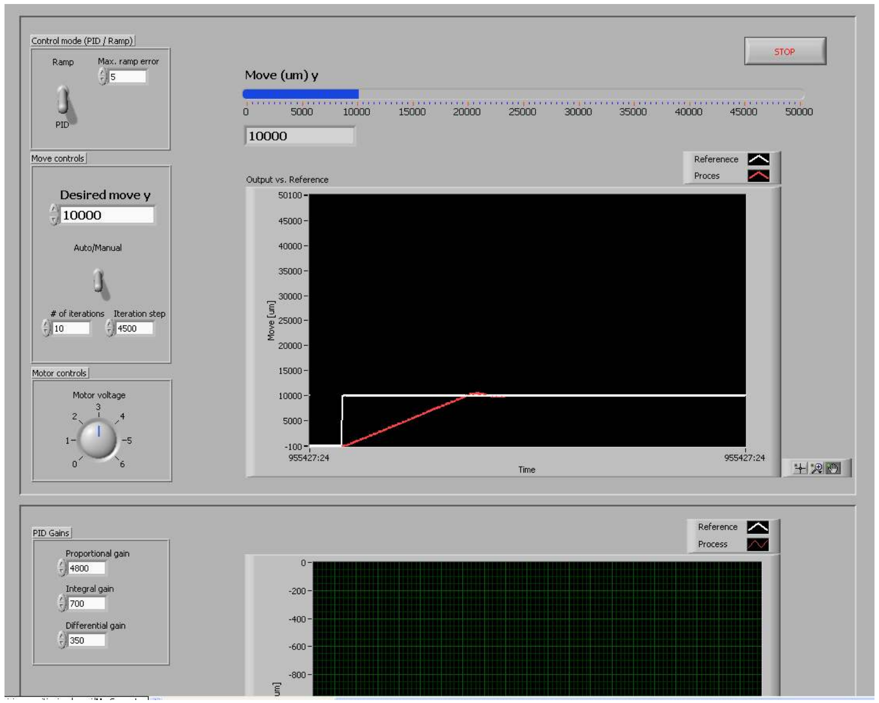
Control system (1/3)

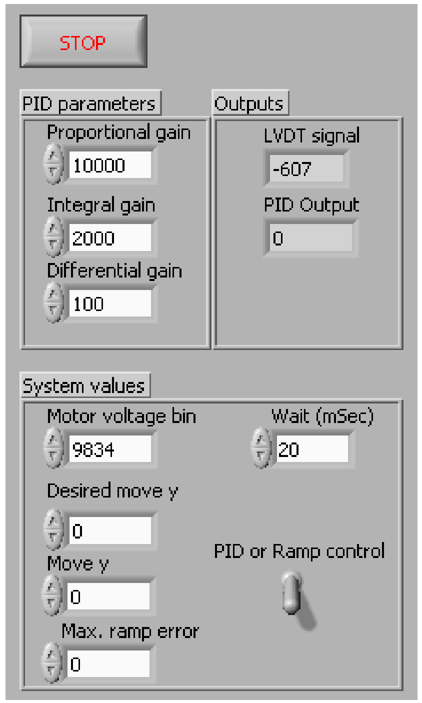
- National Instruments PXI-1050 chassis, PXI-8196 embedded controller, reconfigurable PXI-7833R FPGA module
  - NI PXI-7833R FPGA → Virtex-II 3M gate FPGA chip, 8 16-bit analog inputs, 8 16-bit analog outputs, 96 digital lines (I/O, counters)



