Hand Motion Capture System in Piano Playing

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Abstract—**It is important to measure the dexterous finger movements for piano education. But there are some problems to measure accurately of finger movements with angular position due to the complex finger bones construction. In this research, the complex and soft hand movements of a professional pianist were observed using different melodious music as an example, though it can measure any types of finger movements using magnetic motion capture (MoCap) system. The system can measure the complex finger movements with six degrees of freedom (6DOF). From the measured data, we calculated the finger height in space while playing the piano. We have investigated the hand/fingers status during playing the piano. The knowledge of finger movements of an expert pianist is useful for the skill learning. The data and knowledge of finger movements can be applicable in various fields where dexterous movements are essentials such as piano, computer typing, writing, different games etc.**

***Keywords -Finger movement, Motion capture, Six degrees of freedom*.**

I. INTRODUCTION

Motion capture (MoCap) is the process of sampling the posture and location information of a subject over time. It is widely used for medical researches, biomechanics, ergonomics, humanoid robots, entertainment etc [1]. There are several kinds of MoCap though the most common technologies for MoCap are optical systems and electro magnetic systems. In this research we used magnetic MoCap system instead of optical MoCap system. Magnetic MoCap have some advantages; the resulting data stream consists of positions and orientations six degrees of freedom (6DOF) for each receiver whereas optical MoCap system can measure only position not orientation data from a marker [2]. Optical MoCap system requires obtrusive retro-reflective markers or LEDs and many camera setups. It is prone to light interference, so reflective dots can be blocked by performers or other structures [3]-[6] causing loss of data sometimes. But some other purposes optical MoCap system performs better than magnetic MoCap system.

To acquire the total information for hand/finger movements is a great need in piano education. However, a system is required to capture the dexterous hand movements for educational purposes. But the human hand movements are very complex due to twenty seven bones and nineteen joints in each hand, with which various professionals do their skillful jobs. Pianists' are used to play with their fingers in various positions and it is very difficult to measure the finger movements position during playing the piano.

There are some related research works in the world for finger movements. A pianist can use different combinations of movements in different joints to perform a touch [7]. Biomechanical factors differentially influenced pianists' production of tapping sequences [8]. Timing accuracy is affected by biomechanical and sequential constraints on finger motion in trained pianists' tapping [9]. Finger movements in action sequences may also be constrained by biomechanical and neural factors that can contribute to lack of independence among neighbouring fingers [10]. Biomechanical constraints that influence interactions among finger movements include factors such as the soft tissues in the webs between fingers and connections between the tendons of the finger muscles [11]. They have great limitations that they can measure only position of X, Y and Z but not both position and angle together from the subject. Finger joint movements recorded during ball throwing using pressure detector [12]. During the experiment they setup the sensors on the front side of the fingers so it may affect the experimental subject where as our sensor setup backside of the finger so it can not affect on the experimental subject. Organization of the upper limb movement for piano key-depression shows [13] using electromyography (EMG) and 2-D position sensor. There are more some works on finger joint coordination are found but they used different system. Those works were measured using the electromyography (EMG) and finger joint angles during typing of computer keyboard they used individual miniature goniometers [14]-[17]. They have some limitations that they can not find the phalanx position where our system is suitable to find the receiver's position and posture together.

A magnetic MoCap system was developed for hands with an auto calibration system [2], [18]-[21]. The hands of the pianist were installed with our magnetic MoCap system. From this research our aim is to investigate the pianist's finger movements and from this result to get the way to improve the performance or to improve the skill for the midlevel or beginners/novice player during playing the piano. Midlevel pianist or beginners can get the information that how an expert pianist maintains the timing sequence, tapping rate of particular finger with the score of the music which is evaluated in this research. There were some incomplete works in our previous research [2] for the beginners, about the finger status, musical notes, finger tapping rate, finger height from the keyboard, during piano playing. So we have examined complex finger movements with a professional pianist using different melodious music as an example, for further measurement of more expert pianist and beginners/novice player.

