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

(51) International Patent Classification⁷: **G06K 11/00**

(21) International Application Number: PCT/US00/29758

(22) International Filing Date: 27 October 2000 (27.10.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/161,752	27 October 1999 (27.10.1999)	US
60/195,491	10 April 2000 (10.04.2000)	US
60/230,912	13 September 2000 (13.09.2000)	US

(63) Related by continuation (CON) or continuation-in-part (CIP) to earlier applications:
US	60/161,752 (CON)
Filed on	27 October 1999 (27.10.1999)
US	60/195,491 (CON)
Filed on	10 April 2000 (10.04.2000)
US	60/230,912 (CON)
Filed on	13 September 2000 (13.09.2000)

(71) Applicant *(for all designated States except US)*: **DIGITAL INK, INC.** [US/US]; 70 Hastings Street, Wellesley, MA 02481 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **PITTEL, Arkady** [US/US]; 101 Winthrop Road, Unit 1, Brookline, MA 02445 (US). **SCHILLER, Ilya** [US/US]; 58 University Road, Brookline, MA 02445 (US). **LIBERMAN, Sergey** [US/US]; 26 Wayte Road, Bedford, MA 01730 (US). **SHLEPPI, Garry** [US/US]; Apartment F, 427 Auburn

Street, Auburndale, MA 02466 (US). **FUNK, Ethan, A.** [US/US]; 475 Shawmut Avenue #3, Boston, MA 02118 (US). **SUBACH, Vladimir, V.** [US/US]; 18 April Lane, Lexington, MA 02421 (US). **GOLDMAN, Andrew, M.** [US/US]; Apartment 908, 95 Audubon Road, Wakefield, MA 01880 (US). **REZNIK, Leonid** [US/US]; 52 Tanbark Road, Sudbury, MA 01776 (US). **SELITSKY, Simon** [US/US]; 29 Balfour Street, Lexington, MA 02421 (US). **STEIN, Mario, A.** [US/US]; 54 Evergreen Road, Natick, MA 01760 (US).

(74) Agent: FEIGENBAUM, David, L.; Fish & Richardson P.C., 225 Franklin Street, Boston, MA 02110 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *Without international search report and to be republished upon receipt of that report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: TRACKING MOTION OF A WRITING INSTRUMENT

(57) Abstract: Motion of writing instrument is tracked from sensors located in the vicinity. The signals generated from the sensors are processed and used in a wide variety of ways.

TRACKING MOTION OF A WRITING INSTRUMENT

This application claims the benefit of United States provisional
patent application serial number 60/161,752, filed October 27,
1999, entitled Electronic Portable Pen that Captures Handwriting

5   and Drawing with IR Sensing PSD Beacon System, United States
provisional application serial number 60/195,491, filed April 10,
2000, entitled Using Handwritten Information, and United States
provisional application serial number __, filed September 8, 2000,
entitled Electronic Pen with a Keyboard Template, and is a

10   continuation-in-part of United States patent application serial
number 09/376,837, filed August 18, 1999, entitled Electronic
Portable Pen Apparatus and Method, all incorporated by reference.

BACKGROUND

This invention relates to tracking motion of a writing instrument.

15   By tracking the motion of a pen, for example, as it is used to write
or draw on paper, it is possible to capture and reproduce
electronically what is being written or drawn. Motion of a stylus
that does not leave a mark on a writing surface can also be tracked.

In some proposed approaches, the surface on which the pen is

20   moving may have an array of pixels or other sensing locations each
of which responds when the pen is at that location.

In other techniques, the pen tracking is done entirely by electronics
mounted in the pen. In some schemes, the moving pen
communicates with stationary sensors that are separate from the

25   pen, and triangulation algorithms are used to track the motion.

SUMMARY

In general, in one aspect, the invention features a method that includes conveying light from a moving writing instrument as an indication of the location and path of the writing instrument on a

5   two dimensional writing surface; sensing the light at two or more sensors and generating a sequence of signals representative of the sensed light; and applying a technique to reduce the effect of variations of the light intensity in a third dimension with respect to the generated signals.

10   Implementations of the invention may include one or more of the following features. The technique may be based on optics that are configured to enhance the uniformity of signal response of the sensors. The lens may be a spherical lens or an aspheric lens. The sensors may be arrays of sensitive pixel elements or analog

15   sensors. The technique may be based on algorithmic processing of the generated signals. The algorithmic processing may include linearizing the signal response of the sensors based on parameters associated with the writing instrument. The technique may be implemented in digital hardware or in analog circuitry. The

20   algorithmic technique may reduce the effect of variations of the light intensity based on other than dimensional effects. The signals may be grouped in frames, and the signal processing technique may include processing of multiple frames to cancel noise. The light conveyed from the moving writing instrument may be

25   modulated at a frequency related to the rate at which the signals are

generated by the sensors, and the sensor signals may be chopped at the frequency of modulation. Opposite gains may be applied to each of the chopped signals depending on the on or off state of the light conveyed from the writing instrument that corresponds to the

5   signals. The frame rate may be varied. The chopped signals may be integrated over time. The light conveyed from the writing instrument may include a strong short pulse imposed at on the modulation frequency, a phase lock loop may determine the modulation frequency from the sensor signals, and the sensor

10   signal may be sampled at the times triggered by the phase lock loop during the duration of the strong short pulse. The characteristics of the conveyed light may be used for synchronization between the writing instrument and the sensors. The conveyed light may include periods of lower frequency

15   modulation and bursts of higher frequency modulation, and the sensor signal associated with the higher frequency bursts may be used to lock onto a modulation clock.

In general, in another aspect, the invention features a method that includes conveying light from a moving writing instrument in a

20   time-changing pattern of directions, sensing the light at two or more sensors located at two or more different locations spaced from the writing instrument, and determining the location of the writing instrument by detecting a phase difference between signals measured at the two or more sensors.

3

Implementations of the invention may include one or more of the following features. The time-changing pattern of directions may include a rotating pattern with respect to an X-Y plane on which the writing instrument is moving. The signal radiated in the

5   positive X direction may be in phase quadrature to the signal radiated in the Y direction.

In general, in another aspect, the invention features apparatus that includes sensors configured to receive light from a writing instrument moving across an X-Y writing surface, the light having

10   variations in intensity along a Z-axis normal to the writing surface, andoptics configured to enhance optical power of the light received from the writing instrument.

Implementations of the invention may include one or more of the following features. The optics may be a ball lens or an aspherical

15   lens. The optics may include a single spherical lens and the lens and the corresponding sensor may be together configured to enhance the optical power of light received at large angles or longer distances or at disadvantageous positions of the writing instrument. The optics may include a special lens configured to

20   enhance optical power of the light received from a location on the X-Y surface that is beyond a predetermined position. The optics may include two cylindrical lenses, one nearer the sensor to project light horizontally onto sensor, and the other positioned to collect light in the Z-axis dimension, the other lens having a body that is

25   bent around the first lens. The algorithmic processes may enhance

4

the immunity of the signals to variations in the intensity of the received light caused by distance from or tilt of the writing instrument. The processes may determine the integral power of the overall signal distribution on the sensor and calculate a subpixel

5   position based on half of the integral power position. The processes may use a polynomial approximation on the signal distribution and calculate a subpixel position as a position of approximated maximum. The calibration procedure may produce parameters to be used in combination with data from the sensors.

10   The calibration parameters may correct for manufacturing deficiencies of the optics and the sensors, and the algorithmic processes may use a straight triangulation technique to determine a position of the writing instrument. The calibration parameters may correct for manufacturing deficiencies of the optics and sensors

15   and the algorithmic processes may determine the position of the writing instrument using polynomial series, where coefficients in these polynomials are determined during the calibration procedure.

In general, in another aspect, the invention features a method that includes receiving light from a moving writing instrument at a an

20   array of sensing elements of a sensor, reading the sensing elements in sequence to generate a sequence of signals indicative of light sensed by the elements of the array, and resetting each of the elements after it is read and before at least some of the other elements in the array are read.

Implementations of the invention may include one or more of the following features. The array may include a CMOS or CCD position sensor. All of the elements may be read before all of the elements are reset .

5   In general, in another aspect, the invention features a method that includes determining a sequence of three-dimensional positions of the moving writing instrument based on the signals.

In general, in another aspect, the invention features the combination of a writing instrument having an elongated housing

10   configured to be hand-held, a light source in the housing, and a lens in the housing configured to receive light from the light source and to convey the light through a free-air path to optical sensors spaced from the writing instrument, the lens being configured to be semi-reflective.

15   In general, in another aspect of the invention, the light source includes an array of light sources arranged around an axis of the writing instrument and configured to emit light in a direction normal to the axis.

Implementations of the invention may include one or more of the

20   following features. The lens may be configured to internally reflect and concentrate the light and to emit it by reflection from a reflective external surface of the lens. The lens may have a cylindrical body having an upper surface that receives the light and a lower annular surface that reflects the light toward the optical

sensors. The reflective external surface may include a conical surface oriented at a 45 certain degree angle to a longitudinal axis of the writing instrument. The light source in the pen may include LEDs arranged in a ring.

5   In general, in another aspect, the invention features a device configured to turn the light source on and off in response to a user applying pressure from the writing instrument to a writing surface, the device being configured so that an amount of pressure required to trigger the device is not so large as to disrupt normal writing

10   motion of the writing instrument on the writing surface.

Implementations of the invention may include one or more of the following features. The writing instrument may include a ballpoint cartridge having a writing point and the device may be positioned at the opposite end of the cartridge from the writing point. The

15   device may be a switch or a pressure sensor.

In general, in another aspect, the invention features a holder having a receptacle for receiving at least a portion of the writing instrument for storage of the writing instrument,

the writing instrument and the holder containing respective

20   elements that enable wireless transmission of signals associated with motion of the writing instrument and tracking of the writing motion based on the signals.

In implementations of the invention the holder may be a pen cap and may include a clip configured to attach the holder to a stack of pages or to a notebook. The holder may include at least two light sensors and a processor that processes signals from the light

5   sensors to determine a sequence of positions of the writing instrument. The holder may include a receptacle for holding the writing instrument and for enabling recharging of batteries in the writing instrument.

In general, in another aspect, the invention features an element that

10   enables wireless transmission of a signal associated with motion of the writing instrument and tracking of the writing motion based on the signal, the element being built into a cell phone, a PDA, a webpad, or a clipboard.

In general, in another aspect, the invention features, a holder that

15   has a mechanism for attaching the holder to a writing substrate in an orientation that enables the elements to be used in conjunction with the wireless transmission. The clipping mechanism may include a switch to activate functions of a processor in the holder when the clipping mechanism is manipulated.

20   In general, in another aspect, the invention features, a holder that includes a receptacle for the writing instrument and a recharging circuit connected to recharge the battery when the writing instrument is in the receptacle.

8

In general, in another aspect, the invention features a CMOS
sensor adapted to receive light associated with motion of a writing
instrument and to provide signals indicative of an angle of receipt
of the light with respect to a known direction, and a lens aligned to
5   direct the received light to the CMOS array.

In implementations of the invention, the lens may be optimized for
collection of light from an area in which the motion of the writing
instrument occurs. The lens may be a field lens or a Fresnel lens.
The lens system may be configured to collect light in a dimension
10   normal to a plane of motion of the writing instrument and to
project the light onto the sensor in a direction parallel to the plane
of motion.

In general, in another aspect, the invention features calibrating by
positioning a writing instrument at a succession of positions on a
15   writing surface, generating signals at sensors from light received
from the writing instruments at the succession of positions, and
determining calibration parameters for the writing instrument for
use in calibrating a process that determines the positions of the
writing instrument as it is being moved.