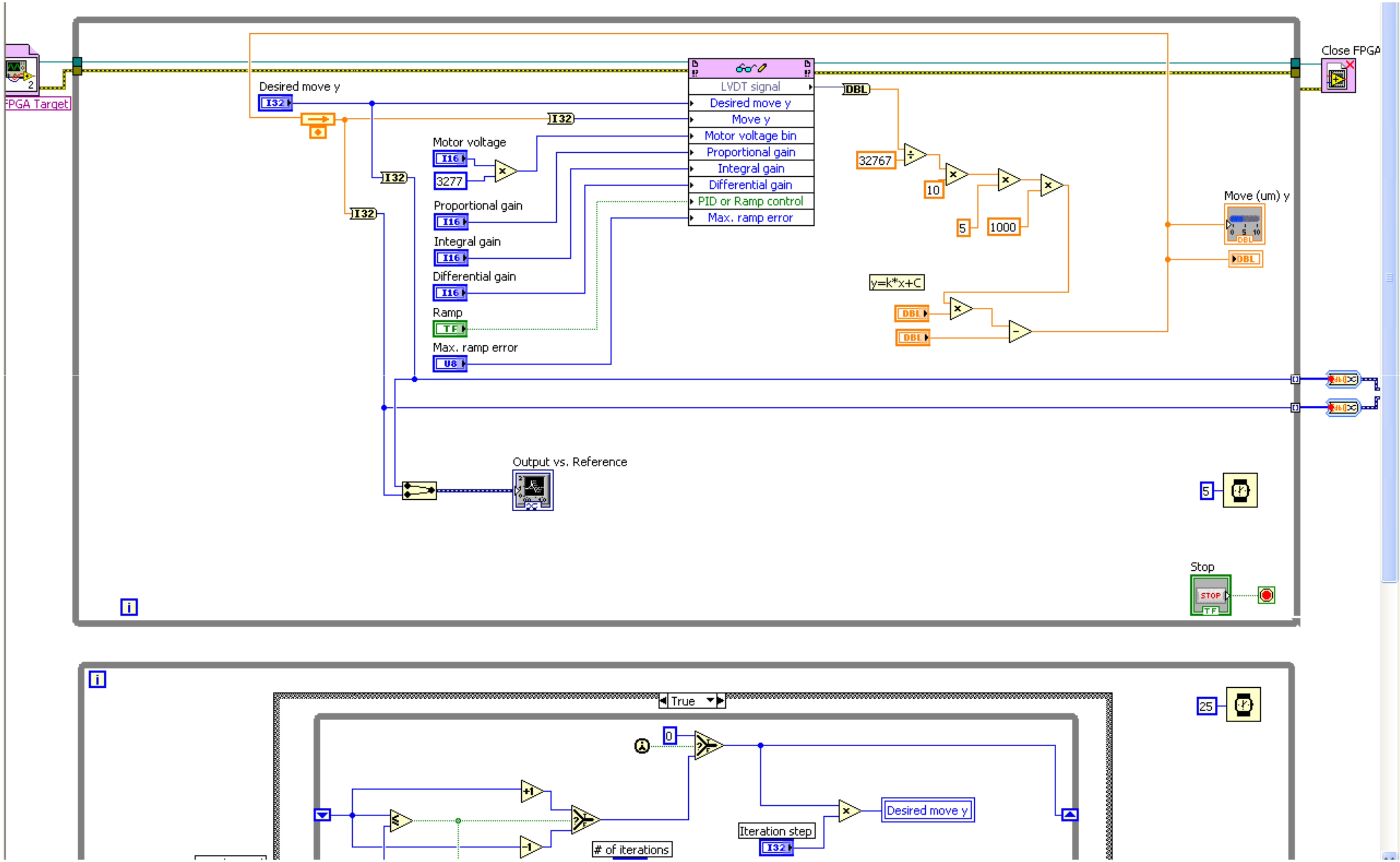
Control system (2/3)

- Control algorithms are programmed in the LabVIEW program environment:
  - Host VI (left) is executed on the host computer (NI PXI-8196) and includes user controls and indicators
  - FPGA VI (right) is executed on the FPGA module (NI PXI-7833R) and consists of the control algorithms.



