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Dynamic and static hand gesture recognition through low-level image analysis
US 5454043 A

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ABSTRACT

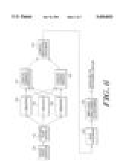
A low-level model-free dynamic and static hand gesture recognition system utilizes either a 1-D histogram of frequency of occurrence vs. spatial orientation angle for static gestures or a 2-D histogram of frequency of occurrence vs. space-time orientation for dynamic gestures. In each case the histogram constitutes the signature of the gesture which is used for gesture recognition. For moving gesture detection, a 3-D space-time orientation map is merged or converted into the 2-D space-time orientation histogram which graphs frequency of occurrence vs. both orientation and movement. It is against this representation or template that an incoming moving gesture is matched.

IMAGES (7)









DESCRIPTION

FIELD OF INVENTION

This invention relates to computer interfaces and more particularly to gesture recognition for computer control.

BACKGROUND OF THE INVENTION

As will be appreciated, there are a variety of computer interface devices for control by hand namely, the mouse, the pen, the joystick, the trackball, and more recently, the data glove. While these devices are presently satisfactory for many applications, some systems require more flexibility for convenient computer control.

By way of example, data gloves which fit over the human hand with an umbilical line to the computer control the motion of icons such as flying figures which move through a virtual reality scene. The use of such a data glove is both cumbersome and expensive in view of the numbers of internal sensors within the data glove and the trouble of having to take it on and off. As a result, researchers have searched for computer control systems which are not so hardware dependent. Gesture recognition is one such class of systems.

The detection of gestures is important because not only does the orientation of the hand give valuable information, so does hand movement. Thus, while a thumbs up static gesture may indicate approval, this same gesture when moving can indicate "thumbing" or the request for a ride. Likewise, although the attitude of a hand is detectable, it is the detection of its dynamic movement which more

CLAIMS (7)

What is claimed is:

1. A machine for detecting a dynamic gesture comprising:

means for providing a training histogram corresponding to a predetermined gesture;

means for generating a video image of a gesturing object;

means for generating a 3-D dynamic gesturing object map corresponding to said video image, points on said image of said dynamic gesturing object each having a local spario-temporal image orientation, said 3-D map including vectors graphing frequency of occurance vs. spatio-temporal orientation;

means for converting said 3-D map into a 2-D histogram graphing angular orientation of the vectors of said 3-D map against position:

means for comparing said histograms; and,

means for indicating a match between said histograms, thereby to detect said gesture.

2. The machine of claim 1, wherein said histogram generating means includes means for taking the derivative of the intensity of the video image of said gesture with respect to two orthogonal directions.

3. The machine of claim 2, wherein said histogram generating means

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In the past, as reported in the March 1992 IEEE conference proceedings, IEEE catalog number 92CH3168-2, entitled "Recognizing Human Action In Time Sequential Images Using Hidden Markov Model" by Yamato, Ohya and Ishii of the NTT Human Interface Laboratories in Yokosuka, Japan, a hand gesture recognition system is described that takes static pictures of some action and utilizes the Hidden Markov Model to infer which of a set of possible gestures a given video input corresponds to. However, such an approach, which was originally developed for speech recognition purposes, can be computationally intense. Another problem with respect to this approach to gesture recognition is that it measures motion only inferentially. This is due to the fact that motion between various of the pictures is never represented or calculated.

As described in a paper delivered at the Imagina '93 Conference entitled "A Human Motion Image Synthesizing By Model-Based Recognition From Stereo Images" authored by Ishii, Mochizuki and Kishino, another approach to vision-based hand gesture recognition employs a stereo camera method. Here a model of the human figure is employed, with the model being fit to stereo range data in order to infer the angles between the joints and therefore the orientation of the arm or hand.

The most serious problem with such a system is that it is model based in that if one wishes to have this work on other than a human figure, a new model must be introduced. As will be appreciated, this system is not a "low level" system because it relies on high level models in the recognition process.

Additionally, as described in MIT Media Laboratory Vision And Modeling Group Technical Report No. 197 entitled "Recognition of Space Time Gestures Using a Distributed Representation" by Trevor J. Darrell and Alex P. Pentland, gestures are detected from a series of templates, not unlike a series of pictures. Gestures are identified in this system by a sequence of static hand positions, where a particular hand position is determined by taking the template and convolving it with the entire image to find the best fit. Even though this technique offers a so-called "low level" approach because high level models are not used, the Darrell/Pentland technique is even more computationally intensive than the above-mentioned Yamato-Ohya-Ishii system due to the need for convolution with large masks. Also, being intensity-based, this system is not particularly robust for changes of lighting, and like the other systems described above, does not measure motion directly but rather analyzes a sequence of static poses.

By way of further background, it will be appreciated that so-called "orientation histograms" have been utilized for texture analysis. This work is described by Mojgan Monika Gorkani of the MIT Media Laboratory, published in the MIT Media Laboratory Perceptual Computing Group Technical Report, No. 222, May, 1993. In this paper, orientation histograms are developed for the purpose of analyzing "textures" by looking at local peaks in the orientation histogram. However, detecting only histogram peaks throws out or destroys certain relevant information which is useful in analyzing static or dynamic gestures.

As an application for gesture recognition, recently, there has been interest generated in so-called teleconferencing. In teleconferencing, rather than transmitting full frame video, various scenarios are depicted at the teleconferencing site. What is actually shown to the teleconference participants is determined by, for instance, hand gestures or head gestures, or a combination of both. Such a system is described in IEEE Transactions on Pattern Analysis of Machine Intelligence, Volume 15, No. 6, June 1993, in an article entitled "Visually Controlled Graphics" by A. Azarbayejani, T. Starner, B. Horowitz, and A. Pentland. In this system corner points are detected as the features of interest, with the corners then being tracked in space and time to determine head position. It will be appreciated that this system is not particularly well adapted to articulated objects, like the human hand.

In summary, most hand-controlled human-computer interface devices have severe limitations. The mouse, the pen and the trackball only give two-dimensional position information. Also, the joystick only gives information about two angles. All these methods require physical hardware for the hand to hold, which is cumbersome to have to carry, pick-up or grasp.

In an effort to get away from physical hardware, model-based visual methods for recognizing hand gestures have been developed, but tend to be slow, because there are many possible ways a hand could be fitted to the visual data. Furthermore, model-based methods require the generation of a new model, and potentially a redesign of the entire algorithm in order to extend the work to analyze non-hand inputs.

It will be appreciated that what people perceive as a gesture is not simply a series of static snapshot type poses of a particular object, such as a hand, but rather what is perceived is the motion of the hand between these static poses. Thus while a system which tries to measure gestures may incorporate the static snapshots of the object as it goes through its motion, it should also describe or recognize the motion itself. Since none of the above systems measure motion directly, they are incapable of the type of gesture recognition which is required.

video image with respect to time.

4. The machine of claim 2, and further including means for taking the arc tangent of said derivatives to obtain the dominant angle of said video image.

5. The machine of claim 2, and further including means for taking the sum of the squares of said derivatives to provide a gradient strength measurement and means for rejecting from the generation of a histogram gradient strength below a predetermined threshhold.

6. The machine of claim 1, and further including means for blurring said histograms to provide a smooth histogram signature.

7. The machine of claim 1, and further including means for applying local gain control to said histograms.

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In order to recognize gestures, in the Subject System the task is broken down into two components, the static and the dynamic. First, in order to analyze the static component, the Subject System analyzes the visual image based on local spatial orientation in the image. For instance, for recognizing static hand position, the distribution of spatial orientations over the image is detected and a spatial orientation map is generated. From the spatial orientation map, a characteristic "signature vector" is derived which characterizes the particular hand position. In one embodiment, the signature vector is a 1-D histogram of the frequency with which each particular orientation occurs in the image graphed against orientation or angle. This is a low level approach because no model of the gesturing object is required.

It will be appreciated for static image analysis that this 1-D histogram is a histogram over space as opposed to over time. This means that what is detected is the set of orientations of the object as they occur in particular positions in space. More specifically, the static case histogram is a graph of frequency of occurrence versus orientation or angle, and it is this histogram which forms the signature for static gesture recognition. In one embodiment, this signature is intentionally blurred by convolution with a low pass filter to provide a smooth signature for signature matching purposes.

Once having derived this low-level image signature, one can compare a signature derived from an actual video camera output with a stored set of signatures. Closest match or curve-fitting techniques are utilized to determine which of the stored signatures has the closest match to the signature of the incoming video signal to identify the hand pose or the static gesture. Even so, static gesture recognition alone may not be sufficient for gesture recognition.

