Construction of a System for Recognizing Touch of Strings for Guitar

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ABSTRACT

In guitar performance, fingering is an important factor. In particular, the fingering of the left hand comprises various relationships between the finger and the string, such as the finger touching/pressing/releasing the strings. The recognition of the precise fingering is applied to a self-learning support system, which is able to detect strings being muted by a finger, and which transcribes music automatically, including the details of fingering techniques. Therefore, the goal of our study is to construct a system for recognizing the touch of strings for the guitar. We propose a method for recognizing the touch of strings based on the conductive characteristics of strings and frets. We develop a prototype system, and evaluate its effectiveness. Furthermore, we propose an application that utilizes our system.

Keywords

Guitar, Touched strings, Fingering recognition

1. INTRODUCTION

Fingering is an important aspect of guitar performances. In guitar performances, fingering affects the ease of playing a phrase as well as musical expression such as timbre. Guitarists explore the best fingerings to best convey their expressions, so there are many styles of fingering, which are different for each guitarist. The real-time recognition and distinction of the fingering of the left hand is applied to a self-learning support system, which is able to detect incorrect fingering. Our research group has developed the real-time fingering detection system for contrabass by integrating simple camera-based image processing and musical rules [1]. However, the system only recognizes the position of the guitarist's left fingers, when he/she plucks the strings of the contrabass.

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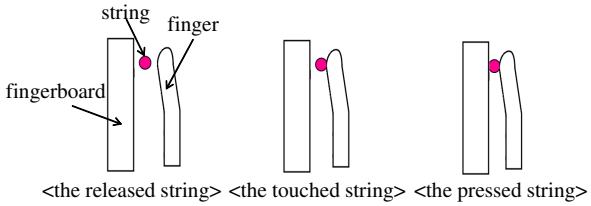

Figure 1: Relationships between finger and string

In guitar performances, the fingering of the left hand comprises various relationships between the finger and the string, such as a finger touching/pressing/releasing the strings, as shown in Figure 1. The recognition of precise fingering of the left hand contributes to a self-learning support system, which detects strings being muted by a finger and touched by a finger before being pressed, and which transcribes music automatically with the details of fingering techniques.

The goal of our study is to construct a system for recognizing the touch of strings for the guitar. The proposed system has a mechanism for recognizing the touch of strings based on the conductive characteristics of the guitar's strings and frets. This method does not require any modification on the guitar itself, simply by attaching the proposed device, which does not interfere with guitar performances. We define the three relationships between the fingers and the strings, and we implement an application utilizing our method.

The remainder of this paper is organized as follows: Section 2 describes the design of the recognition system, Section 3 explains our evaluation and discusses the results, Section 4 describes the implementation of applications, Section 5 explains related work, and finally Section 6 describes our conclusions and future work.

2. DESIGN

There are two requirements for constructing our fingering detection system:
(1) No interference with guitar performances
(2) Accurate and high-speed recognition
(1) means that it is supposed to be used in situations where a player has to concentrate, such as in a concert, a lesson, or self-teaching. Therefore, the performer should not

attach any obstructive device to his/her fingers or hands. Although extra devices such as switches attached to the ends of the fingers enable a system to detect fingering easily, these devices restrict the motion of fingers. (2) means that false recognition leads to a decrease in the usability and the reliability of the system. Additionally, high-speed fingering recognition is important to be used in interactive applications.

2.1 Recognition methods

We show two methods to detect fingering that fulfill the requirements: a method using image processing with the data of output sounds and a method using electric circuits.

2.1.1 *Method using image processing*

This method is used in the system that our research group has developed to recognize fingering of the left hand, when the bassist has plucked (plucks) the strings of the contrabass [1]. In this method, the system recognizes fingers' position on the fingerboard by camera-based image processing using color markers attached to the end of the finger nails. Additionally, the system recognizes the timing of plucking strings by audio signal processing. This method recognizes the position of each finger above/on the fingerboard. However, it cannot distinguish between touched strings, pressed strings, and released strings, since these positions are same.