20   In implementations of the invention, the calibration parameters
may include coefficients used in polynomial series that are part of
the position determining process.

In implementations of the invention, the positions do not lie on a
regular rectangular grid.

In general, in another aspect, the invention features (1) identifying locations on a writing surface that correspond to input elements to be entered into an electronic device, the writing surface being non-electronic and separate from the electronic device, (2) using a

5   writing instrument to point to selected ones of the identified locations corresponding to input elements to be entered, and (3) sensing the locations at which the writing instrument is pointing and entering the corresponding data into the electronic device.

In implementations of the invention, the writing surface includes a

10   sheet of paper, the input elements comprise characters of language or commands that are printed on the writing surface.

In general, in another aspect, the invention features moving a writing instrument across a non-electronic writing surface to indicate a path, and remotely sensing the path and generating

15   signals for use in entering the path into an electronic device that is separate from the writing surface.

In general, in another aspect, the invention features modulating

~   light that is conveyed from a moving writing instrument to light sensors spaced from the writing instrument at a predetermined

20   frequency, and using a phase locked loop associated with the sensors to lock onto the phase of the modulated light.

In general, in another aspect, the invention features, circuitry for tracking writing motion of a writing instrument using wireless transmission of signals between the writing instrument and a

10

stationary element, the stationary element including a main

processor and a separate preprocessor, the preprocessor being

connected to perform at least data capture with respect to motion

of the writing instrument, the main processor being connected to

5   perform at least data communication with respect to the tracking.

In implementations of the invention the preprocessor may also be

connected to perform user interface functions and sub-pixel data

storage and the main processor may also connected to perform

background cancellation and sub-pixel calculation.

10   In general, in another aspect, the invention features a reflective

element configured to reflect light received from outside of the

writing instrument to the sensor for use in tracking motion of the

writing instrument.

In implementations of the invention, the reflective element may

15   reflect light to the sensor when the writing instrument is being used

for writing and disable the reflective element from reflecting light

to the sensor when the writing instrument is not being used for

writing.

In general, in another aspect, the invention features receiving light

20   from a moving writing instrument at a light sensor having an array

of sensitive pixel elements, and determining the location in the

array at which the maximum intensity of light has been received

from the writing instrument, the location being determined with

sub-pixel accuracy.

11

In implementations of the invention, the sub-pixel location is determined by determining the integral pixel location that is closest to the subpixel location, and finding a fractional center of gravity of a subarray that is centered on the integral pixel location.

5   In general, in another aspect, the invention features indicating locations on a non-electronic surface that correspond to inputs to an electronic device, and detecting the locations and inputting them into the electronic device.

In general, in another aspect, the invention features a clip for
10   clipping paper on which the writing instrument is to be moved to the sensor.

In implementations of the invention the mechanism may be part of a clipboard or a notebook, the clip may include a mechanism that enables a user to cause the clip to grip or to release the paper. The
15   clip may include an activation button and a spring and a lever operated by the button. The lever may be configured to rotate in response to the button. The button may be configured to be pushed or pulled.Other advantages and features will become apparent from the following description and from the claims.

20   **DESCRIPTION**

Figure 1 shows pen tracking.

Figure 2 shows a pen.

Figure 3 shows a lens in a pen.

Figure 4 shows a lens in a pen.

Figures 5 and 6 show reflection of light in a pen.

Figure 7 shows a tracking method.

5   Figure 8 shows a pen.

Figure 9 shows a pen.

Figure 10 shows a holder.

Figure 11 shows a lens in front of a sensor.

Figure 12 shows a holder.

10   Figure 13 shows a holder.

Figures 14 and 15 show half of a holder.

Figure 16 shows another half of the holder.

Figure 17 shows a field of view.

Figure 18 shows a block circuit diagram.

15   Figure 19 shows a state diagram.

Figure 20 shows a timing diagram.

Figure 21 shows a timing diagram.

Figure 22 shows geometry of tracking.

Figure 23 shows a circuit diagram.

Figure 24 shows a timing diagram.

Figure 25 and 26 shows a rotating beam technique.

5   Figure 27 shows a channel diagram.

Figure 28 shows a channel circuit.

Figure 29 shows a paper keyboard.

Figure 30 shows a spherical lens.

Figure 31 shows an aspherical lens.

10   Figure 32 shows a two-lens arrangement.

Figure 33 shows a clip.

Figure 34 shows a clip.

Figure 35 shows a sliding belt clip.

Figure 36 shows two views of a clip.

15   Figure 37 shows two views of a clip.

We describe an electronic wireless pen that in addition to its
regular function of leaving a visible trace on the writing surface
also emits infrared (IR) light that is collected by external IR

sensors to measure pen position with respect to the sensors. The
sensors are CMOS or CCD linear or 2D arrays, Position Sensitive
Detectors (PSD) or other light sensitive detectors. The sensors can
be clipped to the edge of writing surface allowing reconstruction of

5   writing on that page. The position of the pen is determined by
mapping the sensor reading to the actual XY position of the pen on
paper.

This electronic input device looks like a regular pen with a holder.
The user writes with it just as with any ordinary pen on paper,

10   notebook or any other flat surface. It is used to capture handwriting
text or drawings. The pen stores all its movements during its use
by recording sensor measurements into its memory. The pen then
downloads it to a computer, personal digital assistant, handheld
computer or cellular phone. The handwriting, as it appears on a

15   page, is then automatically reconstructed from sensor information.

As shown in figure 1, a pen or other writing instrument 10 that
leaves a visible trace 12 of writing or drawing in the usual way on
a sheet of paper or other writing surface 14 may also have a source
16 that emits infrared (IR) light 18 for use in automatically

20   tracking the motion of the pen. The light is detected by IR sensors
20, 22 that are held stationary relative to the pen at a nearby
location, for example, near the edge 23 of the paper.

The sensors deliver sequences of signals that represent the position
of the pen on the writing surface (e.g., angle 24) at which the light

25   is received from the pen for each of a succession of measurement

times. Circuitry associated with the sensors uses an algorithm to process the directional information (and the known distance 26 between the sensors) to determine a succession of positions of the pen as it is moved across the writing surface. The algorithm can

5   use a mathematical model that translates pixel signals of the sensors into positions on the writing surface. The algorithm could be a quasi-triangulation algorithm using calibrated parameters (distance from lens to sensor and horizontal offset between their centers of refractive index) or it could be a polynomial

10   approximation.

The tracked motion of the pen can be used to recognize handwriting or capture drawings created using the pen or used in a wide variety of other applications. The tracked motion information can be sent to a local personal computer or to a central computer

15   through a personal digital assistant, a handheld computer, or a cellular phone for central storage and processing.

TRACKING OF LIGHT SOURCE WITH A TWO OR ONE DIMENSIONAL SENSOR

The problem of tracking XY bearing of a pen can be formalized as

20   follows.

The pen carries a finite source of light close to the tip. This source emits light which intensity in the test point depends on the XYZ position of a test point with the source in the origin.

A multichannel detector is located at another location. It collects
some portion of the light emitted by the source on a pen. Intensity
delivered to different channels varies depending on the XYZ
position of channel inputs with respect to the location of this

5   source. Intensity data are sufficient to calculate the XYZ position
of a source relative to the detector. Intensity data are also subject to
noise including source instability, detector noise, and other kinds.

We are interested in obtaining the XY bearing of the pen only. In
fact, all three coordinates will vary due to thickness irregularities

10   on a writing surface and due to varying tilt of a pen during writing.
Along with noise this will cause complex variations in channels
reading.

There are different ways of processing such signals: weighted
average (center of gravity), median computation, thresholding,

15   etc. They mostly address noise cancellation and treat Z motion of a
source as noise also.

Our goal is to establish such a property of the detected signal that
would be invariant to the motion of a pen in Z direction and to
some sources of noise.

20   For this purpose, we introduce an aperture between a detector and
the source. This aperture may contain a lens, for example. Thus we
obtain a spatially limited signal. This means that there is a closed
group of detector channels that is excited by both the signal and the
noise (a segment in case of a linear array detector). This group is

17

surrounded by channels that are excited by the noise only. In the absence of an aperture, all channels are excited by both the signal and the noise.

After creating such a signal we establish a specific point (e.g.

5   maximum) and define a processing window around this point in such a way that it extends beyond a spatially limited signal. Then a cumulative distribution function of data inside the processing window is calculated versus channel numbers. The projection of this function's half magnitude point on channel numbers produces

10   the invariant property. While channel numbers are integers, the invariant property value may be fractional.

There are basically two types of detectors, whether 2D or 1D. Each detector can be a two channel detector, like a PSD, or a "multichannel" detector like a CMOS and CCD device. PSD

15   detectors have two output signals whose ratio defines a relative position of incident light spot. CMOS and CCD detectors have a number of pixels. Each pixel defines a particular space on the detector and has an analog output. These analog outputs can be digitized for later processing in firmware or software, or can be

20   processed by analog means. Algorithms used in software can alternatively be implemented in hardware in the same way.

ONE CALIBRATION PROCEDURE

There is no need to achieve a linear response of the detectors to pen motion as has been proposed in other known approaches. A

18

linear response would be required if simple triangulation were to be used to interpret a detector reading as an XY position of a pen.

An unambiguous dependency exists between the XY position of a pen and left and right detector (L and R) readings as follows:

5
$$X = Fx(L, R);$$ (1)

$$Y = Fy(L, R).$$

These functions can be expressed as polynomial series. Coefficients in these polynomials can be determined during the calibration procedure.

10   During the calibration procedure, the pen is positioned in different known XY locations on the paper and readings of both detectors are taken and stored for future processing. After a sufficient number of points has been accumulated, common linear algebra methods are used to calculate the coefficients in (1).

15   We know that system (1) is substantially non linear. It is important to locate calibration points in such a way that a necessary resolution is achieved across the entire writing area. We do not locate the calibration points in the nodes of a regular rectangular grid. Instead, we use mathematical models to match a calibration

20   grid to particular nonlinear properties of our detectors.

19

ANOTHER CALIBRATION PROCEDURE

If simple triangulation is used to calculate an XY pen position from detector data, we intentionally introduce an error into the geometrical parameters of our detectors to allow for the nonlinear

5   properties discussed above.

We know exactly the refractive index of the lenses in our detectors and distances between the lenses and sensors by virtue of our design. At the same time it has been proved that varying these values in triangulation computation one can effectively

10   compensate the nonlinear properties of detectors.

To obtain effective values for refractive index and distances between the lenses and sensors we run another calibration procedure. The different XY location calibration points are necessary for proper resolution across the writing area. Locations

15   of calibration points for this disturbed triangulation are obtained through mathematical models.

THE PEN

As shown in figure 2, in one example, the IR source in the pen can be an LED 13 that emits IR light 15 at the tip 17 of the pen when

20   pressure is applied during writing. In this example, the LED source 13 is formed by a ring of LEDs 19 arranged around the longitudinal axis 21 of the pen (only two LEDs are shown).

Light from the LEDs is project downward toward the pen point
and into a body/lens of acrylic material 18 that operates as a light
pipe. The acrylic lens diffuses and transmits the received light so
that light emitted from the pen is delivered along optical paths in

5   all directions around the pen.

As shown in figure 3, the pipe 18 is polished and reflective and
concentrates light 502 from the LEDs 19 inside by not allowing the
light to escape sideways. The bottom part of the pipe is also
polished at the 45 degree conical surface 504 at the bottom of the

10   pipe. A reflective cylindrical shell 506 helps to confine and cause
mixing of the light that is emitted from the LEDs. A conical body
508 supports the light pipe. Downwardly directed light within the
pipe is reflected from the conical surface 504 and delivered to the
air at all angles around the pen.