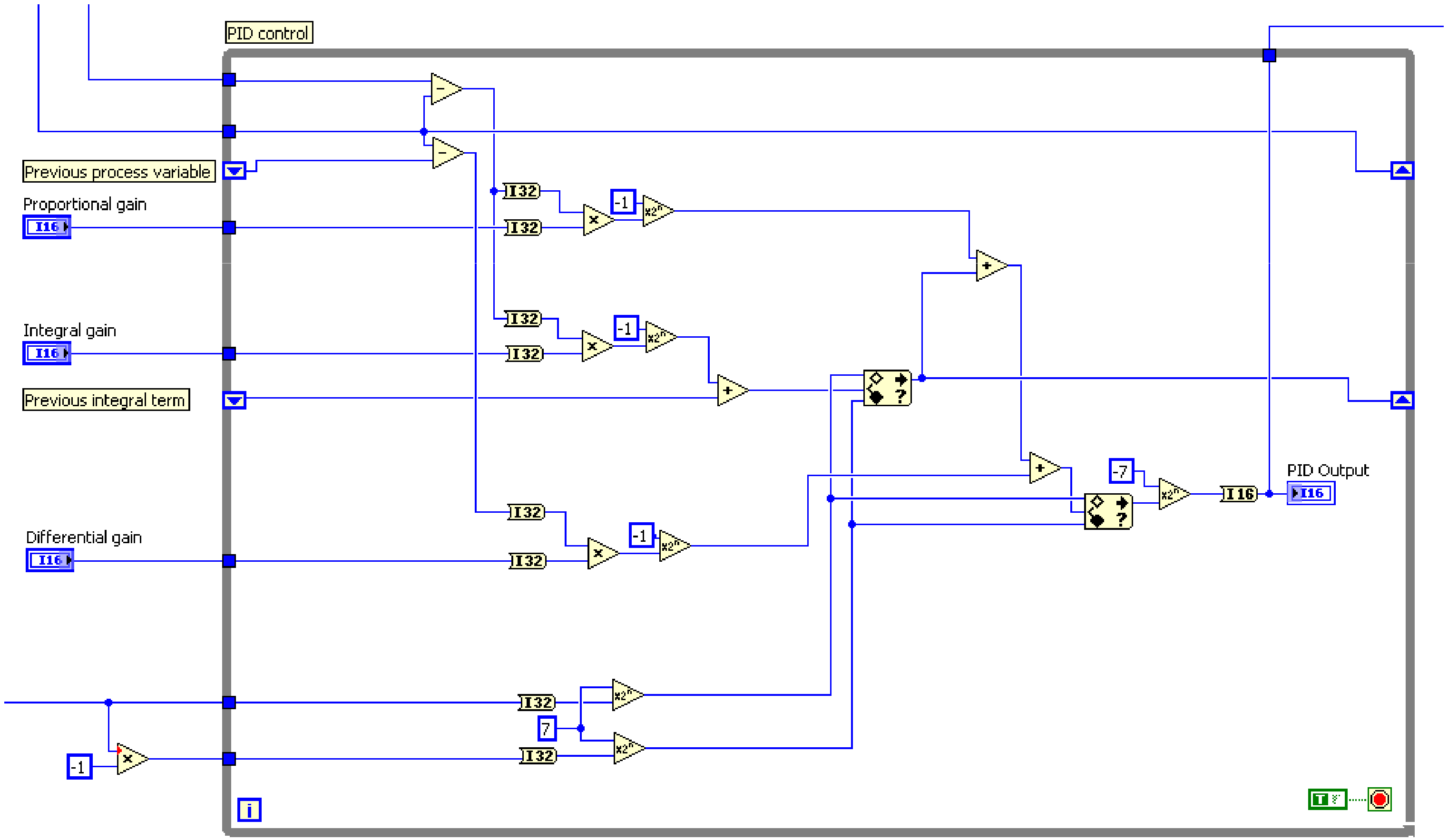


Control system (3/3)

