(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 October 2015 (22.10.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/160921 A2

(51) International Patent Classification:
G06F 3/041 (2006.01)

(21) International Application Number:
PCT/US2015/025926

(22) International Filing Date:
15 April 2015 (15.04.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/981,140 17 April 2014 (17.04.2014) US
14/599,086 16 January 2015 (16.01.2015) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: TOUCH DETECTION IN A CAPACITIVE SENSOR SYSTEM

(57) **Abstract**: A system has a two-dimensional (2D) touch detection system operable to be activated and de-activated and an additional sensor operable in communication with the 2D touch detection system. The additional sensor is capable to determine whether a touch event has occurred or is about to occur and to activate the 2D touch detection system if a touch event has occurred or is about to occur.

WO 2015/160921 A2

TOUCH DETECTION IN A CAPACITIVE SENSOR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/981,140 filed on April 17, 2014, which is incorporated herein in its entirety.

TECHNICAL FIELD

The present disclosure relates to touch detection in a capacitive sensor system, in particular to touch detection for event based multiplexing of a mid-range capacitive sensor system with a touch controller.

BACKGROUND

To perform touch detection for an input device, various technologies are available, in particular capacitive and resistive systems are used to detect a touch on a surface such as a display or trackpad. Other systems have been developed that allow for the detection of three-dimensional, non-touching gestures performed in a defined area.

SUMMARY

There is a need for an improved combination of touch and non-touch detection in electronic devices.

According to an embodiment, a system comprises a two-dimensional (2D) touch detection system operable to be activated and de-activated and an additional sensor operable in communication with the 2D touch detection system, wherein the additional sensor is capable to determine whether a touch event has occurred or is about to occur and to activate the 2D touch detection system if a touch event has occurred or is about to occur.

According to a further embodiment, the additional sensor can be a three-dimensional (3D) gesture detection system. According to a further embodiment, for determination of a touch event, the 3D gesture detection system may use a stochastic filter for noise suppression. According to a further embodiment, the stochastic filter can be an Unscented Kalman filter. According to a further embodiment, the stochastic filter may suppress sinusoidal noise.

According to a further embodiment, the 3D gesture detection system may comprise a plurality of receiving electrodes configured to determine a gesture and a touch detection electrode. According to a further embodiment, the 3D gesture detection system may comprise a plurality of receiving electrodes configured to determine a gesture and shares at least one electrode from the touch detection system as a touch detection electrode. According to a further embodiment, the system may further comprise a multiplexer switch configured to share the at least one electrode between the 3D gesture detection system and the 2D touch detection system. According to a further embodiment, the 3D gesture detection system may comprise a plurality of receiving electrodes configured to determine a gesture and a multiplexer configured to share at least one electrode from the touch detection system to operate as a transmission electrode for the 3D gesture detection system. According to a further embodiment, the touch detection electrode may cover an area used by the 2D touch detection system. According to a further embodiment, a difference signal of subsequent samples from the touch detection electrode can be generated and evaluated over time. According to a further embodiment, the difference signal can be fed to an Unscented Kalman Filter. According to a further embodiment, an output signal of the Unscented Kalman Filter can be subtracted from the difference signal and fed to a threshold comparison unit which is configured to output a touch event signal. According to a further embodiment, the system may determine whether a touch occurred by evaluating whether a characteristic bent in the difference signal is present near the crossing of the zero-line of the difference signal. According to a further embodiment, the 2D touch detection system can be a capacitive touch detection system. According to a further embodiment, the capacitive touch detection system may comprise a projected capacitive touch controller.

According to another embodiment, a method for operating an input device may comprise the steps of: providing a two-dimensional (2D) touch detection system operable to be activated and de-activated; providing another sensor system operable to be in communication with the 2D touch detection system; activating the other sensor system and deactivating the 2D touch detection system; determining by the other sensor system whether a touch event has occurred or is about to occur; and activating the 2D touch detection system if a touch event has occurred or is about to occur.

According to a further embodiment of the method, the other sensor system can be a three-dimensional (3D) gesture detection system. According to a further embodiment of the method, for determination of a touch event, the 3D gesture detection system may use a stochastic filter for noise suppression. According to a further embodiment of the method, the stochastic filter can be an Unscented Kalman filter. According to a further embodiment of the method, the stochastic filter may suppress sinusoidal noise. According to a further embodiment of the method, the 3D gesture detection system may comprise a plurality of receiving electrodes configured to determine a gesture and a touch detection electrode. According to a further embodiment of the method, the 3D gesture detection system may comprise a plurality of receiving electrodes configured to determine a gesture and the method comprises the step of sharing at least one electrode from the touch detection system as a touch detection electrode. According to a further embodiment of the method, sharing can be performed by controlling a multiplexer switch configured to share the at least one electrode between the 3D gesture detection system and the 2D touch detection system. According to a further embodiment of the method, the 3D gesture detection system may comprise a plurality of receiving electrodes configured to determine a gesture and the method comprises the step of sharing at least one electrode from the touch detection system to operate as a transmission electrode for the 3D gesture detection system. According to a further embodiment of the method, the touch detection electrode may cover an area used by the 2D touch detection system. According to a further embodiment of the method, a difference signal of subsequent samples from the touch detection electrode can be generated and evaluated over time. According to a further embodiment of the method, the method may further comprise filtering the difference signal by an Unscented Kalman Filter. According to a further embodiment of the method, the method may further comprise subtracting the filtered signal from the difference signal and feeding the subtracted signal to a threshold comparison unit which outputs a touch event signal. According to a further embodiment of the method, the method may further comprise determining whether a touch occurred by evaluating whether a characteristic bent in the difference signal is present near the crossing of the zero-line of the difference signal. According to a further embodiment of the method, the 2D touch detection system can be a capacitive touch detection system. According to a further embodiment of the method, the capacitive touch detection system may comprise a projected capacitive touch controller.

Brief Description Of The Drawings

Fig. 1A and 1B show block diagrams of combined 2D/3D touch/gesture detection systems;

Fig. 2 shows the 3D system in more detail;

Figs. 3-6, and 8 show various timing diagrams of received signals and their first derivative with respect to time;

Fig. 7 shows a block diagram of an Unscented Kalman filter;

Fig. 9 shows a block diagram of the low-latency touch detection algorithm.