15   Figures 5 and 6 illustrate side and top views of internal reflection
of light in the light pipe. Most light from the LEDs passes along
the length of the body of the pen and is reflected at a 90 degree
angle toward the sensors. Some other light finds its way out of the
pen at angles different from 90 degrees.

20   As shown in figure 2, the light that is emitted from the pen is
confined to a vertical space 11 that is near to the writing surface 13
so that as much of the light as possible can reach the sensors (not
shown), which are also positioned within a small distance of the
writing surface.

Other configurations having different shape light pipes/lenses
could be used, including the one shown in figure 4, which may
have a better coupling between the LED and the light pipe and
more effective splitting and directing of light toward the reflective
5   surface at the bottom of the pipe.

The pen in this example (Figure 2) includes a ball-point pen
cartridge 23 that terminates in a writing point 25. When the user
bears down on the writing point during writing, a pressure switch
26 delivers a signal that can be used to turn on the LEDs and to
10   trigger functions of circuitry 28 also mounted in the pen. Circuitry
28 and LEDs 19 are powered by a battery 30. The components are
all held in a housing 15.

As shown in figure 7, the pen position in an x-y coordinate system
40 parallel to the writing surface is determined from two angles
15   alpha and beta that are sensed by the two sensors 20, 22, and the
known distance 26 between sensors.

In another example, shown in figure 8, the pen is powered by three
miniature AAA-like NiCd rechargeable batteries 51 that are held in
the back of the pen (For better weight distribution the batteries will
20   be moved closer to the tip, with the circuitry placed at the back).
The batteries power the electronic circuitry 28 directly without any
DC-to-DC converter. The power is delivered only when the
pressure switch 26 is activated. The light activation switch travels
only a short distance (e.g., 0.25mm). The switch is preloaded by a

22

spring mechanism to minimize refill travel, which should not exceed 0.008-0.010inches.

Pressure sensors would be an way to effectively match pressure on the pen refill with activation of LED, as many off-the-shelf

5   switches have an activation pressure above the desired level of 20 to 30g.

The electronic board 28 positioned behind the battery generates modulation frequency pulses at approximately 100Hz and a 50% duty cycle for the IR LEDs along with the bursts of 1 to 10kHz to

10   generate pen on and pen off signals for sleep mode.

The light emitted from the pen is visible in all directions to enable the pen to be used in any orientation in the hand. The closer the emitted light is to the tip of the pen, the less is the error due to the variations of pen angel to paper, and the more accurate is the

15   tracking of the tip of the pen. The LED light should be in an IR region away from the visible light spectrum so that ambient light from the sun and light fixtures does not interfere excessively with the IR emission and is not visible to the human eye.

The IR source at the pen and the orientations of the sensors in the

20   holder are arranged to assure that as the pen tilts and rotates during normal writing or drawing, its IR beam reaches the sensors.

Figure 9 shows a more detailed isometric view of a partially assembled pen.

PEN HOLDER

As shown in figures 1 and 10, the sensors can be housed in a typical pen cap 70 in which the pen can be held when not in use. When the pen is being used, the pen is removed from the cap and

5   the cap is positioned at a stationary location near the writing surface and in the vicinity of the pen. In some examples, the sensors are linear CMOS arrays (available, for example, as 1024 pixel arrays from Photo Vision Systems, LLC (PVS) (P.O Box 509, Cortland, NY 13045) (part number LIS1024)). Other linear

10   CMOS sensors from PVS or other companies with the same or a different number of pixels could also be used. The analog output of each sensor is a sequence of 1024 analog signals, one from each sensor pixel.

A shown in figure 10, the holder may include a clip 62 to attach

15   the holder to the edge of a pad of paper or a notebook.

A third sensor in the form of a photodiode 56 in the middle of the holder is used (among other things) to wake up the processor from a sleep mode (described below) when writing begins (e.g., the pen begins to emit light).

20   The third sensor signal may also be used to synchronize the circuitry in the pen with the circuitry in the sensor system. All three sensors are covered by IR filtering windows that face the writing surface.

24

As shown in figure 11, in one example, the front surface 100 of each of the main sensors has a vertical height 104 of 125 micrometers and a distance 106 from the front surface 108 of the lens 110 of four millimeters. The FOV 112 is 10 degrees. The pen

5   tip 114 directs IR light into the FOV when the pen tip is on the paper 116.

As shown in figure 17, the two sensors 88. 90 are positioned 100 mm apart. Each of the sensors has a field of view (FOV) 94, 96 centered on an FOV axis 195, 197. The axes of the FOVs are not

10   parallel but are toed in by an angle 199 to increase amount of overlap of the FOVs. The FOV of each sensor has a breadth of 150° in the horizontal (x-y) plane and a height of +/-5° in the vertical plane.

The FOVs do not cover some locations 101 on the writing surface

15   that are close to the edge of the paper 303, and the FOVs are arranged so that the dead zone 98 does not extend more than 25mm from the holder.

In another example of a pen holder, shown in figure 12, the sensors 117 and the lenses 119 are mounted on a holding bracket 121 with

20   the IR filter 123 in front. The bracket is mounted on a printed circuit board 125 and is held in a housing 127. The centers of two main sensors are separated by 100mm.

The light from the pen is collected from two sensors in order to identify the linear position of a modulated light source within a

defined area (8.5 x 11 inches). The linear position may be computed by triangulation, a lookup table, polynomial approximation, or a combination of any of these.

The sensors are flat, linear, multi-pixel sensors. Different pixels of

5   each of the sensors are illuminated when the light source is in different locations within the field. As the light source moves across the field, the corresponding movement of the light across the pixels of the sensors may not be linear, but the lack of linearity can be handled because the linear position may be computed by

10   math and knowledge of optics combined with calibration data from the pair of sensors.

Instead of seeking a linear response from the sensors, we seek to maximize the light from within writing area that falls onto the sensors. Correct reproduction of writing is achieved by using

15   parameters saved from the prior calibration procedure. The system uses, in some implementations (in the polynomial example shown below, the number of parameters can be greater)and supplied in a separate file) only four parameters to be passed from each pen to a host or server to process the data and linearize it. The particular

20   calibration parameters for a pen are stored in the memory of the pen during production test and calibration. The parameters can also be stored on the server or on a PC used by the user instead of being passed on from the pen during downloads.

A lens or a set of lenses accompanies each sensor. The goals of the

25   optical system are to maximize the efficiency of the light delivery,

26

cover the entire field of view of the field, provide a uniform signal response across the entire field, and make the optical system as small and as cheap as possible. These goals are met in part by the following steps:

5   As shown in figure 30, a spherical lens 753 is used to focus the light on the sensor 755. The focal plane has a shape of a semicircle. The distance 759 from the lens to the sensor is optimized as are the other optical and mechanical properties of the lens including focal length, diameter, thickness, and material.

10   As shown in figure 31, an aspheric lens 760 may be designed with a focal point positioned on the sensor as the light source travels around the periphery of our field where the total power of the light source delivered to the sensor will be the weakest. Thus, this aspherical lens is designed to have a focal plane, which coincides

15   with the plane of the sensor for only the points that are on the periphery of the page. Points within the page will be out of focus, but the amount of light falling onto the sensor will be significantly larger (closer to sensor or better angle), and the signal stronger.

As shown in figure 32 (which includes a top view above and a side

20   view below), two perpendicular cylindrical lenses 770, 771 may be used instead of one lens. The length of the sensor limits the focal length of the lens in the horizontal axis. Therefore the lens diameter must be small and the lens must be located close to the sensor. In the vertical axis the lens may be located further from the

25   sensor so the diameter can be larger. The larger diameter will allow

27

for the collection of more light from the light source. The first
cylinder (closer to the lens) will focus the light in the horizontal
axis. This lens may be spherical because the spot size is not very
important in the horizontal axis and will not vary that much within
5   our given field. The second cylinder will have power in the vertical
axis. It is important to focus as much light as possible on the sensor
in the vertical dimension. For this to be true, the light must travel
an equal distance from the cylinder to the sensor for all angles. To
accomplish this, the second cylinder should be bent into an
10   aspheric shape. Any of these two cylindrical lenses can be Fresnel
lenses in order to save space.

In a more detailed example of a pen holder shown in figures 13,
14, 15, and 16 the sensor system is held in a housing 79 that has a
bottom 80 and a top 82. The bottom 80 holds a clip 62 (not
15   shown). Paper can be inserted between the clip 62 and the bottom
of the pen holder when a clip button 86 is depressed. When the
button is released, the clip grasps the paper. The pen clip holds a
7mm-thick stack of paper sheets or a standard notepad 83. The clip
positions the pen holder on the paper so that the side 87 that faces
20   the pen is vertical with a tilt of no more than +/-1°, thus assuring
that the sensors will receive IR light from the pen when it is being
used to write on the surface.

The holder can also just sit on top of paper or notebook without
use of clip.

In the holder shown in figures 13 through 16, the two sensors are mounted behind IR filtering windows 89, 91, and the photodiode 93 is mounted in the middle. An "ink well" 95 can receive the tip of the pen 97 for temporary storage, and a tube 99 provides a place

5   to store the pen. The pen can be fully inserted into the tube and the batteries in the pen can be recharged during storage.

Various mechanisms for operating the clip are possible including the example shown in United States patent application serial number 09/376,837, filed August 18, 1999.

10   In one arrangement, the clip mechanism shown in figure 33 is used. The figure shows the steps in operating the mechanism, as follows.

Step 1: Mechanism is not activated.

Step 2: When the push button 780 presses on a spring 782, the

15   latter releases the bracket 733, and lets the hinge spring 784 unfold the clip 785.

Step 3: Paper 786 is inserted between the clip and the body 787 of the pen holder.

Step 4: Lever 785 (the clip) is against the paper, and spring 788,

20   which is significantly weaker than the hinge spring gives in and starts collapsing. The clip rotates around rotating point 789.

29

Step 5: The clip presses the paper against the bottom of the holder. Spring 788 collapses, and both levers move down by the amount of paper inserted.

A clip button can be used to transfer horizontal motion to vertical
5   motion by a lever, which lowers the clip. Or, the button can push against a lever that rotates, transferring horizontal motion to vertical movement, which lowers a clip.

This mechanism is shown on Fig. 34. The clip has two vertical sliding bars 790, 791 connected to a horizontal bar 792. There is a
10   spring 793 between the horizontal bar and the body of the holder. There are two vertical guides 794, 795 for the vertical bars to go up and down.

In the side view at the bottom of the figure, when the button is not depressed, the spring is all the way up and the clip is pressed
15   against the penholder body (left side of the figure). When the button is depressed (right side of the figure), the spring is depressed and the clip (see the front view now), goes down between the slides. After paper is inserted and the button released, the spring pushes the clip up and the mechanism grabs the paper
20   between the clip and the penholder body.

The button may move a lever in multiple axes to lower the clip. The button can activate a lever that rotates and moves linearly to lower the clip.

In another arrangement, shown in figure 36, the operator pushes down on a sliding panel (button) 901. The sliding button contacts the center of two spring-loaded levers 903, 905 moving these fulcrums down in the same direction of the button/panel. The

5   bottom ends of the levers are fixed about rotating pins 907, 909 and thus the bottom? ends move downward about twice the distance of the button. The top ends of the levers are fitted with pins 911, 913, which ride in guide slots 915, 917 and in two tabs that are bent up vertically from the bottom clip. The end result is a

10   movement vertically downward of the clip, which is about twice the distance as the button/panel travel.