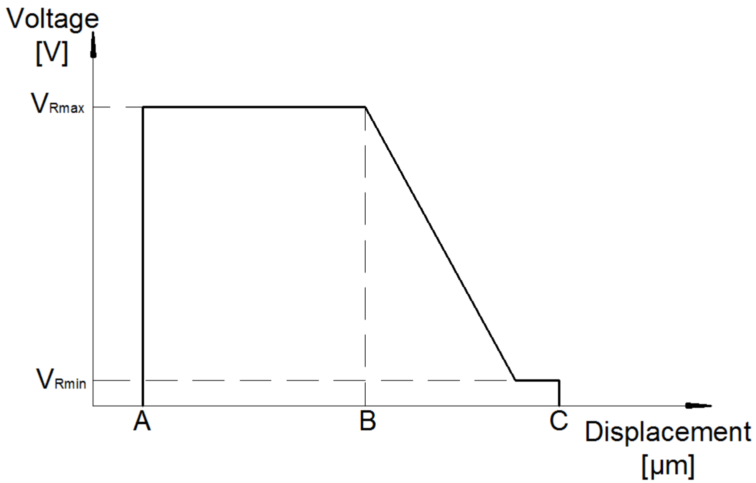


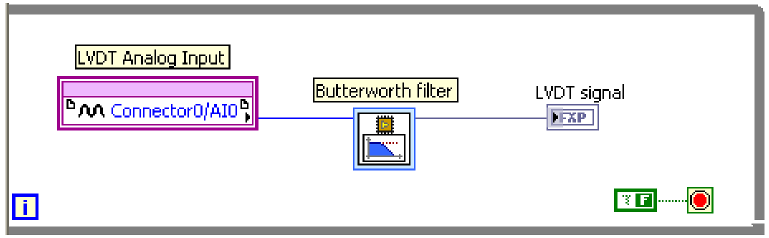
Control algorithms - PID

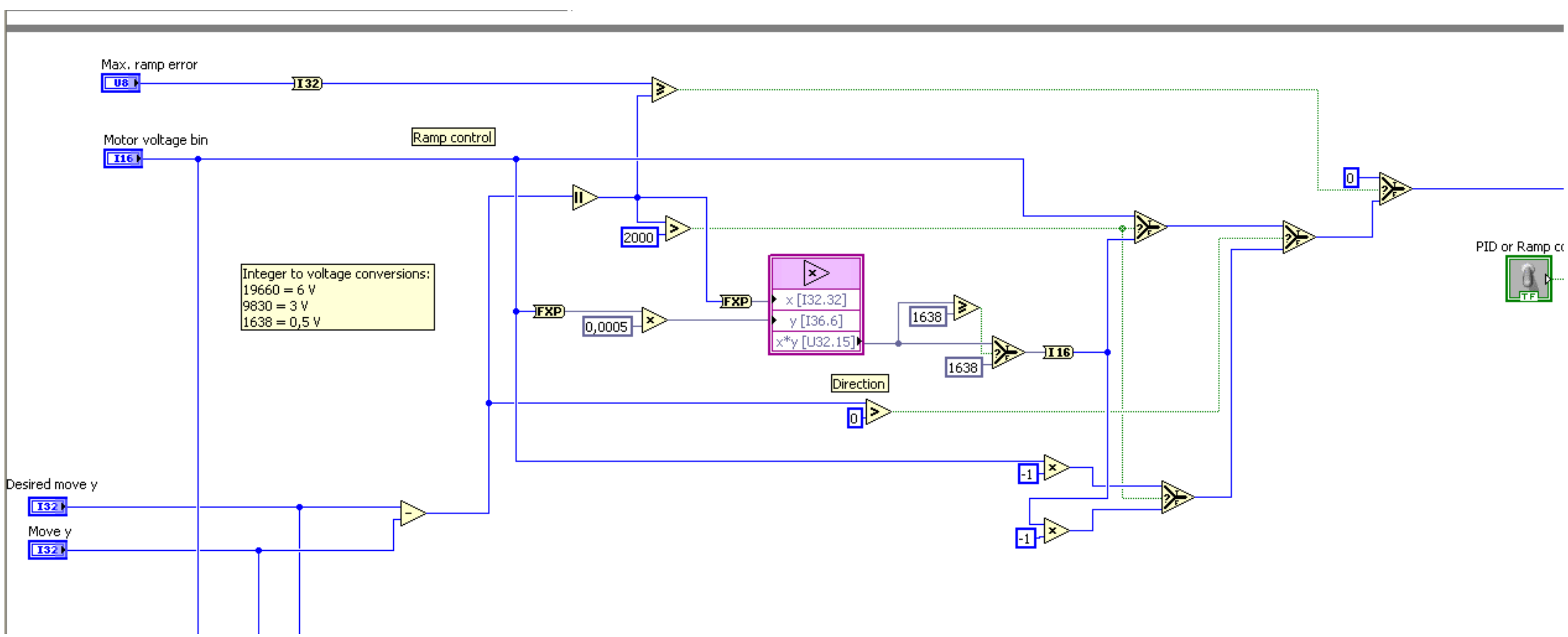
$$u(n) = K_P e(n) + K_I \sum_{k=0}^{n} e(k) + K_D \left[y(n) - y(n-1) \right]$$



