Indesit Company

Digital control of low-cost piezoelectric actuators for household appliances

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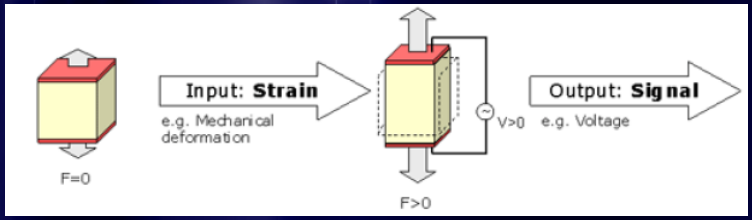
Outline

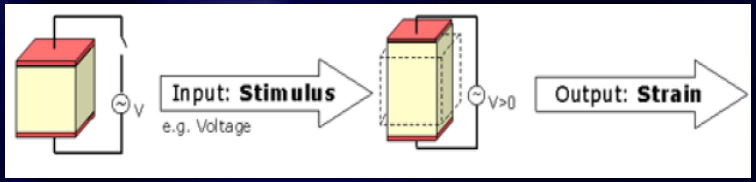
- Piezoelectric devices overview
- Motivations / Strategy
- Prototype illustration
- Hysteresis in piezoelectric actuators
- Proposed hysteresis compensation technique
- Experimental results
- Conclusions

Piezoelectric devices overview

- Discovery of piezoelectric effect: P. and J. Curie, 1880
- Energy conversion (mechanical ↔ electrical)
- Direct piezoelectric effect (⇒ sensors)



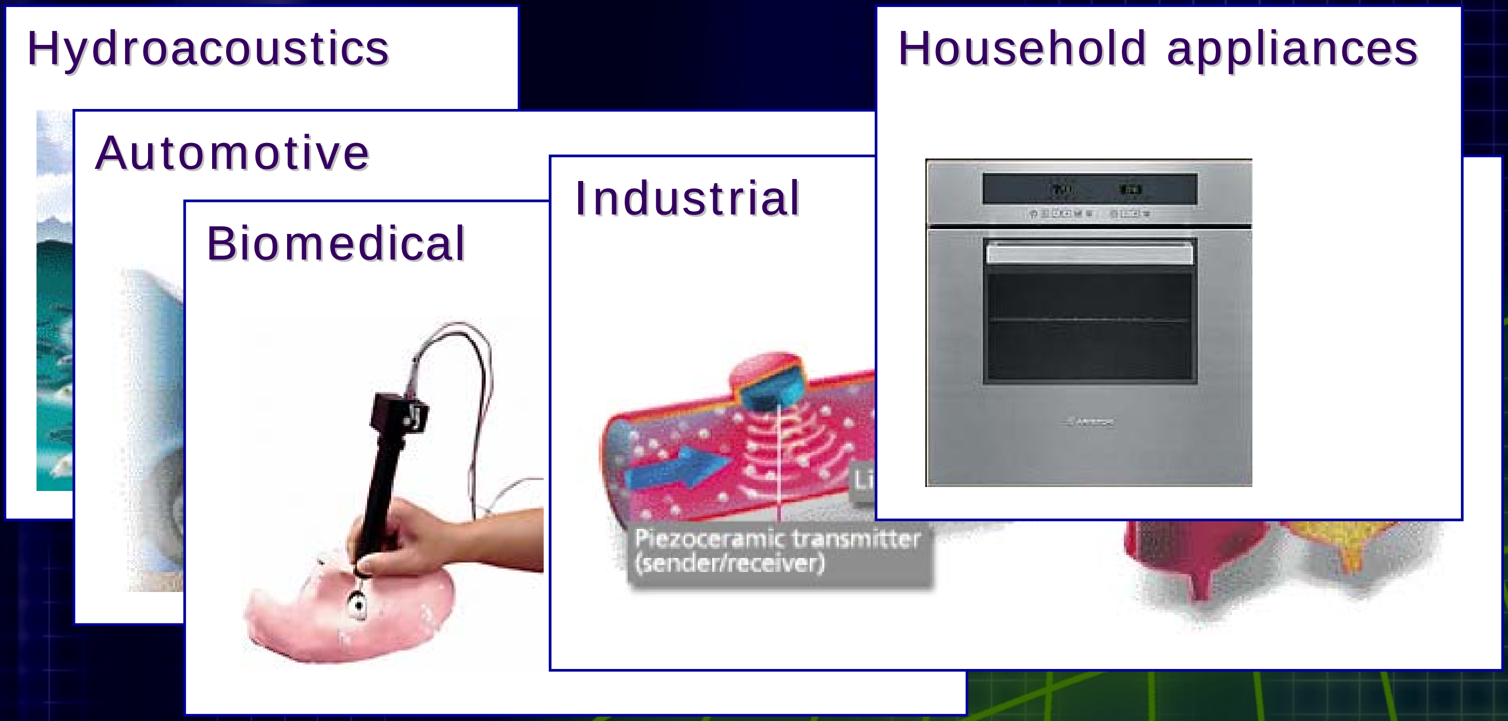
- Inverse piezoelectric effect (⇒ actuators)