When a gesture is more than just a frozen orientation, motion must also be detected. This motion is directly measured in the Subject System by first deriving a 3-D space, time, orientation map. This map is a 3-D plot of spatio-temporal orientations as a function of space and time. Definitionally, this is a plot in 3-D space-time of unit vectors oriented in the direction of the local spario-temporal image intensity gradient. The spatio-temporal image intensity gradients are found by taking derivatives of the image intensity as a function of horizontal, vertical and temporal position.

It is this 3-D map which is converted into a 2-D histogram or template for dynamic gesture matching.

As will be seen the 2-D template combines orientation with movement to characterize a gesture. For instance, a 2-D space-time orientation histogram or template of a thumbing gesture would be an eyebrow curve, with the beginning of the eyebrow starting at zero movement with a stationary thumb at 0°. As the thumb moves to the right the eyebrow curve goes up indicating movement to the right. The eyebrow curve goes down as the thumb ends up stationary at 90°. This 2-D template signature thus uniquely defines the usual thumbing motion.

It will be appreciated that this template is the reference for a moving gesture to which other moving gestures are matched. Thus orientation and movement are accounted for in one template. This technique involving a 3-D space-time-orientation map converted to a 2-D space-time orientation histogram, while being somewhat more computationally intensive than the static low level system described for static images, is easily implemented through well known image processing techniques to provide a unique measure of gesturing.

Note, the subject gesture recognition system while initially achievable through a novel static histogram technique, is improved through the measurement of motion directly through the utilization of 2-D space-time orientation histograms.

Note also that one could average the 2-D space-time orientation histogram of a particular gesture over several different users in order to obtain a space-time orientation histogram reference which is substantially user independent.

In one embodiment for deriving static orientations, spatial filtering provides the x derivative and the y derivative of the video input signal, with the arc tangent of the pair being taken to obtain the spatial orientation. This output may optionally be multiplied by two, and wrapped to zero and 360°. Here, the multiplier and the wrapping are optional to convert the angle measurement to the sign of contrast-independent orientation measurements. However, in some cases, the sign of contrast dependent orientation measurements are sufficient. The arc tangent operation provides the angle of the object, whereas contrast strength is achieved by taking the x and y derivatives and summing their squares. It will be appreciated that contrast strength may be utilized as a threshhold so that angles or orientations having a strength below a certain threshhold are ignored. This is useful in cancelling low-contrast noise in the area surrounding the object.

Having derived the static case histogram as being one of the frequency of occurrence versus orientation, the utilization of the aforementioned blurring technique permits recognition of an angle which is slightly off. This technique provides a process by which angles which are close are detected as one angle, versus an angle which is clearly different.

In terms of recognizing dynamic gesturing, an image is initially digitized as a sequence, followed by low pass spatial filtering and then x, y and z derivatives. This set of derivatives is utilized to compute the spatio-temporal orientation, with the derivatives also utilized to compute contrast strength, thereby to compute the space-time-orientation map. The 3-D space-time-orientation map is then converted to a 2-D space-time orientation histogram by recording, for each possible spatio-temporal orientation represented in the space-time orientation histogram, the number of occurrences of that orientation in the space-time orientation map.

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This histogram may optionally be blurred for the reasons noted above. The output after blurring is then applied to a local gain control to assure that small regions of the image are not swamped by the large regions. This permits recognition of small but characteristic motions which are useful identifiers for a gesture. The output after local gain control is the signature of the dynamic gesture.

Thus the subject dynamic and static hand gesture recognition system for computer control utilizes either a spatial orientation histogram for static images, or a space-time orientation histogram for dynamic gesture recognition. Typically, orientation signatures are derived in a training sequence for a number of different hand positions. Thereafter, a run time algorithm detects a digitized version of the video hand image and directs the requested computer action in accordance with detected hand pose or configuration. Both static and dynamic actions are recognized, with the system capable of detecting normal human hand movement to indicate, for instance, "turn around", "go to the left", or "hello". Static gestures include placing the hand at a particular orientation, with the computer ascertaining the angles describing that orientation.

The system is also capable of recognizing or classifying other visual inputs as well, including, for example, detecting people walking in a video. Applications for more general low-level visual analysis include surveillance, and content-based access to multi-media databases, in which a database can be queried for moving or static images of a predetermined type.

The advantages with the present approach to gesture recognition are first, that the signature vectors are based on local orientation, which is relatively robust to chages in lighting. Secondly, the signature vectors are easy and fast to compute. Additionally, the Subject System is a low-level system and therefore can be used to analyze inputs other than just hand gestures. Finally, the dynamic gesture recognition directly measures motion because it includes motion information contained in the signature vector. This yields gesture characterizations which are in agreement with human perceptual characterizations.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the Subject Invention will be better understood taken in conjunction with the Detailed Description in conjunction with the Drawings of which:

FIG. 1 is a diagrammatic representation of dynamic gesture recognition for the control of a moveable icon on a CRT or display;

FIG. 2A is a diagrammatic representation of a thumbing gesture in one of a number of angular orientations of the thumb;

FIG. 2B is a diagrammatic representation of a 3-D space-time-orientation map of the thumb during the thumbing gesture of FIG. 2A;

FIG. 2C is a 2-D template illustrating an eyebrow-type curve which is the result of the detection by the Subject System of the thumbing motion illustrated in FIG. 2A;

FIG. 3 is a diagrammatic, photographic and schematic diagram illustrating the calculation of the signature vector for a static image from a digitized image of a hand through the formation of a frequency of occurrence vs. orientation histogram which has been optionally smoothed;

FIG. 4 is a diagrammatic, photographic and schematic illustration of the orientation histograms illustrated for various hand positions, showing the characteristic histogram signatures for both an unsmoothed and smoothed orientation histogram;

FIG. 5 is a diagrammatic representation of test results of the static gesture recognition algorithm associated with the detection system of FIG. 3, illustrating that detected hand orientations are in fact intermediate those of the preloaded training images; and,

FIG. 6 is a block diagram illustrating the system utilized to provide a dymanic gesture histogram.

DETAILED DESCRIPTION

Referring now to FIG. 1, it is important for the control of icon 10 displayed at a display 12, that the position of the icon be determined not by hardware operated inputs but rather through gesture recognition in which a video camera 14 scans the hand 16 of an individual 18 in order to determine what the icon should do or more generally what the computer action should be upon hand signal recognition.

As illustrated, the hand is moved in a dotted path 20 to simulate the flight of an airplane, with icon 10 being controlled by virtue of scanning the hand and providing a digital image thereof for processing. For dynamic gesture recognition the processing, as will be seen, includes an algorithm which generates a 2-D template which is utilized as a low-level system to detect various moving gestures.

Prior to describing static gesture recognition which is a part of the dymanic gesture recognition system, it will be appreciated

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that the thumb makes with the vertical. As can be seen, at the start of a thumbing gesture the thumb is in a vertical position at 0°. Thereafter as illustrated at 30', the thumb is moved to 20°, whereas as shown at 30", the thumb moves through 45°, then coming to rest as shown at 30"' at 90°. It will be appreciated that the tip of the thumb is in fact moving to the right. Of course, in normal thumbing gestures the arm as well as the thumb is moving to the right.

What will be appreciated is that rather than a static gesture of an upwardly pointing thumb indicating, for instance, approval, or downwardly pointing thumb indicating, for instance, disapproval, the Subject System is capable of recognizing a moving gesture in which in this case the thumb has moved from a vertical position to a horizontal position, but is also moving in time from one position to the other.

In the Subject System this is captured by a system which generates a 3-D map, as illustrated at FIG. 2B, which in essence captures the digital image 40 at various time positions 40', 40", etc., with the positions being on the time axis 42 as illustrated. As will be seen, unit vectors 44 have their origins at the tip of the thumb, and are oriented in the dominant direction of the thumb over time. Thus as can be seen for the dynamic gesture recognition of a thumbing gesture, the orientation of vectors 44 rotate to the right as would be appropriate in tracking the dominant direction of the thumb during the thumbing motion.

Once having derived the 3-D map through a technique to be described hereinafter, it is then necessary to convert or merge the 3-D map into a 2-D template or histogram as illustrated in FIG. 2C. As will be described, this can be done conveniently with the above-listed algorithms. For present purposes, it will be noted that the 2-D template graphs spatial orientation against movement. Here, while movement to the left and right is depicted, the graphed movement is more precisely either along the spatial gradient or against the spatial gradient. It will be also appreciated that there is a vertical 0° axis shown at 46 and a horizontal 0° axis shown at 48.

Analyzing the thumbing gesture, it will be appreciated that the thumb is originally at 0° and is not moving at all. This is the origin of the graph as illustrated by point 50. As the thumb rotates from 0° through to 9° the position of occurrences moves out along the horizontal, whereas movement is denoted by a vertical rise in the position of the occurrrences of an angular orientation above horizontal line 48. The generation of the 2-D template is that against which all subsequent movements are matched by typical curve matching techniques.