2.1.2 *Method using electric circuit*

This method, which is newly proposed in this paper, utilizes the conductive characteristics of the strings and the frets. This method is mainly composed of two electric circuits: a circuit to detect the pressed strings, and a circuit to detect a string that is touched by a finger. The circuit to recognize the pressed strings applies a voltage to the strings, and the circuit to recognize the touched strings treats each strings as an antenna of a capacitance sensor. Each string is connected to an I/O port of each circuit as shown in Figure 2, and resistance tape is attached to the side of the fingerboard. This tape is connected to the input port of the circuit to recognize the pressed strings. Since the cables between each circuit and the strings are connected to the head of the guitar, it does not affect the sound of the guitar, and does not interfere with the performance. Additionally, the resistance tape is narrow, and is simply stuck onto one side of the fingerboard. The player does not have to attach any obstructive device to his/her fingers or hands. The data generated from each circuit is sent to a PC via serial communication. The system detects the statuses of the strings, which are pressed, released, or touched.

Circuit to recognize touched strings

The circuit for touched strings recognizes whether a finger is touching the strings by detecting a change in capacitance of each string. Note that this circuit cannot distinguish between a finger touching the strings and a finger pressing the strings. It has a RC Low-pass filter that utilizes human capacitance, and calculates the value of capacitance based on reply of an input pulse. A rectangular wave shown in Figure 3 (1) changes to a rectangular wave that has a time delay of Δt. Δt becomes longer when a user touches the strings. To calculate Δt, the wave (2) is reformed by passing a Schmidt trigger circuit, and the pulse with width of Δt is made through an exclusive OR gate between wave (1) and wave (2).

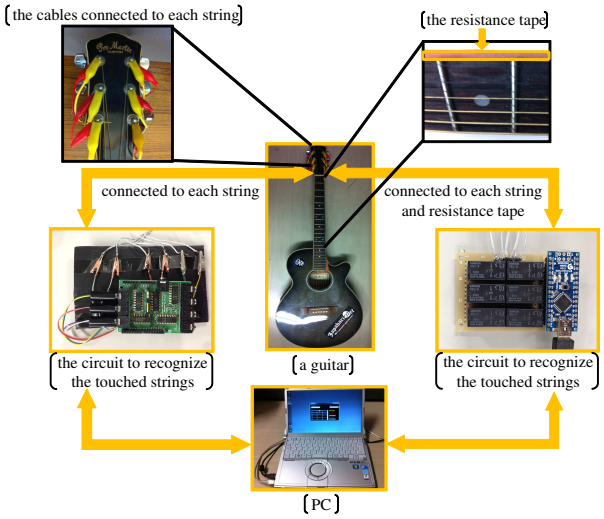

Figure 2: System structure

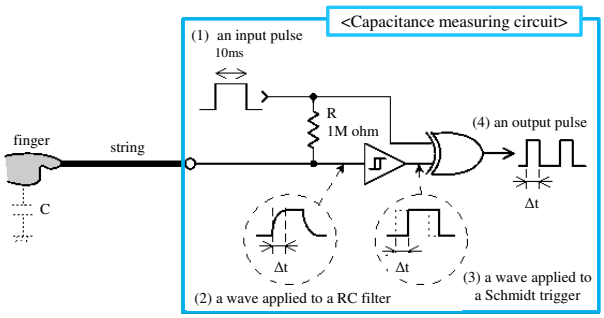

Figure 3: Circuit to recognize touched strings

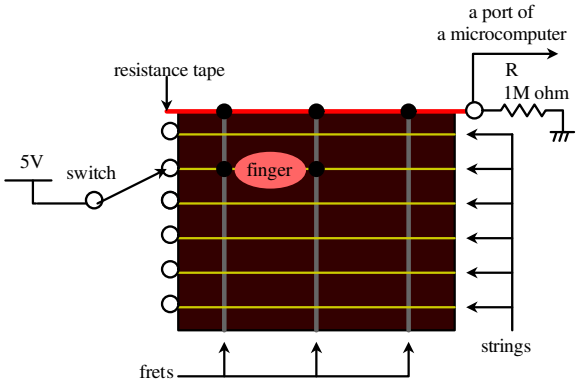

Figure 4: Circuit to recognize pressed strings

Circuit to recognize pressed strings

The circuit to recognize the pressed strings applies voltage to each string of the guitar in time-sharing. An input port of the circuit is connected to resistance tape which is applied to over the frets. The output ports of the circuit are connected to each string at the guitar head as shown in Figure 4. When a string is pressed, an electric current is passed through the string, the fret, and the resistance tape, and the input port detects high voltage.

