2014 5th IEEE RAS & EMBS International Conference on
Biomedical Robotics and Biomechatronics (BioRob)
August 12-15, 2014. São Paulo, Brazil

Touchscreen Device Layout based on Thumb Comfort and Precision

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Abstract— **Thumb workspace analysis on touch-sensitive screen is used to assist designers in laying control buttons out on screen devices which are thought to be one- handed operated, *e.g.* mobile phones. Using inertial motion tracking system, kinematic variables as position and orientation for thumb link are obtained. Based on Euler angles, the motion angle for each thumb joint relative to its comfort position is calculated for a determined number of touch points on the screen. Additionally, touch points are associated to distal phalange link inclination which correspond to a tip thumb contact area that affect the touch precision. The collected data is used to calculate discomfort index and the contact area over the total thumb workspace and map them on the screen. Through calculations it is possible to conclude that some movements are performed easily (comforting) and/or precisely than others, *e.g.* finger vertical sliding is easier than horizontal one. Finally, in order to improve user comfort and precision, on the screen area, where control buttons should be shown. This analysis is applied, as a practical example, on a personal magazine smartphone application, in order to suggest a suitable design for the control buttons.**

I. INTRODUCTION

Applications used on touch-sensitive screen devices, thought to be handled (held and operated) with only one hand, may improve the user comfort or/and precision during handling by repositioning control buttons on the screen.

Recently, professionals in Ergonomics are participating from the beginning in the product design process. The early discipline cooperation results in better and more integrated projects with lower costs. Ergonomics should provide better information (inputs) regarding human beings and their interactions with systems and the total resulting performance [1]. Aiming at total performance, a lot of tools and ergonomic technologies have been developed to previously reinforce the analysis and design process. Computational models and simulation are excellent examples for this interaction in several engineering areas [2]. According Nemeth [3], simulation is useful to preview systems which do not yet exist and it allows users to test systems that in most cases may be complex, dangerous or expensive. Using simulations, solutions may be tested, evaluated and optimized, with low risk and cost.

In recent years, the technology development, reflected in personal electronic devices, are relevant part of our daily life. A special device which is taking over the market is the smartphone. It consists basically on a cell phone that includes various functions previously restricted to computers and various sensors that increase its usability.

An ever more functional and comfortable user interface is required due the amount of smartphone functions. Nowadays, the most of these devices substitute the restricted keys by touch-sensitive screens which allow the user to click on any screen point. Therefore, a touch-sensitive screen allows the same functions than provided by the keyboard and, besides, it adds other interface possibilities.

Initially, touch-sensitive screen allowed only one simultaneously click (one finger at a time) to each command, nowadays modern screens allow more than 10 clicks (*i.e.* it is possible to use all fingers to device control). This is an important breakthrough in interface terms, however there is still a long way to advance in ergonomic terms.

Due to the amount of data that must be acquired through screens, consequence of increased smartphone functionalities, many of them are unsuitable for touch. Often, users require two hands in order to control them because it is impossible to reach all the screen points using only one hand. Eventually, it is even possible to achieve a point but imprecisely due the angle between tip thumb and screen. Some application developers have located functions in accessible points, however there are few studies on this issue.

Almost all works studying the thumb has approached its complex motion, joint coordination and force production [4], [5], [6], [7]. However, these focussed on thumb kinematics, rather than understanding the demand imposed on the thumb to perform particular tasks.

Some works attempt to quantify thumb disability by plotting the thumb workspace. A method for defining thumb disability by comparing the workspace of the injured and uninjured thumbs [8]. However there is no particular work directed to assist designers to project application layouts for touch-sensitive screen devices.