Referring now to FIG. 3, the determination of the histogram for the static gesture is described as follows. First, a digitized image 50 of a hand is provided. The image is low pass filtered at 52 and subsampled at 54 to provide a subsampled image 56 as illustrated. The subsampled image is then utilized in the taking of the x derivative and the y derivative as illustrated at 58 and 60, respectively. These two derivatives form the aforementioned gradient spatial intensity. An arc tangent operation is performed at 62 to derive the particular angle 67 which has been detected. Optionally to convert angle measurement to contrast independent orientation measurement, the result is multiplied by two as illustrated at 64 and is wrapped to 0° or 360° as illustrated at 66. The result of this operation is the detection of the dominant angle which is then applied to a unit 68 which provides a histogram of the frequency of occurrence of an angle as a function of angular orientation for all of those data points which are above a given image intensity strength threshhold. The gradient strength is derived as follows.

The outputs of the x and y derivative generating units 58 and 60 are combined in a squaring operation by a squaring unit 70, with the squares indicating the gradient strength of the particular data point in question. The strength is applied to unit 68 with the threshhold 72 being set such that angles corresponding to image intensity gradients under a predetermined threshhold will be ignored.

The output of histogram generator 68 is a graph as illustrated at 74 of the frequency of occurrence of a given angle vs. orientation or angle. This produces a jagged signature 76 which, with conventional blurring 78, produces a smooth signature of the static gesture as illustrated at 80. It will be appreciated that it is also possible to optionally apply local gain control to the histogram.

For static gesture recognition, the spatial intensity gradient from which the histogram is developed is: ##EQU1## where x, y are unit vectors in the x and y directions, respectively.

The 1-D histogram is generated as follows: ##EQU2##

For dynamic gesture recognition ##EQU3## is added such that the dynamic gesture gradient is ##EQU4## whose t is a unit vector in the temporal direction.

For the 2-D dynamic gesture histogram ##EQU5## where φ=orientation and ⊖=movement.

In general, static gesture analysis starts with a spatial orientation map that one gets when one takes the 2-D gradient and finds the orientation everywhere. From the spatial orientation map, one forms a 1-D spatial orientation histogram by the following algorithm:

1) raster scan the (2-d) spatial orientation map

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2) read-out orientation of each vector

3) go to the (1-d) spatial orientation histogram and add "1" to the count value stored at the orientation corresponding to this vector.

4) continue, from step 1, for the whole spatial orientation map.

Note that for static gesture recognition there is a training phase in which static histogram signatures are developed. In one embodiment, the steps involved in the training phase for a static gesture recognition implementation are as follows. First, the computer displays a target orientation indicator usually by crosshairs. Secondly, the individual orients his hand to match the orientation of the target by placing his fingers in the direction of the crosshairs. Thirdly, the computer digitizes the image of the hand and calculates and stores corresponding signature vectors along with target orientation information. Next, the computer displays the next target orientation indicator and the individual orients his hand to the newly oriented crosshairs. Thereafter the computer digitizes the image of the hand and calculates and stores the signature vector target orientation for this particular orientation, with the steps being repeated until such time as the training sequence have a significant number of signatures against which to match incoming information.

In one embodiment, interpolation is used in signature matching. In one embodiment, a common interpolation is used in which the computer calculates and stores the coefficients for the interpolation function. The interpolation function allows fast calculation of orientation as a function of signature vector.

Note that in order to obtain hand orientation as a function of image signature vector one can use any of several well-known interpolation techniques, such as linear interpolation or radial basis functions. In this example, one can use gaussian radial basis functions. Assuming $\varphi=F(v)$ has the form

$$\varphi=ae^{-}\|v1-v\|^{2}/2\sigma^{2}+be^{-}\|v2-v\|^{2}/2\sigma^{2}+ce^{-}\|v3-v\|^{2}/2\sigma^{2}$$

One can pick the parameter σ by trial and error. A good value to use is the average distance between all the training vectors.

In order to find a, b and c, these can be found by enforcing that the function F yield the known values for for v=the training vectors. For this example, this gives the matrix equation, ##EQU6## By pre-multiplying both sides of the above equation by the inverse of the matrix A, one can find the desired values of a, b and c.

In the run time phase for static gesture recognition, an individual places his hand at some orientation in view of a camera. The computer digitizes the hand image and converts it to a signature vector. Then the computer calculates orientation of the hand from the interpolation function, which uses the training signature vectors, at their respective orientations and the interpolation coefficients. Next the computer changes the display or operates in some way in response to the calculated values of the hand. For example, it may simulate tilting the aircraft of FIG. 1 to have the orientation of the hand. Finally, all of the steps are repeated for different static gestures.

Referring now to FIG. 4, a series of digitized static images of a hand at different angles, namely images 82, 84 and 86 result in training histograms 82', 84' and 86'. The corresponding smooth histograms are illustrated at 82", 84" and 86".

Referring now to FIG. 5, the results of utilizing the Subject System with static gestures illustrates that for intermediate hand positions 90 and 92, the detected angular response lies along a dotted line 94 which includes training points at 10° as illustrated by point 96, 20° as illustrated by point 98 and 30° as illustrated by point 100. The corresponding images and signature vectors are illustrated at corresponding points 106, 108 and 110, with the corresponding signature vectors at 112, 114 and 116.

As can be seen, dominent training image angles lie along a dotted line 94 corresponding to images 106, 108 and 110. These are the detected angles corresponding to the dominant position of the hands in these digitized images. The data points illustrated at 120 and 122 indicate detection of the dominant position through signatures 124 and 126, respectively, derived from the corresponding digitized image of the hand.

Note that for training images, the angular orientation of the hand was prespecified, whereas for test images the angular orientation was calculated by the subject algorithm presented herewith.

Referring now to FIG. 6, as mentioned hereinbefore, the dynamic gesture recognition system makes use of the same technique for determining gradients as described in connection with the static gesture recognition system. As can be seen from FIG. 6, the image is digitized to provide a digitized image sequence as illustrated at 130. This image is low pass spatially filtered as illustrated at 132 from whence x, y and t derivative generators, respectively, 134, 136 and 138 provide the derivatives with respect to the x, y and t directions corresponding to the 3-D map of FIG. 2B.

After having generated the 3-D map of FIG. 2B by virtue of the utilization of derivatives, unit 137 computes the dominant orientation, usually in terms of polar coordinates of the space-time intensity gradients associated with the moving gesture.

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movement. The algorithm for doing the merge or conversion is given hereinafter. Note that means 139 are provided for computing contrast strength so as to be able to ignore image intensities below a preset threshhold.

Having generated the histogram which takes into account both orientation and movement as described above, the histogram may be blurred as illustrated at 142 to smooth the data. Again, local gain control may be applied to the histogram as illustrated at 144 to derive the characteristic signature for the dynamic gesture.

It will be appreciated that the system of FIG. 6 is utilized both in a training mode so as to derive 2-D template signatures against which signatures corresponding to incoming gestures are compared. Again, conventional interpolating techniques are utilized in the curve-matching or more specifically histogram-matching of the incoming histogram vs. those stored in a training sequence.

Note, in order to provide a characteristic signature or template for a dynamic gesture, this 3-D space-time-orientation map is converted into a 2-D space-time orientation histogram which graphs frequency of occurrence versus gesture angle and gesture movement by the following algorithm:

1) raster scan the (3-d) space-time-orientation map;

2) read-out the orientation of each vector;

3) go to the (2-d) histogram and add "1" to the count value stored at the orientation corresponding to this vector;

4) continue, from step 1, for the whole space-time-orientation map.

Spario-temporal orientation can be described in polar coordinates in the space-time orientation histogram, much like latitude and longitude coordinates in a map of the world. The longitude coordinate represents spatial orientation of the image information. The latitude coordinate represents the amount of motion in the direction of that spatial orientation. The "equator" or 0 degree latitude line represents zero motion, or stationary image information. The total number of counts along the 0 degree latitude line of the space-time orientation histogram indicates how much of the gesture was made of stationary image formation.

The 0 degree longitude line represents horizontally oriented image information. The number of counts of the 2-D space-time orientation histogram at the 0 degree longitude, 0 degree latitude position indicates how much of the gesture was composed of stationary, horizontally oriented image information. Higher latutude positions along the 0 degree longitude position indicate the amount of image information which was horizontally oriented, moving at some speed in the direction perpendicular to its horizontal spatial orientation, or vertically.