The system recognizes touched strings, released strings, and pressed strings with these two electronic circuits. However, it cannot recognize the position of fingers on the fin-

Table 1: Definition of technical terms

Technical term			Definition
Recognition target	Strings pressed/Strings touched/Strings Released		Recognizing whether strings are pressed, touched or released
	Pressed Strings		Recognizing whether strings are pressed
	Released strings		Recognizing whether strings are released
	Touched strings		Recognizing whether strings are touched
	Position of each finger		Recognizing the position of each finger
	Timing when the guitar sounds		Recognizing the timing when the guitar sounds
	Pitch		Recognizing the pitch of the sound
	Recognition timing		Timing when the system recognizes fingering
	Number of strings		Number of strings to be recognized at the same time
	Number of fingers	One	Recognizing one finger against a single string(Note 1)
		Two or more	Recognizing all fingers against a single string
	Specific finger		Recognizing which finger is being used
	Restriction of strings		Recognizes only strings plucked
	Restriction of the finger position		Multiple fingers are not placed on the same string
Relationships between fingers and sounds	Fingers related to sound		Fingers that used when the guitar sounds
	Fingers not related to sound	Preliminary operation	Fingers that are prepared to press strings next
		Mute	Fingers to mute each string on strings
Symbols and characters in the table	CN (can)		An item that can be recognized by the method
	LW (low)		An item that can be recognized only with low accuracy
	CNN (cannot)		An item that cannot be recognized by the method
	-		An item that does not affect the result
	ND (Need)		An item needed for recognition
	ND*1 (Need*1)		A item needed when recognizing multiple fingers against a single string
	ND*2 (Need*2)		Needed when considering sound harmonics
	ND*3 (Need*3)		Needed when considering the position of each finger

Note 1: When multiple fingers touch one string, recognizing the finger closest to the body of the guitar

gerboard and the timing when a user plucks the strings.

2.2 Selection of recognition methods

The fingering of the left hand comprises various relationships between the fingers and the strings. Furthermore, as described in 2.1, there are advantages/disadvantages for each method. Therefore, we define the relationships between the fingers and the strings, and consider which relationships correspond to the various possible applications. Table 1 describes the terms used in Tables 2 and 3. Moreover, to clarify our explanation, we summarize the common points of the assumed applications, as shown in Table 3.

2.2.1 Items recognized by each recognition method

Table 2 shows the items that are recognized using camera, pickup, circuits, and their combinations, respectively. The position of each finger is recognized with a camera, and the timing and the pitch in the case where a user plucks the strings are recognized through the sound signal of the pickup. When strings are plucked, it produces a sound that consists of the followings: the pitch of the sound of the strings played without touching the frets, the brushing tone produced by strings being touched, and the pitch of the sound produced by the strings with a finger touching the frets. Accordingly, after plucking strings, it can distinguish among touched strings, pressed strings, and released strings, using the signal of the pickup. Also, it can identify the position of the fingers on the strings with a combination of a camera and a pickup. However, it cannot recognize the position of the fingers on strings that are not plucked. Therefore, these methods cannot recognize the position of fingers that are preparing to press the strings, and the fingers that are muting the strings (touching the strings to silence them). When considering the construction of application that checks whether strings are correctly muted, it cannot provide any information before the guitar sounds. Additionally, concerning the recognition of touched strings, the recognition accuracy is low because of the need to recognize the brushing tone.

The electric circuit can recognize touched strings, pressed strings, released strings, and fingering position, before the guitar sounds. However, it cannot recognize the fingering of multiple fingers. It can recognize the fingering before the output of the guitar sounds, and the position of the fingers on strings that are not plucked because this method can distinguish among touched strings, pressed strings, and released strings without using a pickup. Consequently, the recognition of muting is possible only by this method. Moreover, the system can recognize a finger that is preparing to press the string, using the combination of the electric circuit, camera, and pickup.