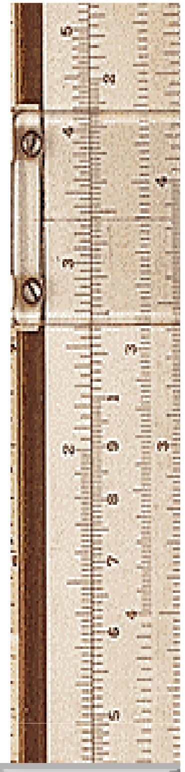
Control algorithms - Ramp



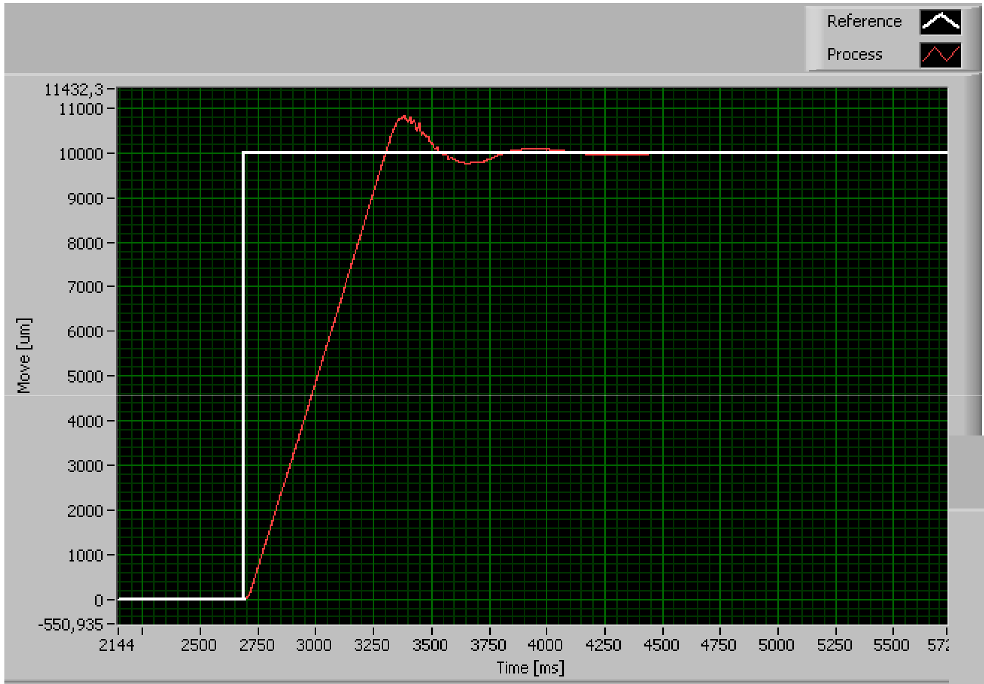




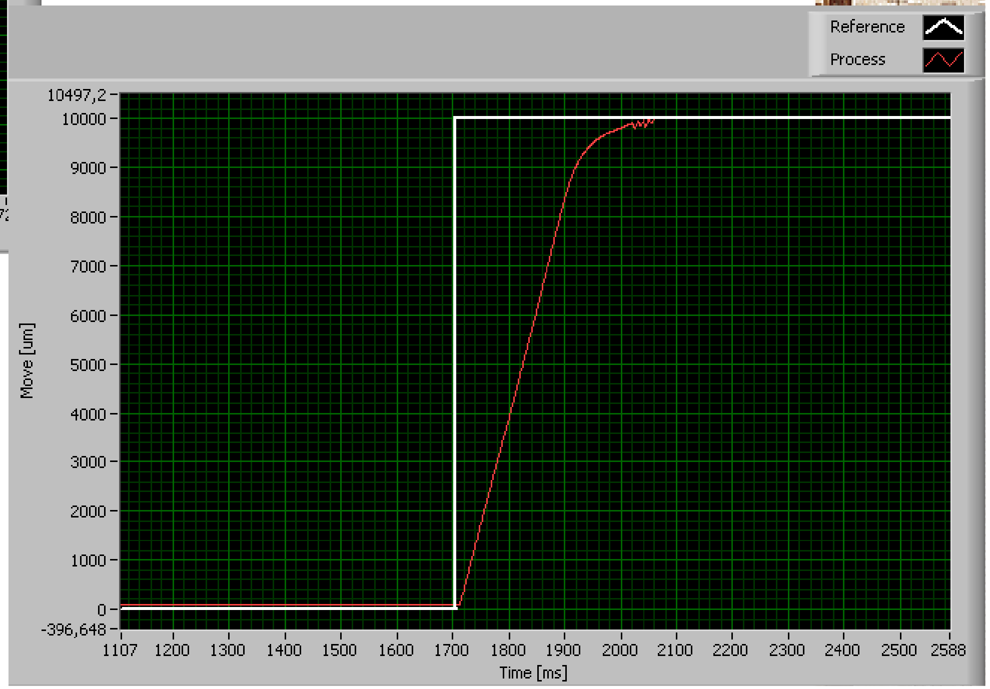
Control algorithms - Step response



PID:

