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Multi Touch: A Finger Synchronized Screen

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Abstract

Multitouch platforms offer new and exciting ways of interacting with computers. Traditional input devices, such as the mouse or keyboard, only allow input from one user at a time. However, multitouch gestures allow for multiple inputs and often resemble physical interactions that are more natural and intuitive for users. Additionally, large multitouch interfaces allow more than one person to collaborate on the same screen easily.

Quite simply, multi touch input expands the range of functionality these devices can support. Two fingers (or activation points) allow users, for example, to zoom in/out or rescale the display, with the right software. The power of this enhanced functionality becomes immediately apparent when we look at industrial applications. In an industrial environment, requiring two activation points – that is, both of the user's hands on the screen can be used before beginning a process to enhance safety. Three and more activation points are also possible by including "gestures," and here custom software affords the ability to be creative while minimizing or eliminating any learning curve. In an industrial environment, requiring two activation points that is, both of the user's hands on the screen can be used before beginning a process to enhance safety.

Keywords: Bimanual interaction technique, Control structure, Gesture/hand-gesture, High-degree-of-freedom, high-DOF, Integral control structure, Multi-touch, multi-point, multi-finger

1. The Benefits of Multi Touch over Single Touch

Quite simply, multi touch input expands the range of functionality these devices can support. Two fingers (or activation points) allow users, for example, to zoom in/out or rescale the display, with the right software. The power of this enhanced functionality becomes immediately apparent when we look at industrial applications. In an industrial environment, requiring two activation points – that is, both of the user's hands on the screen can be used before beginning a process to enhance safety. Three and more activation points are also possible by including "gestures," and here custom software affords the ability to be creative while minimizing or eliminating any learning curve. In an industrial environment, requiring two activation points that is, both of the user's hands on the screen can be used before beginning a process to enhance safety. Three and more activation points are also possible by including "gestures," and here custom software affords the ability to be creative while minimizing or eliminating any learning curve. Another great example is building automation: imagine your building is big enough that when the floor plan fills a display, details are rendered too small to see. At this level, all you can do is get an overview, which is enough for new visitors trying to find their way around but proves insufficient for others needs.

2. Multi-touch and Whole-hand Input Technology

2.1 Touchpads

Touch tablets which can sense more than a single point of contact were first proposed by Lee, Buxton, and Smith in 1985 [1]. Their digitizer is composed of an array of capacitive proximity sensors where the finger and sensor act as two plates of a capacitor. Since capacitance is inversely proportional to the distance between the plates, robust contact detection can be accomplished by simply selecting an appropriate threshold. The resolution of the digitizer can be enhanced beyond the physical resolution of the sensor matrix by interpolating data from neighboring groups of sensors. The touchpad could also approximate pressure sensing by monitoring the increase in capacitance as the fingertip flattens against its surfaces. Another touch-surface based on capacitive coupling is Dietz and Leigh’s Diamond-Touch system [2]. The digitizer is composed of a grid of row and column antennas which capacitively couple with users when they touch the surface. Users in turn, are capacitively coupled through their chairs to a receiver. By driving each antenna with a unique signal, the system can tell which antenna is being touched by which user. A key advantage of this technique over other methods is that it can identify which user is touching the surface. The Diamond Touch system uses time-division multiplexing to cycle through the row and column antennas. This scheme only yields the margins of the capacitively coupled area, which limits the system’s ability to identify multiple points of contact. A user touching the surface at two points can produce two possible interpretations, and so the system is limited to providing axis-aligned bounding rectangles of the area touched by each user. Rekimoto’s SmartSkin [3] can provide an image of a hand’s proximity to each point on its surface. The digitizer consists of a grid of capacitively coupled transmitting and receiving antennas. As a finger approaches at intersection point, the strength of the signal drops. By measuring this drop, the system can determine how close a finger is to the receiving antenna. Through time-division multiplexing the transmitting antenna is identified as well. By thresholding the proximity map, multiple points and complex contact regions can be identified. Several multi-point touchpads have been produced commercially, although their mechanisms of operation are not always known. The TouchStream and iGesturetouchpads by FingerWorks [4] appear to be an array of capacitive sensors, and can report the position, contact area, and eccentricity of multiple fingers. They are likely to be decedent from the multi-touch surface described by Westerman [5]. The Tactex MTC Express uses a series of fiber-optic strain gages to measure pressure on multiple points of its surface. Other multi-point touchpads which appear to respond to pressure are the Tactiva TactaPad [6], and JazzMutant’s Lemur.