As to dynamic gesture recognition, in one test, a set of 16 gestures requiring hand movement was utilized as the histogram signature base. Such gestures included circular stirring motions by the hand; snapping of fingers; up, down, left, right gesturing for pointing purposes; hand motions to come closer and go away; waving goodbye; and a thumbs up hand gesture. In an initial test when utilizing the Subject space-time-orientation histogram for a given set of lighting conditions, 15 out of 16 different dynamic gestures were successfully recognized, whereas with different lighting conditions 10 out of 16 gestures were successfully recognized. While there was some degradation in performance under the different lighting condition, a relatively high recognition rate was maintained. It will be appreciated that because this gesture analysis is based on image orientation, which is robust to lighting changes, rather than image intensities, which can very strongly under different lighting conditions, a good amount of robustness to lighting conditions is maintained.

What is provided therefore is a system both for static gesture recognition and moving gesture recognition in which both systems utilize a histogram that constitutes a signature against which gestures are compared. The static gesture is a histogram of frequency of occurrence vs. orientation angle, whereas the moving dynamic gesture histogram utilizes spatial orientation information along with time information to generate a histogram reflective of not only angular orientation but also movement.

In summary, a low-level model-free dynamic and static hand gesture recognition system utilizes either a 1-D histogram of frequency of occurrence vs. spatial orientation angle for static gestures or a 2-D space-time orientation histogram for dynamic gestures. In each case the histogram constitutes the signature of the gesture which is used for gesture recognition. For moving gesture detection, a 3-D space-time orientation map is merged or converted into the 2-D space-time orientation histogram which graphs frequency of occurrence vs. both orientation and movement. It is against this representation or template that an incoming moving gesture is matched.

More specifically, the moving gesture is detected from the 3-D space-time orientation map merged into the two-dimensional frequency of occurrence vs. angle and movement histogram or template. The 2-D histogram or template is a plot of the frequency of occurrence of a given spatio-temporal orientation. This template is derived from the azimuthal and polar angle of the spatial-temporal gradient vector of the image intensities. The merge from the map to a 2-D space-time orientation histogram facilitates simple moving gesture recognition, with the merge effectively averaging gesture measurement and

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making the measurement independent of the actual time the gesture starts or stops and of the precise position at which the gesture occurs.

For static gesture analysis one starts with a spatial orientation map which is the result of taking a spatial intensity gradient that determines the dominant orientation and finding the orientation for each pixel in the image. Thereafter the characteristic histogram signature is generated. For dynamic gesture analysis one starts with a space-time orientation map, which is the result of taking the gradient of the space-time intensity data and finding spatio-temporal orientations for each pixel in the image. Afterwards the 2-D space-time orientation histogram or template is generated. In both the static and moving gesture embodiments, signatures are derived in a training sequence for a number of different hand positions and/or movements. Thereafter, a run time algorithm operates on a digitized version of the video hand image to detect hand angle and/or movement.

The program for accomplishing both static and dynamic gesture recognition is now presented. ##SPC1##

Having above indicated a preferred embodiment of the present invention, it will occur to those skilled in the art that modifications and alternatives can be practiced within the spirit of the invention. It is accordingly intended to define the scope of the invention only as indicated in the following claims.

PATENT CITATIONS

Cited Patent	Filing date	Publication date	Applicant	Title
US4542657 *	Aug 26, 1983	Sep 24, 1985	General Electric Company	Time domain technique to determine mean frequency
US4567610 *	Jul 22, 1982	Jan 28, 1986	Wayland Research Inc.	Method of and apparatus for pattern recognition
US5010500 *	Jan 26, 1989	Apr 23, 1991	Xerox Corporation	Gesture-modified diagram for retrieval of image resembling diagram, with parts selectable for further interactive retrieval
US5047952 *	Oct 14, 1988	Sep 10, 1991	The Board Of Trustee Of The Leland Stanford Junior University	Communication system for deaf, deaf-blind, or non-vocal individuals using instrumented glove
US5138671 *	Nov 14, 1990	Aug 11, 1992	Matsushita Electric Industrial Co., Ltd.	Image processing method for distinguishing object by determining threshold of image lightness values
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US8523667	Mar 29, 2010	Sep 3, 2013	Microsoft Corporation	Parental control settings based on body dimensions
US8526734	Jun 1, 2011	Sep 3, 2013	Microsoft Corporation	Three-dimensional background removal for vision system
US8531396	Sep 3, 2009	Sep 10, 2013	Oblong Industries, Inc.	Control system for navigating a principal dimension of a data space
US8537111	Sep 3, 2009	Sep 17, 2013	Oblong Industries, Inc.	Control system for navigating a principal dimension of a data space
US8537112	Sep 3, 2009	Sep 17, 2013	Oblong Industries, Inc.	Control system for navigating a principal dimension of a data space
US8537231	Jun 11, 2009	Sep 17, 2013	Koninklijke Philips N.V.	User interface system based on pointing device
US8538562	Apr 5, 2010	Sep 17, 2013	Motion Games, Llc	Camera based interactive exercise
US8542252	May 29, 2009	Sep 24, 2013	Microsoft Corporation	Target digitization, extraction, and tracking
US8542910	Feb 2, 2012	Sep 24, 2013	Microsoft Corporation	Human tracking system
US8548270	Oct 4, 2010	Oct 1, 2013	Microsoft Corporation	Time-of-flight depth imaging
US8553079	Dec 14, 2012	Oct 8, 2013	Timothy R. Pryor	More useful man machine interfaces and applications
US8553934	Dec 8, 2010	Oct 8, 2013	Microsoft Corporation	Orienting the position of a sensor
US8553939	Feb 29, 2012	Oct 8, 2013	Microsoft Corporation	Pose tracking pipeline
US8558873	Jun 16, 2010	Oct 15, 2013	Microsoft Corporation	Use of wavefront coding to create a depth image
US8564534	Oct 7, 2009	Oct 22, 2013	Microsoft Corporation	Human tracking system
US8565476	Dec 7, 2009	Oct 22, 2013	Microsoft Corporation	Visual target tracking
US8565477	Dec 7, 2009	Oct 22, 2013	Microsoft Corporation	Visual target tracking
US8565485	Sep 13, 2012	Oct 22, 2013	Microsoft Corporation	Pose tracking pipeline
US8565535 *	Aug 20, 2008	Oct 22, 2013	Qualcomm Incorporated	Rejecting out-of-vocabulary words
US8569679	Nov 17, 2010	Oct 29, 2013	Silicon Laboratories Inc.	System and circuit including multiple photo detectors and at least one optical barrier
US8570378	Oct 30, 2008	Oct 29, 2013	Sony Computer Entertainment Inc.	Method and apparatus for tracking three-dimensional movements of an object using a depth sensing camera
US8571263	Mar 17, 2011	Oct 29, 2013	Microsoft Corporation	Predicting joint positions
US8577084	Dec 7, 2009	Nov 5, 2013	Microsoft Corporation	Visual target tracking
US8577085	Dec 7, 2009	Nov 5, 2013	Microsoft Corporation	Visual target tracking
US8577087	Jul 6, 2012	Nov 5, 2013	International Business Machines Corporation	Adjusting a consumer experience based on a 3D captured image stream of a consumer response
			Microsoft	