- Materials
  - natural crystals: quartz, tourmaline
  - after polarization: piezoceramic ($BaTiO_3$, $PbTiO_3$, PZT), piezopolymers (PVDF), piezo composite materials

Piezoelectric devices overview applications

- Typologies of transducers
  - Sensors
  - Actuators
- Fields of application

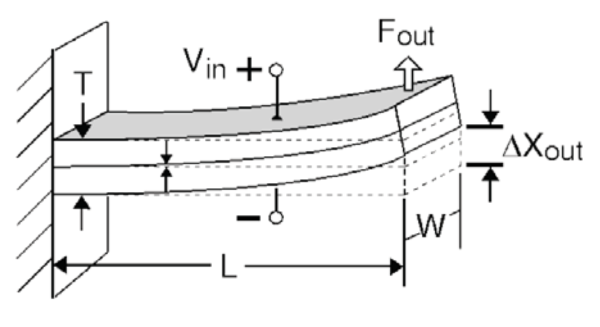


Motivations

- To investigate the possibility of using piezoelectric actuators in domestic appliances as alternatives to classical actuators
- To exploit the advantages of piezoelectric actuators
  - high stiffness
  - fast frequency response
  - high resolution
- Good accuracy
- Low cost
- Low complexity

Strategy

- Bender actuator

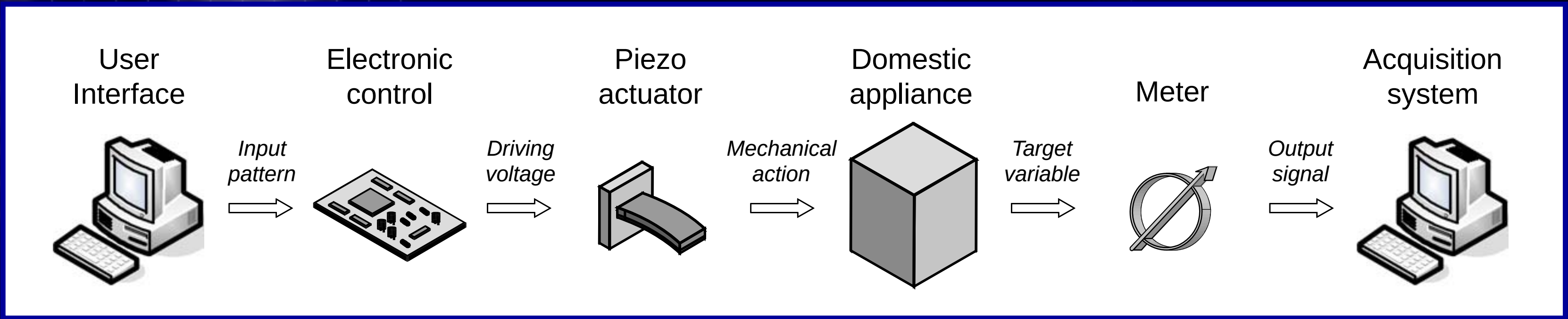


Typical parameters

- motion: 100 ÷1000 μm
- force: 10 ÷ 100 g
- max voltage: 300 ÷ 500 V

- Open-loop control (low cost, feasibility)
- Main problem to be solved: hysteresis!

