Piezoelectric Strings as a Musical Interface

Marcel Ehrhardt
Thuringian Institute of Textile and Plastics Research e.V.
Breitscheidstr. 97
07407 Rudolstadt, Germany
ehrhardt@titk.de

Max Neupert
The Center for Haptic Audio Interaction Research
Helmholtzstr. 15
99425 Weimar, Germany
max@chair.audio

Clemens Wegener
The Center for Haptic Audio Interaction Research
Helmholtzstr. 15
99425 Weimar, Germany
clemens@chair.audio

ABSTRACT

Flexible fibers with piezoelectric properties have been developed but until now had not been evaluated for use as part of a musical instrument. This paper is assessing the properties of these new fibers and highlights their strengths and weaknesses for NIME applications.

Author Keywords

string, fiber, fibre, piezoelectric, piezo, integrated

CCS Concepts

•**Hardware** → *Sensors and actuators;* **Tactile and hand-based interfaces;** •**Human-centered computing** → **Sound-based input / output;**

1. INTRODUCTION

Traditionally, acoustic string instruments are using piezoelectric sensors which are mounted under or behind the saddle or on the instruments body. Electric string instruments use pickups which are measuring the magnetic field disturbances of the oscillating metal string. With piezoelectric fibers we can design instruments without the need for either technologies which removes a limiting design constraint and allows for new applications and concepts. Piezoelectric fibers have been used as sensors for interfaces before [5] but their potential as an acoustic signal source has yet to be explored.

2. PIEZOELECTRIC POLYMER FIBER

With the development of the piezoelectric polymer fiber [2], sensors can be created which are able to detect vibrations in a frequency spectrum from the sub-Hz range to the MHz range. The industry values their flexibility, which allows for fibers to be integrated into components, machines or applications without affecting their basic structure and functions. The fibers are produced using a bi-component melt spinning process and have a core-shell structure. After the melt spinning process, the fibers are subjected to stretching in order to increase the degree of crystallization in the functional layer. The core consists of an electrically conductive thermoplastic polyurethane, while the shell is

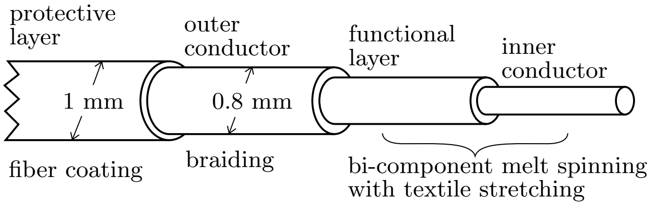

Figure 1: Basic structure of the piezoelectric polymer fiber sensor

made of polyvinyldiflouride (PVDF), a fluoropolymer (Figure 1). To activate the piezoelectric properties, it is necessary to polarize the fibers. This is done by means of a roll-to-roll method within a plate condenser at a high voltage of up to 30 kV (Figure 2). Using a round braiding process, electrically conductive filaments, which consist of metals or electrically conductive plastics, are braided onto the PVDF shell as the outer electrode. It is also possible to implement electrically insulating materials as a protective layer using the round braiding process or other roll-to-roll coating process. The fiber sensors can be characterized by a process developed at the *Thuringian Institute of Textile and Plastics Research e.V.* (TITK) and adapted for a variety of applications.

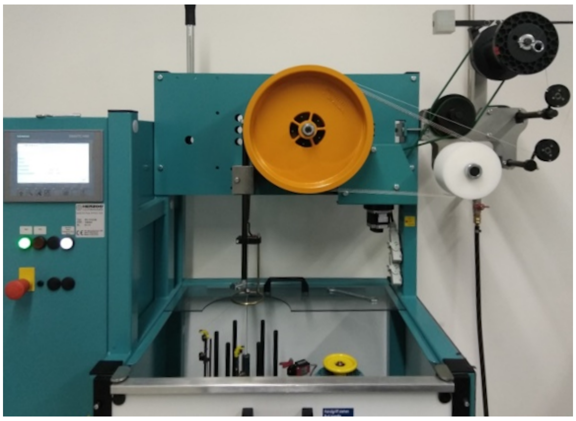

Figure 2: Device for electrodization of the fiber.

3. SIGNAL PROCESSING

3.1 Piezo Amplification

To amplify signals from the piezoelectric fiber, either simple amplifier circuits[1], "opamp with reference voltage" topologies, or a Schoeps differential preamp circuit can be used.

[1] A popular one can be found in Émilie Gillets open source design for the *Ears* Eurorack module

NIME'20, July 21-25, 2020, Royal Birmingham Conservatoire, Birmingham City University, Birmingham, United Kingdom.

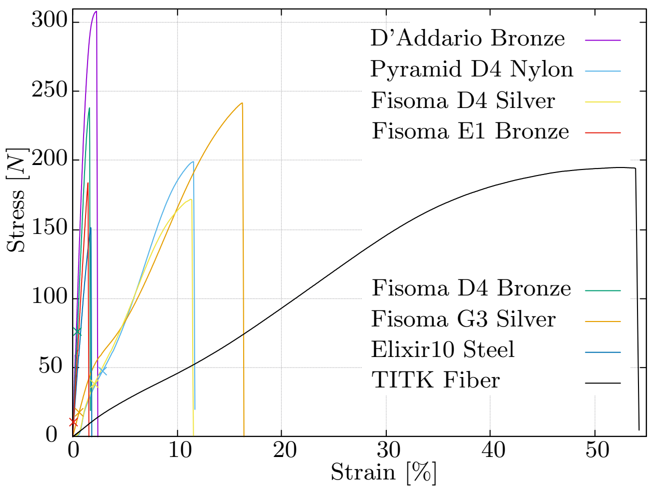

Figure 3: Load elongation curve of a piezoelectric fiber with an outer conductor of silver-plated nylon and without braiding. Compared with common guitar strings. *X* Marking for calculated designated tuning.

