Digital Circumferential Finger Measuring Device for Finger Clubbing Identification

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***Abstract*—This paper presents the development of a digital circumferential measuring device for facilitating measurements at various points along fingers, particularly at the nail-fold (NF) and distal interphalangeal joint (DIP). This project involves hardware and software development for helping clinicians to investigate and identify the early stage of finger clubbing within a short period. The value of Digital Index (DI) in this study is 9.30 ± 0.35 (Mean ± SD) for 20 subjects. The average time taken to measure both NF and DIP circumferences using Digital Circumferential Finger Measuring Device (DCFMD) and to compute DI values using DI Calculation System for a single subject is 5 minutes 10 seconds. The developed device and its system have shown to be reliable in this study and achieve significant time savings in comparison to the existing measurement device.**

***Index Terms*—Assistive Device; Computerized Instrumentation; Design Engineering; Electronic Medical Records; Finger Clubbing.**

I. INTRODUCTION

In medicine, the term finger clubbing, also known as drumstick finger, refers to enlargement of the distal segments of the fingers, reduction in the nail-fold angle, and the sponginess of the nail beds [1]. Clubbing is associated with a number of diseases, such as pulmonary, cardiovascular, hepatic, thyroid and gastrointestinal system [2-4]. Clubbing may occur in stages, where the whole process usually takes years. The presence of drumstick finger identified a high-grade finger clubbing. However, the identification of lower grades or early stage of clubbing is challenging to the clinicians. A general appearance of the fingers' growth abnormalities may indicate the symptoms of clubbing. Obvious observation for finger clubbing includes the swelling of fingers' distal phalanges and change in the nail-fold (NF) angle. NF angles, shape, depth, and width of the terminal phalanges reveal abnormalities in those individuals with finger clubbing symptoms, as compared in Figure 1.

Profile angle measurement, hyponychial angle measurement, and Schamroth test are known as the effective techniques for measuring and accessing finger clubbing [2]. Two objective measures known as the phalangeal depth ratio and digital index (DI) have been proposed for determining the presence of clubbing [5]. This project will be focusing on the DI, where it measures two separate circumferences on each of 10 fingers at the NF and the DIP, as illustrated in Figure 2. The sum of NF:DIP ratios for all 10 fingers determines the DI [5]. DI of 10.2 or higher signifies the presence of clubbing.

Djojodibroto et al. [6] proposed a simple but time-consuming device and method for identifying finger clubbing. It consists of non-elastic thread, a stand device to stabilize the finger, firm and thin paper, a clamp, cellophane tape, scissors and Vernier caliper for measuring NF and DIP. The time taken to perform the measurement and calculate the DI values manually for 23 male subjects and 21 female subjects is ranged from 21:63 to 68:80 minutes with an average of 35:97 ± 9:16 (Mean ± SD). This is considered too time-consuming and impractical for a busy clinic practice. It would be clinically advantageous if a simple and automatic device for measuring finger circumference and calculating DI exists. We hope that the availability of a new device in wards will help the clinicians to speed up the investigation and identification procedure of the early stage of finger clubbing.

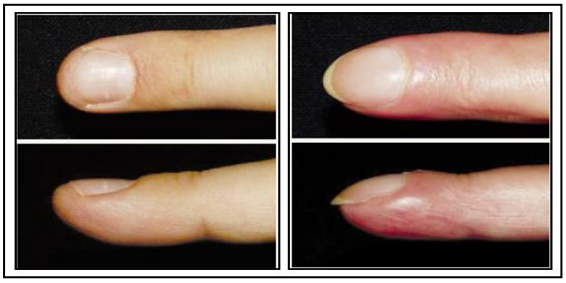


Figure 1: Comparison of normal finger (left) and clubbed finger (right) [6]

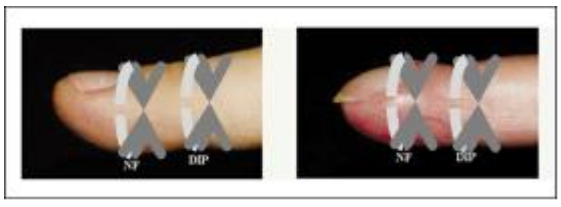


Figure 2: NF and DIP circumferences of a normal and clubbed finger (right) [7]

Masra et al. [7] have developed a first prototype of measuring finger circumference and its GUI interface for digital index calculation system. This device combined features of an analog sensor with a digital readout, and a case was made of acrylic Perspex.