Prototype
schematic representation



User Interface: software program running on a PC

Electronic control: elaborate the input signal, supply the piezoelectric actuator with the proper voltage

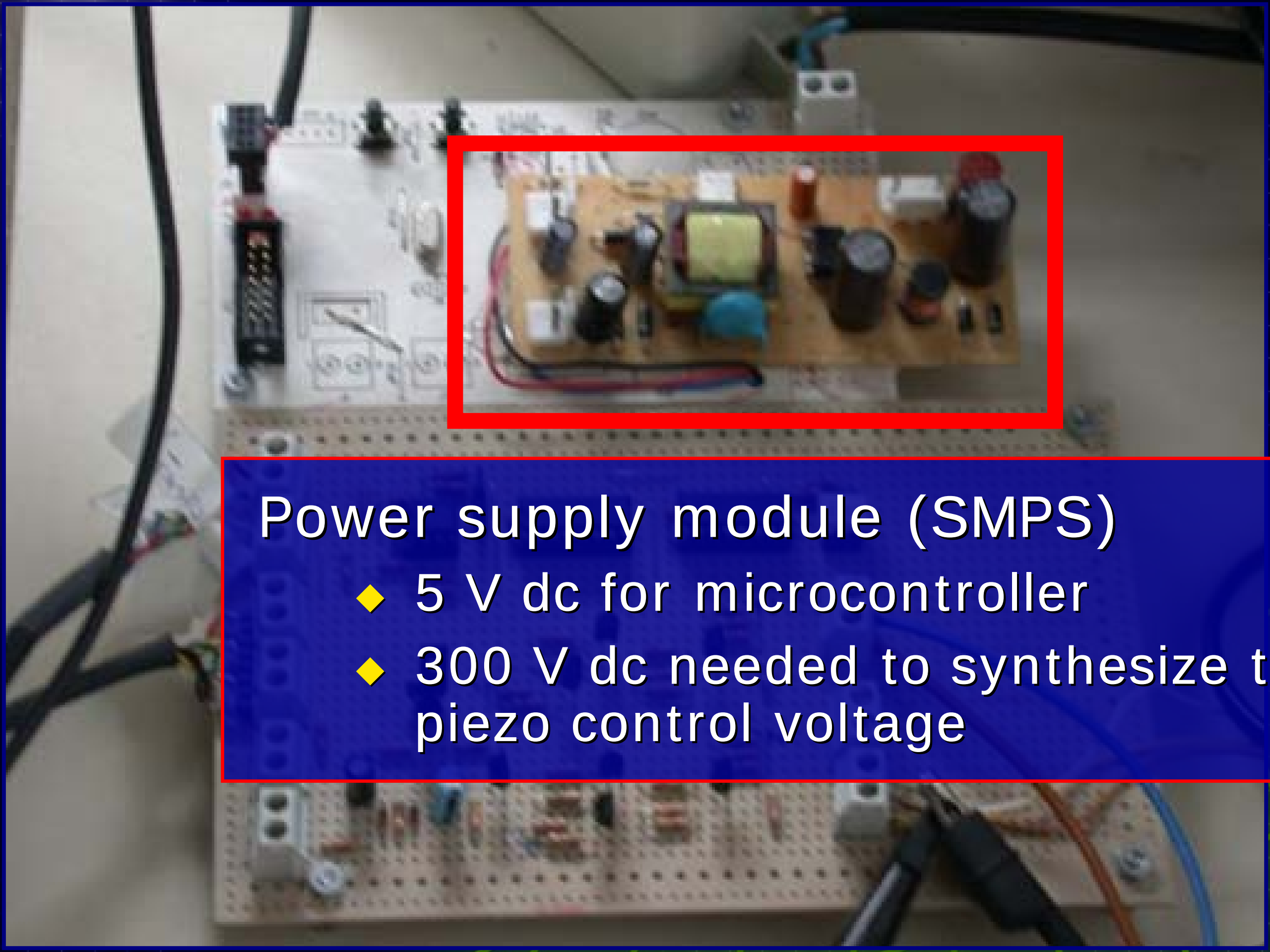
Piezo actuator: capacitor; the applied voltage determines the entity of the mechanical deformation