Detailed Description

According to various embodiments, a touch detection system and non-touch detection system can be combined in electronic devices to form a complex input system. Touch controllers are generally used as stand-alone input devices and integrated, for example, in various electronic devices. However, according to various embodiments, three-dimensional (3D) sensing systems may be combined with such touch sensing system or they can be modified to provide for a touch detection function. A 3D gesture detection system can be configured to work with a quasi-static alternating electric field, for example, using a 100–200 kHz square-wave signal fed to a transmitter electrode to build up such a field. Multiple detector electrodes are then used to determine attenuation caused by an object entering the field. An evaluation circuit, such as for example integrated circuit MGC3130 also known as GestIC® manufactured by Applicant, can be used to determine a 3D position. The MGC3130 is a single-zone 3D tracking and gesture controller device and described, for example, in the "Single-Zone 3D Tracking and Gesture Controller Data Sheet" available from Microchip Technology Inc. which is hereby incorporated by reference. Such a detection device may apply, for example, trilateration with distance estimates derived from received signals from various electrodes to calculate the actual three-dimensional coordinates. However, other sensor systems may be combined with a touch sensing system as will be appreciated by a person skilled in the art. Furthermore, other 3D gesture detection system may be used in combination with a touch sensing system according to various embodiments.

Touch detection systems are generally capacitive or resistive measurement systems that determine a change in capacitance or resistance caused by, for example, a finger touching a respective touch surface, such as, for example, a screen or track-pad.

3D tracking and gesture detection devices or other sensor systems and touch controllers can be configured to collaborate for providing, for example, 3D gesture tracking and precise, high-resolution 2D touch information. However, both systems, the touch controller and the other sensor system, are generally not operated simultaneously for they would interfere with each other.

Therefore, according to various embodiments, a touch detection algorithm in the other sensor system, such as for example the GestIC® device, shall activate the touch controller on a touch event or an upcoming touch event detected by the respective other sensor system.

The activation has to take place with very low latency, so that the touch controller will not miss a quick touch. A noise source which harms the other sensor signal processing (incl. touch detection) is, for example, a 50/60 Hz power grid noise. Conventionally, it is combated by applying low-pass filtering, which, however, introduces some latency that has to be avoided.

According to one embodiment, the new algorithm, which for example can be applied to a GestIC® device, employs a stochastic filter for noise suppression instead of conventional low-pass filter to achieve low latency touch detection. Such a stochastic filter can be, for example, a stochastic filter that suppresses sinusoidal noise. In particular, such a stochastic filter can be an Unscented Kalman Filter.

Fig. 1A and 1B show input systems 100, 200 comprising a human machine interface that consists of a midrange Capacitive Sensor System (CSS) 110 for 3D gesture recognition and a touch controller (TC) 180 for precise, high-resolution 2D touch information. The 2D touch controller 180 can be, for example, a MTCH6301 projected capacitive touch (PCAP) controller manufactured by the Assignee of this application. A detailed description is available in the data sheet “MTCH6301” available from Microchip Technology Inc. and is hereby incorporated by reference. Other capacitive or resistive touch controllers may be used according to other embodiments.

In the shown embodiment of Fig. 1A, the CSS microcontroller 110 is connected to one transmit electrode (Tx) 170 and five receive electrodes (Rx0...4) 120, 130, 140, 150 and 160. The touch controller (TC) 180 drives/senses a touch panel 190. Alternatively, according to other embodiments, as shown for example in Fig. 1B, the CSS microcontroller 110 uses the touch panel 190 or one or more of its electrodes instead of a separate touch sensor electrode 160. A multiplexer switch 195 can then be used to switch between the CSS controller 110 and touch controller 180 as indicated by the connection lines coupling the multiplexer switch 195 with the touch panel electrode(s) 190 and either the touch controller 180 or the CSS microcontroller 110. In another embodiment, the touch panel 160 or one or more of its electrodes can be used as an additional transmit electrode of CSS while it is active.

Both devices 110 and 180 cannot operate simultaneously since their respective receive signals would be interfered by the transmit signal of the other device. However, simultaneous operation is not required because the user will either be performing 3D gestures above the touch panel or touching the touch panel 190.

While the user is not touching the touch panel, the CSS 110 is active, i.e. its transmit (TX) signal is turned on, and the TC 180 is off, i.e. its TX signal is turned off. As soon as the user is touching the touch panel 190, the TX signal of CSS 110 is switched off and that of TC 180 is activated. On release of the touch, the CSS 110 becomes active again and the TC 180 goes off. In order to realize this scheme, the CSS 110 needs a touch detection algorithm that, in the exemplary setup of Fig. 1, will run on the signal of electrode RX4, which covers the touch panel area. The four edge electrodes (Rx0...3) 120, 130, 140, 150 are used for gesture recognition.

Fig. 2 depicts the principle of CSS's signal acquisition. The Tx electrode 170 is driven by a rectangular pulse train of frequency f_{TX} (e.g. 100–200kHz). Depending on the user's interaction, the capacitance C_f between an Rx electrode 120, 130, 140, 150 and the user's finger changes. The voltage on C_f is measured by CSS's ADC 210, and its digital output signal is demodulated by demodulator 220 and down-sampled by down-sampler 230, 240 to obtain signal d at, e.g., 200Hz sample rate. This signal is input to Advanced Signal Processing (ASP) 250 which includes gesture recognition and touch detection.

The first step in ASP 250 is low-pass filtering in order to suppress noise from, for example, the 50/60Hz power grid, yielding signal LPd[k]. Fig. 3 shows the difference signal LPdiff[k] = LPd[k] – LPd[k-1] for a finger approach towards a sensor electrode without (left) and with a touch (right), respectively. In both cases the difference signal is greater than zero during the time of approach, and during the time of removal it is smaller than zero. The significant difference is that in case of a touch there is a characteristic bent in the signal near the crossing of the zero-line which is caused by the sudden deceleration of the finger upon its physical touch of the sensor electrode (or its cover). Therefore, in order to distinguish the signal resulting from a touch event from other movements like for example flick gestures, the signal is checked for this bent.

This is visualized in Fig. 4. The signal LPdiffis first checked for crossing of a positive threshold (1.) corresponding to a minimum speed of the finger in direction towards the sensor electrode. After LPdiff starts decreasing again (2.), a line is fitted onto LPdiff's negative slope, crossing the zero-line at time t_0. This time instance corresponds to zero-crossing of a signal that is observed for finger movement without touching. Hence, if LPdiff is still positive at t_0, the user's interaction is considered to be a touch (3.). The touch state is validated by comparing the offset-compensated LPd signal (signal deviation, SD) to a threshold (the closer the finger to the device, the larger the SD signal).

According to other embodiments, this touch detection algorithm can be used for a stand-alone CSS, too. Then, not only the touch event is evaluated, but additionally the touch state can be tracked on the SD value: the touch state is released as soon as the SD signal drops below a certain threshold again.