II. EXPERIMENTAL SETUP

Figure 1(a) shows a photograph with systematic arrangement of hand MoCap system. In the figure only right hand connection is shown for 16 receivers, left hand is also same configuration. The original cables are replaced with special thin cables by the company for our necessity of 2 mm diameter for not to block the movements of the pianist's finger. It is also shown in the Fig. 1(a). The magnetic tracker that is composed of a transmitter (TX4, 10.34x10.34x10.26

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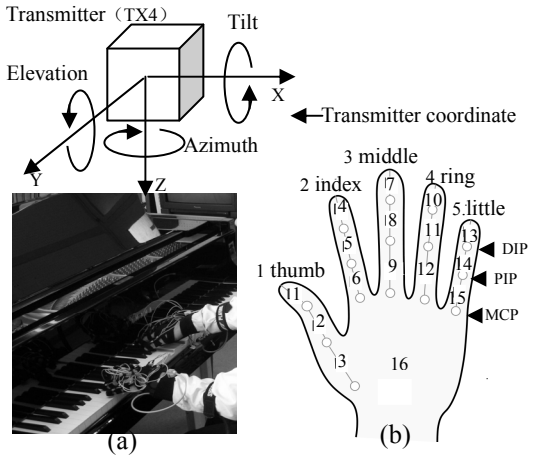

Fig. 1 Experimental arrangement during playing piano

cm) and 16 receivers can digitize the distance (X, Y and Z) from the transmitter to receiver. The magnetic tracker can also track the position and relative angles (Azimuth, Elevation, and Tilt) of a receiver against a transmitter. During the operation of a pianist, his finger moves, as well as each phalanx of fingers also moves to the direction X, Y, Z, azimuth, elevation and tilt. Transmitter coordinates are shown all the directions in Fig. 1(a). LIBERTY^{TM} 240/16 systems which have 16 inputs (Polhemus) connected to a transmitter (TX4) and a computer through a USB interfacing. It can measure the data from the experimental setup of Hand MoCap system of 6DOF by 32 receivers at the rate of 240 Hz simultaneously. The spatial resolution of our MoCap system is 0.0038 mm, 0.0012 deg. and accuracy is 0.76 mm, 0.15 deg. which were supplied by Polhemus. Figure 1(b) shows the actual position of the receivers on finger bone. Each receiver is installed on each bone of fingers in a way so that it fit with the finger. 3 receivers are used to measure each finger. So finally 16 receivers in one hand and totally 32 receivers are used for both hands. The weight of each receiver (RX1-D) is 2 g and the size is 9.6×9.6×9.6 mm, which was modified for us and not available in the market. In the figure the positions of 16 receivers are shown by the number 1, 2, 3 - - to 16. Each receiver is called a channel and attached tightly just on the finger bone using Kinesiotex tape and liquid type plastic in order to prevent the receiver slippage and it had not any affect on pianist performance. The cables with the receivers looked complex but after setup the total system including all light receivers on the pianist's hand, he didn't feel uncomfortable and operated normally.

III. METHODOLOGY

A. Musical Information

Three music of different frequency were selected for this research. During playing the piano, the pianist moves his finger fast, medium and slow as per the characteristics of music. The music for our experiment was complex, different melodies and an expert pianist was selected for playing the piano. Because expert pianists are skilled at accurately timing long sequences of finger movements [9],[22]. The speed of first music was fast. The second music was medium and the third music was slower speed.

B. Intertap Interval Time

Intertap intervals (ITI) are defined as the time interval from one finger tap to the next. For calculating intertap intervals for all music, total taps are calculated of individual music for 40s, from 10s to 50s and then intertap intervals are calculated by dividing the total taps for individual receiver's on finger tip for both hands.

C. Finger Amplitude/Height From Keyboard

We choose 5 receivers (1, 4, 7, 10, and 13) at the end of 5 fingers. So it was receiver's position on finger tip, we called it finger tip though it was not finger tip. Thus when finger moves during playing piano we call it finger movement position instead of receiver movement position in this paper. We calculated finger height from the keyboard using finger tip position data. For calculating finger height, the total taps in 40 s individually were considered for all the music. Then we calculated mean height from the keyboard.