This paper uses Euler angles [12] to describe the thumb configuration and the touch-sensitive screen positioner to detect the cartesian thumb tip location, *i.e.* workspace position in order to obtain a comfort and a touch area map which helps designers to locate touch buttons in a suitable way. Inertial sensor are used to map reachable points for a user who grasps the device and control it with the same hand. A Samsung Galaxy S4 smartphone device is used for the experiment. Therefore, in the next section some inertial sensor properties are presented, in the sequence the experiment is described and the results are analyzed. Finally, some design conclusions are discussed for the location of touch points that assure user comfort and usability using an

*This work was supported by CAPES, Brazil

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example.

II. Sensorial system

Motion capture systems consist of a set of sensors and interfaces that allow mapping complex movements for certain applications. Most of these commercial systems are composed of several capture centrals and a signal processing central.

Capture central are commonly composed of three sensors, each one with three degrees of freedom: accelerometer, gyroscope and compass. This redundancy arises from the fact that real sensors are imperfect. So a sensor is used to correct the deficiency of another. This results in a more accurate and rapid measurement.

A. Accelerometer

An accelerometer provides the acceleration experienced by the station at a given instant. Sensors such as these can be modeled as a mass supported by several springs. For microchips, strain gauges are used instead of springs, which provides a signal to impedance variation for applied force. This signal is converted to voltage through a Wheatstone bridge and then it is captured by the plant.

In general, accelerometers present good dynamic response. For human movement measurement, it is possible disregard any uncertainty due to system response. However, the acceleration signal is very noisy, therefore the hand tremor may be an unsuitable source of noise. However this interference possess a very high frequency and may be removed using a low-pass filter. It is important to notice that filtering impact drastically on the system dynamic response.

B. Gyroscope

The gyroscope measures the body angular acceleration. It is based on the Coriolis effect, *i.e.* a deflection of moving objects when viewed from a fixed and rotating reference. Previously, gyros were mechanical components with a rotating mass. Currently sensors are MEMS (microelectromechanical system). A modern gyroscope consists of an oscillating mass at 25-30 kHz. Linear accelerations on the sensor, cause a mass deflection, which is then measured by sensors.

Gyroscope presents suitable dynamic response and low noise. Its weakness lies on its signal integration (rotating body) that tends to drifting.

C. Compass

Compass consists basically of a magnetic field and Hall effect sensor. Motion capture centrals use compasses with 3 degrees of freedom to measure the magnetic field of the earth regardless center orientation and errors due non-horizontal earth magnetic field.

Compasses are extremely sensitive to magnetic instruments . In practice, this results into an extremely noisy signal. For applications such as the one described in this paper it is possible to use a low-pass filter and get a fairly accurate sensor signal. Another sensor limitation is its low dynamic response. Therefore, applications where a compass is used may present small rotational variations and low angular speeds.

In spite of these restrictions, a compass provides the body rotation with good precision and without any drift.

D. Sensor Fusion

In sensor fusion, multiple sensors are used to provide a collective information better than if it is used alone. The various uncertainties discussed above require a construction in which the uncertainty of each sensor is corrected by the other. The orientation used in Xsens [9] is computed by a Kalman Filter in 3 degrees of freedom (commercially named XKF -3). This occurs in signal processing hardware level and uses data from accelerometers, gyroscopes and compasses to estimate the orientation with high accuracy and without drift. This approach avoids the gyro integration problem discussed above.

The data with the correction made in hardware are stored via a rotation matrix, which expresses the local coordinate system relative to the global system. Then is possible to calculate the Euler angles in each thumb joint.

III. Experiment description

A. Work area and discomfort index

Data acquisition is obtained using the kit motion capture Xsens MTx [9], see Fig. 1. This system consists in a core for motion capture (sensor), a system of data acquisition and a computer software. Sensors and computer use wireless communication, with range up to 150 m (in open areas) and 50 m indoors. According to the manufacturer's manual 3D orientation provides less than 0.5 degrees accuracy and the accelerometer and gyroscope are respectively in the range of $\pm$ 180 m/s^2 and 1200 deg/s precision . Each sensor has its local coordinate system .