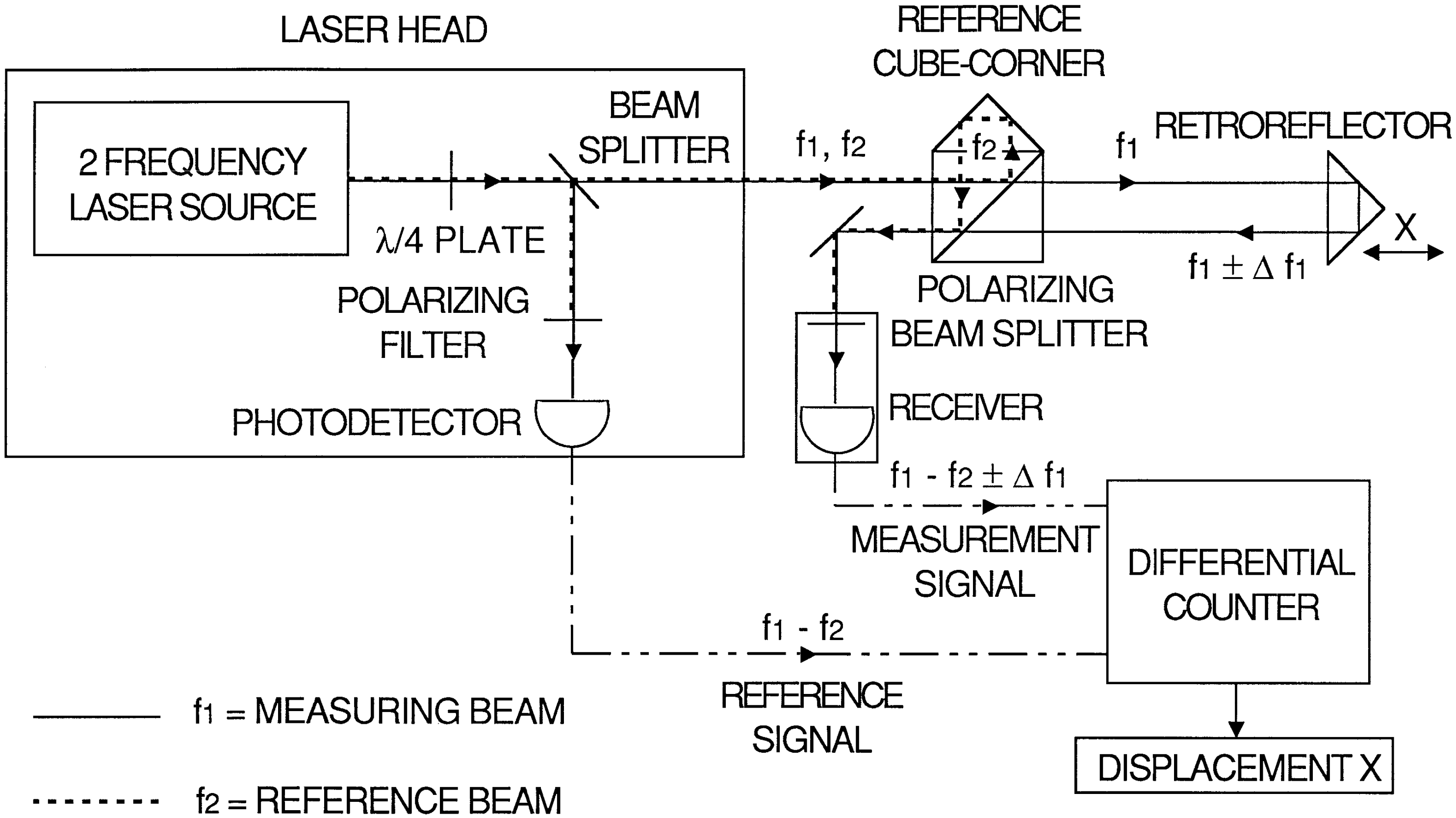


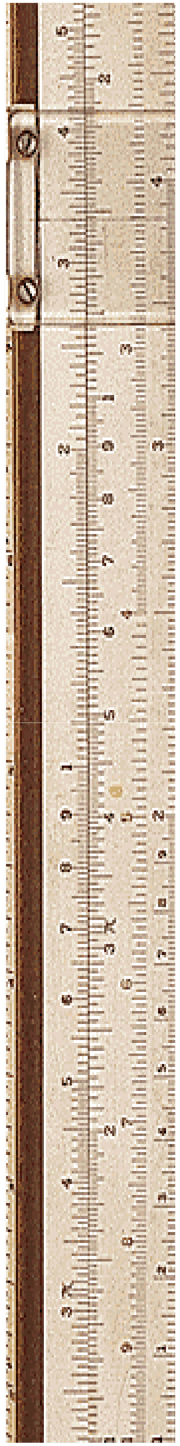
Ramp:



Experiments (1/4)

- Lasertex LSP 30-3D Michelson-type laser Doppler interferometric system is used to assess positioning accuracy and repeatability



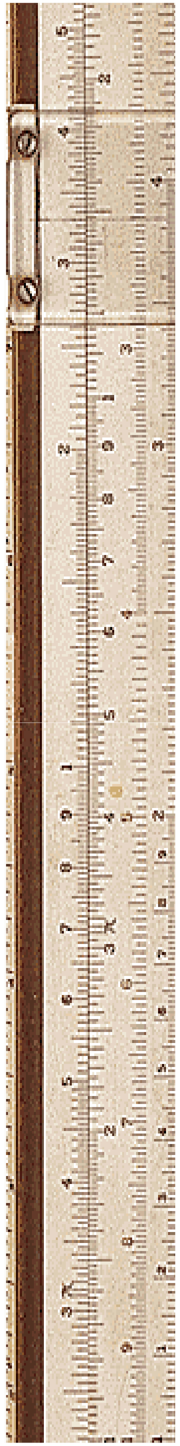


Experiments (2/4)