D. Velocity

In this research the velocity was calculated using finger tip position data for all music. We choose 5 receivers (1, 4, 7, 10, and 13) at the end of 5 fingers for calculating the velocity. Velocity was calculated for 40s for all music. To calculate the velocity, we first calculated finger movement trajectory. Finger movement trajectory was calculated using 3 dimensional distance formula among all positions (x_n ,y_n , z_n) of individual receiver data, where "n" indicates the number of data of an individual receiver. Velocity was calculated using the length divided by time. Time was recorded from the sampling rate 1/240 s. After that the average velocity was calculated.

IV. RESULTS AND DISCUSSION

Figure 2 shows a sample period of pianist's finger movements during playing the piano with a sample bar (score) of the music. In the sample period of the figure, only right hand operation is shown. Upper portion of the figure shows the graph of Z components of the pianist finger movements and lower portion shows the beginning part of the score of the music 3. Different types of notes (quarter, half, eighth) exist in this music but only quarter type note are seen in the sample bar. Note is the musical pitch with specific frequency. In the figure it is shown that pianist plays the piano with the musical notes of the score. Musical tone is mainly a property of a group of notes and depends on the musical sensitivity of the pianist. In this sample period it is shown 3 fingers thumb, index and ring are operating the keyboard out of 5 fingers. In

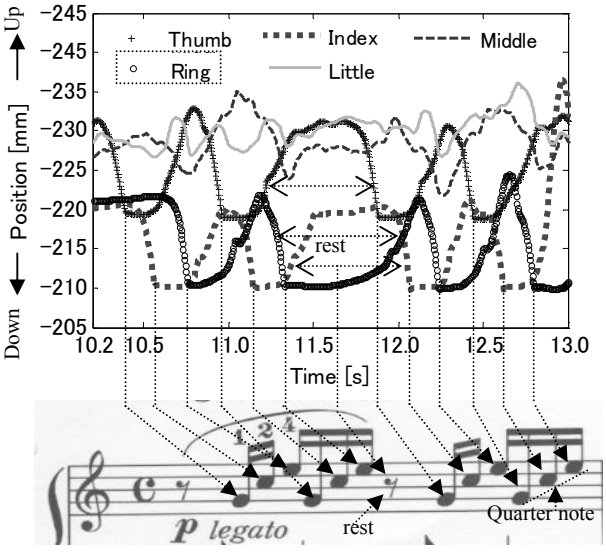

Fig. 2. Pianist's finger movements with musical notes (Right hand, Music 3)

the sample period it is observed in each cycle that pianist taps the keyboard one after another finger after each 200 ms. After completing 2 cycles he maintained the rest as per the score. So that each finger-tap takes about 600 ms and maintained rest after two consecutive taps. From Fig. 2 it is observed that pianist maintains the time sequence as per the score of the music. So using this data it is possible to calculate the tapping duration among all fingers and also the duration of individual finger tapping of the pianist during playing the piano which is important to calculate pianist's finger tapping rate. Larger duration of finger tapping shows the rest of the score. In the sample period we can observe the individual tapping amplitude so that using this data it is also possible to calculate the finger amplitude from the keyboard. Finger amplitude is the important factor to vary the finger tip velocity during piano playing. Velocity also can control by pianist wrist and hand movement in different status during piano playing. Pianists can control the tone by playing loudly or softly using his wrist and hand movement during playing the piano [23]. The ring finger is particularly problematic for most people. Part of this difficulty arises from the fact that it is the most awkward finger to lift, which makes it difficult to play fast and avoid hitting extraneous notes inadvertently. But the expert pianist can maintain the movement equally for all fingers including the ring finger. It is observed in the sample bar about the switching time, index finger to ring finger, ring finger to thumb finger and thumb finger to index finger during playing the piano. When ring finger pushes the key, index finger starts increasing upper height and at the same time thumb finger maintains upper height from the keyboard. When thumb finger pushes the key, ring finger starts increasing upper height and at the same time index finger maintains upper height from the keyboard. When index finger pushes the key, thumb finger starts increasing upper height and at the same time ring finger maintains upper height from keyboard. In the sample bar it is observed that pianist maintains the similar switching sequence during playing the piano which is useful information for the novice player.

