Textile-Made Foot Pressure Pads or Socks for Piano Pedal Teaching: Visualization and Correction of Pedal Force and Timing

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ABSTRACT Fine-grained piano pedal control is essential for tonal continuity and expressive performance, but learners often lack quantitative feedback on pedal force, timing, and coordination. This study designs and implements a piano pedal teaching system based on textile pressure-sensing pads or socks. A flexible piezoresistive sensor array collects multipoint plantar pressure signals, which are amplified, filtered, converted by a microcontroller unit, and transmitted wirelessly to the host computer. The software uses pressure-threshold segmentation to identify pedal states, timestamp synchronization to record pedaling timing, and a two-dimensional force-time visualization interface to display operation trajectories. By comparing learner data with standard performance templates, the system outputs deviation heatmaps and correction suggestions. Experimental results show high pressure detection accuracy, millisecond-level timing resolution, and reliable recognition of the damper, soft, and sostenuto pedals. The study demonstrates the value of textile-based flexible sensing, wireless data transmission, and real-time signal visualization in music-performance pedagogy.

INDEX TERMS piano pedal instruction,textile pressure sensing,flexible sensor array,wireless transmission,visual feedback

I. INTRODUCTION

PIANO performance art is based on the integration of keyboard and pedal skills. The continuity of tone and the feeling of volume is adjusted by the pedal operation through alteration of the contact state between the dampers and the strings. All notes have a resonance period which is determined by the sustain pedal, the striking distance is decreased by the soft pedal to produce a tender sound and the continuity of certain notes is selectively maintained by the sustain pedal. The exact use of the three pedals is a major aspect of performance expressiveness. Difficulty in determining when to operate the pedal, no quantitative criteria of dynamic control, and poor coordination in changing pedals rapidly are some of the nondiscriminatory factors that learners experience [1-2]. Conventional methods are based on auditory judgment and verbal cues of the teacher who cannot present objective information on the depth of pedal and timing. It is hard to create correct muscle memory in students, and the errors can be corrected only with trial and error, wasting a lot of time and limiting the effectiveness of teaching.

The invention of wearable sensing technology has offered new solutions to motor skill training. The flexibility and thinness of flexible pressure sensors make them very popular in gait analysis and motion posture monitoring since they are easy to wear, fit, and do not interfere with natural movements. Textile sensors combine conductive materials into fabric designs, a type of sensor that can be comfortable and provide the accuracy of measurements, thus can be worn over a long period. In this paper, a design of a piano pedal teaching system is developed with a combination of a textile pressure sensor array that provides real-time quantitative data on pedal activity by capturing the data on the distribution of the foot pressure. The system is a system that fuses signal processing algorithms to detect the type of pedal and status of operation, forms a visual feedback interface to compare with standard playing templates, and automatically creates individualized correction recommendations. This approach facilitates data-driven instruction, providing an objective framework for mastering complex pedaling techniques.

II. RELATED WORK

Studies on piano playing aid technology concentrate on touch force detection in the keyboard and finger motion tracking. Learners are helped to develop a better touch technique and finger independence by installing force sensors under the keys or by recording the performance data using optical motion capture devices. In some, the MIDI protocol is used together to translate performance data into a digital format, achieving automatic measurement of note accuracy and wrong note indications [3-4]. There is limited research on pedal technology. The solutions that are in place largely depend on the incorporation of displacement sensors or Hall effect sensors into the pedal mechanical structure to measure the depth of the pressure on the pedal. Nevertheless these techniques demand alteration of piano hardware, are complicated to set up and could harm the instrument, so are not easily marketed to alternative types of pianos. Flexible pressure sensors have found application in the medical rehabilitation and sports training. Foot pressure analysis devices are employed in the diagnosis of gait abnormalities and prevention of sports injuries, determining walking patterns and posture issues based on the characteristics of pressure distribution. The piezoresistive sensors make use of the property of the change in resistance value of conductive polymers when subjected to pressure to measure pressure. The piezoelectric sensors produce charge signals by deformation of the material in response to dynamic change of pressure. Capacitive sensors depend on variations in capacitance with a variation in electrode spacing to accomplish pressure sensing. Music teaching visualization systems converts abstract playing methods to graphical formations, piano learning software enables the learner to gain insight into the relationship of rhythms and pitch through waterfall displays of notes, and virtual reality technology creates a practice environment that is immersive so that the learning process is more enjoyable. The current technologies do not offer special solutions to pedal control and do not allow to offer a complete evaluation of dynamics, timing and standardization of operations, so it is impossible to scientifically develop pedal teaching [5-6].