However, that additional low-pass filter in ASP 250 introduces some delay. With a typical delay of 50ms, a quick touch of 40ms would not be recognized by the TC 180 for the hand-over would take place too late. Consequently, a further touch detection has to work on signal d in order to feature low-latency hand-over to the TC 180.

Fig. 5 is a plot of an exemplary noisy signal d, which includes four touches. A touch cannot be identified by the absolute value as there is no reliable absolute reference. But a steep signal increase may serve as a feature.

Fig. 6 contains the difference signal of d (diff), i.e. diff[k] = d[k] – d[k-1]. The touch events do not appear very clearly due to the 50Hz noise, which might be even stronger in other environments and/or systems. In order to get rid of this sinusoidal noise, an Unscented Kalman Filter (UKF) is used to track and subtract it. The model the UKF is based on is presented in Fig. 7. The system state x comprises of amplitude, frequency and phase ([U; f; Φ]) of the power grid sinusoid. For complexity reason, states [U; f] or [U; Φ] may be chosen, too. The system state x is assumed to change at every time instance k according to $x_k = x_{k-1} + q_{k-1}$, where q denotes some process noise. From the system state, a measurement value y is calculated by $y_k = U_k \sin(2\pi f_k + \Phi_k) + r_k$, where r denotes some measurement noise.

The concept of Kalman filtering is to calculate a predicted system state x' (and measurement value y') from a known measurement value y with lowest error. Core of Kalman filtering is the Kalman gain K which is needed to correct the predicted state depending on the true measurement y: $x_k = x' - K(y_k - y')$. K depends on statistical properties of x', y', q and r.

The original Kalman filter is derived for linear systems, for non-linear systems several derivatives are known such as the Extended Kalman Filter, the Particle Filter, and the Unscented Kalman Filter.

The key point of Unscented Kalman filtering is to derive the above mentioned statistical properties of x' and y' by means of so-called sigma points. This implies complex computations including a matrix square root, but avoids linearization of the sine function and results in precise estimation of the sinusoid.

Having estimated the parameters of the power grid sinusoid, it can be subtracted from the diff signal shown in Fig. 6, thus yielding a cleaned diff signal, which is plotted in Fig. 8. Now, the touch events are unveiled from the noise. They can be detected easily and without false alarms by comparing the cleaned diff signal to a threshold 800, which has a value of 10 in this example.

Fig. 9 summarizes the low-latency touch detection algorithm. Starting with signal d, its difference signal is calculated by storage element 910 and summing point 920 and fed into the Unscented Kalman Filter 930. The filter 930 estimates the 50/60Hz component in the differential signal. The estimated sinusoid is then subtracted from the diff signal at summing point 940. Finally, the so cleaned diff signal is input to a threshold comparison 950, which outputs touch events. On these touch events, the CSS 110 is switched off and the TC 180 becomes active.

In summary, according to various embodiments, the concept of an external sensor activating the touch controller is provided. Furthermore, a touch detection algorithms for a midrange capacitive sensor system is provided which allows for a) exploiting the characteristic signal shape when the finger stops on the sensor's surface and b) suppressing sinusoidal noise by prediction, e.g. a UKF, thus avoiding delays of conventional filters.

CLAIMS

WHAT IS CLAIMED IS:

1. A system comprising:

a two-dimensional (2D) touch detection system operable to be activated and de-activated;

an additional sensor operable in communication with the 2D touch detection system; wherein the additional sensor is capable to determine whether a touch event has occurred or is about to occur and to activate the 2D touch detection system if a touch event has occurred or is about to occur.

2. The system according to claim 1,
wherein the additional sensor is a three-dimensional (3D) gesture detection system.

3. The system according to claim 2,

wherein for determination of a touch event, the 3D gesture detection system uses a stochastic filter for noise suppression.

4. The system according to claim 3, wherein the stochastic filter is an Unscented Kalman filter.

5. The system according to claim 3, wherein the stochastic filter suppresses sinusoidal noise.

6. The system according to claim 2, wherein the 3D gesture detection system comprises a plurality of receiving electrodes configured to determine a gesture and a touch detection electrode.

7. The system according to claim 2, wherein the 3D gesture detection system comprises a plurality of receiving electrodes configured to determine a gesture and shares at least one electrode from the touch detection system as a touch detection electrode.

8. The system according to claim 7, further comprising a multiplexer switch configured to share the at least one electrode between the 3D gesture detection system and the 2D touch detection system.

9. The system according to claim 2, wherein the 3D gesture detection system comprises a plurality of receiving electrodes configured to determine a gesture and a multiplexer configured to share at least one electrode from the touch detection system to operate as a transmission electrode for the 3D gesture detection system.

10. The system according to claim 6, wherein the touch detection electrode covers an area used by the 2D touch detection system.

11. The system according to claim 10, wherein a difference signal of subsequent samples from the touch detection electrode is generated and evaluated over time.

12. The system according to claim 11, wherein the difference signal is fed to an Unscented Kalman Filter.

13. The system according to claim 12, wherein an output signal of the Unscented Kalman Filter is subtracted from the difference signal and fed to a threshold comparison unit which is configured to output a touch event signal.

14. The system according to claim 11, wherein the system determines whether a touch occurred by evaluating whether a characteristic bent in the difference signal is present near the crossing of the zero-line of the difference signal.

15. The system according to claim 1, wherein the 2D touch detection system is a capacitive touch detection system.

16. The system according to claim 15, wherein the capacitive touch detection system comprises a projected capacitive touch controller.

17. A method for operating an input device, comprising:

providing a two-dimensional (2D) touch detection system operable to be activated and de-activated;

providing another sensor system operable to be in communication with the 2D touch detection system;

activating the other sensor system and deactivating the 2D touch detection system;

determining by the other sensor system whether a touch event has occurred or is about to occur; and

activating the 2D touch detection system if a touch event has occurred or is about to occur.

18. The method according to claim 17, wherein the other sensor system is a three-dimensional (3D) gesture detection system.

19. The method according to claim 18,

wherein for determination of a touch event, the 3D gesture detection system uses a stochastic filter for noise suppression.

20. The method according to claim 19, wherein the stochastic filter is an Unscented Kalman filter.

21. The method according to claim 19, wherein the stochastic filter suppresses sinusoidal noise.

22. The method according to claim 18, wherein the 3D gesture detection system comprises a plurality of receiving electrodes configured to determine a gesture and a touch detection electrode.