Alternatively, as shown in figure 35, the sliding panel 930 may be placed in a horizontal orientation and, by means of a rigid flexible belt, achieve the desired result with a horizontal pushing motion as

15   opposed to the vertical motion of the button.

As shown in figure 37, another approach may be achieved by a pulling motion of the button 951 if the forces acting on the two levers 953, 955 in the mechanism is moved from the middle of the levers to the bottom ends, and the fulcrums of the levers are moved

20   to a point 1/3 the distance from the top? ends to the bottom? ends. This would provide the necessary mechanical advantage to maintain the 2:1 ratio of the distance the clip moves to the travel of the button.

In both mechanisms, the location of pivoting points to points of
applying force on levers can be used to increase mechanical
displacement of the clip.

PEN HOLDER CIRCUITRY

5   A circuit block diagram of the holder is shown in figure 18. An
ASIC 205 is powered by a battery 511, or from an AC adaptor 513,
or from a USB connection to a host computer 211. The two CMOS
sensors 201, 203 have outputs that are connected 165, 167 through
operational amplifiers 169, 171 through a multiplexer 180 and a
10   12-bit A-to-D converter to the ASIC.

The analog output of the CMOS sensor is subjected to signal
processing in the form of offset cancellation and automatic gain
control. The signal-to-noise ratio requirements of the processing
implies use of 5V power for the CMOS sensors and all analog
15   signal processing circuitry. Some A/D converters are operated at a
2.5v reference, and the signal from the CMOS sensor may scaled
down by factor of 2 using a resistive divider.

The ASIC could be model Clarity 2B from Sound Vision, located
in Framingham, MA) and is based on an ARM7 core. The ASIC
20   firmware implements data acquisition, data storage, file system
management, I/O service (LEDs and switches), RS232, and USB
communications, power management for idle and sleep modes,
optical calibration, and test mode.

32

The multiplexer enables the A-to-D converter 182 to alternate
between the two CMOS arrays 201 and 203 to minimize the time
skew between the two sensors. The clock frequency of the A-to-D
converter is 1.2 MHz. Each CMOS sensor is clocked at 600kHz.

5   Data acquisition uses the ASIC's direct memory access (DMA)
facility.

A wakeup input of the ASIC is driven by a PLL 513 that receives
an input signal from the photodiode 515. The photodiode is driven
by modulated light from the pen.

10   The ASIC is clocked by a 48 MHz crystal and a clock divider 517.
I/O features are provided through a USB port 211 and an
RS232/IrDA port 209. Firmware and data are processed in
SDRAM 207 and stored in a flash memory 519. An optional LCD
172 can be provided for user display.

15   USB provides two data transfer modes from the holder to a PC:
bulk and real-time. Real time transfer is interrupt driven and is
used for keyboard and mouse replacement applications.

A dual function transceiver is used to implement both RS232 and
IrDA communication. The RS232 communication is used as a dial
20   up connection to the server over cellular phone.

The holder can support different types of external connections,
including USB, Serial, Parallel, IrDA, Bluetooth, Firewire, or any
kind of communication port. When powered down, if the holder is

33

connected to any external device, it has a capability to automatically power itself up. It also has a capability to power itself down when an external device is disconnected. There are two types of connections for the holder:

5   One connection is an external storage type of connection. Such a connection is made with a computer, or other device, called host, that is capable of displaying graphics and has an adequate user interface. While connected to a host device, the holder behaves as an external storage device. A user of the host device can browse

10   through the holder file system, copying, viewing, and editing files previously collected by the holder. The software residing on the host is capable of converting, displaying, printing, and editing on the host screen files stored on the holder or copied from the holder to the host. While connected to the host, the pen can also behave as

15   a real-time input device.

The other type of a connection is with a portable internet or modem enabled device, such as a cellular phone. Upon detecting such a connection, the pen holder automatically initiates transmission of all the data previously collected to be sent as e-

20   mail or fax.

The optional LCD display notifies a user of the pen's status, for example, with respect to connections and downloads over Internet-ready cellular phones where communications are not reliable. This display can be mounted on top of the holder. If an LCD is used, the

25   LED may not be needed.

A single three-color (green, yellow, red) LED 170 (see also figure 18) indicates normal acquisition of writing data, downloads to a PC and over cellular phone, and monitoring of battery and memory status.

5   Pen, clip, and inkwell switches 141, 143, and 145 are used to control the ASIC and a reset switch 147 is used to reset the ASIC.

Figure 19 shows a state diagram of the states of operation of the invention. Shaded blocks indicate study states. Clear blocks indicate transition states. Among other things, the figure identifies

10   the manner in which the multicolor LED is used to indicate the state of operation.

At power up, the green light blinks as many times as there are pages in memory. The green light is not on at power up when the memory is empty, and stops blinking after 30 seconds or sooner if

15   the user starts to write.

During writing, when data acquisition is proceeding properly, the LED is pale green. The green light goes off for faulty acquisition triggered by, for example, obstructed light, a pen that is off the writing surface, or a discharged battery.

20   Low battery status is indicated by a blinking yellow light when no writing is occurring. However, when writing, the yellow light blinks intermittently with pale green if the battery is low.

Memory nearly full status is indicated by a double-blink of the
yellow light when writing is not occurring and a yellow light
blinking intermittently with pale green when writing is occurring.

Download status (which may start independently whether the pen
5   is in or out of the holder or ink well) is indicated by a bright green
light after successful download. Blinking green, signifies that
download is in progress. When no service is available for
downloading or the download signal is week, a red light blinks.
The red light double blinks for an Internet problem, for example
10   when a server is down. A triple blinking red light indicates a
wrong setup for communication including a wrong user ID or
server address. This requires a code sent back to pen from server
after unsuccessful match of data from pen with account on
database.

15   Battery recharge status is indicated by a solid green light after a
successful recharge and by a multiple blinking green light when
the holder is plugged into the AC adapter and charging. A
combination of signals from the battery monitoring circuitry and
the fast charge signal from a charger (high when not charging) can
20   identify the state, whether charge in process or trickle charge.

The pen can be used during recharging. If the pen is removed from
the ink well and is used during recharging, the yellow light is
replaced with all normal indicator lights described above.

Writing to flash status is indicated by a continuous yellow light.

All errors are reset by activation of any of the two pen or ink well switches mentioned later. The only exception is when a download was successful, and the user started writing. Then the constant bright green light will switch to a pale green light.

5   In sleep mode, all trouble indications, low memory, and low battery continue as in the normal mode. All download troubles stay on also.

If the ASIC needs to indicate low memory or low battery conditions during power up, the power up indications take the
10   priority. Then the trouble indications are displayed up after a 30 second timeout. If the ASIC needs to indicate low memory or low battery conditions during download, the download indications take precedence. After a reset of download status, the trouble indications are displayed.

15   Of the four switches on the holder, the clip switch 141 indicates that the clip is being opened and closed as a way to notify the circuitry that the user is beginning a new page. The pen switch 143 indicates when pen is in or out of the holder. An ink well switch 145 indicates when the pen is in or out of the ink well. The reset
20   switch 147 is hidden but accessible through a hole in the bottom using a paper clip.

The pen switch and the inkwell switch indicate when the pen is in the holder or the inkwell and remove power from the data acquisition and storage electronics when the pen is in the holder or

37

the inkwell. The pen switch also opens new files (or pages) on activation, while the ink well switch does not.

The clip switch indicates when the clip is activated, as well as a new page and beginning of a new file (each page is a file).

5   The reset switch resets the ASIC if the software freezes. The switches are normally ON as follows:

Pen	ON when the pen is out of the holder.
Ink Well	ON when the pen is out of the ink well.
Clip	ON when the clip button is released.
Reset	ON when switch is depressed.

10

The holder also includes a miniature connector for USB and RS232 interfaces as well as an antenna for use with Bluetooth or other wireless technology. The USB and RS232 connector are also connected to the wake-up power circuitry so that pen holder can

15   power itself up when cable is plugged into the miniature connector.

Angle signals generated by the sensors are processed by the ASIC and stored in flash for later transmission to other devices such as cellular phones, PDAs, and PCs (not shown) where they can be used for handwriting recognition or to capture drawings. The

20   transmission can be done using, for example, USB, RS232, IrDA, or Bluetooth protocols.

38

FILE SYSTEM

The flash memory is structured as a FAT (file allocation table)-compatible file system, where each file represents one page of handwritten information. Each file has a unique name of 12

5   characters, including 3 characters of extension and a separating "dot".

DATA FILE CREATION

When a user brings the pen into writing mode by taking the pen out of the holder, or by pressing the new page clip button if the pen

10   is already in the writing mode, a new file is created, and the subsequent writing is saved in a new file. If the user does not actually do any more writing after new file was created, the newly created file is deleted, and the next time pen is brought to the writing mode, the same file name will be reused.

15   During data acquisition, uncompressed data is stored in a temporary buffer in SDRAM and compressed by a data store task before being stored into a file in flash memory. Each page is stored in a separate file. A previous page is compressed before new page acquisition is started.

20   **DATA FILE FORMAT**

We use a binary compressed format based on a variable rate Huffman encoding with cubical appoximation. Such a format comprises encoded data coordinates and timestamps.

39

Before being compressed, the file has the following format:

The file is structured in four byte segments. Each segment
corresponds to either one pixel or one timestamp. Each pixel has a
most significant bit (MSB) of zero, and consists of two 15-bit
5   numbers that are the sub coordinates of corresponding CMOS
sensors. Timestamps are distinguished by a MSB of one, and can
store either full date and time of the next pixel (called full
timestamp), or incremental counter of pixels since the last full
timestamp.

10   Each file begins with the full timestamp. An incremental
timestamp is inserted in the end of every written stroke. Because
all pixels are scanned evenly in time, such a combination of
timestamps enables efficiently recover the whole history of
handwriting in the future processing.

15   **DOWNLOADING OF DATA**

When the holder is connected to a PC using a USB cable, the PC
automatically recognizes the holder as a PC-compatible USB
device, and the contents of the holder file system becomes visible
for the PC through the PC-file system extension. The user can
20   browse through it and view the files using a handwriting viewer.

When an RS232 cable is connected between the holder and, for
example, a cellular phone, the holder automatically powers itself
up, and starts transmission of data files from the memory of the

holder to the phone. IR transmission of data to the phone could
also be done.

The data is sent in the compressed form to the server and is kept
there until requested for an addressee. Then it is decompressed and

5   translated into one of the following formats: .tif, .pdf, .gif, .ps
specific to e-mail or FAX service.

SENSOR SIGNAL PREPROCESSING

In some examples, a preprocessor (not shown) can be used for
background cancellation, and storage into flash memory, while the

10   ASIC processor performs all communication and I/O functions.
The preprocessor can be implemented as a programmable device
such as PLD, FPGA or digital ASIC or a DSP. In this example, a
frequency multiplication is performed to generate a high-frequency
pixel clock and a clock for the preprocessor from the pen LED

15   modulation frequency that is recovered by the PLL.

The second processor can be a processor of another portable device
such as a cellular phone or PDA.

DATA ACQUISITION

Position data is collected in a succession of samples spaced 10

20   milliseconds apart to adequately capture writing motion at a typical
speed of 5 cm per seconds for a resolution of 0.5 mm. The ASIC
operates as a master, generating the clock and all necessary signals
for the sensors.

The sensors in the holder use the pixel clock from the ASIC. A frame signal is generated by each sensor and read back into the ASIC. Thus, the LED pulses from the pen and the signal acquisition performed on the holder are not synchronized in some

5   implementations. In other examples, the data acquisition is synchronized with the pen modulation frequency. Synchronization significantly improves angle resolution.

