Evaluation of Commercial Force-Sensing Resistors

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ABSTRACT

Pressure and force touch sensors are pervasive in electronic musical instruments. While there are a variety of ways to sense pressures and forces, many instrument builders tend towards force-sensing resistors (FSR). These sensors are often implemented with only two design parameters in mind: their minimum and maximum resistances. While commercial FSRs are qualitative devices and not meant for accurate force measurement, if we want to design electronic musical instruments and interfaces which can compete in terms of expressivity with acoustic ones, care should be taken in choosing and implementing sensors properly. In an effort to better understand the electrical response of the commercially available sensors, several tests were performed to measure the time-varying response of the device itself, specifically the resistance drift and hysteresis under different forces. We present quantitative results of two tests performed to characterize the behavior of three commercial touch sensors and comment on ways to best use them in interface design. Results show a wide variation in drift and hysteresis characteristics among the different models.

Keywords

Touch Sensors, Force-Sensing Resistors, Sensor characterization

1. INTRODUCTION

Force (touch) sensors – specifically the Interlink Force Sensing Resistor – are very common devices in digital musical instrument design [4]. Thanks to their wide availability, ease of use and low cost, designers have extensively relied on touch sensors for various applications [5].

Force sensing resistors are thin isometric force sensors whose resistance decreases with the force applied in a non-linear way [1]. At least three commercial force touch sensors are currently vailable in the market: the Interlink FSR, the LuSense PS3 and the Tekscan FlexiForce A201.

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The Interlink FSR is comprised of 2 polymer films: one with a conductive surface and the other with printed (interdigitated) electrodes facing the first. Contact between the two surfaces causes the conductive layer to short circuit the printed electrodes, thereby reducing the electric resistance of the component. Typically, its resistance will drop from more than 1 Mohm to about 10 kohm for an applied load of 100 g (a force of roughly 1N) to 10,000 g [3]. Interlink FSRs are available in four shapes: Two round, one square and one long FSR.

A similar product is commercialized by LuSense in Luxembourg, called PS3, also available in a few different shapes (two round and one square one, the last one a bit smaller than the square FSR from Interlink). It is commercialized in several sizes, with a typical resistance variation between 1 Mohm and 2 kohm for a pressure range between 0.5 and 100 N/cm2 [2].

The FlexiForce A201 force sensor from Tekscan is constructed of two layers of substrate (polyester/polyimide) film. On each layer, a conductive material (silver) is applied, followed by a layer of conductive ink. Adhesive is then used to laminate the two layers of substrate together to form the force sensor. The active sensing area is defined by the silver circle above the conductive ink. Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads [7].

Figure 1: Three touch sensors from Interlink, LuSense and Tekscan.

Fabrizio Vecchi and colleagues [8] have experimentally evaluated both the Interlink FSR and the Tekscan FlexiForce through a series of measurements. They concluded that the FlexiForce sensors present better response in terms of linearity, repeatability, time drift, and dynamic accuracy, while the Interlink FSRs are more robust.

2. TESTS

In musical interface design one does not necessarily need to perform quantitative characterization tests in order to choose sensors – as is the case in most industrial applications – but it is still interesting to compare the various existing options of sensors commercially available. One obvious reason comes from the fact that commercial sensors from different manufacturers most of the time employ different technologies, that in turn may have different behaviors influencing the sensors' response to performer actions.

In this work, we performed two separate tests: a dead-weight test and a ramped force test, both using on a Model 402 Interlink FSR, a 12 mm LuSense PS3 Standard 151, and a Tekscan FlexiForce A201 sensor. The sensors' resistance and time responses were collected.

2.1 Dead-Weight Tests

Resistance drift is an important parameter in force touch sensors because their resistances vary with time, for a constant load applied to the device. This is one reason why force-sensing resistors cannot be used in quantitative or absolute measurements of force.

We have chosen a dead-weight test where a pre-load calibration mass is placed on the sensor being tested. A concern with the dead-weight test setup is the difficulty in placing the weight in the same position on the sensor every time the sensor is tested. This accounts for the variation in absolute resistance under the same applied load. Nevertheless, this test can give an initial ideal of the response of such sensors over time.