23. The method according to claim 18, wherein the 3D gesture detection system comprises a plurality of receiving electrodes configured to determine a gesture and the method comprises the step of sharing at least one electrode from the touch detection system as a touch detection electrode.

24. The method according to claim 23, wherein sharing is performed by controlling a multiplexer switch configured to share the at least one electrode between the 3D gesture detection system and the 2D touch detection system.

25. The method according to claim 18, wherein the 3D gesture detection system comprises a plurality of receiving electrodes configured to determine a gesture and the method comprises the step of sharing at least one electrode from the touch detection system to operate as a transmission electrode for the 3D gesture detection system.

26. The method according to claim 22, wherein the touch detection electrode covers an area used by the 2D touch detection system.

27. The method according to claim 26, wherein a difference signal of subsequent samples from the touch detection electrode is generated and evaluated over time.

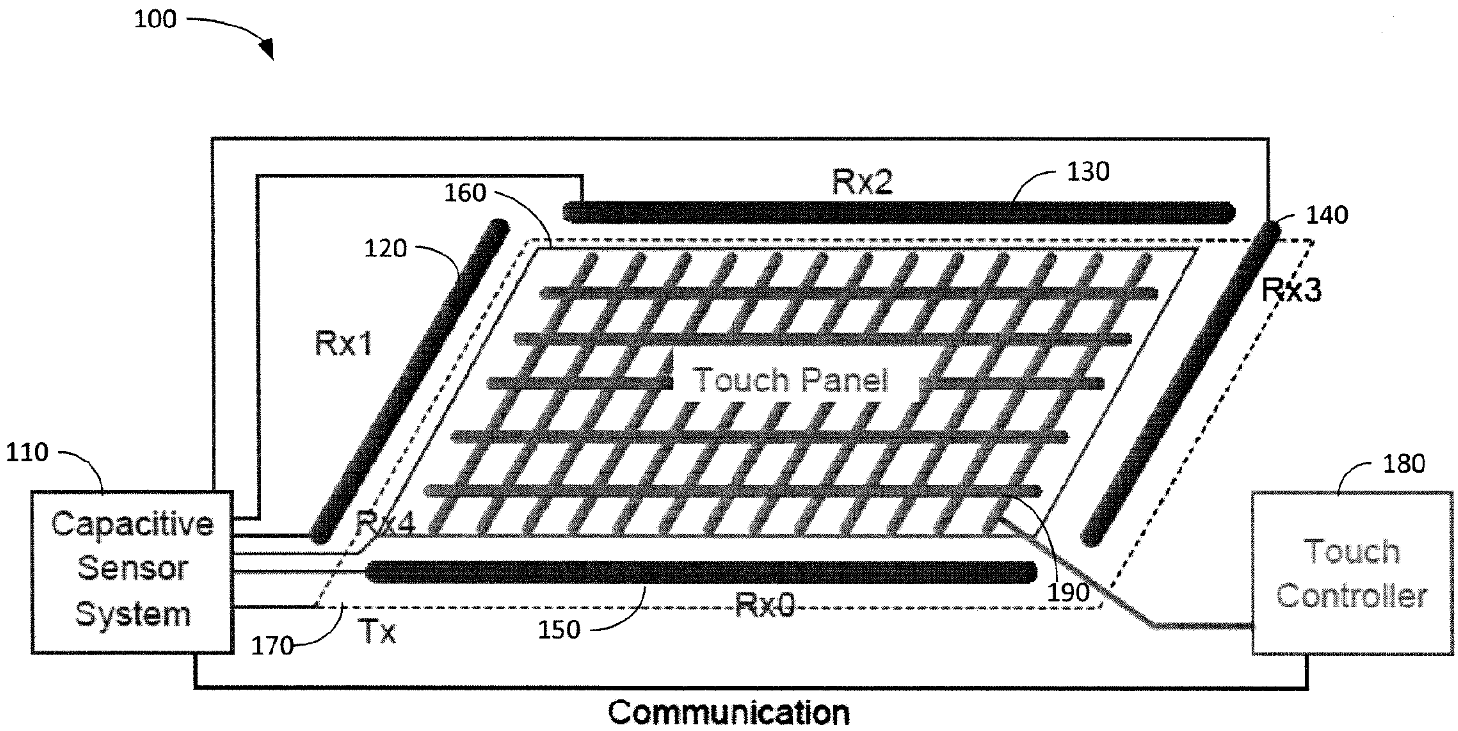
28. The method according to claim 27, comprising filtering the difference signal by an Unscented Kalman Filter.

29. The method according to claim 28, comprising subtracting the filtered signal from the difference signal and feeding the subtracted signal to a threshold comparison unit which outputs a touch event signal.

30. The method according to claim 27, comprising determining whether a touch occurred by evaluating whether a characteristic bent in the difference signal is present near the crossing of the zero-line of the difference signal.