- A set of point-to-point experiments using both the PID and the ramp control typologies is performed:
  - Micrometric displacements with 100 μm steps
  - Long range displacements with 10 mm steps
  - PID parameters set to: $K_P = 4700$, $K_I = 600$, $K_D = 190$

Table I. Measurements for 100 μm steps – errors in μm

	PID	Ramp		PID	Ramp
Point no.	Error	Error	Point no.	Error	Error
1	-2.8	-1.2	6	-6.2	-1.8
2	-7.6	-0.8	7	3.9	-0.8
3	-2.5	-1.9	8	-1.1	-1.1
4	-1.1	2.5	9	-6.5	0.4
5	-6.5	3.0	10	-4.6	-1.5



Experiments (3/4)

- When longer travel ranges are implemented, output results in a marked nonlinearity that significantly influences the resulting positioning error

Table II. Measurements for 10 mm steps w/o linearization – errors in μm

	PID	Ramp		PID	Ramp
Point no.	Error	Error	Point no.	Error	Error
1	37.3	47.4	6	49.4	55.5
2	48.8	50.3	7	46.4	52.7
3	44.5	49.8	8	42.5	48.5
4	40.3	46.6	9	45.1	44.1
5	42.9	46.7	10	46.2	44.6

Experiments (4/4)

- Repetitive measurements with 1 mm steps in the 0 - 10 mm range are conducted and the linearization function

$$f(x) = 1{,}006 \cdot x + 7$$

  is obtained and programmed in the Host VI

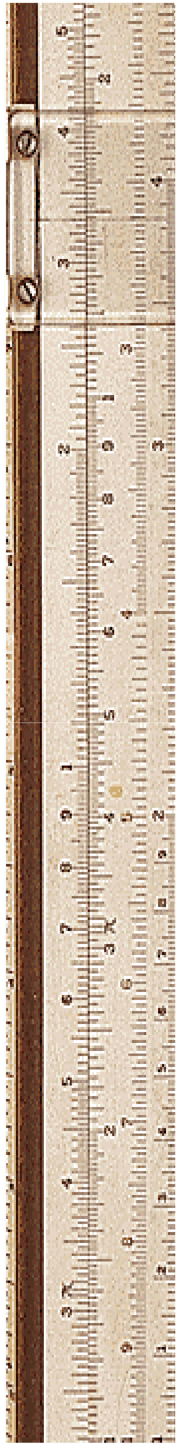
- PID parameters are set to: $K_P = 4800$, $K_I = 700$, $K_D = 350$

Table III. Measurements for 10 mm steps with linearization – errors in µm

	PID	Ramp		PID	Ramp
Point no.	Error	Error	Point no.	Error	Error
1	1.1	0.6	6	3.6	3.6
2	0.7	2.4	7	3.2	-0.5
3	2.6	-2.7	8	2.2	0.2
4	-0.6	-2.6	9	-1.7	-1.2
5	2.4	-3.6	10	-1.7	-3.5

Conclusions

- A single-axis micropositioning mechatronics system with PID and ramp control is developed
- A marked nonlinearity, which induces errors of about 50 μm, is observed for 10 mm travel range
- The nonlinear effect, caused mainly by the LVDT, is characterized via interferometric measurements and compensated via system linearization
- In the final configuration, the calculated positioning accuracies and repeatabilities are always within 3 μm



Future work

- More complex control typologies - PWM based control
- Usage of other types of feedback sensors - optical encoders (linear gauges)
- Final goal: multi-axes micropositioning mechatronics systems based on FPGA architecture

Thank you for your attention!

Questions