Domestic appliance: mechanical, thermodynamic, fluid dynamic system inside the domestic appliance

Meter: provides the measure of the physical variable to the Acquisition system

Acquisition system: PC

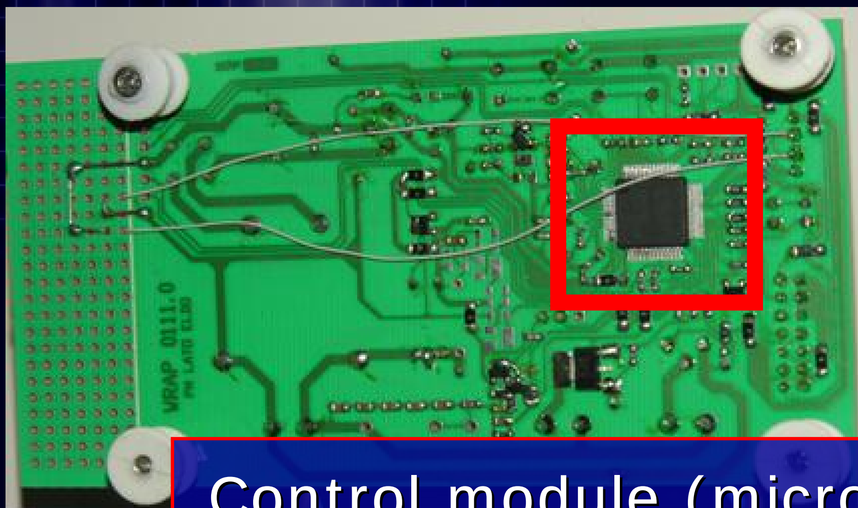
Prototype
electronic board - 1



Power supply module (SMPS)

- 5 V dc for microcontroller
- 300 V dc needed to synthesize the piezo control voltage

Prototype
electronic board - 2



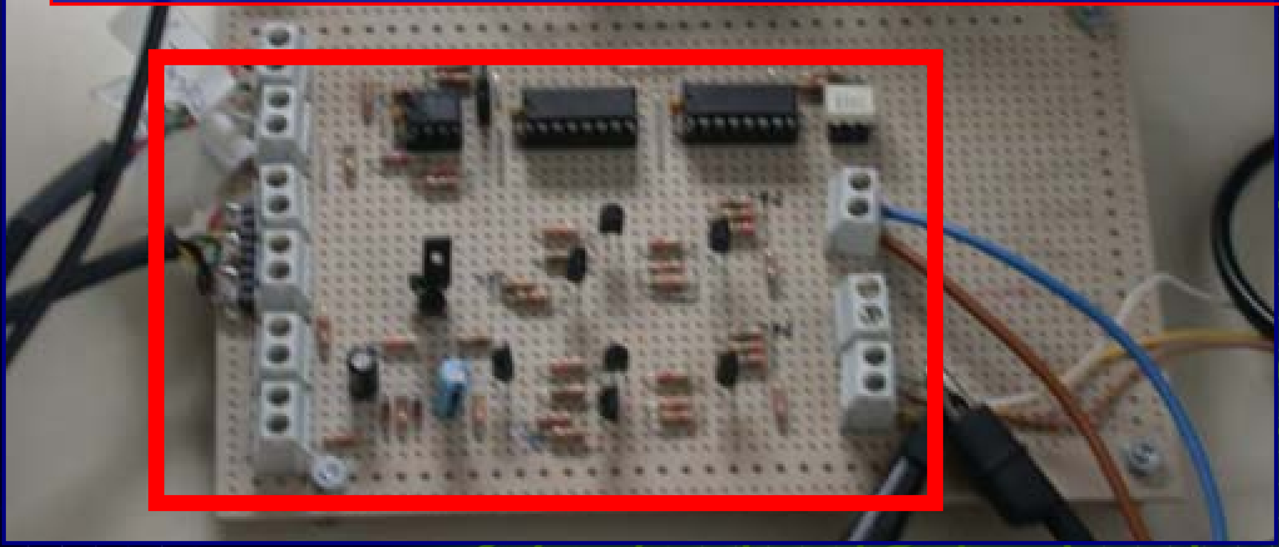
Control module (microcontroller)