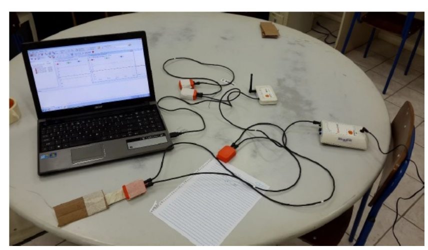

Fig. 1. Data Capture System

At the experiment beginning coordinates are reset, so that all sensor axes align in the same direction. Subsequently , using the photos of the experiment, it is possible to fix the axis sense via software, thus leaving all sensors in the same coordinate system . The experiment home position is defined as the thumb horizontal position, so that the thumb is touching the screen left medial corner. Aiming to set the system start position (home), it is carried out the measurement of proximal and distal thumb phalanges length and the metacarpal bone length. Figure 2 shows the anatomical scheme of each bone hand. Comfort position is defined, where the thumb phalange muscles are relaxed.

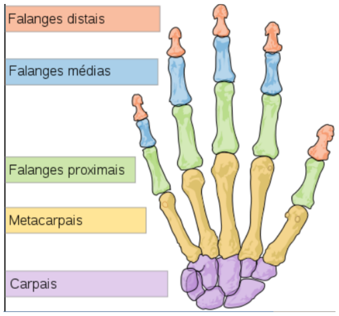

Fig. 2. Human hand bones

Additionally, a discomfort index D at a current position is defined as the sum absolute differences between Euler angles at comfort and current position. Euler angles at comfort position are three for metacarpal bone $(\alpha_{MC}, \beta_{MC}, \gamma_{MC})$,three for proximal $(\alpha_{PC}, \beta_{PC}, \gamma_{PC})$ and three for distal $(\alpha_{DC}, \beta_{DC}, \gamma_{DC})$ phalanges. So, for instance, let the Euler angles at workspace (screen area) point $n(x_n, y_n)$ be $(\alpha_{Mn}, \beta_{Mn}, \gamma_{Mn})$ for metacarpal bone, $(\alpha_{Pn}, \beta_{Pn}, \gamma_{Pn})$ for proximal and $(\alpha_{Dn}, \beta_{Dn}, \gamma_{Dn})$ for distal phalange, therefore the discomfort index for point n is

$$\begin{aligned} D = &|\alpha_{MC} - \alpha_{Mn}| + |\beta_{MC} - \beta_{Mn}| + |\gamma_{MC} - \gamma_{Mn}| + \\ &|\alpha_{PC} - \alpha_{Pn}| + |\beta_{PC} - \beta_{Pn}| + |\gamma_{PC} - \gamma_{Pn}| + \\ &|\alpha_{DC} - \alpha_{Dn}| + |\beta_{DC} - \beta_{Dn}| + |\gamma_{DC} - \gamma_{Dn}| \end{aligned} \tag{1}$$

note that the discomfort index is null for the relaxed muscle (total confort) position and increase as the thumb joints get far from it, thence discomfort becomes bigger.

Movement mapping is performed using five sensors, see Fig. 3. One sensor is used as trigger for data capture. Three sensors are fixed, through an elastic tape, at thumb phalanges (proximal and distal) and at metacarpal bone. These sensors are used to obtain the orientation for each phalange (link). Another sensor, fixed at the screen device (base link), is used to obtain the reference coordinate system. During the experiment, movements are performed slowly, so that the tape flexibility do not alter the results.

Fig. 3. Sensors fixed at phalanges

Several grasping types are used to hold mobile devices. In this paper, the palm grasping is used, because it ensures a firmness to hold and operate simultaneously the device, see Fig 4.

It is important to notice that it is unfeasible to wear three sensors (one per link) simultaneously because in some

Fig. 4. Palm grasping

positions sensor collide. Therefore, the measurement are carried out discreetly, where the sensor inclinations at certain screen points (thumb tip contact points) are captured. For this purpose, fifty one points are located on screen in order to provide reference points for data capture.