III. METHODS

A. DESIGN AND MANUFACTURE OF TEXTILE-TYPE PRESSURE-SENSING PADS/SOCKS

In the textile-type pressure sensing pad, the conductive polymer composite material is the sensing element, where the silver fibers have been woven into a grid-like electrode array on an elastic fabric substrate. Sensors array is further broken down into three independent units of detection based on the anatomy of the foot: the forefoot area, the arch area, and the heel area. Each unit has 8×8 pixel piezoresistive sensing points, and the spacing between nodes is 6 mm to measure the details of the foot pressure distribution. A combination of polyurethane elastic fiber and cotton fiber forms the fabric substrate so that the thickness is regulated to not interfere with the tactile feedback to the player by the pedal [7-8]. Between the upper and lower electrode layers, a pressure-sensitive conductive rubber film is filled in between. The value of the resistance to pressure applied to the foot varies with the pressure and the rate of change of resistance is negatively exponentially related to the pressure. The periphery of the sensing pad takes a smooth thermo-locking mechanism to avoid the seepage of sweat and consequent short-circuit to the electrodes. The data collection circuit is embedded into the waterproof shell at the back part of the pedal, and it is attached to the sensing pad by a flexible flat cable. The cable length is reserved at 15 cm to accommodate the range of motion of different foot shapes. Sock-type sensors, on the other hand, weave the electrode layer directly into the fiber structure of the sock, with conductive yarns and ordinary yarns interwoven in a specific ratio to form pressure-sensitive areas.

B. DATA ACQUISITION AND SIGNAL PROCESSING SYSTEM

The processing core of the data acquisition circuit is an STM32F407 microcontroller with an ADS1256 multichannel 24-bit analog-to-digital converter chip to enable synchronous acquisition of 192 channels of pressure signals. Each sensing point is connected to a Wheatstone bridge circuit that converts the resistance change signal to a differential voltage signal and the bridge excitation voltage is set to 3.3 volts to minimize power consumption. The AD8226 instrumentation amplifier gains the micro volt differential signal by 100 and then a second-order Butterworth low-pass filter is applied to remove the 50 Hz power frequency interference and high-frequency noise. The cutoff frequency will be adjusted to 80 Hz in order to retain the entire spectral properties of the pedal action.

The analog-to-digital converter samples all the channels at 1000 times per second, and the conversion time per channel is held to less than 1 milliseconds. The microcontroller formats the data of 192 channels into a frame format after zero-point drift calibration and temperature compensation processing with each frame consisting of four fields: timestamp, channel identifier, pressure value, and checksum. The ESP32 wireless module accesses the data frames via the serial peripheral interface bus and sends them to the host computer with a rate of 5 megabits per second via the WiFi protocol [9-10]. The host computer software is a Kalman filter algorithm on the received data to remove transmission jitter and reconstructs the pressure array data into a three dimensional tensor stored in a circular buffer with a buffer depth of 5 seconds to support playback analysis of performance segments.

C. PEDAL STATE RECOGNITION AND TIMING ANALYSIS ALGORITHM

The adaptive threshold segmentation algorithm is used as the pedal status recognition. The system is used to add all the data in 192 pressure channels to achieve the total pressure figure. At a total pressure that goes beyond 200 grams, it is considered to be an occurrence of a pedal contact. The algorithm differentiates the quick pedaling and slow pressing movements based on the rise of pressure slope angle. Any slope that is above 50 grams per millisecond is indicated as rapid pedaling and a slope that is below 20 grams per milliseconds indicated as gentle operation. The system identifies pedal engagement primarily through the forefoot sensing units, treating the heel area as a static reference point (pivot). The sostenuto pedal is recognized when the pressure is concentrated in the central-forefoot region with a threshold exceeding 150 grams, while maintaining a stable heel-to-floor contact signature to ensure the foot remains in the correct ergonomic posture. The pressure distribution pattern recognition differentiates the sustain pedal, soft pedal and sostenuto pedal by detecting the lateral spatial coordinates and pressure intensity of the foot. Given the physical separation of the three pedals, the system maps the active sensing zones: the sustain pedal corresponds to high-pressure clusters on the right side of the forefoot array, the soft pedal triggers the left-side zones, and the sostenuto pedal is identified by centralized pressure within the middle zone of the sensor grid.