2.1.1 Test Setup

The first set of dead-weight testing was performed by placing a pre-load calibration mass on the device under test (DUT) so that the sensor would always be "ON" and provide a resistance reading to an HP 34401A multimeter. A solenoid was used to drop and pick up a test load which was cycled by a 33220A Agilent function generator with a square wave (50% duty cycle).

2.1.2 Data Collection

Data collection was performed with the aforementioned multimeter and a windows PC running Labview 7.1, through a 16 channel, 16 bit PCI data acquisition board by National Instruments (NI PCI-6036E). All measurement instruments were connected to the PC through a National Instruments GPIB (IEEE 488.2) PCI card.

2.1.3 Loading Tests

The first set of dead-weight tests was done with a 20g preload and test masses of 50g, 100g, 200g, 500g, and 1000g with a 240s solenoid period, capturing 250 samples with a delay of 1.5s period (a test duration of 375s).

Testing was also performed with the 20g preload with test masses of 50g and 1000g for solenoid periods of 20s and 1200s capturing 250 data points at 0.126s and 7.5s intervals (test durations of 31s and 1875s) for the respective solenoid periods.

2.1.4 Load Removal Test

Another set of dead-weight tests was performed with a 700g (500g + 200g) preload mass applied for a duration of more than 30 minutes then 500g was removed whilst the 200g mass was maintained. A total of 250 samples with a 7.5s sample period was obtained from each of the sensors.

2.2 Ramped Force (Hysteresis) Test

A second test setup was created to apply a dynamic force to the sensors in order to measure the hysteresis and resistance versus force characteristics. The test setup synchronization of force and resistance data was solved through time-stamping of each of the data sets.

2.2.1 Test Setup

The tests were performed on the same three sensors with an Instron 3342 Universal Electromechanical Materials Testing Machine with a 100N load cell and 10mm diameter force-to-pressure transducer. A ramp from zero to 20N and back to zero was performed five times followed by a ramp up to 25N. Upon reaching a force of 25N, the test was terminated and collection of force data ceased.

2.2.2 Data Collection

The force data from the load cell was collected at a sampling rate of 10Hz with proprietary software by Instron and the resistance data was obtained by collecting voltage data, on an SC-2075 National Instruments Digital Acquisition board interfaced with a PCMCIA DAQCard-6036E on a Windows portable PC running Labview 7.1, sampling at 100Hz. While the Instron machine was unable to apply a constant change of force, it was able to apply a constant rate of compression of 0.1mm/minute. Various test times were obtained depending on the compressibility of the sensor.

3. RESULTS

3.1 Dead-Weight Test (240s)

It was found that the Tekscan FlexiForce sensor had the most consistent percent drift independent of the applied load. While the Tekscan maintained a drift of between 10.34% and 11.42%, the Interlink FSR drifted as little as 3.05% and as much as 12.37%, while the LuSense PS3 drifted as little as 6.18% and as much as 11.74%[1].

While the drift over a period of time is more stable with FlexiForce the output signal has significantly more noise over the course of the test than that found in the FSR and in the PS3(2% for the FlexiForce, 0.1% for the FSR, and 0.6% for the PS3).

3.2 Dead-Weight Test (1200s)

It was found that the Tekscan sensor drifted 4.08% (again with noise) over ten minutes, while the Interlink drifted 7.41% and the LuSense drifted 6.14%.

Another measurement to note is the amount of time needed for the sensor to settle to its end resistance. In order to reach 90% of their final resistance value, the Interlink FSR took 345 seconds, the LuSense PS3 took 427.5 seconds, and the Tekscan took 450 seconds.

[1]The value for a load of 220g represents an error in the measurement due to bad placement of the weight and has not been considered