2.2 Vision-based Systems

Vision based systems can be roughly classified as “direct” systems, where cameras are aimed directly at the users hands, and “indirect” systems, where the cameras are aimed at a touch-surface that produces a change in the image when touched by a finger or object. As the body of research on direct vision systems for hand and finger tracking is very large, we only describe a few representative systems.

One of the earliest direct vision systems for whole-hand interaction is Krueger’s VIDEOPLACE [7]. The system captures an image of the user, who stands in front of a plain background. It segments the image, and displays it as a silhouette in real-time. The moving silhouette can then be used to interact with digital objects and animated characters. Wellner’s DigitalDesk system [8] segments an image of a pointing finger against a cluttered background by calculating a difference image between two consecutive frames. Contact with the desk is determined by using a microphone to listen to the sound of a finger tapping the desk. The Visual Touchpad system of Malik and Laszlo [9] uses the disparity between the images of two cameras to determine the height of fingers above the touchpad. The system reports that a finger is in contact with the touchpad if it is bellow a threshold height above the touchpad. By tracking the position of the hand, the Visual Touchpad can make an informed guess as to the identity of each finger, and also calculate its orientation. Rekimoto and Matsushita’s HoloWall is a typical example of an “indirect” vision system. An infrared illuminant and a camera equipped with an infrared filter are placed behind a diffusive projection panel. As objects begin to approach the panel they are faintly lit by the infrared light. The illumination rises dramatically when object touch the diffusive panel, which allows the system to unambiguously determine the contact areas by simply thresholding the infrared image. A similar system by Han [10] uses frustrated total internal reflection to highlight the touched area. In contrast to most touch-systems, which can only determine the position, shape, or area of contact, the GelForce system of Vlack et al. [11] measures the traction force applied to the touchpad. The system tracks a dense array of colored markers embedded in a block of clear silicone to determine the traction field. Since the system detects deformation due to both pressure on the surface as well as lateral forces, it can be used for both isotonic and isometric input. This ability makes the device appropriate for both position and rate control. A different approach to vision-based touchpads is described by Wilson [12, 13], who instead of relying tracking finger positions for input calculates an optical flowfield. This technique uses the motion of the entire hand to move and rotate objects.

2.3 Whole Hand Input

A large body of work has been dedicated to accurate estimation of whole-hand posture and movement. This has generally been done either through vision-based methods, or by instrumenting the hand with sensors to measure a large number of hand parameters (e.g., extension and adduction of all fingers). While the stated goal of many of these system is to allow users to interact with the digital world using their real-world manipulation skills, successful vision and glove-based interaction systems have been primarily limited to gesture-based interaction.

2.4 High Degree-of-freedom Input

Several general purpose input devices attempt to make use of our ability to manipulate the many degrees of freedom of physical objects. A large number of these devices are 6 DOF controllers designed to control the three spatial and three angular degrees of freedom of a rigid body in space. These devices can be categorized as free moving isotonic controllers such as the “Bat” by Ware [14] and the Fingerball of Zhai et al. that allow for isomorphic position and orientation control, and isometric controllers such as the Spaceball and Space Mouse that use the forces applied by a user to a static object to control the rate of change of parameters. In between these extremes are elastic controllers such as the “poor man’s force-feedback unit” of Galyean and Hughes [16] and the EGG of Zhai [17]. These devices provide more kinesthetic feedback than isometric devices, but retain the self-centering property needed for rate control. Hybrid devices also exist. For example, the GlobeFish [18] is an elastic position controller coupled to an isotonic orientation controller. The rockin’ mouse is a different sort of hybrid; it uses two spatial dimensions and one angular dimension to control position in three dimensions.

Specialized multi DOF devices have been created for a variety of applications. Motion capture systems are one example [19], as are instrumented armatures [20]. ShapeTape is a length of rubber tape instrumented with 32 bend and twist sensors.

3. Multi-touch and Whole-hand Interaction Techniques

3.1 Classification of Multi-touch and Whole-hand Interaction Techniques

Struman [21] describes a taxonomy of whole-hand interaction techniques which divides them into a class of discrete and a class of continuous input methods. Within each class a technique is described as a direct interaction, a mapped interaction, or a symbolic interaction. Zhai and Milgram [22] point out that interaction methods form a continuum ranging from the direct to the indirect. Direct interaction methods are based on an isomorphism between the control space and the display space, while indirect methods or “tools” rely on more complex mappings. In the light of Struman’s classification, this continuum can be further extended from isomorphism to tool to symbol. Using a touchscreen to select an object would lie on the isomorphism end of the continuum, while using a gesture to execute a command would lie on the symbol end. Many of the techniques described below are hybrid methods that rely on a gesture or hand posture as a symbolic mode-switch that determines the interpretation of a subsequent mapped or direct manipulation.