In each sampling cycle in which the pen position coordinates are obtained, data is captured from both sensors. One version of the

10   background cancellation algorithm (asynchronous with pen) requires capturing three consecutive frames at each sensor. An additional frame is used by the ASIC architecture for sensor reset.

To minimize any skew between coordinates from the two sensors, the multiplexer data acquisition alternates between the two sensors

15   for each pixel.

Operating the A-to-D converter at a sampling rate of 1.2MHz maximum and alternating between the two sensors allows for a pixel sampling frequency up to 600kHz. Each CMOS array has 1024+4 pixels, which produces a frame rate of approximately

20   600Hz. A slower rate of 300Hz might be used to achieve more pixel exposure to light and accordingly better signal-to-noise ratio.

Each sensor operates in a mode in which each pixel is reset after being read into A/D converter.

The IR LED duty cycle is 50% out of three frame intervals. For
that duty cycle, the LED frequency cannot exceed 200Hz.

For purposes of cancellation of background noise and low
frequency interference without synchronization, three data frames

5   of 1024 pixels are required, as described below.

In addition to the main analog output each CMOS delivers
END_FRAME signals. From each CMOS the acquisition cycle for
each of the three sequential frames of data is started by the
END_FRAME signal, which coincides with the last pixel of the

10   frame. Each A-to-D conversion occurs on the falling edge of the
PIXEL_CLOCK pulse. The total number of points is essentially
(1024+4)*3, where 1024 is the length of the CMOS array, 4 is the
number of clock pulses between the END_FRAME signal and the
beginning of the next frame, and 3 is the number of sequential

15   frames needed to implement background compensation.

From the acquired waveform, the ASIC extracts three arrays, each
corresponding to 1024 pixels. The arrays must be correctly aligned
so that the i-th element in each of them corresponds to the i-th
pixel of the CMOS.

20   Let us call the arrays A1, A2, and A3. Background compensation
is based on the fact that the LED in the pen is modulated with a
frequency equal to 1/3 of the frame rate and with a 50% duty cycle.
To achieve background compensation, the following calculations

43

are performed element-wise on the arrays: A12 = abs(A1 - A2);

A23 = abs(A2 - A3); A13 = abs(A1 - A3). Then arrays A12, A13

and A23 are added element-wise to form a new array called A.

This array A is 1024 elements long and carries the beam

5   information with the background removed.

To reliably get rid of the large peaks appearing in the pixel

waveform during the END_FRAME pulses, subarrays shorter than

1024-elements long can be extracted, for example, three 1020-

element long subarrays, that start at pixels 3, 1032 and 2061 (base

10   0).

The readouts of the two sensors are digitized simultaneously (or

quasi-simultaneously when using only one A-to-D converter with a

multiplexer).

FINDING PEAK POSITION ALONG CMOS ARRAY WITH

15   **SUBPIXEL RESOLUTION**

Determining the angle of receipt of the light at each of the sensors

depends on determining the pixel location of the peak light

intensity along the array of the sensor. The algorithm to find peak

position with subpixel resolution uses two parameters: T, the

20   intensity threshold in volts and W, the window width in pixels.

Typical values of these parameters are T = 0.1 V and W = 15.

As an initial step, the peak value and its index in the array A are

found, call them Amax and M. If either of the two Amax values

44

(corresponding to the two sensors) is smaller than T, then the point is discarded. In that instance the LED is considered to be off with the pen not touching the paper. If M < W/2 or M > (1024-W/2), the point is discarded as being too close to the edge of the field of

5   view.

From A, extract a W-element-long subarray starting from element M - W/2. Find its fractional center of gravity as follows: create an array of running sum of elements of the extracted subarray (call it S). Take the value of its last element. Divide it by 2. Find the

10   fractional index of the position of this value in S using linear interpolation/lookup. Add M – W/2 to this value. This will be the fractional index of the center of gravity of the beam in the original 1024-element array. Invert its sign and add 512 (in the case of an A that is 1024 elements long or 510 in the case of an A that is 510

15   elements long). The result, P, is the fractional position of the beam with respect to the axis of the sensor (in pixels).

The use of a subpixel algorithm permits an increase of the pixel resolution by a factor of 8 to 10.

CALCULATING LIGHT SOURCE ANGLE WITH
20   ## RESPECT TO SENSOR AXIS

As a result of the previous calculation, we have the angular position of the beam for each sensor (in pixels). We call them Pleft and Pright (looking at the sensors from the pen point of view). We

recalculate the Ps in radians based on the sensor geometry. In one example, the pixel pitch L = 7.77 microns, the distance from the lens to the CMOS is D = 4800 microns (typical), the refraction coefficient of the lens material is N (1.5 for glass, 1.4 for plastic,

5   1.8 for SF6). Parameters, distance D, index of refraction N, and horizontal offset, Off, will be adjusted using calibration data for correct mapping of writing.

Then the angle (in radians) is calculated as F = arcsin(N * sin(arctan((P * L) / D))).

10   As illustrated in figure 22, the following parameters are required for calculating the light source position in Cartesian coordinates:

        Sensor convergence angle (toe-in) C (radians), typically
        30/57

        Base B, the distance between sensors (mm); typically 150

15   Left sensor: Kleft = tan (C – Fleft)

        Right sensor: Kright = tan (C + Fright)

        X (mm) = B * Kright / (Kleft + Kright);

        Y (mm) = Kleft * X.

CRITERIA FOR ACCEPTING A POINT AS VALID

Points are stored as coordinate pairs (X,Y). When saving points into the memory, coordinates are saved continuously, except as follows:

5   If the signal is found to be below the threshold (as described above), then a marker (a pair of unique values) is written into the memory, for example (NaN,NaN) which will signify later that the pen was lifted (NaN stands for not-a-number as defined in the IEEE arithmetic standard). After that, no new points are added to

10   the file until the signal is detected again. This approach allows the pen to tell the playback program exactly where to interrupt the restored trajectory line.

      If the signal is significant, but the pen position did not change significantly as compared to the previous position, then no new

15   point is added to the memory, but unlike the case of no signal, no markers are written to the memory. The size of the move squared is calculated as $(X1-X0)^2 + (Y1-Y0)^2$. The typical value for the significance of the move squared is 0.04 mm^2.

      No timestamps are included in a file because this information is

20   not required for restoration of the pen trajectory.

      Coordinates are stored in the temporary buffer and are compressed only before storing in flash memory. Each page is stored in a separate file. Therefore, there is no need for an end of page mark.

Full time stamps will be inserted before the first valid pixel. All other timestamps on a page (file) will be incremental and inserted whenever the pen is lifted off the paper. Only one time stamp is inserted regardless of how long the pen was off the paper.

5   **SLEEP MODES**

When the pen is taken out of the holder or the ink well for writing, the ASIC turns on in the sleep mode and waits until an optical signal is detected from the pen.

When the holder is awake and it detects that writing is interrupted
10   for a predefined period of time, the holder returns to the power-saving sleep mode. The ASIC enters sleep mode by reducing its normal 48MHz clock frequency to 750kHz. SDRAM update refresh rate also changes accordingly to keep data intact.

The holder power is almost entirely off when the pen is inside the
15   holder or in the inkwell. RS232 receiver and USB monitoring circuits consume very little standby current. These circuits wake up and enable power to the rest of the electronics on detection of active levels for RS232 or USB, when connected to a cellular phone over the cable or by USB cable to a PC. The pen holder is
20   completely off when the pen is inside the holder.

In sleep mode, the only function of the holder electronics is to watch for a WAKEUP input from photodiode and associated PLL circuitry indicating that the pen is active. In sleep mode, the pen

consumes little power between the time intervals when it checks
the photodiode.

During writing, the pen transmits modulated IR pulses. The pulses
are detected at the holder causing the PLL to wake up the

5   processor, which starts normal acquisition mode as soon as the
ASIC switches back to the 48 MHz system clock.

PHASE LOCK LOOP (PLL)

When the modulated IR light from the pen is being detected, the
modulation clock of the pen LED (represented by 1kHz bursts in

10   the output light) is extracted using PLL circuitry 132 tuned to the
modulation frequency of the IR light.

All acquired data is initially stored in SDRAM 134 using DMA.
The update rate of the SDRAM remains unchanged when going
from acquisition mode to sleep mode. The memory requirement is

15   1Mbyte for 50 pages of compressed or 10 pages of uncompressed
data. The 5:1 compression algorithm must have fast and
computationally simple coding with no limitation on decoding.

The acquired data is initially stored in SDRAM during writing.
When the pen is returned to the ink well or the pen, or when the

20   new page switch 136 is activated, the ASIC writes all data from
SDRAM into flash memory 138. Only a short time is needed to
write a full page of hand-written text data into flash. The transfer is
indicated to the user by lighting a yellow LED 140 on the holder.

8Mbit flash memory stores compressed files representing a maximum of 50 pages of handwritten text. The compression algorithm allows at least 6-to-1 compression without observable distortion of text.

5   **POWER FOR THE HOLDER**

The holder is powered by two AA NiMH batteries connected in series to provide 3.0V. When the pen is in the ink well or the holder, the pen's three NiCd batteries are recharged by a trickle current. The pen batteries have a large capacity and are almost

10   never recharged completely. The trickle current charging is enough to maintain the battery charge. A special mode is provided when the pen and the pen holder are both in the charger to charge all the batteries including the pen batteries with the full charging current.

Battery life is ten handwritten pages or a week of average use

15   without compression of data for storage in memory. An average user may write 2 characters per sec, or 120 char/min, or 7200 char/hr. The average handwritten page is approximately 700 characters. To produce ten pages, the battery must work for 5 hours.

20   When connected to a USB port, the holder can get power from the USB host. The charge on batteries is maintained at a high enough level to start the circuitry prior to switching to USB power. Power from the USB connector is provided only after the ASIC establishes communication over the USB link and notifies a PC on

the other end of the USB link that the connection is "high power".
In response, the PC provides up to 0.5A. Battery charging current
is set at 0.4A and is monitored to switch the charger into trickle
charge.

5   The holder circuitry is activated when the pen is taken out of the
holder or the ink well. Some holder circuitry, like the RS232 driver
and wake-up power circuitry take power directly from the battery.
Other circuitry takes power from a 3.3v supply generated by an on-
board switching regulator from the battery voltage of 2 to 3 volts.

10   When connected to a USB link, the 3.3v is generated from USB
power.

5v is generated for the analog circuitry from the 3.3v supply.

SYNCHRONIZATION OF PEN AND HOLDER

Synchronization of the pen and the pen receiver can produce a

15   better signal resolution and correspondingly better angle resolution
and resolution of writing.

As shown in figure 20, for synchronization, the pen produces
periodic bursts 401 of higher frequency pulses, such as pulses at 1
– 10kHz (suggest we show some timing diagrams) that can be

20   easily detected by the PLL. The PLL will detect not only the actual
modulation clock but also its phase, which enables a signal to be
generated to start data acquisition and synchronize it with the pen
LED.

51

As shown in figure 21, the control signals, LED_ON and LED_OFF, trigger signal acquisition. In such a case, only two frames will be required for background cancellation, one for the IR signal when the pen LED is on, and the other, when the LED is off.

5   For a CMOS sensor, a shutter mode is provided that resets all pixels at one time.

Having only two frames per sample raises the sample rate and resolution and may allow the processor to go into idle mode in between the samples to save power.

10   **USE OF 2-D CMOS ARRAYS**

Vendors to manufacturers of digital sensors produce small power-saving sensors and sensors along with the image processing circuitry that can be integrated into the pen on paper or 3-D pen applications.