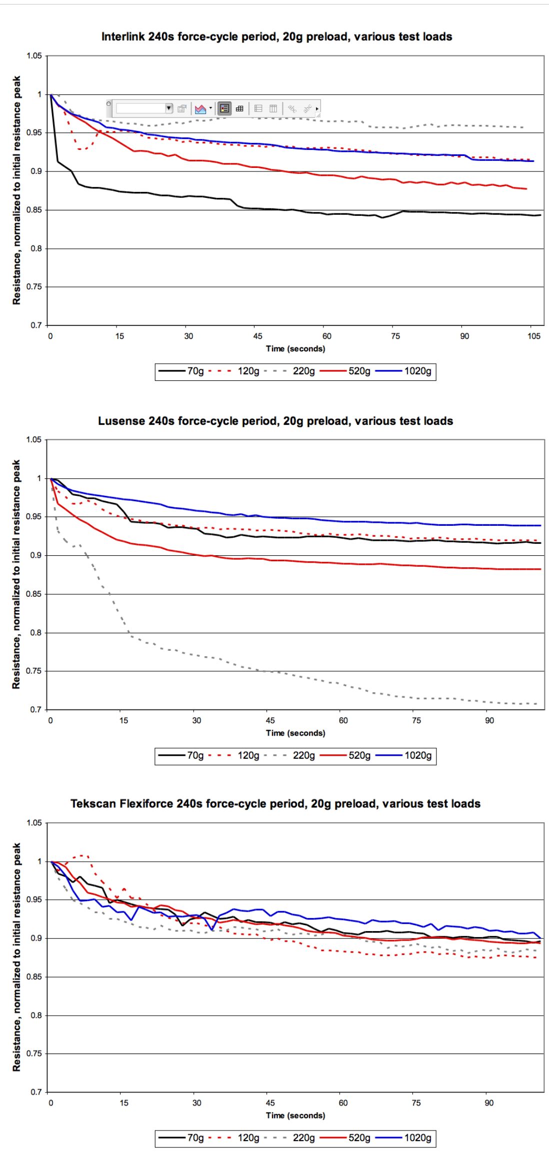

Figure 2: Dead weight drift for the three samples, period of 240s.

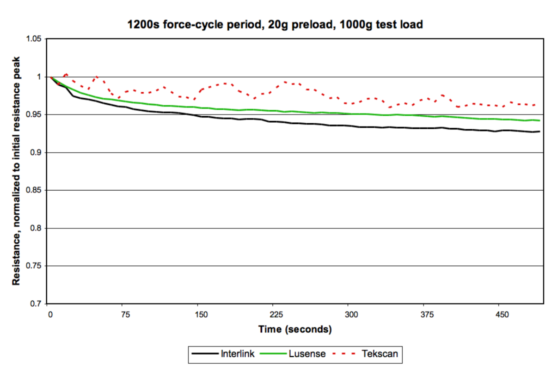

Figure 3: Resistance drift with time, 1000 g load for 1200s.

3.3 Dead-Weight, Load Removal of 500g

It was found that the Tekscan sensor drifted 2.0%, while the Interlink drifted 7.2% and the Lusense drifted 17.3%. In order to reach 90% of their final resistance value, the Interlink FSR took 800 seconds, the Lusense FSR took 350 seconds, and the Tekscan took 475 seconds.

3.4 Hysteresis

There is significantly more hysteresis in the Tekscan FlexiForce sensor that the Interlink FSR, which in turn has more hysteresis than the LuSense PS3.

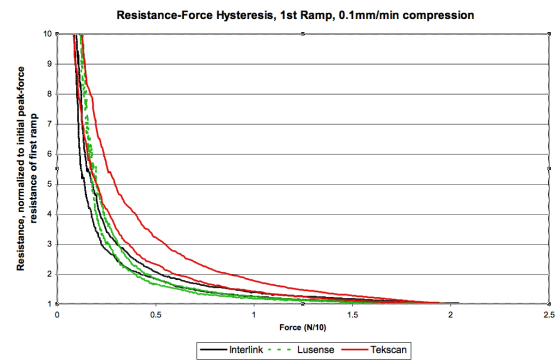

Figure 4: Hysteresis in the three samples.

An interesting finding is that the resistance in each subsequent force peak significantly increases with the FlexiForce sensor, whereas it stays relatively constant in the LuSense and Interlink FSRs.

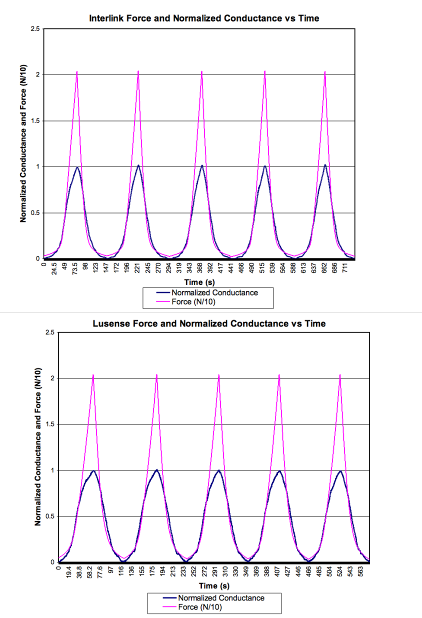

Figure 5: Variation of conductance (normalized) with applied force for the FSR and PS3.