31. The method according to claim 17, wherein the 2D touch detection system is a capacitive touch detection system.

32. The method according to claim 31, wherein the capacitive touch detection system comprises a projected capacitive touch controller.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160
140
120
Rx3
Rx1
Touch Panel
110
180
Capacitive
Sensor
System
Rx4
Touch
Controller
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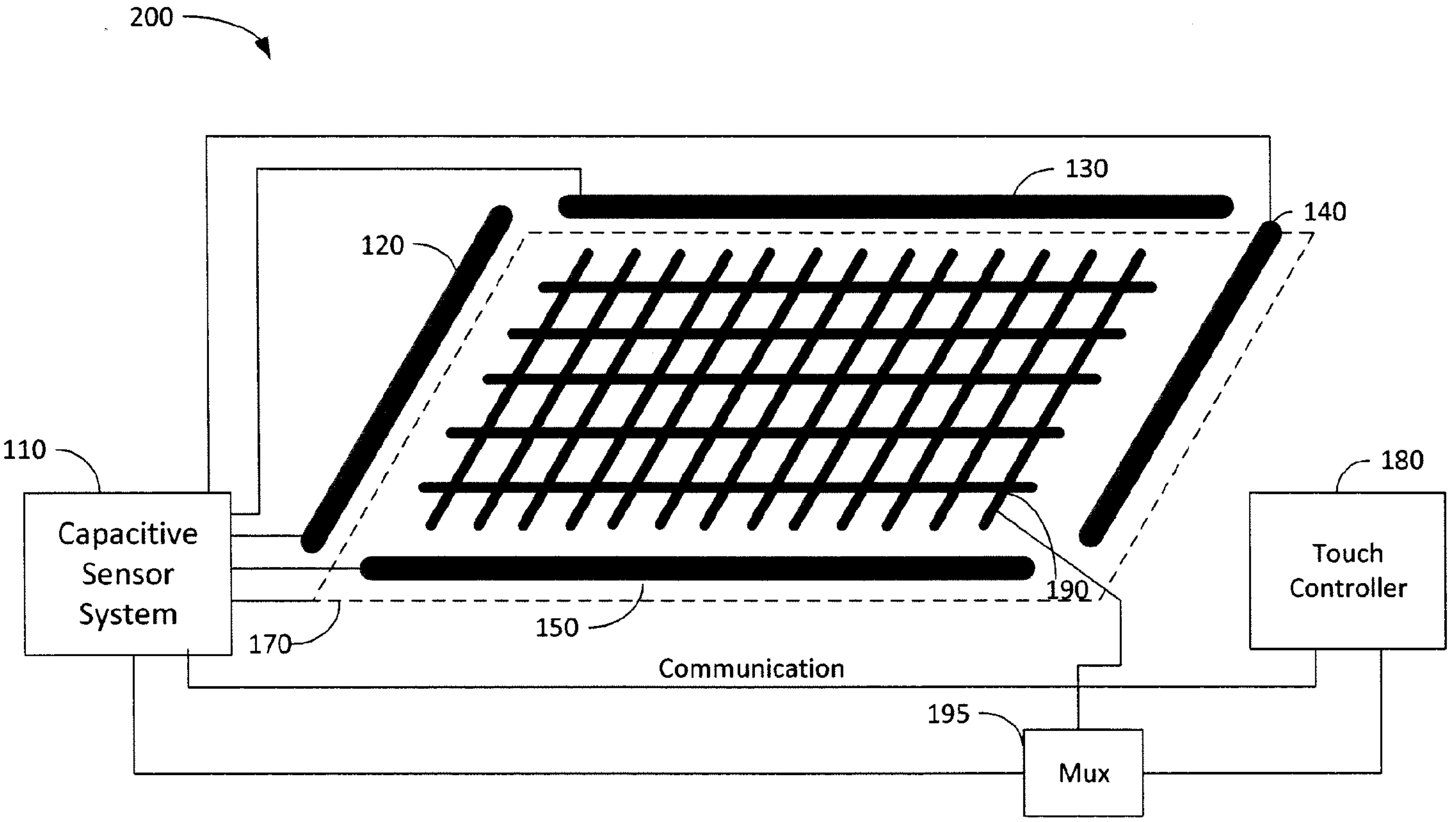
Rx0
170
Tx
150
Communication

Figure 1A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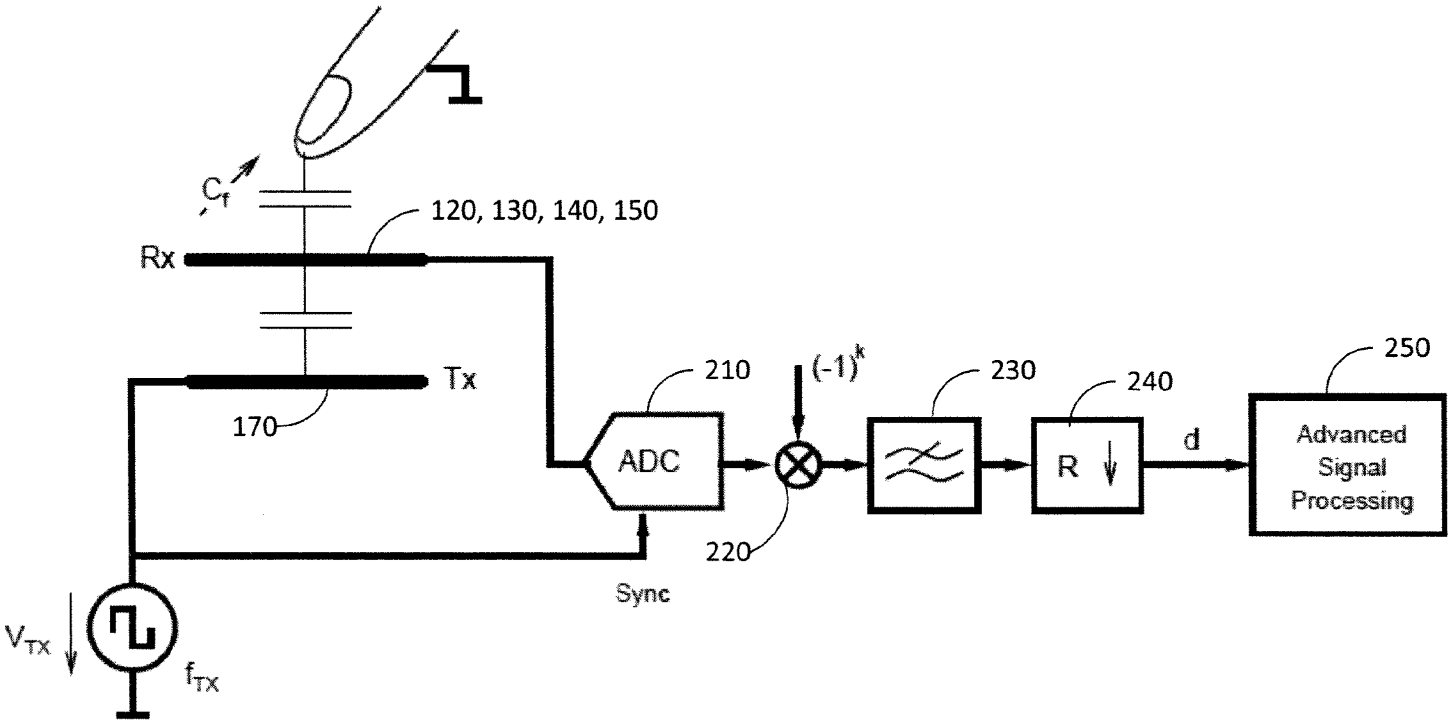
110
Capacitive
Sensor
System
180
Touch
Controller
190
150
170
Communication
195
Mux