2.2.2 Recognition items to satisfy application requirements

Table 3 shows the assumed applications with our proposed recognition methods. Fingering information related to sound is applied to an application that transcribes music automatically including the fingering number with which a user plucks the strings. Therefore, it is constructed using the conventional method involving a camera and a pickup. The application that checks the allocations of fingers to press strings next in a piece of music requires the recognition of preliminary operations. This application is constructed by combining the conventional method and the proposed electrical circuit method when the recognized finger is the one closest to the body of the guitar. The application that checks whether the strings are appropriately muted only requires the recognition of whether each string is muted, and this application is constructed using only the electrical circuit method. The application that transcribes music automatically including fingering information not related to sound requires the distinction among touched strings, pressed strings, and released strings when multiple fingers relate to each string.

Thus, by using the electrical circuit method, it is possible to construct an application that checks whether the strings are appropriately muted, and that checks the fingering of fingers prepared before pressing the strings.

Table 2: Items recognized by our method

Recognition item							Recognition method							Relationships between fingers and sounds		
							Only the conventional method			Including proposed method						
							Camera	Pickup	Camera Pickup	Circuit	Camera Circuit	Pickup Circuit	Camera Pickup Circuit	Fingers related to sound	Fingers not related to sound	
	Recognition timing	Number of strings	Number of fingers	Specific finger	Restriction of strings	Restriction of finger position									Preliminary operation	Mute
Pressed strings/ Touched strings/ Released strings	Before	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
	After	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN			ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN			ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN			ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN			ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
	Before	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN		ND*1	ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN		ND	ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN		ND	ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN		ND	ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN		ND*1	ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN		ND	ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN		ND	ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN		ND	ND
Pressed strings	After	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN		ND*1	ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN	ND	ND	ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN	ND	ND	ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN	ND	ND	ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN	ND	ND	ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN	ND	ND	ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN	ND	ND	ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN		ND*1	ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN	ND	ND	ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN	ND	ND	ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN	ND	ND	ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN	ND	ND	ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN	ND	ND	ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN	ND	ND	ND
	Before	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
Touched strings	After	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN			ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN			ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN			ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN			ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
	Before	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	-	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	-	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
Released strings	After	Two or more	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN			ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN			ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
		One	Two or more	-	-	-	CNN	CNN	CNN	CNN	CNN	CNN	CNN			ND*3
			One	apply	apply	apply	CNN	CNN	LW	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	LW	CNN	CNN	CNN	CN			ND*2,3
					not apply	apply	CNN	CNN	CNN	CNN	CN	CNN	CN			ND*2,3
						not apply	CNN	CNN	CNN	CNN	CNN	CNN	CN			ND*2,3
				not apply	apply	-	CNN	LW	LW	CN	CN	CN	CN			ND
					not apply	-	CNN	CNN	CNN	CN	CN	CN	CN			ND
Position of finger	-	-	-	-	-	-	CNN	CN	CN	CNN	CNN	CN	CN	ND	ND	ND*2,3
Timing when guitar sounds	-	-	-	-	-	-	CNN	CN	CN	CNN	CNN	CN	CN	ND	ND	ND
Pitch	-	-	-	-	-	-	CNN	CN	CN	CNN	CNN	CN	CN	ND	ND	

3. EVALUATION

We develop a prototype system for recognizing touch/press of strings for guitar, as mentioned in Section 2. We conducted an evaluative experiment to investigate if the system can distinguish among touched strings, pressed strings, and released strings, in order to confirm the effectiveness of the prototype system. In this evaluation, we used two basic phrases as trial phrases. Three test subjects took part in this evaluation.