15   3-D positioning of a light spot is possible using two 2-D photo arrays. Projection of a point of light onto two planes defines a single point in 3-D space. When a trajectory of 3D positions is available, motion of an IR pointer-pen can control a 3-D object on a PC screen. When the pen moves in space, it drags or rotates the

20   object in any direction.

SLAVE MODE

In other implementations, using the ARM7 based ASIC in a slave mode , the DMA can handle the data acquisition, but the vertical

synchronization signals are provided by the pen light detection circuitry (PLL).

TWO ANALOG CHANNELS ALTERNATIVE

Two separate channels can be used for analog signal processing
5 and A-to-D conversion. Such an implementation could use more economical parts that do not require fast settling times, frequency bandwidth and slew rate.

FRAME VARYING ALTERNATIVE

CMOS sensors have a limited dynamic range. Although an
10 adjustable electronic gain may be used for both CMOSs simultaneously after the output of the CMOSs, this arrangement may be not be ideal, for two reasons.

First, the signals for the two CMOSs may be different in magnitude when the pen is being moved in certain areas of the
15 paper, so changing the gain for both may fix one signal while degrading another signal to an unacceptable level. To get suitable signals across the page, it is useful to have separate gains for each CMOS. Second, using an electronic gain does not do anything to prevent saturation of the actual CMOS, which is unavoidable with
20 the area that the sensors must cover.

The gain of the CMOS can be changed by changing the exposure rate for each CMOS independently. As shown in figure 21, the pen transmission rate remains 100Hz, while the frame rate 601 of the

53

CMOS is shifted among 300Hz, 600Hz, and 1200Hz. At 300Hz, the background cancellation is straightforward. For 600Hz, the algorithm uses every other frame (frames 1, 3, and 5). For 1200Hz, the algorithm uses every fourth frame (frames 1, 5, and 9). The

5   pixel rates are 300kHz, 600kHz, and 1.2MHz. Changing the frame rate can be accomplished by the ASIC without any additional hardware.

Each CMOS may be connected directly to its own ADC or both could be connected to one ADC that would be able to handle 1.5

10   megasamples/sec and have a 4V reference voltage. The ADCs then may feed into a digital multiplexer so that the signals can be fed into the ASIC.

PSD BASED APPROACH

Instead of CMOS arrays, two PSDs may be used to detect the IR

15   light from the pen. Each PSD determines the angle between the page and a line of sight between the pen and the PSD. The two angles from the two PSDs and the distance between the PSDs are sufficient to compute the location of the tip of the pen.

Even with IR filters, ambient light will introduce errors in PSD

20   positioning measurements. To reduce the errors, the IR light at the pen is modulated to generate pulses at a modulation frequency and with a 50% duty cycle, as described above.

54

Two analog techniques may be used to discriminate the PSD signal
that is translated into the angle for use in triangulation.

In one approach, called synchronous demodulation and used in
instrumentation electronics, the incident synchronous light pulses

5   are chopped at the light modulation frequency, and opposite gains
(+1 and −1 respectively) are applied to those signals, depending on
whether the LED is on or the LED is off. This allows for
subtraction of background noise. Then the signal is integrated
using a time constant that it is responsive to the signal variations

10   on one hand and averages out noise on the other. In one example,
the modulation frequency could be 3kHz, and the pulse amplitude
could be ILEDpeak = Xma.

A second approach to discrimination uses a sample and hold
technique. The shape of the optical signal has a 50% duty cycle at

15   the 3kHz modulation frequency, as before, but also has a
significantly stronger short pulse imposed on the modulation
frequency. The modulation frequency is discriminated using a PLL
and is used to trigger the sample and hold circuitry, while the
strong optical pulse is actually sampled. The pulse amplitude is

20   ILEDpeak = Xma and the pulse duration T = Y usec.

PSDs are extremely accurate in sensing and measuring the position
of light on their photosensitive surfaces. They are inexpensive and
require very little power consumption. The PSD implementation is
also simpler than the CMOS one.

As shown in figure 23, current-to-voltage transformation is done on each of four channels, two for each PSD. The four analog signals pass through low frequency filtering 605, synchronous detection 607, integration 609, and digitization 611 by

5   microcontroller 613 (12-bit A/D converters). A-to-D conversion is performed at a 100Hz sampling rate. The processor is active when the pen is making a trace on paper. The processor performs signal acquisition and periodic storage into flash memory. Figure 24 shows a system timing diagram. When no trace is being made, the

10   microcontroller enters the idle mode, and after an arbitrary period of time, the sleep mode.

The microcontroller is awakened from idle mode or sleep mode by either an interrupt or polling (TBD) of the following inputs: one of the four analog channels, when the signal at its modulation

15   frequency exceeds a certain threshold of the comparator; an interrupt from a USB port when presence of activity from a host is detected; one of its key buttons is pushed.

When the RAM becomes full or/and the boundary of a flash memory page is reached, the processor writes data from RAM to

20   flash memory. If acquisition continues and the page is full, the microcontroller start writing to flash. However, most of the flash operations should be done during idle cycles when there is no writing.

Each PSD has two channels of analog signal processing. Each

25   channel has a current-to-voltage converter whose output is AC

56

coupled into the first gain amplifier. The signal is chopped with the modulated frequency of the pulsing IR LED (on pen), currently 1kHz.

5   When LED emits light, the chopper has a gain of +1. When there is no light, the gain is −1, therefore the signal is synchronously demodulated. The last stage is an integrator, whose output is close to DC. More precisely, it is a saw-tooth waveform due to charging and discharging of the integrating capacitor in the feedback of the amplifier.

10   The A/D converter, either a PC-based DAQ or an A/D of the microcontroller, samples the output at specified time intervals synchronously with the modulation frequency to cancel errors due to saw-tooth waveforms.

To use all 12 bits of the A/D converter resolution, a dynamic

15   change in reference voltage for the converter is used. The microcontroller always starts reading the A/D channels with the highest range and then divides it in half until the range is the most optimum for the signal.

The chopper amplifier uses a replica of the modulation frequency

20   detected with an analog circuitry on each channel (four channels altogether). This signal is taken after the second gain stage, processed for detection of signal transitions, and then the recovered modulation pulses pass through OR gate to drive the chopper amplifier analog switch to change its gain between +1 and −1.

PHASE SHIFT USING PHOTO DIODES, ROTATING PEN TIP

As shown in figure 25, if a rotating light source 617 is used at the tip of the pen, it is possible to measure the phase difference among

5   signals on three photodiodes 619, 620, 621 on the holder to find the pen position.

The rotating light on the pen tip can be realized using several (e.g., eight) LEDs 623 that are triggered at times spaced apart by T/N, where T is the overall time period of the LED cycle, and N (e.g., 8)

10   is the number of LEDs.

The signal source is at some location on an X-Y plane. Two signal detectors 619, 620 are located at two other fixed locations on the same plane. If the signal source has a radiation pattern such that the signal radiated in the positive X direction is in phase

15   quadrature to the signal radiated in the Y direction (spatially rotating at the signal frequency), and the propagation delay is negligible compared to the signal period, then the angle A1, formed by two intersecting lines 637, 639 drawn from the detectors to the signal source will be the same as the phase difference

20   between the signals measures at the detectors.

If a third fixed location detector 621 is added, then a second angle A2 will be formed as three lines intersect at the signal source. Again, the angle A2 between the lines at the intersection will be the same as the phase difference of the signal measured between

58

the detectors. By applying some basic trigonometry, it becomes possible to find the location of the signal source in the X-Y plane by knowing the fixed locations of the detectors and measuring the phase differences of the signals at the detectors. If the three

5   detectors are arranged in a straight line with equal distances between them, the computation becomes trivial.

Referring to figure 26, the calculation of B and A angles based on the angles measured by the sensors, "a" and "b" is as follows:

Having: $a/A = d/R$ (1)

10   and $b/B = d/R$ (2)

and $B + A + b + a = 180°$ (3),

from basic geometrical theorems,

We get: $B/A = b/a$,   (4),

and accordingly $B = A \times b/a$ (5)

15                    $A = B \times a/b$ (6);

Now plugging (3) into (5) and (6) we get:

$A \times b/a + A + b + a = 180°$ (7) and

$B \times a/b + B + b + a = 180°$ (8);

We solve them for A and B:

59

$$A = a \times (180° - b - a)/(a + b) \quad (9)$$

$$B = b \times (180° - b - a)/(a + b) \quad (10)$$

The rotating light on the pen tip can be realized using several (e.g.,
eight) LEDs 623 that are triggered at times spaced apart by T/N,
5   where T is the overall time period of the LED cycle, and N is the
number of LEDs. For example, eight light emitting diodes (LED)
could be arranged in a circle pointing outward, spaced 45 degrees
apart and driven by an signal oscillator with a 45 degree phase
difference between adjacent LEDs.

10   As shown in figures 27 and 28, the three detectors 641 could be
Positive Intrinsic region Negative (PIN) diode optical detectors
driving a signal processing chain 642 consisting of a trans-
impedance amplifier 643 and a high gain limiter 645 to remove
any amplitude modulation in the detected signals.

15   Phase detection could be accomplished with two edge-triggered
one bit Up-Down counter type phase detectors 649, two binary
counters and a clock running several decades above the signal
frequency. If the counters are connected such that they count up
with every clock cycle where the one sensor leads the phase of the
20   other and count down when the phase lags, and a third counter is
set to count up continuously, then a microprocessor can
periodically read and reset all the counters, scaling the reading
from the two counters connected to the phase detectors (dividing
by) by the reading from the continuously running counter. This

number is the phase difference (in gradients) between the three sensors and as such, the angles between the intersection of the lines from the sensors to the source. It is then a trivial task to calculate the location of the source relative to the sensors.

5   **PEN LIGHT ACTIVATION SWITCH ALTERNATIVES**

Different pen light activation methods can be used, including conductive rubber, pressure sensitive materials or strain gauges.

Pressure sensitive material allows for a variable pressure threshold and coordination of the switching point with the ink flow. This
10   would prevent loss of data when the ink is making a trace while the pen is not active yet. Most ball point refills release ink at 20 to 30 gf +/- 30%, while an off-the-shelf switch activates at 50 to 100 gf and +/- 40gf, for example, making a reliable coordination of ink flow and data capture impossible. Special refills can be also
15   designed to prevent ink flow below 50 gf that might enable the use of off-the-shelf chip switches.

PEN OPTICS ALTERNATIVES

Other approaches for emitting light from the tip of the pen are possible. Optical fibers could be used to collect light from an LED
20   and emit it in a 360° pattern around the tip of the pen. Individual LED chips could be located around the tip of the pen and emit light through a half reflective lens/window, such that 50% of light is emitted and the other 50% is reflected internally to be mixed with

other light, ultimately producing uniform 360° illumination. Light could be mixed from a single LED using special rings that redistribute the light for uniformity.

PASSIVE PEN ALTERNATIVE

5   The pen may be completely passive if the IR light source is located next to the sensor. A reflective surface would be provided near or at the tip of pen. The sensors would see reflection of IR light from the tip of the pen and compute angles as described above.

The tip of the pen must be reflective only when pressed against
10   paper and ink is forming traces. Otherwise there will be erroneous traces in digital form with no corresponding traces on paper.

Activation of the reflective mechanism can be mechanical or electrical. In a mechanical implementation, pressure on the tip will open up a sheath and expose reflective surface around the tip. In a
15   electrical implementation, pressure on the tip will activate liquid crystals or other photo technology that will make that material reflective to light. Reflection from other objects, like fingernails and rings, can be handled by using polarized IR light.