Figure 1B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Rx
Tx
170
210
ADC
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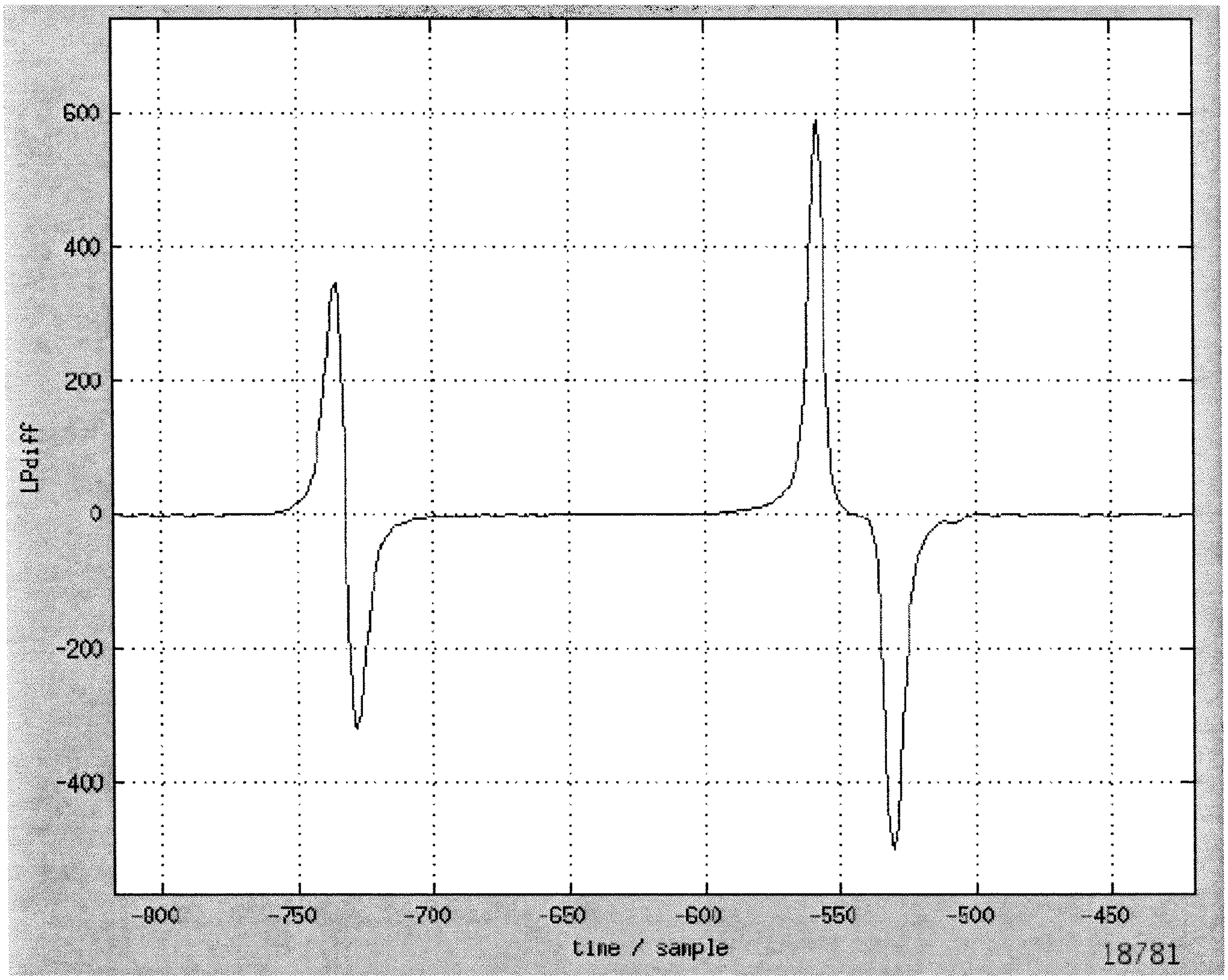
220
230
240
R
d
250
Advanced
Signal
Processing
Sync
V_{TX}
f_{TX}

Figure 2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400
200
0
-200
-400
LPdiff
-800
-750
-700
-650
-600
-550
-500
-450
time / sample
18781

Figure 3

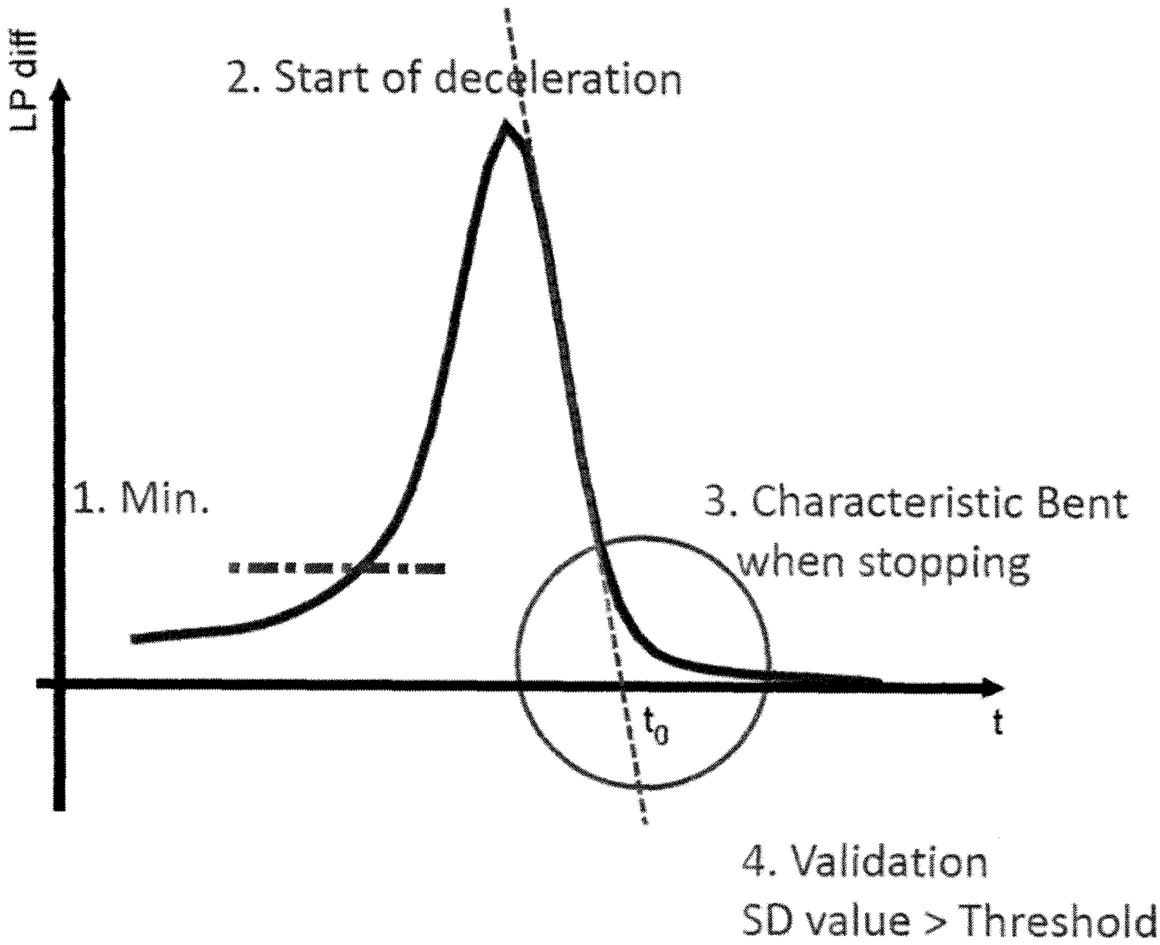
LP diff
2. Start of deceleration
1. Min.
3. Characteristic Bent
when stopping
t
t_0
4. Validation
SD value > Threshold