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Citing Patent	Filing date	Publication date	Applicant	Title
US8582866	Feb 10, 2011	Nov 12, 2013	Edge 3 Technologies, Inc.	Method and apparatus for disparity computation in stereo images
US8587583	Jan 31, 2011	Nov 19, 2013	Microsoft Corporation	Three-dimensional environment reconstruction
US8587773	Dec 13, 2012	Nov 19, 2013	Microsoft Corporation	System architecture design for time-of-flight system having reduced differential pixel size, and time-of-flight systems so designed
US8588464	Jan 12, 2007	Nov 19, 2013	International Business Machines Corporation	Assisting a vision-impaired user with navigation based on a 3D captured image stream
US8588465	Dec 7, 2009	Nov 19, 2013	Microsoft Corporation	Visual target tracking
US8588517	Jan 15, 2013	Nov 19, 2013	Microsoft Corporation	Motion detection using depth images
US8592739	Nov 2, 2010	Nov 26, 2013	Microsoft Corporation	Detection of configuration changes of an optical element in an illumination system
US8595218	Jun 12, 2009	Nov 26, 2013	Intellectual Ventures Holding 67 Llc	Interactive display management systems and methods
US8597142	Sep 13, 2011	Dec 3, 2013	Microsoft Corporation	Dynamic camera based practice mode
US8600196	Jul 6, 2010	Dec 3, 2013	Google Inc.	Optical scanners, such as hand-held optical scanners
US8605763	Mar 31, 2010	Dec 10, 2013	Microsoft Corporation	Temperature measurement and control for laser and light-emitting diodes
US8610665	Apr 26, 2013	Dec 17, 2013	Microsoft Corporation	Pose tracking pipeline
US8610831 *	Oct 12, 2010	Dec 17, 2013	Nokia Corporation	Method and apparatus for determining motion
US8611607	Feb 19, 2013	Dec 17, 2013	Microsoft Corporation	Multiple centroid condensation of probability distribution clouds
US8613666	Aug 31, 2010	Dec 24, 2013	Microsoft Corporation	User selection and navigation based on looped motions
US8614668	Oct 6, 2011	Dec 24, 2013	Motion Games, Llc	Interactive video based games using objects sensed by TV cameras
US8614673	May 30, 2012	Dec 24, 2013	May Patents Ltd.	System and method for control based on face or hand gesture detection
US8614674 *	Jun 18, 2012	Dec 24, 2013	May Patents Ltd.	System and method for control based on face or hand gesture detection
US8618405	Dec 9, 2010	Dec 31, 2013	Microsoft Corp.	Free-space gesture musical instrument digital interface (MIDI) controller
US8619122	Feb 2, 2010	Dec 31, 2013	Microsoft Corporation	Depth camera compatibility
US8620083	Oct 5, 2011	Dec 31, 2013	Google Inc.	Method and system for character recognition
US8620113	Apr 25, 2011	Dec 31, 2013	Microsoft Corporation	Laser diode modes
US8625837	Jun 16, 2009	Jan 7, 2014	Microsoft Corporation	Protocol and format for communicating an image from a camera to a computing environment
US8625855	Feb 7, 2013	Jan 7, 2014	Edge 3 Technologies Llc	Three dimensional gesture recognition in vehicles
US8627332	Jul 25, 2012	Jan 7, 2014	Elet Systems L.L.C.	Web based video enhancement apparatus, method, and article of manufacture
US8629976	Feb 4, 2011	Jan 14, 2014	Microsoft Corporation	Methods and systems for hierarchical de-aliasing time-of-flight (TOF) systems
US8630457	Dec 15, 2011	Jan 14, 2014	Microsoft Corporation	Problem states for pose tracking pipeline
US8631355	Jan 8, 2010	Jan 14, 2014	Microsoft Corporation	Assigning gesture dictionaries
US8633890	Feb 16, 2010	Jan 21, 2014	Microsoft Corporation	Gesture detection based on joint skipping
US8633914 *	Jun 13, 2013	Jan 21, 2014	Adrea, LLC	Use of a two finger input on touch screens
US8635637	Dec 2, 2011	Jan 21, 2014	Microsoft Corporation	User interface presenting an animated avatar performing a media reaction
US8638363	Feb 18, 2010	Jan 28, 2014	Google Inc.	Automatically capturing information, such as capturing information using a document-aware device
US8638985	Mar 3, 2011	Jan 28, 2014	Microsoft Corporation	Human body pose estimation
US8638989	Jan 16, 2013	Jan 28, 2014	Leap Motion, Inc.	Systems and methods for capturing motion in three-dimensional space

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Citing Patent	Filing date	Publication date	Applicant	Title
US8644609	Mar 19, 2013	Feb 4, 2014	Microsoft Corporation	Up-sampling binary images for segmentation
US8649554	May 29, 2009	Feb 11, 2014	Microsoft Corporation	Method to control perspective for a camera-controlled computer
US8654198	Apr 30, 2012	Feb 18, 2014	Timothy R. Pryor	Camera based interaction and instruction
US8655069	Mar 5, 2010	Feb 18, 2014	Microsoft Corporation	Updating image segmentation following user input
US8655093	Feb 10, 2011	Feb 18, 2014	Edge 3 Technologies, Inc.	Method and apparatus for performing segmentation of an image
US8659547	Oct 20, 2009	Feb 25, 2014	Industrial Technology Research Institute	Trajectory-based control method and apparatus thereof
US8659658	Feb 9, 2010	Feb 25, 2014	Microsoft Corporation	Physical interaction zone for gesture-based user interfaces
US8660303	Dec 20, 2010	Feb 25, 2014	Microsoft Corporation	Detection of body and props
US8660310	Dec 13, 2012	Feb 25, 2014	Microsoft Corporation	Systems and methods for tracking a model
US8666144	Feb 10, 2011	Mar 4, 2014	Edge 3 Technologies, Inc.	Method and apparatus for determining disparity of texture
US8667519	Nov 12, 2010	Mar 4, 2014	Microsoft Corporation	Automatic passive and anonymous feedback system
US8670029	Jun 16, 2010	Mar 11, 2014	Microsoft Corporation	Depth camera illuminator with superluminescent light-emitting diode
US8675915	Dec 14, 2010	Mar 18, 2014	Sony Computer Entertainment America Llc	System for tracking user manipulations within an environment
US8675981	Jun 11, 2010	Mar 18, 2014	Microsoft Corporation	Multi-modal gender recognition including depth data
US8676581	Jan 22, 2010	Mar 18, 2014	Microsoft Corporation	Speech recognition analysis via identification information
US8681255	Sep 28, 2010	Mar 25, 2014	Microsoft Corporation	Integrated low power depth camera and projection device
US8681321	Dec 31, 2009	Mar 25, 2014	Microsoft International Holdings B.V.	Gated 3D camera
US8682028	Dec 7, 2009	Mar 25, 2014	Microsoft Corporation	Visual target tracking
US8687044	Feb 2, 2010	Apr 1, 2014	Microsoft Corporation	Depth camera compatibility
US8693724	May 28, 2010	Apr 8, 2014	Microsoft Corporation	Method and system implementing user-centric gesture control
US8699748 *	Dec 23, 2010	Apr 15, 2014	Industrial Technology Research Institute	Tracking system and method for regions of interest and computer program product thereof
US8702507	Sep 20, 2011	Apr 22, 2014	Microsoft Corporation	Manual and camera-based avatar control
US8705877	Nov 15, 2011	Apr 22, 2014	Edge 3 Technologies, Inc.	Method and apparatus for fast computational stereo
US8707216	Feb 26, 2009	Apr 22, 2014	Microsoft Corporation	Controlling objects via gesturing
US8717469	Feb 3, 2010	May 6, 2014	Microsoft Corporation	Fast gating photosurface
US8718387	Dec 12, 2011	May 6, 2014	Edge 3 Technologies, Inc.	Method and apparatus for enhanced stereo vision
US8723118	Oct 1, 2009	May 13, 2014	Microsoft Corporation	Imager for constructing color and depth images
US8723801	Mar 26, 2013	May 13, 2014	Gesture Technology Partners, Llc	More useful man machine interfaces and applications
US8724887	Feb 3, 2011	May 13, 2014	Microsoft Corporation	Environmental modifications to mitigate environmental factors
US8724906	Nov 18, 2011	May 13, 2014	Microsoft Corporation	Computing pose and/or shape of modifiable entities
US8736548	Mar 26, 2013	May 27, 2014	Timothy R. Pryor	Interactive video based games using objects sensed by TV cameras
US8743076	Jan 21, 2014	Jun 3, 2014	Lester F. Ludwig	Sensor array touchscreen recognizing finger flick gesture from spatial pressure distribution profiles