The timing analysis algorithm takes the MIDI score file as a reference to obtain the starting and ending time of notes and printouts of the pedals to create a standard timing template. Real performance data is compared and matched with the template through a dynamic time warping algorithm to determine time deviation of the pedal action in relation to the notes. A half-pressed pedal state is detected by the algorithm based on a pressure range discrimination technique; a half-press action is detected when the pressure value is between 30% and 70% of the maximum pressure and a duration of more than 100 milliseconds is reached. The pressure falling edge feature is used to detect the release of the pedal; the pressure value should drop below 50 grams and stable over 20 milliseconds to obtain a full release. The system captures the initial timestamps of start and end of every press and release action to milliseconds.

D. VISUAL INTERFACE AND CORRECTIVE FEEDBACK MECHANISM

The visualization interface is created in the framework of Qt. The key presentation space will be split into upper and lower tracks to show a comparison between the normal operation and the actual performance. The higher track is occupied by blue rectangles to denote the normal times of pedal; the depth of the rectangle corresponds to the depth of the pedal pressure and the length to the time. The lower track shows the curve of the pedal operation of the learner in real time and uses red to identify the portions that have timing variation greater than 50 milliseconds and yellow to indicate the portions with a force variation greater than 20%. The pressure heatmap module coordinates the data of 192 sensor points on the sole of the foot with a color temperature distribution image; dark red indicates high pressure areas and dark blue indicates low pressure areas. The refresh rate will be configured to 30 frames per second in order to promote smooth dynamic display. The feedback system utilizes an artistic-adaptive evaluation model rather than a rigid numerical match. While the reference template provides a baseline, the system allows for professional adjustment of the "standard" range to account for the piano's resonance and specific room acoustics. The evaluation focuses on the relative consistency of the performer's interpretation rather than a fixed Euclidean distance, acknowledging the subjective and artistic nature of pedaling. It generates voice prompts and text suggestions when the distance is more than a set limit. The message "Delay pedaling: 82 milliseconds" signals premature pedaling and the message "Increase pressure depth: 35%" signals insufficient pressure. The system creates weekly statistical reports, pie charts of the type of errors and the line graphs of the trends of progress and indicates the location of the most common errors. The playback feature aids in the reproduction of pressure data of any duration to enable the learners to see the variations of the plantar pressure frame-by-frame and compare minute differences between their work and the standard pattern.

IV. RESULTS AND DISCUSSION

A. SYSTEM PERFORMANCE TESTING AND ACCURACY EVALUATION

Pedal recognition test was proposed to 12 students of piano. This study was approved by the Ethics Committee of Xinzhou Normal University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.To ensure the tasks were appropriate for their technical level, students were asked to play excerpts from basic pedagogical works such as Czerny Op. 599 or simple Beyer exercises. These pieces were selected because they feature clear, repetitive pedaling marks, allowing the study to focus on the accuracy of basic pedal timing and force control rather than the technical difficulties of advanced repertoire. The length of each of the excerpts was 3 minutes, and 216 performance data were gathered. Prior to the test, the markings of the standard pedal operation positions depending on the score were made by two teachers of piano and it was used as the ground truth label dataset. The results of automatic recognition of the system were compared frame-by-frame with the manually labeled results. The sample size of the four groups of true positives, false positives, true negatives and false negatives were counted, precision, recall and F1 score were computed to determine the recognition performance. Table 1 shows the measurement accuracy data under different pressure ranges.

TABLE 1. Statistics on Pressure Measurement Accuracy

Pressure range (g)	Test points	Mean relative error (%)	Maximum absolute error (g)	Linearity
50–500	15	1.8	8.5	0.996
500–2000	20	1.6	28.3	0.998
2000–5000	10	2.1	89.7	0.997
Full range	45	1.9	89.7	0.998

The average relative error is 1.8% in the light pressure range of 50g to 500g, 1.6% in the medium pressure range of 500g to 2000g, and 2.1% in the heavy pressure range of 2000g to 5000g, with a full-range linearity coefficient of 0.998. Temperature drift testing shows that the output value changes by less than 0.5% within the range of 15 to 35 degrees Celsius. In long-term stability testing, after 8 hours of continuous operation, the zero-point drift does not exceed 3 grams of force, and the repeatability error is controlled within ±1.2%.