3.2 Hand Gesture Interfaces

Much research on whole hand interaction techniques has examined the concept of gestures. Hand gestures in the context of HCI are much like hand gestures in everyday communications. They are hand postures and movements that express an idea. These may be simple, iconic symbols used to invoke a command, or, like a pointing index finger, they may also serve to indicate the parameters of an operation [23]. While such gestures may allow a user to select which of several parameters to adjust, the additional degrees-of-freedom are generally used for specifying the gesture, and not for coordinated high DOF control. This term is used somewhat loosely in the literature, generally as a reference to an isometry or similarity transformation.

An early example of whole hand gestures is the Charade system [24] which recognizes hand postures as commands to slide a presentation system. This type of gestural interaction can be thought of as simply an implement-free instance of keyboard command-shortcuts, and is found in many gesture-based systems. For example, Wuand Balakrishnan’s RoomPlanner application [25] uses a tapping gesture to invoke menus, and a horizontal hand gesture to brink up a private display area. However, the system also uses compound gestures in which a hand posture can be followed by motion to adjust a parameter. Placing two fingers on the touch-surface initiates rotation, a flat hand gesture pans the work area, while a vertical hand gesture lets users sweep items along the table. In a similar vein, Malik et al. [84] describes a set of hand gestures for panning, resizing, and zooming a 2D workspace. The posture of the hand is used to select one of several system parameters which can be mapped to continuous parameters of the hand. For example, a two finger touch initiates a mapping from the inter-finger distance to the zoom-scale of the workspace. Gestures do not have to be restricted to one person—Morris et al. extends the concept to cooperative multi-user gestures. A set of 3D multi-finger hand gestures is introduced by Grossman et al. [26] for object manipulation on a volumetric display. For example, a thumb “trigger” gesture is used to select an object, and a pinch gesture is used to move it. Vogel et al. [27] makes use of 3D hand gestures for pointing on very large displays. Studies and observation of the usability of the above systems reveal that a well designed gesture set can lead to fast, fluid interaction in settings, such as table-top collaboration, which are not well served by traditional mouse and keyboard methods. However, gesture-based systems are difficult to design and extend. Gestures must be carefully designed so as to be easy to learn, easy to differentiate from one another, and to accept parameters in a meaningful manner. Adding a single gesture to such a carefully designed system may invalidate the entire design. The design is often ad hoc, and few guidelines regarding gesture design and mapping assignment exist. Wu et al. [28] offer some thoughts on how to design usable systems through gesture reuse.

3.3 Bimanual Interaction

Two-handed interaction techniques have much in common with multi-touch interfaces, as both attempt to increase parallelism in continuous parameter input by measuring multiple hand parameters. A 1986 study by Buxton and Myers [29] reveals that parallel two-handed continuous input can reduce task completion time for scrolling and graphical manipulation tasks. Numerous studies have since increased our understanding of bimanual interaction, and many techniques have been proposed for making use of our two-handed interaction abilities.

Depending on the task, bimanual interaction may have several advantages over unimanual techniques. The most obvious advantage is parallelism. If users can successfully control parameters using two hands simultaneously, they can accomplish a multi-parameter manipulation task in less time. However, some researchers have found that the benefits of bimanual interaction are not limited to mechanical efficiency, but that using two hands changes the way users think about a task [30].

Bimanual interaction methods can be categorized as techniques where the hands are used symmetrically, such as steering a bicycle, and techniques where they are used asymmetrically, such as peeling a potato. Guiard puts forward an influential model of cooperative, asymmetric bimanual interaction [31] which attempts to explain the advantage of manual specialization. According to the model, the hands are coupled through the arms and body to form a kinematic chain, with the non-dominant hand as the base link. The model predicts many properties observed in asymmetric bimanual interaction. The first, is that the non-dominant hand serves to set a dynamic reference frame for the dominant hand's operation. Handwriting, where the non-dominant hand keeps the paper in the dominant hand's most effective work-area is a good example of this. The second, is a scale differences in motion where the dominant hand acts on a finer scale both spatially and temporally than the non-dominant hand. The third is non-dominant hand precedence in action, as dominant hand action is not sensible before its reference frame is set. Hinckley et al. [30] confirms the reference frame roles of the hands in cooperative action. The model is widely used as a guideline for designing bimanual interaction (for example, Kurtenbach et al.'s T3 system [32]), and also explains why the benefits of two handed interactions do not extend to task that fail to meet Guiard's description. For example, a study by Dillon et al. [33] found only a nominal benefit in using two mice for distinct tasks.