Data capture is performed in three stages, one for each thumb phalange. Initially, distal phalange sensor is fixed. The thumb tip is positioned in one of the control marks and inclination data are recorded. This experiment is repeated for all marks (54 points) with sensors at proximal phalange and metacarpal bone. So, using a program for data analysis, 162 distinct rotation arrays are obtained.

B. Touch Contact Area

During device operation, touch contact area is significant, so a big contact area may activate more than one control buttons at same touch, *i.e.* imprecise touching. Therefore, larger the contact area lower the thumb precision.

In order to measure the touch contact area, a second experiment is done. In a Samsung Galaxy S4, it is used the function “display cursor information” provided for testing applications. This function displays user information such as the position of each click, speed and contact area. The area displayed on the screen corresponds to a normalized size value of the touch contact area in relation to the largest area detectable by the device. The value is within the range between 0 and 1 [10]. These informations may be seen at the top of Fig. 5.

Fig. 5. Android developer mode

So, 213 points are marked on the screen corresponding to the thumb work area. For each point, it is made a touch and the correspond area information is saved.

IV. Analysis of results - a case study

In this section the above described experiment is applied to an aleatory user using a specific touch-sensitive screen divice: Samsung Galaxy S4 [13].

A. *Work area and discomfort index - a case study*

Through the data capture software, it is possible to obtain the rotation matrix for each sensor. This matrix is the result of sensor fusion, discussed above, and therefore it avoids the effects of *drift*. Each sensor rotation matrix is then converted to the same coordinate system (fixed at the device), to obtain a consistent result. Using forward kinematics, it is carried out a mapping of the thumb tip, as well as a serial robot it consists of three joints, four links (3 phalanges and 1 fix screen) and one end effector. Using the geometrical data previously measured, *e.g.* user phalange lengths, see I, the home position is included in calculation program. Rotation matrix captured by the sensors is used as the rotation information of each robot link. With this information and converting rotation matrix into Euler angles [12] is possible to discover the range of each robot joint in its three degrees of freedom.

TABLE I
BONE LENGHTS

Bone	Lenght [mm]
Proximal phalange	38
Distal phalange	30
metacarpal	55

Initially, it is made a collection of data where the thumb begins at home position and is moved to the comfort position. This collection goal is to obtain the Euler angles that match the position of user comfort, see Table II.

TABLE II
COMFORT POSITION

Metacarpal bone			Proximal Phalange			Distal Phalange		
α_{MC}	β_{MC}	γ_{MC}	α_{MP}	β_{MP}	γ_{MP}	α_{MD}	β_{MD}	γ_{MD}
-4.5^o	15.7^o	-22.9^o	-10^o	-24^o	9.5^o	1.5^o	15.8^o	-9.8^o

This index is calculated for each one of 213 marked points on the device screen. Low discomfort index values correspond to a small variation in relation to the comfort angles and therefore a more comfortable position.

After the data mapping experiment, it is used the thumb tip (end effector) position relative to the screen and their respective comfort indices, see Fig. 6. Abscissa and ordinate axis correspond, respectively, the X and Y axe described on the screen phone. Numbers into circles (contact point) refer to the discomfort index in this point. Lower numbers