Figure 3 shows the 3D trajectory of pianist finger tapping for 5 fingers' tip during playing the piano. A sample period is chosen (28.2 s to 28.5 s) from music 1 for observing the 3D view of pianist finger tapping during playing the piano. Figure 3 shows the actual finger tapping position of the pianist. It is observed in the Fig. 3 that 3 fingers thumb, index and little are touching the surface line of keyboard during this short period. Surface line is also shown in the figure. So using this data, novice player can observe their finger movements in 3D and tapping sequence in various ways by changing finger movement's direction and the axis of 3 components X, Y and Z.

Figure 4 shows the comparison of intertap interval time of different music. Fingers are numbered from 1 to 5 starting with thumb which is also shown in the Fig. 1(b). From these figures it can observe which music operates higher rate and which operates lower rate. That is during playing the piano, pianist moves his fingers at different tapping rate as per the musical characteristics of different frequencies for all music. Shorter ITI time indicates faster music; i.e pianist operates his fingers at higher frequency in the music and larger ITI time indicates slower music; i.e pianist operates his fingers at lower frequency in the music. So from these figures it is observed that pianist operates the first music as the highest

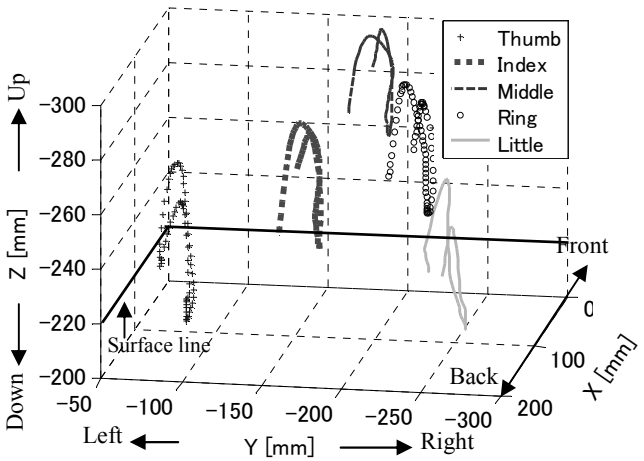

Fig. 3. A sample period of 3D trajectory of pianist finger tapping

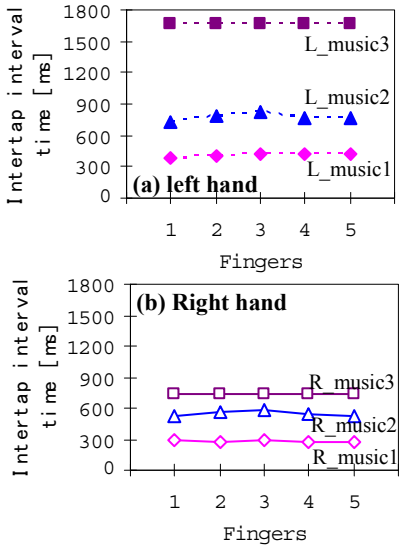

Fig.4 Mean intertap interval time of three music (10s to 50s)

frequency rate, second music is medium and third music is the lowest frequency rate among all the music. The variability of the intertap intervals of Figs. 4(a) and 4(b) indicated that pianist played faster with the right hand than his left hand as per the musical notes of different music. It is observed in Fig. 4 that ITI of each finger for individual music is almost similar timing rate. That is pianist can use his all fingers in equal rate during piano playing which is evaluated in our research using hand MoCap system. Tapping rate is important factor for musical tempo. Similarly using this MoCap system it is also possible to calculate the timing rate of any types of finger movements during their activities.