Figure 4

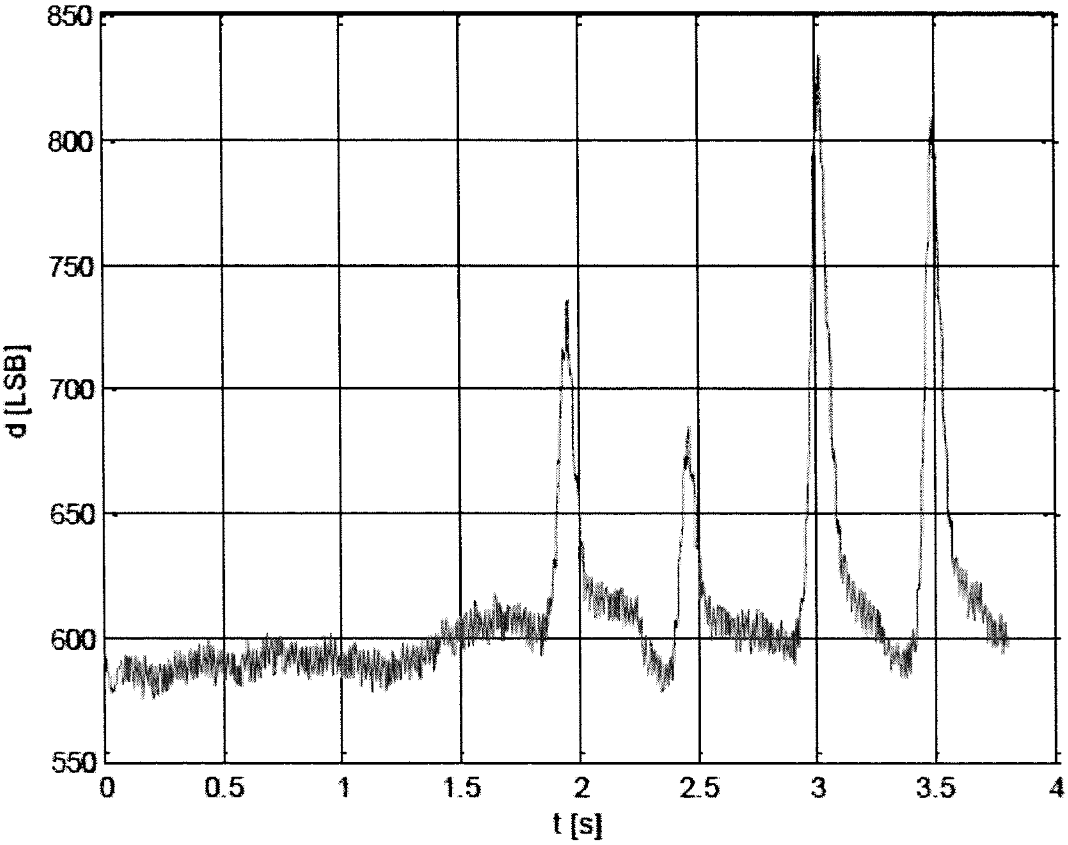

Figure 5

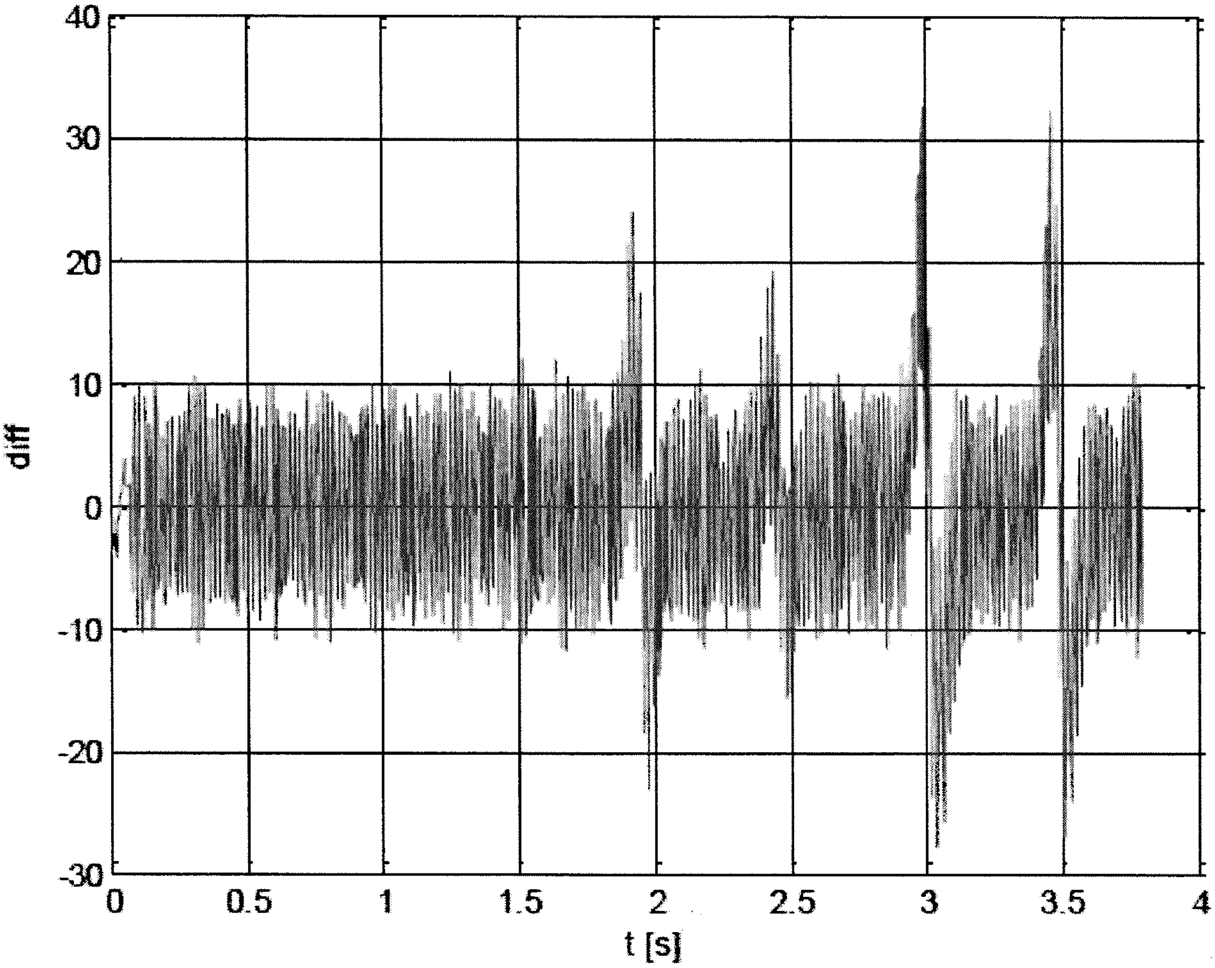

Figure 6

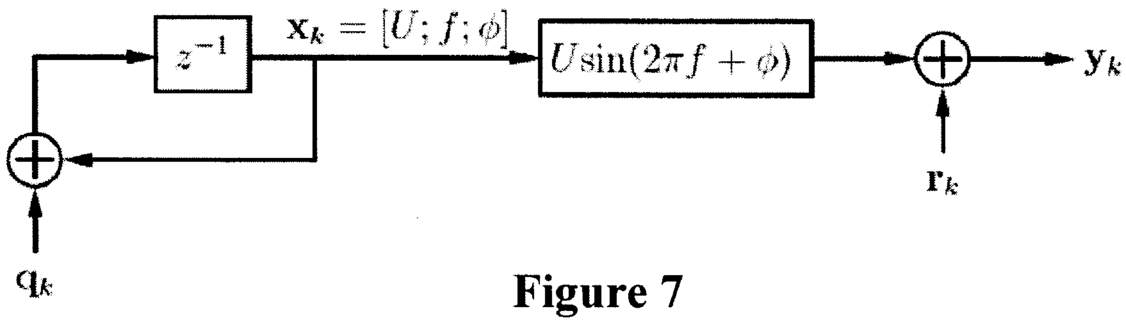

Figure 7