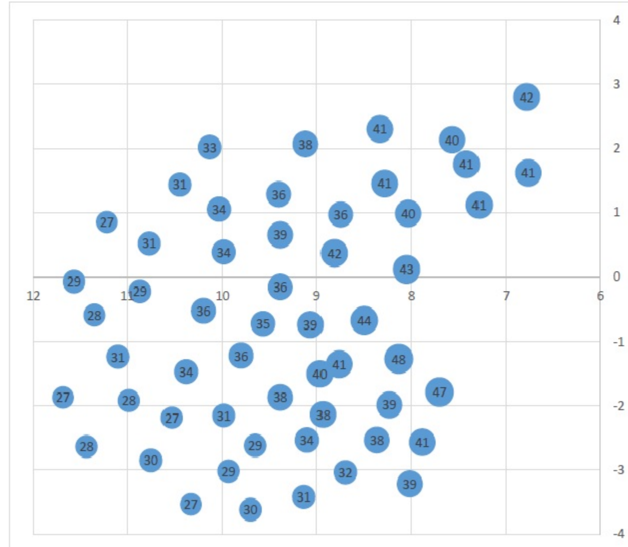

Fig. 6. Experimental results

correspond to less discomfort, *i.e.* more comfortable positions. On the other hand, the higher numbers corresponding to uncomfortable positions.

Interpolated results, are used to show a discomfort *heatmap* on the screen work area. Discomfort index calculation for non-experimentals data is done using the weighted average of all points and the inverse square of the Euclidean distance as a weighting parameter, see Fig. 7.

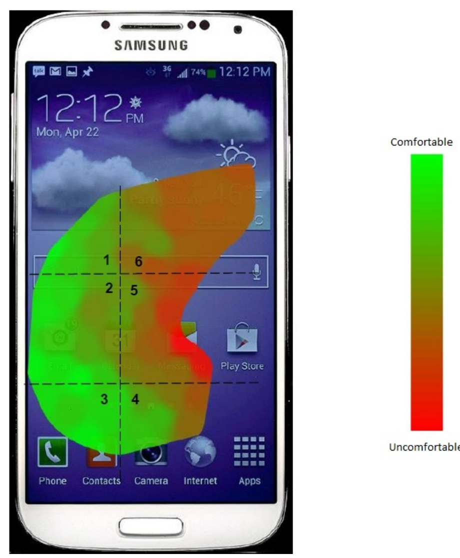

Fig. 7. Heatmap comfort superimposed on screen

The analysis of the graph above shows that zones 1, 2 and 3 correspond to better comfort in device using. Positions within this area correspond to a minimum variation of the joints angles from the comfort position. This area is recommended for placement frequent access control buttons.

Region 6 has a moderate discomfort index, making it favorable for positioning buttons with infrequent use. This big work area also helps in better button layout. In general, vertical sliding movement is performed more comfortably than slide horizontally. This comes from the fact that, the work area width is smaller in the horizontal direction, additionally the high discomfort caused in the sensor positions of the screen further makes the movement of horizontal slide harder.

B. Touch Contact Area - case study

Contact area data is provided in three values (0.03, 0.04 and 0.05). Larger values correspond to a larger contact area and, consequently, a lower accuracy in touch. Using the digital measurement on the display, it is possible to calculate the contact area for each screen point obtained in the application, see Table III.

TABLE III
AREA IN RELATION TO EACH APPLICATION POINT

Output Application	*area* [cm^2]
0.05	3.84
0.04	1.21
0.03	0.80

Then, points are plotted on the device image using green to value 0.03, yellow to value 0.04 and red to value 0.05, and a new heatmap is calculated, see Fig. 8 and 9.

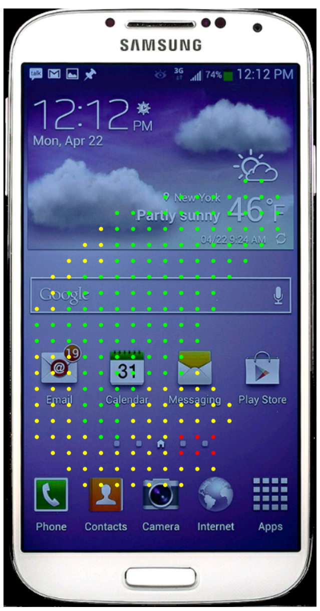

Fig. 8. Superimposed data points to the device screen

Through the analysis of Figures 8 and 9, it is observed that the touch accuracy remains acceptable in most working area. The region with the lowest accuracy (in red), also corresponds to the region with the smallest comfort touch.