It was found that the average time required to complete the measurement of both NF and DIP circumferences using the developed device, and DI calculation using the developed interface was 6:36 ± 1:24 minutes (Mean ± SD) with a range

of 4 minutes 31 seconds to 9 minutes 30 seconds, compared to 35:97 ± 9:16 minutes (Mean ± SD) if using string and caliper. It proved that the developed device and its interface led to significant time savings in comparison to the previous device and method.

However, we identified some drawbacks in order to improve the quality, repeatability, and ease of taking circumference measurements. First, the device must be of a reasonable size so that the clinician can carry it easily and use directly at the bedside. It must also be lightweight for ease of carrying and taking the measurements. Second, the device should use a battery instead of using a USB cable for mobility. Third, multiple measurements should be performed at NF and DIP per single subject to evaluate the accuracy and reliability of data. Finally, the replacement of a string to a measuring tape that can be looped around the finger can avoid inconsistency of tension applied by different clinicians.

II. Materials and Methods

This paper presents the design and development of a new device with extended features that provides portable, easy to use and may become a clinically useful tool in the future.

A. Deficiencies in Design Requirements

We assessed the existing design [7] to ensure that the developed prototype would perform as intended. As a result, we propose some solutions to improve the prototype in order to fit the design with clinicians' requirements and engineering targets, as summarized in Table 1.

Table 1
Summary of deficiencies in design requirements

Clinicians' Requirements	Engineering Targets
Measurement Accuracy	Multiple repeat measurements for precision and accuracy
Weight	Weight less than 300 gram
Size	Easy to carry by clinicians
Easy to Use	Smooth and efficient
Power source	Use standard battery

B. Description of Extended Device

A new, innovative device called the Digital Circumferential Finger Measuring Device (DCFMD), as shown in Figure 3 was developed for addressing the problems of measuring NF and DIP circumferences of a finger. This device offers extended or additional features to the existing prototype, based on the deficiencies listed in Table 1. The new device consisted of an Arduino UNO R3, an ultrasonic sensor, a reflective plate, a slider, a thin vinyl measurement tape, an LCD, and a battery. The dimension of the device was 25 cm × 6.5 cm × 2.5 cm, weighted of 250 grams, and housing made of plastic material. The use of plastic material as a substitute for acrylic Perspex casing yielded a more lightweight prototype.

The device took a measurement of finger circumference by adjusting a vinyl tape loop attached to a reflective plate once one's finger properly fitted into the loop. The ultrasonic sensor detected the distance of the reflective plate embedded in the device where this value was the corresponding representation of the measured points. Then, the liquid crystal display (LCD) displayed the reading for data collection and analysis. Figure 4 shows the procedure of taking NF and DIP circumference measurements.

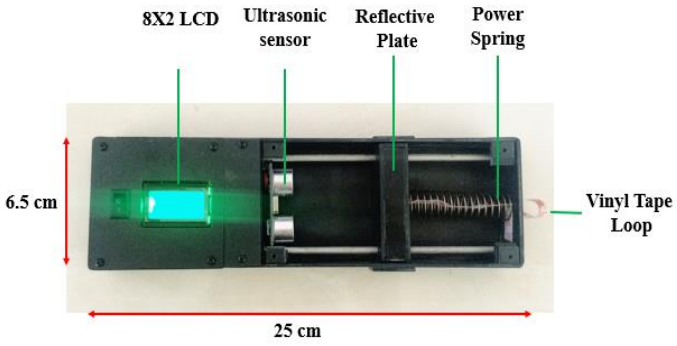
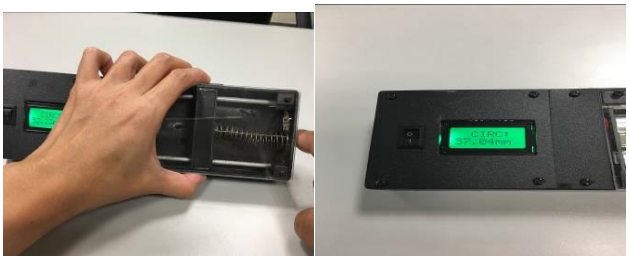