Our implementation uses the OPA1671 JFET based opamp in two stages.

3.2 Digital Resonators

The sounds from the string may be fed into digital resonators as described in [4]. It is also possible to quantize and extend the frequency range by pitch-shifting the input sound or re-tuning the resonators based on fundamental frequency recognition.

4. WEAKNESSES AND CHALLENGES

The piezoelectric string is currently not a drop-in replacement for any instrument string. The most important differences and weaknesses are: 1. It can't withstand the tensions used for most instruments (Figure 3). A comparative plot for nylon, fluorocarbon and natural gut can be found in [3]. However, it is possible to produce fibers with a metal core [1] 2. Its outer layer is the shielding and is braided, not wound. While the tensile strength in traditional strings comes from the solid core, the melt spun core of the piezoelectric fibers is the most delicate part of the fiber. 3. The piezoelectric fibers don't come with a ball end or any kind of construction which facilitates the mounting. 4. The core and shielding needs to be connected to the preamp circuit. Since the piezoelectric effect vanishes if the core is exposed to heat, its electrical contacts must be made with solder-free processes like silver-particle acetone. Ideally only the part of the string between nut and bridge where the string is freely moving would be sensitive. This is technically possible, since it needs to be activated by a strong electromagnetic field. Here are opportunities for innovation.

5. INSTRUMENTS

We prototyped simple instruments which we demonstrate in a video `https://vimeo.com/429431847`

5.1 Electronic Mandolin

We modified a mandolin and replaced one string with a piezoelectric fiber. For comparison with the resonant sound a piezoelectric disc was placed on the body.

5.2 Finger Violin

A very portable string instrument is the finger-violin (Figure 4). It allows the excitation of one string suspended between thumb and index finger. The other hand can be used to pluck or bow the string. Bowing proved more difficult than expected because it's hard to create the required medium to high tension by spreading the fingers. The string is mounted on rings on both ends. On the side of the thumb the coaxial shielded cable has connections for the preamp.

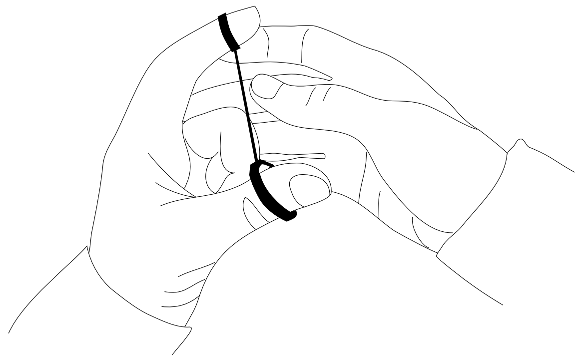

Figure 4: Finger-"Violin". May be played by plucking it with the other hand, the pitch can be controlled by stretching the fingers apart and thus varying the tension of the string.

6. DEVELOPER KIT

We believe that piezoelectric fibers have an enormous potential for innovative NIME applications. To make them available to the community and interested developers CHAIR and TITK have partnered to make a developer kit available composed of piezoelectric strings and a preamp. Schematics, pricing and availability are published at `https://discourse.chair.audio/t/piezoelectric-string-devkit`

7. CONCLUSIONS

We show that piezoelectric strings can make unconventional instrument designs possible and allow access to previously unknown sonic experiences. Amplified noises from the interaction with the string let us explore ASMR-like micro-sounds with an intimate control and a wide range of expressions.

8. REFERENCES

[1] Y. Bian and R. Liu. Fabrication of a biomimetic piezoelectric polyvinylidene difluoride (PVDF) fibre with a metal core and its application in vibration sensors. *Transactions of the Institute of Measurement and Control*, 40(1):3–11, Jan. 2018.

[2] A. Lund, C. Jonasson, C. Johansson, D. Haagensen, and B. Hagström. Piezoelectric polymeric bicomponent fibers produced by melt spinning. *Journal of Applied Polymer Science*, 126(2):490–500, Oct. 2012.

[3] N. Lynch-Aird and J. Woodhouse. Comparison of Mechanical Properties of Natural Gut and Synthetic Polymer Harp Strings. *Materials*, 11(11):2160, Nov. 2018.

[4] M. Neupert and C. Wegener. Interacting with digital resonators by acoustic excitation. In *Proceedings of the 16th Sound & Music Computing Conference*, pages 80–81, Malaga, May 2019. Universidad de Málaga.

[5] M. Åkerfeldt, A. Lund, and P. Walkenström. Textile sensing glove with piezoelectric PVDF fibers and printed electrodes of PEDOT:PSS. *Textile Research Journal*, 85(17):1789–1799, Oct. 2015.