Micropositioning mechatronics system based on FPGA architecture

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About us...

 Faculty of Engineering (<u>riteh.uniri.hr</u>) and Centre for Micro and Nano Sciences and Technologies (<u>www.cmnzt.uniri.hr</u>),







- 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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 - 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)



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Experimental Set-Up (2/2)



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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	Туре	Manufacturer	Parameters
Actuator	M 1724 006 SR DC	Faulhaber	$U_N = 6 V,$ $n_0 = 8600 \text{ rpm},$ $\emptyset = 17$ 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	Туре	Manufacturer	Parameters
Ball screw	SHS6X2R	SKF	$d_0 = 6 \text{ mm}$ 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	$D_C = 16 \text{ mm}$ inner diameters $d_1 = d_2 = 3 \text{ mm}$ $l_C = 13 \text{ mm}$
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

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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.



STOP	
PID parameters	Outputs
Proportional gain	LVDT signal -607
Integral gain	PID Output
Differential gain	
System values	
Motor voltage bin 9834	Wait (mSec)
Desired move y	
2 0	
Move y	PID or Ramp control
	3
Max. ramp error	-0
0	



Control system (3/3)

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Control algorithms - PID

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



Control algorithms - Ramp



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Control algorithms - Step response

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8000 -

7000 -6000 -

5000 -4000-3000-2000-1000-

-396,648

Move [um]

PID:





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: $K_P = 4700$, $K_I = 600$, $K_D = 190$

	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

	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

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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: $K_P = 4800$, $K_I = 700$, $K_D = 350$

	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!