Figure 3: Overall structure of the developed device

(a)



(b) (c)

Figure 4: (a) The finger is fitted into the loop at NF or DIP; (b) Tighten the loop by adjusting the reflective plate; (c) Read the measurement on the LCD

Since some tension was applied to keep the string tight against the measured digit, it was necessary to replace the string in the previous design with a tape in order to avoid inconsistency tension applied by different clinicians. The replacement of a string with a 1 cm wide made of non-stretchable plastic measurement tape that can be wrapped around the NF and DIP will hopefully aid conformity around the digit. The reflective plate connected to a measuring Vinyl tape in a spring hole inside the housing.

The length of the tape, Y mm, which was connected to the slider and reflective plate, will change accordingly to the size of measured digit. X represents the minimum distance that the sensor can detect, which was equal to 25 mm. The distance that was measured by the sensor will be $(Y + 25)$ mm, as illustrated in Figure 5. However, this offset eliminated by adjusting the source code of Arduino, so that the LCD will display the reading of the exact circumference of the finger.

The Arduino operated and functioned as microcontroller to take the analog readings and converted them into digital forms. The Arduino received the range value detected by the sensor, which corresponded to measured digit, and then converted the values into digitalized data for output display on the LCD screen. The values displayed in millimeter (mm) unit that ranged from 0 mm to the maximum measurable

value of finger circumference of the subjects. A battery housed inside the device and connected through a switch. The replacement of the USB cable with a battery for supplying power to the prototype in the previous design has transformed the new prototype become more portable and can be used directly at the bedside. Figure 6 shows the flowchart of taking NF and DIP circumference measurements [7].

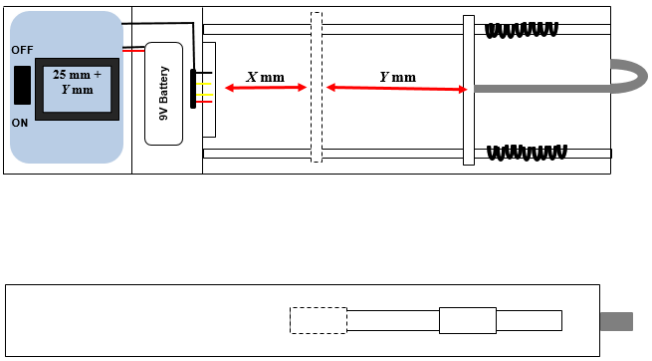


Figure 5: The total distance measured by the ultrasonic sensor will be (*Y*+25) mm (Top), Side view of the slider button (Bottom)