C. Comfort and precision data

Through a graphical overlay, it is possible to obtain a consolidated map of comfort and touch contact area. From Figure 10, it is observed that heatmap central portion provides the best compromise between comfort and accuracy.

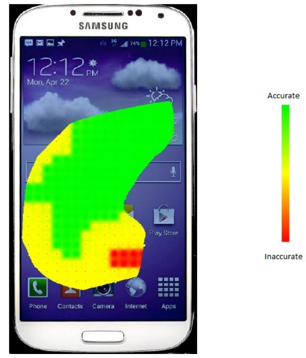

Fig. 9. Heatmap area superimposed on the device screen

Fig. 10. Consolidated heatmap overlay the screen Device

V. CONCLUSIONS AND FURTURE WORK

Touch-sensitive devices when held and operated with the same hand may be benefited from this work to distribute control buttons in an optimum layout. This layout is based on thumb tip work area and finger comfort. A practical use of this technique is applied in a case study for Flipboard [11], a personal magazine smartphone application is done. This is an application focused on reading news, magazines and feeds. The user sets up a list of subjects that interest, the summary of each message is shown in the form of the page, as shown in Figure 11.

Figure 12a shows a schematic representation of the main commands used in this application. In order to change a page, the user does a slip from the bottom to the top, similarly as passing a notebook page. The messages may be completely viewed through a clicking anywhere (no buttons) on the screen. Go back to page index is done through the back button in the upper left corner or through a slide horizontally.

This application command layout demonstrates that it is designed to be used with only one hand, but we can see several weaknesses in its design. In order to propose changes in the buttons arrangement, the heatmap developed in this work is overlaid on the Flipboard application. Then the

Fig. 11. Smartphone Flipboard application

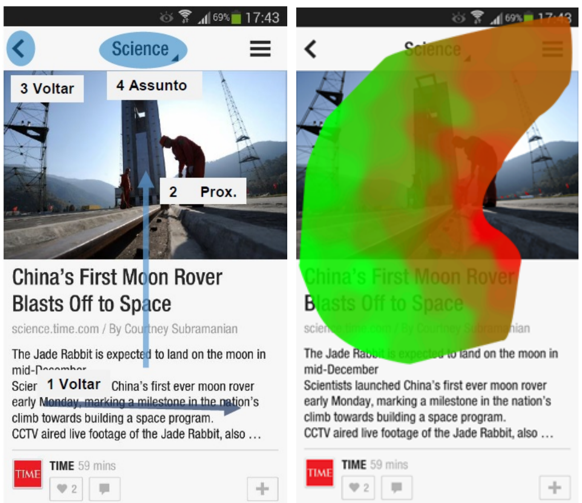

Fig. 12. a) Major commands Flipboard b) Heatmap Fliboard

heatmap is moved up in order to reach most of commands into comfort area, see Fig 12b.

The biggest problem in this application is the back (return) action in its two configurations: the horizontal slip mode, as discussed earlier, is unsuitable and the back button position is out of the work area.

A solution may be done by moving button 3, in place of button 4. Thus, the return command is into the work area. The button 4 is also often used, so it may be moved to the upper right corner, where is a menu button underutilized. The suggested setup may be seen in Fig. 13.

This work area study on touch-sensitive screens has immediate application in various technologies. Further work may be carried out intending to detect parameters that change work area format for different users. Additionally, more suitable size sensors may be used aiming at only one data collection, avoiding two collection errors. Some factors such as screen size and physical user characteristics may be of relevance for mapping the positions for more comfortably handling. Finally, knowing some factors that affect discomfort index, a developing applications framework may be created, so that the user provide their physical characteristics and the system place all the command buttons in appropriate locations.

Fig. 13. Suggested design for Flipboard

ACKNOWLEDGMENT

This work was partially sponsored by CAPES, Brazil.

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