3.1 Experimental procedure

Trial phrase

There are two trial phrases: **Music A** that consists of chords and **Music B** that consists of single notes. Music A is composed of a phrase, which has four passages and different chords for each passage. The subjects repeat the phrase four times. The number of passages in Music A is 16. Subjects play Music A while touching/pressing/releasing the strings. Figure 5 shows the chord progression on fingerboard for Music A. In the figure, each black circle shows the point to be pressed by a finger, each white circle shows a string being plucked without it being held down on the fret, and each cross mark shows a strings to be muted by being touched. Music B consists of a phrase that has 6

Table 3: Relationships among applications, fingers, and sounds

Applications	Required recognition		
	Fingers related to sound	Fingers not related to sound	
		Preliminary operation	Mute
Transcription of music (using information of plucking)	ND		
Check of fingers prepared before pressing strings		ND (Recognition of multiple fingers on the same string is possible by ND*1)	
Check of mute			ND (Recognition of harmonics is possible by ND*2)
Transcription of music (Contains information that does not relate to sound)	ND	ND (ND*1 is required)	ND (ND*3 is required)

Table 4: Recognition ratio of the system

Tempo	Subject A	Subject B	Subject C
	Music A (chord)		
100	99.4% *(1987/2001)	98.5% (1866/1894)	99.3% (1925/1938)
120	98.6% (1616/1639)	99.2% (1367/1379)	99.6% (1522/1528)
140	97.3% (1367/1405)	94.1% (1064/1131)	98.5% (1237/1256)
160	97.2% (1428/1469)	98.9% (1125/1137)	98.9% (991/1002)
180	96.3% (1071/1113)	98.3% (923/939)	99.2% (1212/1221)
200	97.2% (1151/1184)	99.6% (678/681)	99.6% (837/841)
	Music B (single note)		
100	99.1% (820/827)	99.9% (1966/1986)	98.0% (1715/1749)
120	99.6% (1545/1550)	99.9% (1684/1701)	98.4% (1722/1749)
140	99.9% (1286/1287)	99.9% (1493/1508)	99.5% (1312/1318)
160	99.3% (1215/1224)	99.3% (1327/1333)	99.6% (1229/1233)
180	98.7% (900/912)	99.9% (1259/1260)	99.9% (1257/1258)
200	99.1% (921/929)	99.8% (961/963)	99.4% (923/928)

*(Number of correct data/Number of all data)

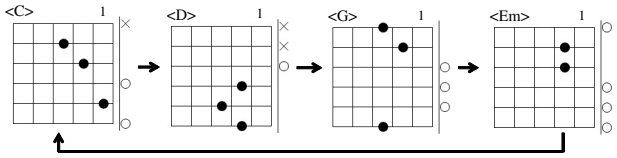

Figure 5: Chord progression of Music A

passages and the subjects pluck a single string throughout each passage. They play from 1st string to 6th string, then repeat twice. The number of passages in Music B is 12. In Music A, all strings are plucked at a time. In Music B, only one string is plucked at the same time. Experiments were performed in different tempos: 100, 120, 140 , 160, 180, 200 bpm (beats per minute).

Flow

Three subjects took part in this evaluation. Each subject was experienced guitarist, and was an able to play the trial phrases fully at a specified tempo. The subjects played Music A and then Music B, at all the different tempos while listening to sound of a metronome. The prototype system recognized the fingering contexts and recorded them. The correct data was obtained from the video that recorded the left hand of subjects using a digital video camera. When it was difficult to determine the correct data visually from the video, we got the correct data by interviewing the subjects.

3.2 Result and Consideration

Table 4 shows the recognition rates. The average recognition rate is approximately 98%, which means that the prototype has high accuracy regardless of the tempo and phrase. As for the false recognition, there were many cases of errors in 3rd and 4th strings. This is because the setting of the threshold capacitance for recognition of touching for 3rd and 4th strings were not appropriate. In future, it will be necessary to investigate the optimal thresholds.

4. APPLICATION

We implemented an application that checks whether the strings are appropriately muted by our electrical circuit. It recognizes the timing of the guitar sounding by using a microphone. Figure 6 shows a screenshot of the application. It shows a score, a current position in a piece of music, correct relationships between the fingers and the strings matched to the current point of performance (the lower left of figure) and current relationships between the fingers and the strings (the lower right of figure). When a player performs with the correct relationships between each finger and string, the current position of performance in a score progresses to the next point. Especially for beginners, it is difficult, from only the sound of the guitar, to determine whether the strings are appropriately muted. Since this application prevents a player from forgetting to mute or muting too much, he/she can learn to play the guitar effectively.