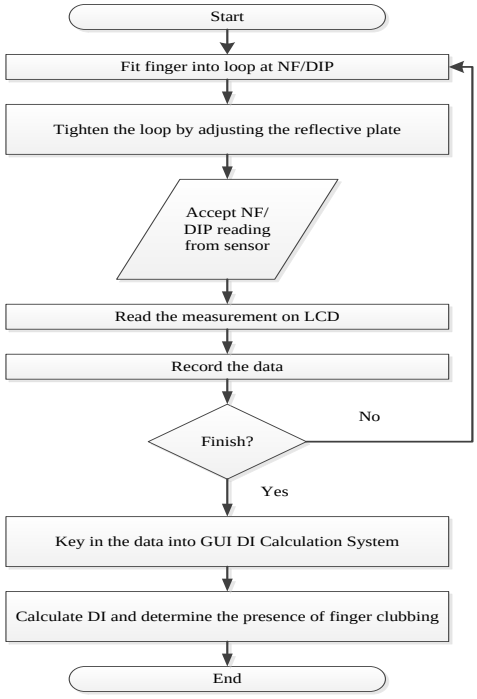


Figure 6: Flowchart of measuring and identifying finger clubbing

C. GUI of Digital Index (DI) Calculation System

The developed interface of DI Calculation System is tailored for faster estimation of DI, keeping the diagnosis data, and tracking the past medical check-up particulars. Figure 7 shows the GUI interface for calculating DI value after taking 20 measurements of NF and DIP circumference by using the newly developed prototype. The clinician has to click the "Evaluate DI" button in order to calculate and display the DI value reading. A digital index of 10.2 or higher signifies the presence of finger clubbing [8]. The system performed the calculation of the DI value using Equation (1) and data as tabulated in Table 2 [7].

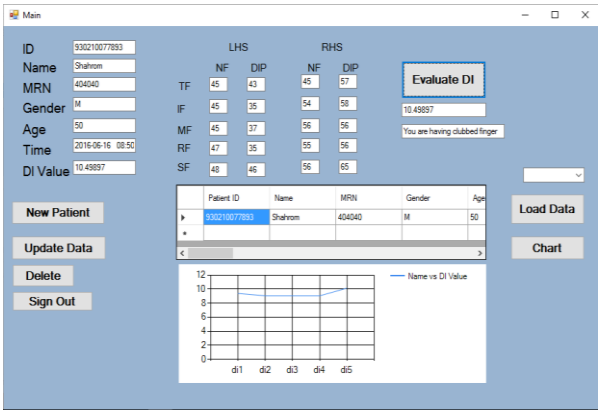


Figure 7: GUI of Digital Index (DI) Calculation System

$$\mathrm{DI} = \frac{a}{f} + \frac{b}{g} + \frac{c}{h} + \frac{d}{i} + \frac{e}{j} + \frac{k}{p} + \frac{l}{q} + \frac{m}{r} + \frac{n}{s} + \frac{o}{t} \quad (1)$$

Table 2
Measurements of NF and DIP for all 10 fingers

Left-hand finger	NF (mm)	DIP (mm)	Right-hand finger	NF (mm)	DIP (mm)
Thumb	*a*	*f*	Thumb	*k*	*p*
Index Finger	*b*	*g*	Index Finger	*l*	*q*
Middle Finger	*c*	*h*	Middle Finger	*m*	*r*
Ring Finger	*d*	*i*	Ring Finger	*n*	*s*
Pinky Finger	*e*	*j*	Pinky Finger	*o*	*t*

III. RESULTS, ANALYSIS AND DISCUSSIONS

Participants in this study included 10 females and 10 males who were considered healthy and not suffering from any diseases. Their age ranged between 19 to 25 years old to assess the performance of the improved device. The study investigated and analyzed-in-depth three major aspects: analysis of DI data, time taken to measure circumference and calculate DI, and the degree of agreement between the two raters.

A. Data Collected Using DCFMD

Stage 1 of this study measures all the NF and DIP circumferences of the subjects by using DCFMD. The raters performed five times measurements per location (i.e NF and DIP) for a single subject. Then, we keyed in the NF and DIP data of all subjects and DI Calculation System computed the DI values. Table 3 summarizes the data of all subjects, the DI values and the time taken to take finger measurements and computed DI values.

Off the 20 normal and healthy subjects, no one had a DI more than 10.2. Overall, the value of DI for all 20 subjects was 9.30 ± 0.35 (Mean ± SD). In comparison to the previous researchers, we found that the subjects in this study had almost the same DI value compared to 9.33 for subjects without any clubbing obtained by Vazquez-Abad et al. [9]. However, this DI value is higher than 8.66 obtained by Djojodibroto et al. [6].