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Citing Patent	Filing date	Publication date	Applicant	Title
US8745541	Dec 1, 2003	Jun 3, 2014	Microsoft Corporation	Architecture for controlling a computer using hand gestures
US8749557	Jun 11, 2010	Jun 10, 2014	Microsoft Corporation	Interacting with user interface via avatar
US8751215	Jun 4, 2010	Jun 10, 2014	Microsoft Corporation	Machine based sign language interpreter
US8754910	Oct 1, 2008	Jun 17, 2014	Logitech Europe S.A.	Mouse having pan, zoom, and scroll controls
US8760395	May 31, 2011	Jun 24, 2014	Microsoft Corporation	Gesture recognition techniques
US8760398	Dec 14, 2012	Jun 24, 2014	Timothy R. Pryor	Interactive video based games using objects sensed by TV cameras
US8760571	Sep 21, 2009	Jun 24, 2014	Microsoft Corporation	Alignment of lens and image sensor
US8761434	May 4, 2009	Jun 24, 2014	Sony Computer Entertainment Inc.	Tracking system calibration by reconciling inertial data with computed acceleration of a tracked object in the three-dimensional coordinate system
US8761509	Nov 15, 2011	Jun 24, 2014	Edge 3 Technologies, Inc.	Method and apparatus for fast computational stereo
US8762894	Feb 10, 2012	Jun 24, 2014	Microsoft Corporation	Managing virtual ports
US8773355	Mar 16, 2009	Jul 8, 2014	Microsoft Corporation	Adaptive cursor sizing
US8775916	May 17, 2013	Jul 8, 2014	Microsoft Corporation	Validation analysis of human target
US8781151	Aug 16, 2007	Jul 15, 2014	Sony Computer Entertainment Inc.	Object detection using video input combined with tilt angle information
US8781156	Sep 10, 2012	Jul 15, 2014	Microsoft Corporation	Voice-body identity correlation
US8781228	Sep 13, 2012	Jul 15, 2014	Google Inc.	Triggering actions in response to optically or acoustically capturing keywords from a rendered document
US8782566 *	Feb 22, 2011	Jul 15, 2014	Cisco Technology, Inc.	Using gestures to schedule and manage meetings
US8782567	Nov 4, 2011	Jul 15, 2014	Microsoft Corporation	Gesture recognizer system architecture
US8786576 *	Dec 21, 2010	Jul 22, 2014	Korea Electronics Technology Institute	Three-dimensional space touch apparatus using multiple infrared cameras
US8786730	Aug 18, 2011	Jul 22, 2014	Microsoft Corporation	Image exposure using exclusion regions
US8787658	Mar 19, 2013	Jul 22, 2014	Microsoft Corporation	Image segmentation using reduced foreground training data
US8788973	May 23, 2011	Jul 22, 2014	Microsoft Corporation	Three-dimensional gesture controlled avatar configuration interface
US8798358	Oct 9, 2013	Aug 5, 2014	Edge 3 Technologies, Inc.	Apparatus and method for disparity map generation
US8799099	Sep 13, 2012	Aug 5, 2014	Google Inc.	Processing techniques for text capture from a rendered document
US8803800	Dec 2, 2011	Aug 12, 2014	Microsoft Corporation	User interface control based on head orientation
US8803888	Jun 2, 2010	Aug 12, 2014	Microsoft Corporation	Recognition system for sharing information
US8803952	Dec 20, 2010	Aug 12, 2014	Microsoft Corporation	Plural detector time-of-flight depth mapping
US8810803	Apr 16, 2012	Aug 19, 2014	Intellectual Ventures Holding 67 Llc	Lens system
US8811938	Dec 16, 2011	Aug 19, 2014	Microsoft Corporation	Providing a user interface experience based on inferred vehicle state
US8818002	Jul 21, 2011	Aug 26, 2014	Microsoft Corp.	Robust adaptive beamforming with enhanced noise suppression
US8818040 *	May 3, 2013	Aug 26, 2014	Qualcomm Incorporated	Enhanced input using flashing electromagnetic radiation
US8824732	Jan 24, 2012	Sep 2, 2014	Samsung Electronics Co., Ltd	Apparatus and method for recognizing hand rotation
US8824749	Apr 5, 2011	Sep 2, 2014	Microsoft Corporation	Biometric recognition
US8831365	Mar 11, 2013	Sep 9, 2014	Google Inc.	Capturing text from rendered documents using supplement information
US8843857	Nov 19, 2009	Sep 23, 2014	Microsoft Corporation	Distance scalable no touch computing

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Citing Patent	Filing date	Publication date	Applicant	Title
US8847887	Dec 14, 2012	Sep 30, 2014	Timothy R. Pryor	Interactive video based games using objects sensed by TV cameras
US8854426	Nov 7, 2011	Oct 7, 2014	Microsoft Corporation	Time-of-flight camera with guided light
US8856691	May 29, 2009	Oct 7, 2014	Microsoft Corporation	Gesture tool
US8860663	Nov 22, 2013	Oct 14, 2014	Microsoft Corporation	Pose tracking pipeline
US8861839	Sep 23, 2013	Oct 14, 2014	Microsoft Corporation	Human tracking system
US8864581	Jan 29, 2010	Oct 21, 2014	Microsoft Corporation	Visual based identitiy tracking
US8866785	Dec 26, 2013	Oct 21, 2014	Lester F. Ludwig	Sensor array touchscreen recognizing finger flick gesture
US8866889	Nov 3, 2010	Oct 21, 2014	Microsoft Corporation	In-home depth camera calibration
US8867820	Oct 7, 2009	Oct 21, 2014	Microsoft Corporation	Systems and methods for removing a background of an image
US8869072	Aug 2, 2011	Oct 21, 2014	Microsoft Corporation	Gesture recognizer system architecture
US8874504	Mar 22, 2010	Oct 28, 2014	Google Inc.	Processing techniques for visual capture data from a rendered document
US8878807 *	Mar 11, 2013	Nov 4, 2014	Lester F. Ludwig	Gesture-based user interface employing video camera
US8878810	Jan 21, 2014	Nov 4, 2014	Lester F. Ludwig	Touch screen supporting continuous grammar touch gestures
US8878949	Aug 7, 2013	Nov 4, 2014	Gesture Technology Partners, Llc	Camera based interaction and instruction
US8879831	Dec 15, 2011	Nov 4, 2014	Microsoft Corporation	Using high-level attributes to guide image processing
US8882310	Dec 10, 2012	Nov 11, 2014	Microsoft Corporation	Laser die light source module with low inductance
US8884968	Dec 15, 2010	Nov 11, 2014	Microsoft Corporation	Modeling an object from image data
US8885890	May 7, 2010	Nov 11, 2014	Microsoft Corporation	Depth map confidence filtering
US8888331	May 9, 2011	Nov 18, 2014	Microsoft Corporation	Low inductance light source module
US8891067	Jan 31, 2011	Nov 18, 2014	Microsoft Corporation	Multiple synchronized optical sources for time-of-flight range finding systems
US8891827	Nov 15, 2012	Nov 18, 2014	Microsoft Corporation	Systems and methods for tracking a model
US8891859	Jan 1, 2014	Nov 18, 2014	Edge 3 Technologies, Inc.	Method and apparatus for spawning specialist belief propagation networks based upon data classification
US8892219	Nov 5, 2012	Nov 18, 2014	Motion Games, Llc	Motivation and enhancement of physical and mental exercise, rehabilitation, health and social interaction
US8892495	Jan 8, 2013	Nov 18, 2014	Blanding Hovenweep, Llc	Adaptive pattern recognition based controller apparatus and method and human-interface therefore
US8894489	Mar 5, 2014	Nov 25, 2014	Lester F. Ludwig	Touch user interface supporting global and context-specific touch gestures that are responsive to at least one finger angle
US8896721	Jan 11, 2013	Nov 25, 2014	Microsoft Corporation	Environment and/or target segmentation
US8897491	Oct 19, 2011	Nov 25, 2014	Microsoft Corporation	System for finger recognition and tracking
US8897493	Jan 4, 2013	Nov 25, 2014	Microsoft Corporation	Body scan
US8897495	May 8, 2013	Nov 25, 2014	Microsoft Corporation	Systems and methods for tracking a model
US8898687	Apr 4, 2012	Nov 25, 2014	Microsoft Corporation	Controlling a media program based on a media reaction
US8908091	Jun 11, 2014	Dec 9, 2014	Microsoft Corporation	Alignment of lens and image sensor
US8917240	Jun 28, 2013	Dec 23, 2014	Microsoft Corporation	Virtual desktop coordinate transformation
US8920241	Dec 15, 2010	Dec 30, 2014	Microsoft Corporation	Gesture controlled persistent handles for interface guides
US8926431	Mar 2, 2012	Jan 6, 2015	Microsoft Corporation	Visual based identity tracking
US8928579	Feb 22, 2010	Jan 6, 2015	Andrew David Wilson	Interacting with an omni-directionally projected display