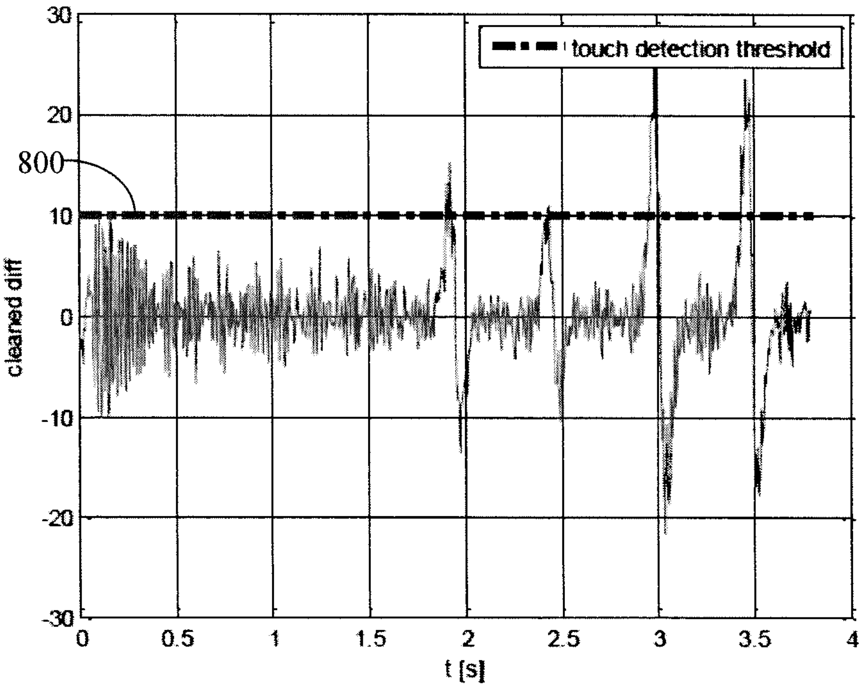

Figure 8

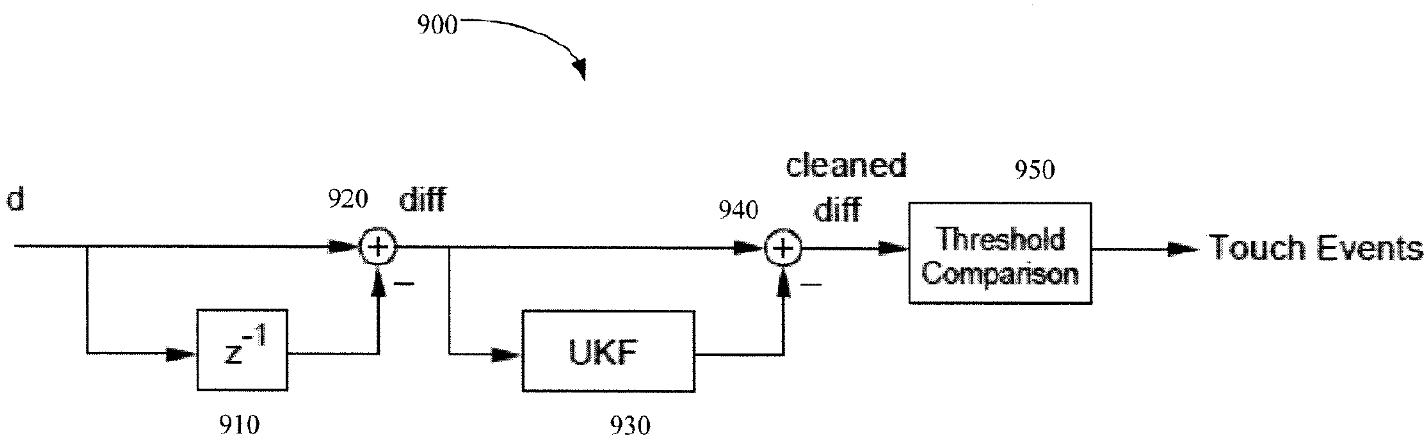
900
d
920
diff
940
cleaned
diff
950
Threshold
Comparison
Touch Events
z-1
910
UKF
930

Figure 9