- communication with the UI (standard RS-232 serial line; Indesit proprietary communication protocol)
- decoding of input pattern and conversion into the corresponding voltage pattern to be generated
- generation of the control signal for the piezo actuator interface (PWM signal; closed loop-control of voltage signal; PID control algorithm)

Prototype
electronic board - 3

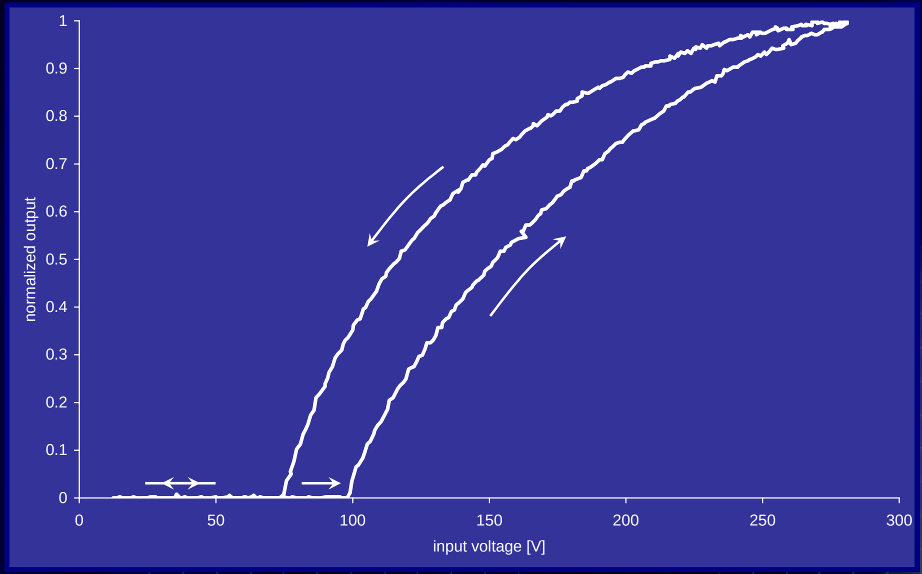
Piezo actuator interface (analog circuit)

- adapts the 0-5 V PWM signal from the microcontroller to the 0-285 V range
- generates a continuous voltage in the range up to 285 V dc (uses a LPF)
- voltage feedback to the microcontroller



Prototype
response without hysteresis compensation

- Main hysteresis loop of the system
  - Input voltage: 0-285-0
  - Output: normalized



- The hysteretic behaviour of the piezo device is reflected to the output quantity
- Effect: the entity of the deformation (output) of the piezo actuator is influenced by the history of input

Hysteresis in piezoelectric actuators
approaches for compensation

- 1. Electric charge control (Newcomb and Flinn): the linearity of piezoceramic actuators can be improved if an electric charge is applied and varied to control the deformation. Issues: it needs specially designed charge amplifier, good linearity cannot be guaranteed in a wide frequency range.
- 2. Closed-loop displacement control. Typically: strain gauges are used as feedback sensors. Good results, but additional cost.
- 3. Open-loop control: linear control with feedforward inverse hysteresis model. Idea: find a proper model of the hysteretic behaviour of the piezo actuator and use its mathematical inverse in the control chain.