This can be explained with the relatively high drift time of the Tekscan sensor, as well as the reduced compressibility. Recall that the testing was performed with a constant rate of change of compression (0.1mm/min), so the tests took 200 s, 220 s, and 122 s for the LuSense, Interlink, and Tekscan sensors respectively. Thus the Tekscan sensor had the least time to relax to its rest state. This coupled with the fact that the Tekscan sensor takes the longest to relax to its rest state means that the drift associated with each subsequent force ramp is compounded causing a reduced resistance with each force peak.

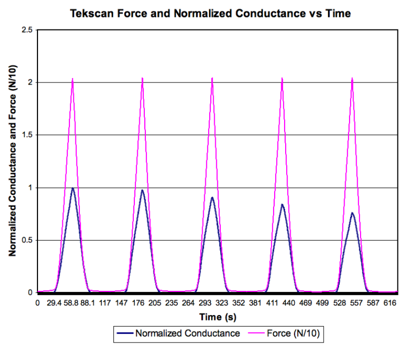

Figure 6: Variation of conductance (normalized) with applied force for the Tekscan A201.

Force-resistance linearity is not a factor, as none of these sensors demonstrate such a response. Though when plotted on a log-log scale, the force-resistance curve can be approximated with a straight line above a certain applied force. This is more apparent in the Tekscan sensor and to a lesser degree in the Interlink sensor.

4. DISCUSSION

In order to select a touch sensor, the designer has to look to the application to choose which sensor is the most suitable for a given functionality. The FlexiForce showed the highest precision (i.e. the quality that characterizes the capability of a measuring instrument of giving the same reading when repetitively measuring the same quantity under the same prescribed conditions [6]) if compared to both the FSR and the PS3, but with higher noise than the other two. Also, the FlexiForce showed the the slowest response (time to reach 90% of its final resistance value). This fact, together with the short time it took to apply the hysteresis test in the FlexiForce (122s compared to 200s for the LuSense and 220s for the Interlink) is probably what explains the decrease in conductance with repeatable forces (c.f. Figure 6).

In short, if large changes in force are applied at a relatively high frequency, it appears the Interlink or LuSense sensors should be selected, whereas if large slowly-varying forces are applied infrequently for long durations, the Tekscan sensor is likely to perform better. In the actual application however, the ability to maintain a consistent and accurate area and position of the applied force will be the limiting factor in terms of sensor accuracy and precision.

Indeed, the time needed for the sensor to relax is an important variable. When not taken into account, it may induce errors in the measurement that could explain the differences in some of the drift measurements in [8] [2].

[2]The difference in drift error for the FlexiForce in figures 10 to 12

Sensor Test	*Interlink Model 402*	*LuSense PS3 Standard 151*	*Tekscan FlexiForce A201*
Drift – Various loads			
- Min. Drift, 240s period	3.05%	6.18%	10.34%
- Max. Drift, 240s period	12.37%	11.74%	11.42%
Drift – 1020g load	7.41%	6.14%	4.08%
Load removal	7.2%	17.3%	2%
Hysteresis			
- Variation of R in subsequent tests	Constant	Constant	Increases
- Total test time	220s	200s	122s
- Value	Low	Lowest	High

Figure 7: Tests results for the three samples.

5. CONCLUSION

We presented a preliminary evaluation of three commercially available force/load touch sensors used in musical interface design: the Interlink FSR, the LuSense PS3 and the Tekscan FlexiForce. We tested the resistance drift with time and the hysteresis of each sensor for multiple load conditions, as well as the time it took the sensors to reach their final resistance values. Differences were found in the precision of the devices, as well as in the linearity and time responses. This information can be useful in the choice of touch sensors when precision or time response are important factors.

6. ACKNOWLEDGMENTS

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