PASSIVE PEN HOLDER

20   Conversely, the holder may have two reflectors, while the pen both emits light and receives reflections. The sensing element on the pen could be a 2-dimensional PSD or CMOS array. If flat 2-D sensors are used, the pen would not be omni-directional, but it

would be possible to make a custom circular 2-D sensor that would have 360° coverage.

KEYBOARD AND MOUSE REPLACEMENT ARCHITECTURE

5   The pen described above can be used to replace standard PC input devices such as a mouse and a keyboard.

When used as a replacement for a keyboard or a mouse, the sheet of paper, plastic or other flat surface, may bear a printed keyboard pattern that will serve as a keyboard and mouse pad for, e.g., PC's,

10   handheld computers, and cellular phones.

Users today are, for the most part, limited to keyboards, keypads or stylus input on screens when inputting data into PC's, handheld computers or cell phones. Keyboards are efficient and convenient when they are full size but do not lend themselves to portable

15   devices such as palm computers and cellular phones. Cell phone keypads, while efficient for dialing phone numbers, require excessive keystrokes when trying to generate ASCII letters and symbols, making any type of data input a very tedious and time-consuming process. Styli on screen input with palm devices

20   requires either that the user use unique writing styles such as "graffiti" in order to minimize the amount of handwriting recognition needed on the device or that the user tap on small virtual keyboards represented on the screen. Both styli approaches

63

often result in incorrect input, which limits the functionality of these devices.

An electronic pen can be used in a mode that provides a highly reliable method for inputting text characters in addition to

5   recording handwritten images and lines. A sheet of paper or any other surface (with or without a printed pattern of a keyboard) is all that users need to type with a pen.

The spatial transcription capabilities of the electronic pen together with the keyboard template are used to substitute for the mouse or

10   keyboard.

The paper keyboard can be multiple sizes based on the user's needs. The size can range from an 8 ½ x 11 sheet of paper to the size of a cell phone cover. The user first selects the size of keyboard he desires and then calibrates by touching the pen to

15   specified characters on the keyboard. To type a message, the user touches the tip of the pen on the appropriate keys. When the pen touches the square area of the paper that corresponds to a certain letter the location of the tip of pen is computed and the designated letter is determined. This approach allows the user to generate text

20   on a computing device with an electronic pen without any dependency on handwriting recognition software.

This approach is an improvement over the built in keypads, software keyboards or styli on screen input approaches currently used on ever-shrinking personal appliances. The paper keyboard

allows the user to enter messages on handhelds and cellular phones
faster and more reliably than with alternative approaches. The
paper can also be used in other modes to record drawings and
handwritten notes and images. When done, the paper keyboard can
5   be discarded or folded for future use.

In addition to characters, the keyboard can also contain shortcut
keys and function keys that enable more efficient interaction with a
small device. Short cut keys can minimize the number of
keystrokes required to enable commands. Short cut keys can be
10   customized based on the type of device being input into.

The keyboard can also incorporate a section that serves as a paper
mouse pad. Using the electronic pen's spatial transcription
capabilities, the user can move the pen within a designated square
space on the paper that in turn moves a pointer on the screen of a
15   device. The paper mouse thus serves as an alternative to keys and
styli on screens as a means for navigating on the screen of a
handheld or cellular phone.

The paper keyboard also enables flexibility in inputting foreign
characters. Keyboards can be created for several languages such as
20   Japanese, Korean, Spanish, French and Russian. A user can simply
print out a new keyboard if they desire to input a different
alphabet.

As shown in figure 29, to type a message, the user touches the tip
of the pen 701 on the appropriate keys 703 printed on a paper

65

keyboard 705. The positions at which the pen is touched are
tracked by tracker 707, converted to text and then sent to a portable
device such as a cellular phone 711 or a palm computer 709.

The keyboard can be folded or discarded after the use.

5   In other implementations, there is no printed paper keyboard;
rather the tracked motions of the pen can be used through
handwriting recognition to derive text, commands, and drawings as
the pen is used for writing on any surface.

In one implementation of this approach, the mouse and keyboard
10   can continue to be used and the pen serves as an alternative. The
pen can operate in either a "pointing device" (mouse) or a
"character input" (keyboard) mode. The mode can be selected by a
dedicated hardware switch or button, on a pen holder or pen, or by
sending a command from PC to a holder..

15   In mouse mode, pen operation is indistinguishable from that of a
secondary (USB) mouse. It is a relative positioning pointing device
moving the cursor on the screen. In keyboard mode, pen input can
be received by a specially designed application using an available
character recognizer to convert graphical input (strokes) into
20   characters. Other applications are not aware of the pen presence
and continue to operate using the regular (legacy) keyboard.

In another approach, the pen is the only input device to the system.
In this case, a software driver stack is modified to provide

keyboard functionality system-wide. Mouse-mode operation is not affected and is identical to the first-described approach. When operating in keyboard mode, pen input is recognized by available handwriting recognition software built into a keyboard filter driver and then delivered to system input queue in a similar way to traditional keyboard input.

This second approach requires a platform usability model and (most likely) modification of certain system components such as Basic Input/Output System (BIOS).

Both approaches raise human factor and usability issues. In particular, there are two basic approaches to handwriting recognition: discrete (single character at a time) and continuous (word, phrase or page at a time). In the former case, the user must continuously rely on computer screen output for feedback. This may be awkward, because the handwriting process must be constantly interrupted by looking at the computer screen for feedback. In latter case, the user must only look at the screen once in a while, when a writing unit (word or phrase) is completed and correct it as necessary.

Switching from mouse to pen input mode could be done by retractable pen refill action. When the refill is inside the pen (pen cannot write), it is used as a mouse. When writing is activated, the pen acts as a keyboard.

Other embodiments are within the scope of the following claims.

The holder need not be of the kind that includes an inkwell as described above but can be any kind of device that can hold the sensors. The holder can be a simpler pen cap, as shown earlier, or could be any other kind of device whether or not it mates with or

5   caps the pen and whether or not it includes a clip or not. The holder could be incorporated into a clipboard or a notebook, for example.

The light in the pen can be fiber optics that deliver light to the tip and convey it in all directions around the pen in a disk-like pattern.

10

CLAIMS

1   1.   A method comprising

2   conveying light from a moving light source on the writing
3   instrument as an indication of the location and path of the writing
4   instrument on a two dimensional writing surface,

5   sensing the light at two or more sensors and generating a
6   sequence of signals representative of the sensed light, and

7   applying a technique to increase the stability of subpixel
8   reading.

9   2.   The method of claim 1 in which the technique is based on
10   optics.

11   3.   The method of claim 1 in which the optics are configured
12   to enhance the uniformity of signal response of the sensors.

13   4.   The method of claim 3 in which the lens comprises a
14   spherical lens.

15   5.   The method of claim 3 in which the lens comprises an
16   aspheric lens.

17   6.   The method of claim 3 in which the sensors comprise
18   arrays of sensitive pixel elements.

19   7.   The method of claim 3 in which the sensors comprise
20   analog sensors.

21   8.   The method of claim 1 in which the technique is based on

22   algorithmic processing of the generated signals.

23   9.   The method of claim 8 in which the algorithmic processing

24   comprises mapping the signal response of the sensors based on

25   parameters associated with the writing instrument.

26   10.   The method of claim 8 in which the technique is also based

27   on optics.

28   11.   The method of claim 8 in which the sensors comprise

29   arrays of sensitive pixel elements.

30   12.   The method of claim 1 in which the technique is

31   implemented in digital hardware.

32   13.   The method of claim 1 in which the technique is

33   implemented in analog circuitry.

34   14.   The method of claim 1 in which the technique comprises an

35   algorithmic technique that also reduces the effect of variations of

36   the light intensity based on other than dimensional effects.

37   15.   The method of claim 1 in which

38   the sensors comprise pixel arrays,

39   the signals are grouped in frames, and

40   the signal processing technique comprises processing of

41   multiple frames to cancel noise.

70

1   16.   The method of claim 1 in which the light conveyed from

2   the moving writing instrument is modulated at a frequency related

3   to the rate at which the signals are generated by the sensors.

1   17.   The method of claim 1 in which

2   the light conveyed from the writing instrument is

3   modulated at a frequency, and

4   the sensor signals are chopped at the frequency of

5   modulation.

1   18.   The method of claim 17 in which opposite gains are applied

2   to each of the chopped signals depending on the on or off state of

3   the light conveyed from the writing instrument that corresponds to

4   the signals.

1   19.   The method of claim 17 in which the frame rate is varied.

1   20.   The method of claim 18 in which the chopped signals are

2   integrated over time.

1   21.   The method of claim 1 in which

2   the light conveyed from the writing instrument includes a

3   strong short pulse imposed on the modulation frequency, and

4   a phase lock loop determines the modulation frequency

5   from the sensor signals, and

6   the sensor signal is sampled at the times triggered by the

7   phase lock loop during the duration of the strong short pulse.

1 22. The method of claim 1 in which characteristics of the
2 conveyed light are used for synchronization between the writing
3 instrument and the sensors.

1 23. The method of claim 1 in which the conveyed light
2 includes periods of lower frequency modulation and bursts of
3 higher frequency modulation, and the sensor signal associated with
4 the higher frequency bursts is used to lock onto a modulation
5 clock.

1 24. A method comprising

2 conveying light from a moving writing instrument in a
3 time-changing pattern of directions,

4 sensing the light at two or more sensors located at two or
5 more different locations spaced from the writing instrument, and

6 determining the location of the writing instrument by
7 detecting a phase difference between signals measured at the two
8 or more sensors.

1 25. The method of claim 24 in which the time-changing pattern
2 of directions includes a rotating pattern with respect to an X-Y
3 plane on which the writing instrument is moving.

1 26. The method of claim 25 in which the signal radiated in the
2 positive X direction is in phase quadrature to the signal radiated in
3 the Y direction.

1 27. Apparatus comprising

2   sensors configured to receive light from a writing

3   instrument moving across an X-Y writing surface, and featuring

4   instability in subpixel reading.   optics configured to enhance

5   optical power of the light received from the writing instrument.

6   28.   The apparatus of claim 27 in which the optics comprise a

7   ball lens or an aspherical lens.

8   29.   The apparatus of claim 27 in which the optics include a

9   single spherical lens and the lens and the corresponding sensor are

10   together configured to enhance the optical power of light received

11   at large angles or longer distances or at disadvantageous positions

12   of the writing instrument.

13   30.   The apparatus of claim 27 in which the optics include a

14   special lens configured to enhance optical power of the light

15   received from a location on the X-Y surface that is beyond a

16   predetermined position.

17   31.   The apparatus of claim 27 in which the optics include two

18   cylindrical lenses, one nearer the sensor to project light

19   horizontally onto sensor, and the other positioned to collect light in

20   the Z-axis dimension, the other lens having a body that is bent

21   around the first lens.

22   32.   The apparatus of claim 27 also including algorithmic

23   processes that enhance the immunity of the signals to variations in

24   the intensity of the received light caused by distance from or tilt of

25   the writing instrument.

26   33.   The apparatus of claim 32 in which the processes determine

27   the integral power of the overall signal distribution on the sensor

28   and calculate a subpixel position based on half of the integral

29   power position.

30   34.   The apparatus of claim 32 in which the processes use a

31   polynomial approximation on the signal distribution and calculate

32   a subpixel position as a position of approximated maximum.

33   35.   The apparatus of claim 34 also including a calibration

34   procedure to produce parameters to be used in combination with

35   data from the sensors.

36   36.   The apparatus of claim 35 in which the calibration

37   parameters correct for non linearity of our sensors, and the

38   algorithmic processes use a quasi triangulation technique to

39   determine a position of the writing instrument.