Hysteresis in piezoelectric actuators
proposed compensation technique

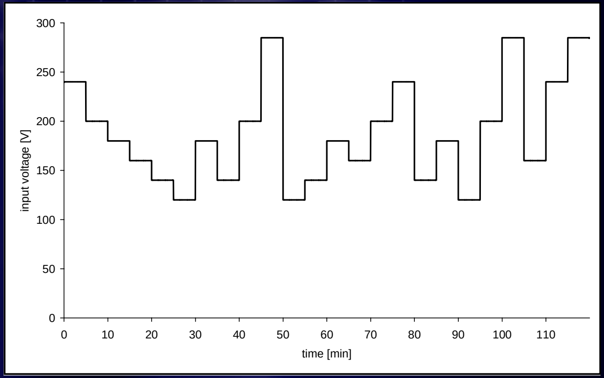
- Key factors
  - fast frequency response of the actuator (50 ms to cover the whole voltage range)
  - inertia of the physical appliance (LPF response)
  - stepwise variables (the output varies according to levels)
- Idea: biasing the actuator to the upper branch of the hysteresis curve, hence making it to work in a well defined path

Hysteresis in piezoelectric actuators
proposed compensation technique

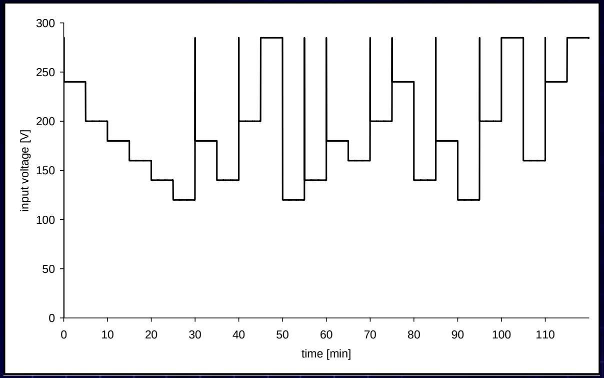
- Method: applying a transformation to the stepwise input signal as follows:
  - step-down transitions (VH → VL): unchanged
  - step-up transitions (VL → VH): converted to a combined transition (VL → VMAX → VH)
- Effect: the stable operating points of the piezo actuator lie in the upper branch of the hysteresis curve, resulting in a nonlinear hysteresis-free behaviour
- Implementation in the digital system (64-pin, 8 MHz microcontroller; 4 KB assembly code)

Experimental results

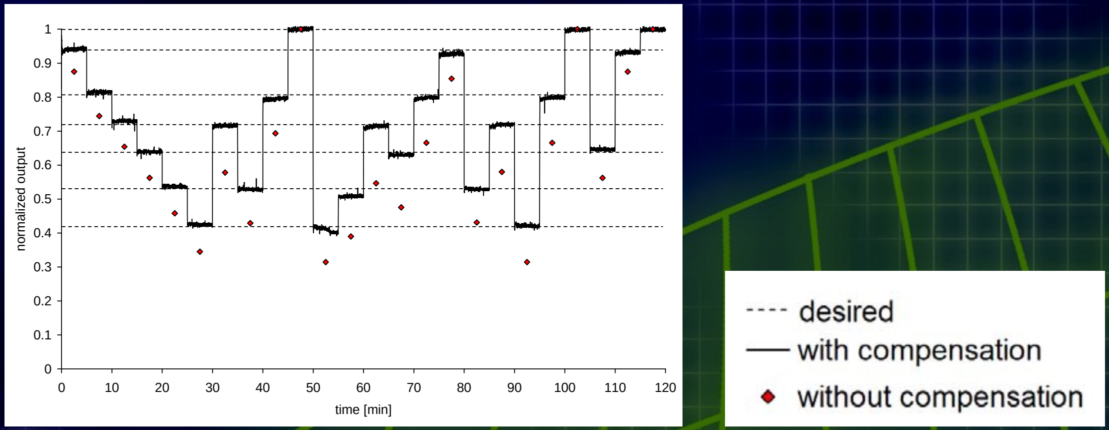
- Input pattern used in the test (7 levels, 24 steps)