Figure 5 shows the finger height/amplitude from the keyboard for all music. It shows the average finger height from the keyboard for both hands. Standard error (SE) of finger amplitude is also shown in the figures. From the Figs. 5(a) and 5(b), it is shown that middle finger is the highest amplitude and thumb is the lowest amplitude than all other fingers for all music. So it is observed that pianist maintained his middle finger quite higher than other fingers during piano playing. Another observation from the musical notes and performed video that pianist maintains the similar sequence for music 1 and music 3 for both hands. So he has also maintained finger height at similar sequence for both hands as per the characteristics of music 1 and music 3 which is

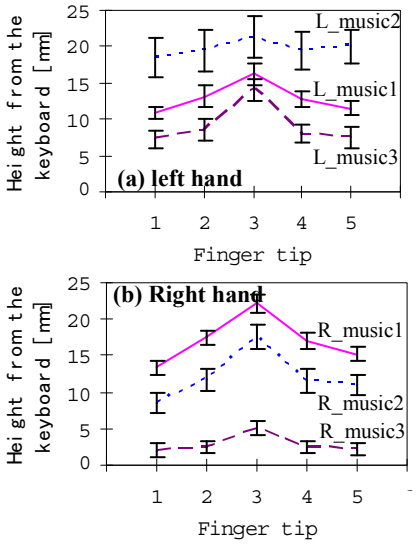

Fig.5 Mean finger height from the keyboard (10s to 50s)

shown in the Fig. 5. But the height of left hand for music 2 was quite different than others two music. Some of the bars of music 2 were completely 'rest' symbol for left hand so pianist did not operate his left hand at that time but at the same time he operated only his right hand at normal sequence as per the musical notes. That is pianist sometimes did not operate his left hand for the absence of musical notes but kept his hand quite high and then operated softly after some time. So it affected on average finger height during piano playing. Thus the mean finger height pattern of music 2 for left hand is quite difference than other two music. This result is similar to the result of Janeen D. Loehr and Caroline Palmer 2007 [8], but they showed only one hand of pianist. Their purpose was to analyze biomechanical influences in pianists' finger tapping, whereas we examined and described both hands for piano education.

Figure 6 shows the computer graphics of pianist finger movement using MoCap data. It is the sample period of 3 sequences during piano playing. In the sample period, it is shown the different attitude and different height of finger movements during playing the piano. Figure 6(a) shows the hands of pianist kept on the keyboard before playing the piano, Fig. 6(b) shows the movements during playing the piano and Fig. 6(c) shows the movement of interval during playing the piano. Thus our system can identify every sequence of finger movements during playing the piano. So from this research a novice player can observe every moment of finger movements, as well as every sequence of finger status which they can apply in piano lesson.

Figure 7 shows the average finger tip velocity for all music. Figure 7(a) shows mean velocity for left hand and Fig.7(b) shows mean velocity for right hand. Standard error (SE) of finger tip velocity is also shown in the figures. From the Figs. 7(a) and 7 (b), it is shown that velocity of middle finger is the highest among all others fingers for all music for both hands and velocity of thumb finger is the lowest among all other fingers for all music for both hands. It was observed in the Fig. 5 that middle finger was the highest peak height and thumb finger was the lowest peak height among all other fingers for all music. All other finger tip velocity also maintained the value with the corresponding finger height for individual music. The velocity curves of Fig. 7 and finger height curves of Fig. 5 show like pyramid shape which are similar to finger tip position of human hand.

Fig.6 Computer graphics of finger movement during playing the piano

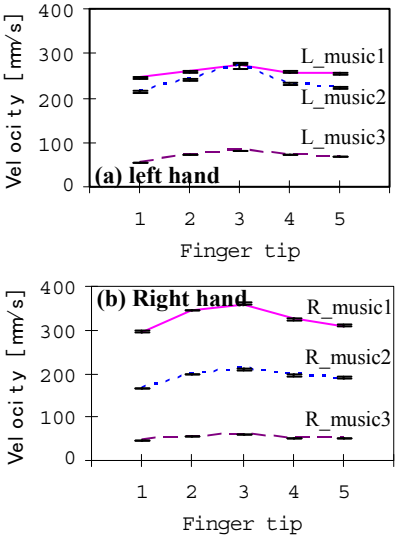

Fig.7 Mean velocity of both hands (10s to 50s)