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Citing Patent	Filing date	Publication date	Applicant	Title
US8929612	Nov 18, 2011	Jan 6, 2015	Microsoft Corporation	System for recognizing an open or closed hand
US8929668	Jun 28, 2013	Jan 6, 2015	Microsoft Corporation	Foreground subject detection
US8933884	Jan 15, 2010	Jan 13, 2015	Microsoft Corporation	Tracking groups of users in motion capture system
US8942428	May 29, 2009	Jan 27, 2015	Microsoft Corporation	Isolate extraneous motions
US8942917	Feb 14, 2011	Jan 27, 2015	Microsoft Corporation	Change invariant scene recognition by an agent
US8947347	May 4, 2006	Feb 3, 2015	Sony Computer Entertainment Inc.	Controlling actions in a video game unit
US8953844	May 6, 2013	Feb 10, 2015	Microsoft Technology Licensing, Llc	System for fast, probabilistic skeletal tracking
US8953886	Aug 8, 2013	Feb 10, 2015	Google Inc.	Method and system for character recognition
US8959541	May 29, 2012	Feb 17, 2015	Microsoft Technology Licensing, Llc	Determining a future portion of a currently presented media program
US8963829	Nov 11, 2009	Feb 24, 2015	Microsoft Corporation	Methods and systems for determining and tracking extremities of a target
US8968091	Mar 2, 2012	Mar 3, 2015	Microsoft Technology Licensing, Llc	Scalable real-time motion recognition
US8970487	Oct 21, 2013	Mar 3, 2015	Microsoft Technology Licensing, Llc	Human tracking system
US8970589	Jul 24, 2011	Mar 3, 2015	Edge 3 Technologies, Inc.	Near-touch interaction with a stereo camera grid structured tessellations
US8970707	May 4, 2009	Mar 3, 2015	Sony Computer Entertainment Inc.	Compensating for blooming of a shape in an image
US8970725	Sep 4, 2013	Mar 3, 2015	Koninklijke Philips N.V.	User interface system based on pointing device
US8971612	Dec 15, 2011	Mar 3, 2015	Microsoft Corporation	Learning image processing tasks from scene reconstructions
US8971629	Mar 31, 2011	Mar 3, 2015	Koninklijke Philips N.V.	User interface system based on pointing device
US8976986	Sep 21, 2009	Mar 10, 2015	Microsoft Technology Licensing, Llc	Volume adjustment based on listener position
US8982151	Jun 14, 2010	Mar 17, 2015	Microsoft Technology Licensing, Llc	Independently processing planes of display data
US8983178	Oct 9, 2013	Mar 17, 2015	Edge 3 Technologies, Inc.	Apparatus and method for performing segment-based disparity decomposition
US8983233	Aug 30, 2013	Mar 17, 2015	Microsoft Technology Licensing, Llc	Time-of-flight depth imaging
US8988432	Nov 5, 2009	Mar 24, 2015	Microsoft Technology Licensing, Llc	Systems and methods for processing an image for target tracking
US8988437	Mar 20, 2009	Mar 24, 2015	Microsoft Technology Licensing, Llc	Chaining animations
US8988508	Sep 24, 2010	Mar 24, 2015	Microsoft Technology Licensing, Llc.	Wide angle field of view active illumination imaging system
US8990235	Mar 12, 2010	Mar 24, 2015	Google Inc.	Automatically providing content associated with captured information, such as information captured in real-time
US8994718	Dec 21, 2010	Mar 31, 2015	Microsoft Technology Licensing, Llc	Skeletal control of three-dimensional virtual world
US8994751	Jan 18, 2013	Mar 31, 2015	A9.Com, Inc.	Method and system for placing an object on a user
US9001118	Aug 14, 2012	Apr 7, 2015	Microsoft Technology Licensing, Llc	Avatar construction using depth camera
US9007417	Jul 18, 2012	Apr 14, 2015	Microsoft Technology Licensing, Llc	Body scan

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Citing Patent	Filing date	Publication date	Applicant	Title
US9008355	Jun 4, 2010	Apr 14, 2015	Microsoft Technology Licensing, Llc	Automatic depth camera aiming
US9013489	Nov 16, 2011	Apr 21, 2015	Microsoft Technology Licensing, Llc	Generation of avatar reflecting player appearance
US9015638	May 1, 2009	Apr 21, 2015	Microsoft Technology Licensing, Llc	Binding users to a gesture based system and providing feedback to the users
US9019201	Jan 8, 2010	Apr 28, 2015	Microsoft Technology Licensing, Llc	Evolving universal gesture sets
US9030699	Aug 13, 2013	May 12, 2015	Google Inc.	Association of a portable scanner with input/output and storage devices
US9031103	Nov 5, 2013	May 12, 2015	Microsoft Technology Licensing, Llc	Temperature measurement and control for laser and light-emitting diodes
US9039528	Dec 1, 2011	May 26, 2015	Microsoft Technology Licensing, Llc	Visual target tracking
US9052382	Oct 18, 2013	Jun 9, 2015	Microsoft Technology Licensing, Llc	System architecture design for time-of-flight system having reduced differential pixel size, and time-of-flight systems so designed
US9052746	Feb 15, 2013	Jun 9, 2015	Microsoft Technology Licensing, Llc	User center-of-mass and mass distribution extraction using depth images
US9053381 *	Jan 25, 2013	Jun 9, 2015	Wistron Corp.	Interaction system and motion detection method
US9054764	Jul 20, 2011	Jun 9, 2015	Microsoft Technology Licensing, Llc	Sensor array beamformer post-processor
US9056254	Oct 6, 2014	Jun 16, 2015	Microsoft Technology Licensing, Llc	Time-of-flight camera with guided light
US9058058	Jul 23, 2012	Jun 16, 2015	Intellectual Ventures Holding 67 Llc	Processing of gesture-based user interactions activation levels
US9058063	May 27, 2010	Jun 16, 2015	Sony Computer Entertainment Inc.	Tracking system calibration using object position and orientation
US9063001	Nov 2, 2012	Jun 23, 2015	Microsoft Technology Licensing, Llc	Optical fault monitoring
US9067136	Mar 10, 2011	Jun 30, 2015	Microsoft Technology Licensing, Llc	Push personalization of interface controls
US9069381	Mar 2, 2012	Jun 30, 2015	Microsoft Technology Licensing, Llc	Interacting with a computer based application
US9070019	Dec 21, 2012	Jun 30, 2015	Leap Motion, Inc.	Systems and methods for capturing motion in three-dimensional space
US9075434	Aug 20, 2010	Jul 7, 2015	Microsoft Technology Licensing, Llc	Translating user motion into multiple object responses
US9075441	Apr 2, 2009	Jul 7, 2015	Oblong Industries, Inc.	Gesture based control using three-dimensional information extracted over an extended depth of field
US9075779	Apr 22, 2013	Jul 7, 2015	Google Inc.	Performing actions based on capturing information from rendered documents, such as documents under copyright
US9081799	Dec 6, 2010	Jul 14, 2015	Google Inc.	Using gestalt information to identify locations in printed information
US9092657	Mar 13, 2013	Jul 28, 2015	Microsoft Technology Licensing, Llc	Depth image processing
US9092665	May 22, 2013	Jul 28, 2015	Aquifi, Inc	Systems and methods for initializing motion tracking of human hands
US9098110	Aug 18, 2011	Aug 4, 2015	Microsoft Technology Licensing, Llc	Head rotation tracking from depth-based center of mass
US9098493	Apr 24, 2014	Aug 4, 2015	Microsoft Technology Licensing, Llc	Machine based sign language interpreter
US9098739 *	May 21, 2013	Aug 4, 2015	Aquifi, Inc.	Systems and methods for tracking human hands using parts based template matching
			Microsoft	

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Citing Patent	Filing date	Publication date	Applicant	Title
US9100685	Dec 9, 2011	Aug 4, 2015	Microsoft Technology Licensing, Llc	Determining audience state or interest using passive sensor data
US9111135	Jun 11, 2013	Aug 18, 2015	Aquifi, Inc.	Systems and methods for tracking human hands using parts based template matching using corresponding pixels in bounded regions of a sequence of frames that are a specified distance interval from a reference camera
US9116890	Jun 11, 2014	Aug 25, 2015	Google Inc.	Triggering actions in response to optically or acoustically capturing keywords from a rendered document
US9117281	Nov 2, 2011	Aug 25, 2015	Microsoft Corporation	Surface segmentation from RGB and depth images
US9123255	Sep 4, 2013	Sep 1, 2015	Iplearn-Focus, Llc	Computing method and system with detached sensor in a window environment
US9123316	Dec 27, 2010	Sep 1, 2015	Microsoft Technology Licensing, Llc	Interactive content creation
US9128519	Apr 15, 2005	Sep 8, 2015	Intellectual Ventures Holding 67 Llc	Method and system for state-based control of objects
US9129155	Jun 11, 2013	Sep 8, 2015	Aquifi, Inc.	Systems and methods for initializing motion tracking of human hands using template matching within bounded regions determined using a depth map
US9135516	Mar 8, 2013	Sep 15, 2015	Microsoft Technology Licensing, Llc	User body angle, curvature and average extremity positions extraction using depth images
US9137463	May 12, 2011	Sep 15, 2015	Microsoft Technology Licensing, Llc	Adaptive high dynamic range camera
US9141193	Aug 31, 2009	Sep 22, 2015	Microsoft Technology Licensing, Llc	Techniques for using human gestures to control gesture unaware programs
US9143638	Apr 29, 2013	Sep 22, 2015	Google Inc.	Data capture from rendered documents using handheld device
US9147253	Jun 19, 2012	Sep 29, 2015	Microsoft Technology Licensing, Llc	Raster scanning for depth detection
US9152246 *	Dec 23, 2009	Oct 6, 2015	Sony Corporation	Input apparatus, control apparatus, control system, electronic apparatus, and control method
US9152248 *	Feb 25, 2013	Oct 6, 2015	Ailive Inc	Method and system for making a selection in 3D virtual environment
US9152853	Dec 2, 2013	Oct 6, 2015	Edge 3Technologies, Inc.	Gesture recognition in vehicles
US9153028	Dec 13, 2013	Oct 6, 2015	Leap Motion, Inc.	Systems and methods for capturing motion in three-dimensional space
US9154837	Dec 16, 2013	Oct 6, 2015	Microsoft Technology Licensing, Llc	User interface presenting an animated avatar performing a media reaction
US9159151	Jul 13, 2009	Oct 13, 2015	Microsoft Technology Licensing, Llc	Bringing a visual representation to life via learned input from the user
US9165368	Aug 26, 2011	Oct 20, 2015	Microsoft Technology Licensing, Llc	Method and system to segment depth images and to detect shapes in three-dimensionally acquired data
US9171264	Dec 15, 2010	Oct 27, 2015	Microsoft Technology Licensing, Llc	Parallel processing machine learning decision tree training
US9174119	Nov 6, 2012	Nov 3, 2015	Sony Computer Entertainement America, LLC	Controller for providing inputs to control execution of a program when inputs are combined
US9182814	Jun 26, 2009	Nov 10, 2015	Microsoft Technology Licensing, Llc	Systems and methods for estimating a non-visible or occluded body part
US9191570	Aug 5, 2013	Nov 17, 2015	Microsoft Technology Licensing, Llc	Systems and methods for detecting a tilt angle from a depth image
US9195305	Nov 8, 2012	Nov 24, 2015	Microsoft Technology Licensing, Llc	Recognizing user intent in motion capture system
US9196055 *	Dec 31, 2010	Nov 24, 2015	Nokia Technologies Oy	Method and apparatus for providing a mechanism for gesture recognition
US9208571	Mar 2, 2012	Dec 8, 2015	Microsoft Technology	Object digitization