B. ACCURACY ANALYSIS OF THREE TYPES OF PEDAL RECOGNITION

The pedal recognition test invited 12 piano students to participate. Each student played a Chopin etude excerpt containing three different pedal operations. Each excerpt was 3 minutes long, and a total of 216 performance data were collected. Before the test, two piano teachers marked the standard pedal operation positions according to the score, which served as the ground truth label dataset. The system's automatic recognition results were compared frame by frame with the manually labeled results. The number of samples in the four categories of true positives, false positives, true negatives, and false negatives was counted, and the precision, recall, and F1 score were calculated to evaluate the recognition performance. Table 2 shows the recognition accuracy data for the three pedals :

TABLE 2. Statistics on the recognition performance of three types of pedals

Pedal type	Number of tests	Correct identification	Number of misjudgments	Number of missed detections	Accuracy (%)	Recall rate (%)	F1 score
Sustain pedal	1847	1816	23	8	98.3	99.6	0.989
Soft pedal	982	958	15	9	97.6	99.1	0.983
Hold pedal	563	545	12	6	96.8	98.9	0.978

The sustain pedal was detected 1847 times, with 1816 correct identifications, 23 false positives, and 8 missed detections, achieving an accuracy rate of 98.3% and a recall rate of 99.6%. The soft pedal was detected 982 times, with 958 correct identifications, 15 false positives, and 9 missed detections, achieving an accuracy rate of 97.6% and a recall rate of 99.1%. The hold pedal had the lowest usage frequency, with only 563 operations, resulting in 545 correct identifications, 12 false positives, and 6 missed detections, achieving an accuracy rate of 96.8% and a recall rate of 98.9%. Analysis of false identification cases showed that initial errors were primarily due to the lack of lateral spatial constraints. The system was subsequently optimized to incorporate a dual-foot coordinate mapping: the right-foot sensor array is dedicated to the sustain pedal, while the left-foot array monitors the soft and sostenuto pedals. This spatial separation ensures that the 62% of errors caused by similar pressure patterns between the left and right sides are eliminated, providing clear differentiation between the pedals based on their physical installation positions.

C. COMPARATIVE EXPERIMENT ON LEARNER TRAINING EFFECTS

The experiment was training effect, where 24 piano beginners were recruited and randomly assigned an experimental group and a control group of 12 people each. The respondents had the age range of 18-25 years, and their learning period on piano was short-term (less than 6 months). The experimental group had a textile pressure pad system to train pedal where they were instructed to practice 3 times a week of 40 minutes each session. A graphic interface was used to show operational deviations in real-time and offer correction recommendations. In the control group, conventional teaching techniques were used where teachers verbally taught the students and the practice frequency and duration were the same. The training repertoire included the elementary piano pieces by Bach and the etudes of Czerny, and simple operating techniques with the sustain and soft pedal. Three assessment parameters were put into place pedal timing accuracy and dynamic control stability and operational fluency. Three teachers of piano gave the scores on their own and the average score was computed. Table 3 shows no significant difference in skill level between the two groups before training.

TABLE 3. Comparison of training effects over 8 weeks

Evaluation indicators	Experimental group	Control group	Difference
Pre-training Standardization (score)	52.3	51.8	0.5
Post-training standardization (score)	74.6	63.5	11.1
Increase (%)	42.7	22.6	20.1
Timing accuracy (%)	89.7	76.3	13.4
Strength standard deviation (g)	156	243	87
Smoothness (score)	78	61	17

The initial standardization score for the experimental group was 52.3, while that for the control group was 51.8. After 8 weeks of training, the standardization score for the experimental group improved to 74.6, and that for the control group to 63.5. Specific analysis revealed that the experimental group's timing accuracy improved to 89.7%, the standard deviation of force control decreased to 156 grams, and the fluency score rose to 78. In the control group, these three indicators improved to 76.3%, 243 grams, and 61 points, respectively. Statistical tests showed a significant difference between the experimental and control groups after training. Learners in the experimental group demonstrated enhanced perception of pedal depth and were able to accurately reproduce subtle force variations in the standard template.

V. CONCLUSION

Textile pressure sensing technology offers a quantitative evaluation process of teaching piano pedals and eliminates the issue of inaccurate feedback of force and timing in conventional teaching. A flexible sensor array in combination with an adaptive recognition algorithm provides high-precision distinction of three kinds of pedals. The learning cycle is greatly reduced through the use of the visual interface and correction mechanism to master pedal technique. The reliability of the system to detect pressure, timing and pedal recognition was also tested in experiments. So experiments in control groups showed that there are great benefits of using such a method compared to the traditional teaching methods. The current system is programmed to operate in single-pedal mode; the resulting complexity of pattern distribution of pressure distribution when multiple pedals are operated together can impact the accuracy of recognition. The nature of fatigue of the sensors during prolonged usage and the mechanical variations of the piano pedals of other brands should be studied further. The further work will involve the deep learning approaches to enhance the ability to recognize the complex patterns in the pedaling, create the individual training programs, which are adjusted to the playing style, and extend the system with pedal-finger coordination analysis.

AUTHOR CONTRIBUTIONS

Yufei Dai designed, collected and analyzed the data, and drafted the manuscript. Yufei Dai conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Yufei Dai participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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