B. Time Consumption

Stage 2 analyzes the efficiency of the developed device by examining the time taken to measure both NF and DIP

circumferences and computing the DI values. Table 3 summarizes these data. The average time taken for performing these two tasks for each subject was about 310 seconds or 5 minutes and 16 seconds, which was over 7 times faster than the existing measurement method as proposed by Djojodibroto et al. [6], and about 1.3 times faster than the first developed electronic prototype [7]. It proves that the developed device and its GUI to be more efficient by achieving significant time savings compared to previous methods.

Table 3
Average data collected using DCFMD

Subject	Gender / Age	DI	Time taken (sec)
1	Male / 23	9.45	298
2	Male / 24	9.64	312
3	Male / 20	9.55	298
4	Male / 21	9.32	296
5	Male / 23	8.58	320
6	Male / 20	9.52	330
7	Male / 21	9.47	296
8	Male / 22	9.64	348
9	Male / 21	9.59	346
10	Male / 25	9.67	288
11	Female / 19	9.20	280
12	Female / 23	9.14	310
13	Female / 23	9.15	320
14	Female / 20	9.20	315
15	Female / 21	9.17	321
16	Female / 21	9.14	330
17	Female / 20	9.13	300
18	Female / 20	9.21	288
19	Female / 21	9.29	296
20	Female / 23	9.20	312
Average		9.31	310

Table 4
DI values measured by first- and second-rater

Subject	Digital Index (DI)	
	First-rater	Second-rater
1	9.45	9.48
2	9.64	9.92
3	9.55	9.66
4	9.32	9.71
5	8.58	9.57
6	9.52	9.53
7	9.47	9.47
8	9.64	9.57
9	9.59	9.69
10	9.67	9.21
11	9.20	9.15
12	9.14	9.16
13	9.15	9.21
14	9.20	9.17
15	9.17	9.02
16	9.14	9.47
17	9.13	9.16
18	9.21	9.21
19	9.29	9.20
20	9.20	9.20

C. Inter-Rater Reliability

Stage 3 evaluates the accuracy and reproducibility of the data determined using the developed device and its interface. Table 4 summarizes the data that have been measured and computed by the two raters. Then, its inter-rater reliability is calculated and studied. Inter-rater reliability shows agreement between different raters. The Pearson's coefficient was 0.3959, which was greater than the critical *P*-value of 0.361. We assumed that there was a positive linear correlation exists between these two sets of the collected DI data. Therefore, the concept and technique of evaluating finger clubbing using the new device and its GUI interface is consistent and has good inter-rater reliability.

Table 5 summarizes the improvement features compared to the previous design [7] and Table 6 compares the time consumed for measuring NF and DIP circumferences, and calculating DI values for three different devices.

Table 5
Summary of improvement features from previous prototype

Features	Ref. [7]	Our project
Power Supply	Computer through USB port	9V battery
Casing	Acrylic Perspex	Plastic material
Size	720 cm x 36 cm x 5 cm	650 cm x 25 cm x 2.5 cm
Weight	500 grams	250 grams
Measurement tape	String	Vinyl tape

Table 6
Comparison of time consumed using three different measuring tools

Reference	Device & Method		
	Ref. [6]	Ref. [7]	Our project
Time consumed (min) (Mean ± SD)	35:97 ± 9:16	6:36 ± 1:24	5:10 ± 1:40

IV. CONCLUSIONS

In this study, the Digital Circumferential Finger Measuring Device has been successfully developed for facilitating measurements at various points along fingers, particularly at the NF and DIP, to obtain data for the studies of finger clubbing assessment. The value of DI in this study was 9.30 ± 0.35 (Mean ± SD) for all 20 subjects. The average time taken to measure both NF and DIP circumferences using DCFMD, and to compute DI values using DI Calculation System for one subject was 5 minutes and 16 seconds, compared to 22 - 69 minutes if using string and calipers. The availability of this device and its interface in wards will increase efficiency and create simpler and faster method for helping the clinicians in evaluating and identifying the early stage of finger clubbing. This invention overcomes the disadvantages of the conventional caliper and string method that may be inefficient, time-consuming and impractical for a busy clinic practice.

ACKNOWLEDGMENT

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