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Citing Patent	Filing date	Publication date	Applicant	Title
US9208678	Feb 9, 2012	Dec 8, 2015	International Business Machines Corporation	Predicting adverse behaviors of others within an environment based on a 3D captured image stream
US9210401	May 3, 2012	Dec 8, 2015	Microsoft Technology Licensing, Llc	Projected visual cues for guiding physical movement
US9215478	Nov 27, 2013	Dec 15, 2015	Microsoft Technology Licensing, Llc	Protocol and format for communicating an image from a camera to a computing environment
US9223405 *	Mar 14, 2012	Dec 29, 2015	Electronics And Telecommunications Research Institute	Apparatus and method for inputting information based on events
US9224304	Mar 20, 2015	Dec 29, 2015	Iplearn-Focus, Llc	Computing method and system with detached sensor in a network environment
US9229107	Aug 13, 2014	Jan 5, 2016	Intellectual Ventures Holding 81 Llc	Lens system
US9240047 *	Jan 16, 2015	Jan 19, 2016	Kabushiki Kaisha Toshiba	Recognition apparatus, method, and computer program product
US9242171	Feb 23, 2013	Jan 26, 2016	Microsoft Technology Licensing, Llc	Real-time camera tracking using depth maps
US9244533	Dec 17, 2009	Jan 26, 2016	Microsoft Technology Licensing, Llc	Camera navigation for presentations
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US9261979	Aug 20, 2008	Feb 16, 2016	Qualcomm Incorporated	Gesture-based mobile interaction
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US9264807	Jan 23, 2013	Feb 16, 2016	Microsoft Technology Licensing, Llc	Multichannel acoustic echo reduction
US9268404	Jan 8, 2010	Feb 23, 2016	Microsoft Technology Licensing, Llc	Application gesture interpretation
US9268852	Sep 13, 2012	Feb 23, 2016	Google Inc.	Search engines and systems with handheld document data capture devices
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US9280203	Aug 2, 2011	Mar 8, 2016	Microsoft Technology Licensing, Llc	Gesture recognizer system architecture
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US9298287	Mar 31, 2011	Mar 29, 2016	Microsoft Technology Licensing, Llc	Combined activation for natural user interface systems
US9304593 *	Mar 26, 2013	Apr 5, 2016	Cybernet Systems Corporation	Behavior recognition system
US9304677	May 16, 2012	Apr 5, 2016	Advanced Touchscreen And Gestures Technologies, Llc	Touch screen apparatus for recognizing a touch gesture
US9305229	Nov 29, 2012	Apr 5, 2016	Bruno Delean	Method and system for vision based interfacing with a computer
US9310891	Sep 3, 2014	Apr 12, 2016	Aquifi, Inc.	Method and system enabling natural user interface gestures with user wearable glasses
US9311560	Aug 12, 2015	Apr 12, 2016	Microsoft Technology Licensing, Llc	Extraction of user behavior from depth images
US9311715	Oct 31, 2012	Apr 12, 2016	Microsoft Technology Licensing, Llc	Method and system to segment depth images and to detect shapes in three-dimensionally acquired data
US9313376	Apr 1, 2009	Apr 12, 2016	Microsoft Technology Licensing, Llc	Dynamic depth power equalization
US9317128	Mar 17, 2014	Apr 19, 2016	Oblong Industries, Inc.	Remote devices used in a markerless installation of a spatial operating environment incorporating gestural control
US9323337 *	Dec 29, 2010	Apr 26, 2016	Thomson Licensing	System and method for gesture recognition
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US9323784	Dec 9, 2010	Apr 26, 2016	Google Inc.	Image search using text-based elements within the contents of images
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US9342139	Dec 19, 2011	May 17, 2016	Microsoft Technology Licensing, Llc	Pairing a computing device to a user
US9342146 *	Aug 7, 2013	May 17, 2016	Apple Inc.	Pointing-based display interaction
US9347716 *	Feb 28, 2013	May 24, 2016	Mitsubishi Electric Corporation	Indoor unit of air-conditioning apparatus
US9349040	Nov 19, 2010	May 24, 2016	Microsoft Technology Licensing, Llc	Bi-modal depth-image analysis
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US9377863	Mar 24, 2013	Jun 28, 2016	Apple Inc.	Gaze-enhanced virtual touchscreen
US9381424	Jan 11, 2011	Jul 5, 2016	Sony Interactive Entertainment America Llc	Scheme for translating movements of a hand-held controller into inputs for a system
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US9393487	May 7, 2006	Jul 19, 2016	Sony Interactive Entertainment Inc.	Method for mapping movements of a hand-held controller to game commands
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US9405375 *	Sep 13, 2013	Aug 2, 2016	Qualcomm Incorporated	Translation and scale invariant features for gesture recognition
US9412011	Dec 8, 2015	Aug 9, 2016	International Business Machines Corporation	Warning a user about adverse behaviors of others within an environment based on a 3D captured image stream
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US9465980	Sep 5, 2014	Oct 11, 2016	Microsoft Technology Licensing, Llc	Pose tracking pipeline
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US9524028	Mar 14, 2013	Dec 20, 2016	Fastvdo Llc	Visual language for human computer interfaces
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CLASSIFICATIONS

U.S. Classification	382/168, 345/473, 715/863, 345/419, 382/170
International Classification	A61B5/11, G06F3/00, G06F3/01, G06K9/50, G06K9/00
Cooperative Classification	G06F3/0304, A61B5/1122, G06K9/00355, A61B5/1123, A61B5/1121, G06K9/00335, G06F3/017, G06K9/50
European Classification	G06F3/03H, A61B5/11S2, A61B5/11S, A61B5/11T, G06K9/00G, G06F3/01G, G06K9/50

LEGAL EVENTS

Date	Code	Event	Description
Jul 30, 1993	AS	Assignment	**Owner name:** MITSUBISHI ELECTRIC RESEARCH LABORATORIES, INC., M **Free format text:** ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNOR:FREEMAN, WILLIAM T.;REEL/FRAME:006645/0729 **Effective date:** 19930730
Sep 23, 1996	AS	Assignment	**Owner name:** MITSUBISHI ELECTRIC INFORMATION TECHNOLOGY CENTER **Free format text:** CHANGE OF NAME;ASSIGNOR:MITSUBISHI ELECTRIC RESEARCH LABORATORIES, INC.;REEL/FRAME:008186/0570 **Effective date:** 19960424
Apr 20, 1999	REMI	Maintenance fee reminder mailed	
May 10, 1999	FPAY	Fee payment	**Year of fee payment:** 4
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Jan 23, 2001	AS	Assignment	**Owner name:** MITSUBISHI ELECTRIC RESEARCH LABORATORIES, INC., M **Free format text:** CHANGE OF NAME;ASSIGNOR:MITSUBISHI ELECTRIC INFORMATION TECHNOLOGY CENTER AMERICA, INC.;REEL/FRAME:011564/0329 **Effective date:** 20000828
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