In contrast to asymmetric interaction, where the hands play different but complementary roles, in symmetric bimanual interaction both hands serve the same manipulative function. Experiments by Balakrishnan et al. [34] indicate that symmetric bimanual interaction requires an integrated task with a single focus of attention to be successful (in terms of low error and high parallelism). Latulipe et al. have shown that symmetric mappings can be more effective than asymmetric mappings for certain tasks

Researchers and designers have developed a large number of bimanual interaction techniques. For example, the toolglass and magic lenses techniques let users click through a pallet held in the non-dominant hand. 2D navigation methods take advantage of two hands for unified zooming and panning [35]. Various techniques for figure drawing [32,36] and curve editing [37,38,and 39] have also been proposed. Since 3D navigation and manipulation tasks require the user to control a large number of parameters, bimanual interaction methods seem to be a promising solution. Techniques have been devised for object visualization and manipulation [40, 41] as well as for camera control and navigation [42,43,44].

3.4 Tangible Interfaces

Another way of using multiple fingers for input is to manipulate physical tools and props whose properties (e.g., orientation) are mapped to parameters of the software. The idea, known as tangible or graspable interface, is to make use of our natural prehensile abilities and the affordances provided by physical objects.

Fitzmaurice et al. point out some advantages of graspable UIs [45]. They include parallel and bimanual input, spatial multiplexing of input rather than temporal multiplexing, support for collaboration, and making use of our spatial reasoning and manipulation skills.

To illustrate this concept Fitzmaurice et al. introduce “bricks,” tracked physical blocks that serve as handles to digital objects. Users can associate a brick with a digital object by placing it on its display image. Moving the brick produces a corresponding movement in the object. By attaching bricks to the control points of an object (e.g. a spline curve) users can perform more complex manipulations. The metaDESK of Ullmer and Ishii extends this idea by creating physical icons that serve as specialized handles and tools who’s physical constraints translate to digital constraints in the software. Hinkley’s system for neurosurgical visualization used tracked physical props including a head model and a rectangular plate. These props serve to do more than provide 6 DOF input—their shape gives the user a tangible clue as to the state of the system.

3.5 Continuous Multi-touch Interaction

This dissertation is particularly concerned with continuous, coordinated multi-touch control of multiple parameters. Several systems show examples of this type of control. Most of the techniques fall into one of three categories: 1D valuators or sliders, object transport and scaling, and specification of rectangles.

Buxton first introduced the idea of partitioning a multi-touch digitizer into strips to emulate a bank of sliders such as those found in audio mixers and studio light control panels [46]. A similar technique is described by Blask´o and Feiner, although in their system multiple contacts are used to increase the effective number of strips rather than for parallel control [47]. Benko et al. [48] take a different tack, and use the distance between two contact points to adjust the control-display ratio between a touchscreen and a cursor. A similar idea is used by Morris et al. [49] where the distance between one user’s fingers on a table controls the width of a stroke drawn by another user.

Rekimoto [3] first introduced a technique for using two or more fingers to simultaneously translate, rotate, and scale a 2D object. The system finds a similarity transformation that is most similar, in a least-squares sense, to the transformation of the fingers, and applies it to the selected item. A similar two-finger technique is used by Wu [25]. Wilson [50] takes a related approach, by finding a rigid transformation that matches the optical flow of the user’s hand. Malik et al. [9] take a slightly different approach to translating and rotating items, by measuring the change in a single finger’s position and orientation, and applying it to the object.

Dietz and Leigh [2] show how two contact points can determine an axis aligned rectangle. This technique was later used by Forlines and Shen [51] to specify regions of -interest for fish-eye-lenses. Benko et al. [48] uses a similar technique for zoompointing. One finger is used to specify the initial center of a rectangle to magnify, while the other stretches the rectangle. After the center has been specified, the first finger is used to precisely point at a small target.

A few multi-touch techniques do not fall into the above classes. Rekimoto [3] shows a curve manipulation techniques where four finger contact points are mapped to the control-points of a B´ezier curve. The work also shows an example of "potential field" manipulation, where objects slide down the gradient of a distance field from the touch-surface to the hand. A different type of interaction is described by Malik et al. [52] where one hand positions the works space of the other to access a large display.

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