- Voltage signal produced by the controller

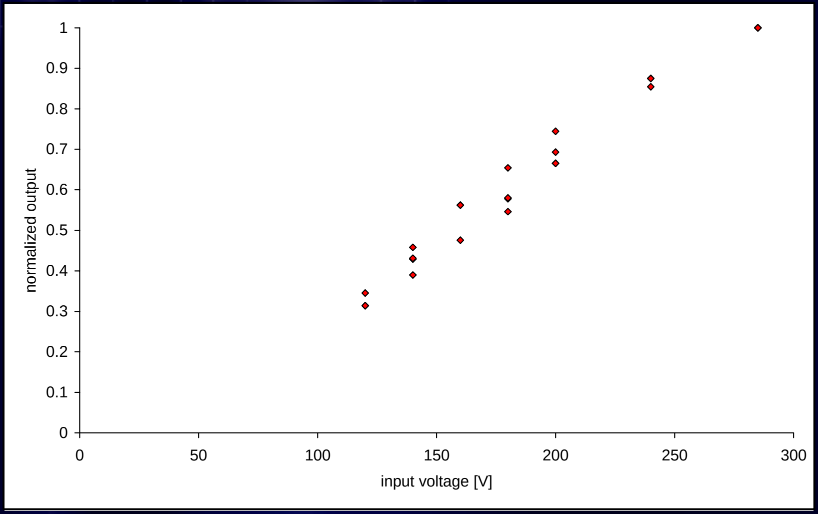


- Output with compensation and without compensation

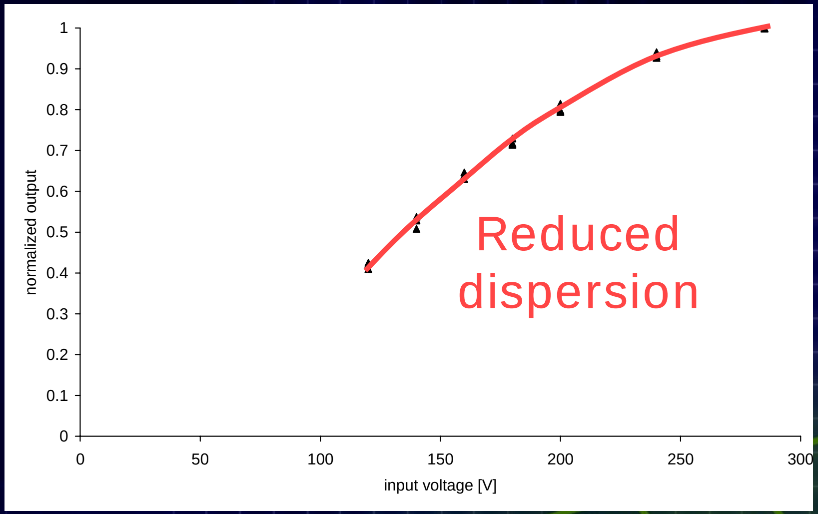


Experimental results

- Scatter diagrams
  - without compensation



  - with compensation



- Error reduction
  - maximum error: reduces from 9 % to 2.8 %
  - average error: reduces from 5.3 % to 1.3 %

Conclusions

- We have presented a new digital open-loop control of piezoelectric bender for real-time applications when low cost is a fundamental requirement
- Preliminary results for the prototype realized in Indesit Company laboratories show the effectiveness of the proposed technique, which allows for a good hysteresis compensation
- The illustrated technique is suitable to be directly implemented in the same microcontroller already present on currently marketed appliances
- Piezoelectric actuators seem to be interesting for future applications on domestic appliances...