Now it is observed in Fig. 4 that music 1 is the quickest, music 2 is medium and music 3 is the slowest of all music. From Fig. 7 it is observed that velocity of music 1 is the fastest; music 2 is faster and velocity of music 3 is the slowest of all music. This result shows that finger tip velocity was increasing when the tapping rate increased and finger tip velocity was decreasing when the tapping rate decreased. So it is possible to evaluate the all finger movements individually of the pianist using our hand MoCap system.

From the results of Figs. 4, 5, 6 and 7, it can be said that our system can evaluate the difference of individual music and the pianist performance with individual finger movements during piano playing. So a novice player can get the knowledge from these results about finger tapping rate, timing sequence, different finger height from the keyboard, finger position and its status and different finger tip velocity for different melodious music. Using these results they can apply the knowledge for varying the musical tone or musical tempo for increasing their performance for different music during piano playing. Moreover they can observe their performance directly, adding the augmented reality (AR) technique with our system which can be useful for increasing their performance during piano education. During piano playing if we place an additional sensor of AR technique on the piano keyboard then beginners can observe the computer graphics (CG) animation directly on the keyboard or on the table beside the piano. It is already working one of our groups

with AR technique so that we can make and provide an educational tool on piano playing for a novice player.

In our previous study we have calculated the finger joint angles distal interphalangeal (DIP), proximal interphalangeal (PIP) and metacarpophalangeal (MCP) of index finger [2]. This time we have compared the finger joint angles for different melodious music of index finger though we can calculate and compare for all fingers.

TABLE 1 VARIATION OF FINGER JOINT ANGLES OF THE PIANIST

	Music 1	Music 2	Music 3
	Range (deg)	Range (deg)	Range (deg)
MCP	5-43	9-44	9-33
PIP	26-49	26-43	27-39
DIP	1-38	2-31	7-32

Table 1 shows the finger joint angles of right hand index finger of the pianist for different music. The finger joint angles are important to know about the fingers status about 'curled position'. During piano playing when fingers are curl which form the joint angles (MCP, PIP and DIP) among the finger bones or normally curl the fingers, it is called 'curled position' in piano practice [23]. When the finger joint angles decrease gradually as fingers are straight to the hand during piano playing, it is called flat finger position. Experienced pianist can use both curled position and flat finger position. So using this data it is possible to know the finger movement status whether it is curled position or flat finger position during playing the piano.

From Table 1 it is observed the variation of joint angles of index finger of right hand; music 1 is the widest range of joint angles, music 2 is wider range and music 3 is the wide range among all the music. Now we can observe in the velocity curve in Fig. (7b) for right hand index finger that music 1 is the highest velocity, music 2 is higher and music 3 is the lowest velocity of all music. That is, when variations of finger joint angles increase then fingertip velocity also increases and when variations of finger joint angles decrease then fingertip velocity also decreases. So beginners can apply these phenomena for increase or decrease the finger tip velocity during piano playing.

V. CONCLUSION

In this research, we have evaluated the soft and dexterous finger movements of a pianist using MoCap system with 6DOF while playing the piano with musical notes. We have observed that pianist played the piano according to the musical notes with interval time and maintained the similar timing rate and timing sequence for individual fingers during playing the piano. We have calculated the intertap interval time, finger tip velocity and finger amplitude of the pianist. We have described about the finger status, whether it was curled position or flat finger position which is useful information for the beginners during piano education. It is also observed that finger tip velocity depends on finger status that is more curl the fingers, increase the finger tip velocity and less curl the fingers, decrease the finger tip velocity. These results show that magnetic MoCap for hands can measure the hands' movements which can be applicable for the beginners during piano education. There is a limitation in our system that magnetic MoCap system can not measure in presence of metal objects, so to overcome this we can use plastic or wooden materials instead of the metal object during our measurement.

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