In addition to the above implemented application, we can construct a variety of applications that take advantage of the framework of the proposed system, which passes a current through the conductive part of an instrument.

Analysis of performance: By analyzing acquired fingering information that does not relate to sound, we can compare the performance with those in different skill levels and body characteristics, such as the size of the hand, and those in different mental states such as during practicing and when the player feels stress or excitement. Feature

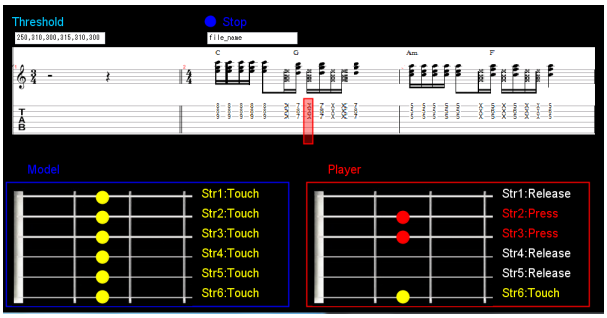

Figure 6: A screenshot of the mute check application

values that can be detected our mechanism enhance the capability of performance analysis.

Providing fingering information in remote lesson: Even in remote lessons in which teachers and students are geographically separated, a teacher can obtain the detailed fingering information that cannot be grasped from video. Therefore, a teacher can check the playing of students in detail, and give better guidance.

Application for other instruments: The contrabass is a stringed instrument that does not have a fret, however, the proposed system can be applied to it by creating frets using conductive tape. Also, in brass instruments like clarinet or the trumpet, recognition of detailed behaviors like *Whether the mouth and the mouthpiece touch* and *Whether the finger and the piston touch.*

Teaching by electric shock: For example, by giving a learner a small electric shock by passing a large current through the string momentarily when a learner plays incorrectly, the application can indicate that the performance is wrong.

Command input by touching strings: Touching the strings in specific patterns can be used to perform commands such as applying effects and turning the pages of musical score. Touching does not output any sound, then it is appropriate to use for inputting commands.

5. RELATED WORK

As examples of devices for measuring the position of fingers, Lightglove [2] and Dataglove [3] are mentioned. For recognition of the position of fingers, Lightglove uses LED and photosensors, Dataglove uses magnetic sensors and optical fibers embedded in the glove. It is possible to obtain fingering information by using the data of the position of the fingertip which is output from these devices. Dataglove, in particular, can be applied to the recognition of touching strings, owing to the fact that it is touch sensitive. However, these devices are not designed for use in playing stringed instruments. Therefore, the circuit fixed to the wrist and the sensor that covers the finger interfere with performance.

In the case of Motion Capturing of Guitar Fingering [4], the guitar body has a built-in imaging system with a photo-reflector method. Therefore the instrument itself recognizes fingering. However, this system can only be used with specially adapted instruments. Moreover it cannot recognize touching strings.

In the case of the system that can alter linear conductive material to touch a sensor by using TDR (Time Domain Reflectometry) [5], the system alters the strings of a stringed instrument to touch the sensor. Moreover, the system recognizes the points touched by two fingers against each string. However, TDR sensing is susceptible to radio interference. Therefore, noise affects the accuracy of recognition. In addition, a time domain reflectometer is bulky and expensive, and therefore it is not suitable for general use.

As examples of a system with capacitive sensors, SmartSkin [6] and theremin are given. In addition, the system with capacitive sensors for detecting movements of the left hand in guitar performance is also given [7]. These systems utilize the capacitance of the human body. They use a method similar to the one used in our study for contact recognition. However, they do not have a mechanism to distinguish between the string being touched and the string being pressed. Therefore, we cannot use these systems for recognition of touching strings.

6. CONCLUSIONS

In this study, we constructed a system for recognizing the touch of strings for guitar performances. The proposed mechanism recognizes the touch of strings based on the conductive characteristics of strings and frets and a change in capacitance of each string when the finger touches each string. We investigated the possible applications that use our method in detail, and relationship between requirements and techniques including our method and conventional methods using a camera and a pickup. In addition, our evaluative experiment confirmed that the prototype system has a high degree of accuracy.

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