40   37.   The apparatus of Claim 36 in which the calibration

41   parameters correct for non linearity of our sensors and the

42   algorithmic processes determine the position of the writing

43   instrument using polynomial series, when coefficients in these

44   polynomials are determined during the calibration procedure.

45   38.   A method comprising

46   receiving light from a moving writing instrument at an

47   array of sensing elements of a sensor,

48   reading the sensing elements in sequence to generate a

49   sequence of signals indicative of light sensed by the elements of

50   the array, and

51   resetting each elements after it is read and before at least

52   some of the other elements in the array are read.

1   39.   The method of claim 38 in which the array comprises a

2   CMOS or CCD position sensor.

1   40.   The method of claim 38 in which each of the elements is

2   reset before the next element in the sequence is read.

1   41.   The method of claim 38 in which all of the elements are

2   read before all of the elements are reset .

3

1   42.   A method comprising

2   conveying light from a moving hand-held instrument,

3   sensing the light at two or more sensors, each of the two or

4   more sensors comprising a two-dimensional array of sensing

5   elements,

6   generating signals representing the two-dimensional

7   locations on the arrays of light that is sensed, and

8   determining a sequence of three-dimensional positions of

9   the moving writing instrument based on the signals.

10   43.   Apparatus comprising

11   a writing instrument system that can track three-

12   dimensional motion of the writing instrument.

13   44.   The apparatus of claim 43 in which the system includes

14   sensors having 3 linear arrays.

15   45.   The apparatus of claim 43 in which the system includes

16   sensors that are a two-dimensional array or a one-dimensional

17   array.

18   46.   Apparatus comprising

19   a writing instrument including

20   an elongated housing configured to be hand-held,

21   a light source in the housing, and

22   a lens in the housing configured to receive light

23   from the light source and convey the light through a free-air

24   path to optical sensors spaced from the writing instrument,

25   the lens being configured to enable light to be directed

26   parallel to the writing surface no matter what the

27   orientation or position of the writing instrument to the

28   writing surface.

29   47.   Apparatus comprising

30   a writing instrument including

31   an elongated housing configured to be hand-held, and

32   a light source in the housing, the light source comprising a

33   an array of light sources arranged around an axis of the writing

34   instrument and configured to emit light in a direction normal to the

35   axis.

1   48.   The apparatus of claim 46 in which the lens is configured

2   to internally reflect and concentrate the light and to emit it by

3   reflection from a reflective external surface of the lens.

1   49.   The apparatus of claim 46 in which the lens comprises a

2   cylindrical body having an upper surface that receives the light and

3   a lower annular surface that reflects the light toward the optical

4   sensors.

1   50.   The apparatus of claim 46 in which the light source emits

2   light in a direction toward a writing end of the writing instrument.

1   51.   The apparatus of claim 48 in which the reflective external

2   surface comprises a conical surface oriented at a certain degree

3   angle to a longitudinal axis of the writing instrument.

1   52.   Apparatus comprising

2   a writing instrument including

3   an elongated housing configured to be hand-held,

4   and

5   a light source in the housing, the light source being

6   arranged to emit light in a direction parallel to a

7   longitudinal axis of the writing instrument.

1   53.   The apparatus of claim 52 in which the light source

2   comprises one or more LEDs.

1   54.   The apparatus of claim 52 in which the light source

2   comprises a ring of light sources.

1   55.   Apparatus comprising

2   a writing instrument,

3   a light-source in the writing instrument configured to

4   convey light to sensors spaced from the writing instrument, and

5   a device configured to turn the light source on and off in

6   response to a user applying pressure from the writing instrument to

7   a writing surface, the switch being configured so that an amount of

8   pressure required to trigger the switch is not so large as to disrupt

9   normal writing motion of the writing instrument on the writing

10   surface.

1   56.   The apparatus of claim 55 in which the writing instrument

2   includes a ballpoint cartridge having a writing point and the device

3   is positioned at the opposite end of the cartridge from the writing

4   point.

5   57.   The apparatus of claim 56 in which the device could

6   comprise a switch.

7   58.   The apparatus of claim 56 in which the device could

8   comprise a pressure sensor.

1   59.   A method comprising

2   sending light from a moving writing instrument, the light

3   being indicative of a position and path of the writing instrument,

4   and

5   directly sensing, at one or more sensors spaced from the

6   writing instrument, angles from which light is received from the

7   writing instrument.

1   60.   The method of claim 59 in which the angles are directly

2   sensed by an array of sensitive elements of a sensing device.

1   61.   The method of claim 60 in which the sensing device

2   comprises a CMOS or CCD device.

1   62.   The method of claim 60 in which the sensing device

2   comprises a PSD.

1   63.   Apparatus comprising

2   a writing instrument, and

3   a holder having a receptacle for receiving at least a portion

4 of the writing instrument for storage of the writing instrument,

5   the writing instrument and the holder containing respective

6 elements that enable wireless transmission of signals associated

7 with motion of the writing instrument and tracking of the writing

8 motion based on the signals.

1 64. The apparatus of claim 63 in which the holder comprises a

2 pen cap.

1 65. The apparatus of claim 63 in which the holder includes a

2 clip configured to attach the holder to a stack of pages or to a

3 notebook.

1 66. The apparatus of claim 63 in which the holder includes at

2 least two light sensors and a processor that processes signals from

3 the light sensors to determine a sequence of positions of the

4 writing instrument.

5 67. The apparatus of claim 63 in which the holder includes a

6 receptacle for holding the writing instrument and enabling

7 recharging of batteries in the writing instrument.

1 68. Apparatus comprising

2   a writing instrument,

3   an element that enables wireless transmission of a signal

4   associated with motion of the writing instrument and tracking of

5   the writing motion based on the signal,

6   the element being built into a cell phone, a PDA, a webpad,

7   or a clipboard.

1   69.   Apparatus comprising

2   two optical sensors separated by a known distance and

3   arranged to

4   receive light from a source associated with a writing

5   instrument,

6   determine directions from which the light is

7   received relative to a known direction,

8   provide signals representing the directions for use in

9   determining a sequence of locations of the writing

10   instrument,

11   at least one of the two sensors comprising a CMOS

12   of CCD array.

1   70.   The apparatus of claim 69 in which the CMOS or CCD

2   array comprises a linear array of sensor elements.

1   71.   The apparatus of claim 69 in which the CMOS or CCD

2   array comprises a two-dimensional array of sensor elements.

1   72.   Apparatus comprising

2   a holder for a writing instrument,

3   the holder having elements used in wireless transmission of
4   signals associated with motion of a writing instrument in the
5   vicinity of the holder,

6   the holder having a mechanism for attaching the holder to a
7   writing substrate in an orientation that enables the elements to be
8   used in conjunction with the wireless transmission.

1   73.   The apparatus of claim 72 in which the clipping mechanism
2   includes a switch to activate functions of a processor in the holder
3   when the clipping mechanism is manipulated.

1   74.   The apparatus of claim 72 in which one of the functions
2   comprises a new page function.

1   75.   Apparatus comprising

2   a holder for a writing instrument,

3   the writing instrument including electronic circuitry
4   configured to be used in conjunction with tracking writing motion
5   of the writing instrument, the writing instrument including a
6   rechargeable battery connected to power the electronic circuitry,

7   the holder including a receptacle for the writing instrument
8   and a recharging circuit connected to recharge the battery when the
9   writing instrument is in the receptacle.

1   76.   Apparatus comprising

2   a CMOS sensor adapted to receive light associated with

3   motion of a writing instrument and to provide signals indicative of

4   an angle of receipt of the light with respect to a known direction,

5   and

6   a lens aligned to direct the received light to the CMOS

7   array.

1   77.   The apparatus of claim 76 in which the lens comprises a

2   half-ball lens.

1   78.   The apparatus of claim 76 in which the lens comprises an

2   aspherical lens.

3   79.   The apparatus of claim 76 in which the lens is optimized

4   for collection of light from an area in which the motion of the

5   writing instrument occurs.

1   80.   The apparatus of claim 76 in which the lens comprises a

2   flat field lens.

1   81.   The apparatus of claim 76 in which the lens comprises a

2   Fresnel lens.

3   82.   The apparatus of claim 76 in which the lens system is

4   configured to collect light in a dimension normal to a plane of

5   motion of the writing instrument and to project the light onto the

6   sensor in a direction parallel to the plane of motion.

7   83.   A method comprising

8   positioning a writing instrument at a succession of positions

9   on a writing surface,

10   generating signals at sensors from light received from the

11   writing instruments at the succession of positions, and

12   determining calibration parameters for the writing

13   instrument for use in calibrating a process that determines the

14   positions of the writing instrument as it is being moved.

15   84.   The method of claim 83 in which the calibration parameters

16   comprise coefficients used in polynomial series that are part of the

17   position determining process.

18   85.   The method of claim 83 in which the positions do not lie on

19   a regular rectangular grid.

20   86.   The method of claim 83 in which (I need help in reciting

21   the pseudo geometrical concept.)

22

1   87.   A method comprising

2   identifying locations on a writing surface that correspond to

3   input elements to be entered into an electronic device, the writing

4   surface being non-electronic and separate from the electronic

5   device,

6   using a writing instrument to point to selected ones of the

7   identified locations corresponding to input elements to be entered,

8   and

9   sensing the locations at which the writing instrument is

10   pointing and entering the corresponding data into the electronic

11   device.

1   88.   The method of claim 87 in which the writing surface

2   includes a sheet of paper.

1   89.   The method of claim 87 in which the input elements

2   comprise characters of language.

1   90.   The method of claim 87 in which the input elements

2   comprise commands.

1   91.   The method of claim 87 in which the input elements are

2   printed on the writing surface.

1   92.   A method comprising

2   moving a writing instrument across a non-electronic

3   writing surface to indicate a path, and

4   remotely sensing the path and generating signals for use in

5   entering the path into an electronic device that is separate from the

6   writing surface.

1   93.   A method comprising

2   modulating light that is conveyed from a moving writing

3   instrument to light sensors spaced from the writing instrument at a

4   predetermined frequency, and

5   using a phase locked loop associated with the sensors to

6   lock onto the phase of the modulated light.

1   94.   Apparatus comprising

2   circuitry for tracking writing motion of a writing instrument

3   using wireless transmission of signals between the writing

4   instrument and a stationary element, the stationary element

5   including a main processor and a separate preprocessor,

6   the preprocessor being connected to perform at least data

7   capture with respect to motion of the writing instrument,

8   the main processor being connected to perform at least data

9   communication with respect to the tracking.

1   95.   The apparatus of claim 94 in which the preprocessor is also

2   connected to perform user interface functions and sub-pixel data

3   storage.

1   96.   The apparatus of claim 94 in which the main processor is

2   also connected to perform background cancellation and sub-pixel

3   calculation.

4　　97.　　The apparatus of claim 94 in which the main processor is

5　　also connected to perform conversion of sub-pixel data into paper

6　　coordinates.

7　　98.　　The apparatus of claim 95 in which data storage is done in

8　　the form of paper coordinates.

9

1　　99.　　Apparatus comprising

2　　　　　　a writing instrument and a sensor,

3　　　　　　the writing instrument including a reflective element

4　　configured to reflect light received from outside of the writing

5　　instrument to the sensor for use in tracking motion of the writing

6　　instrument.

1　　100.　　The apparatus of claim 99 also including a mechanism to

2　　enable the reflective element to reflect the light to the sensor when

3　　the writing instrument is being used for writing and to disable the

4　　reflective element from reflecting light to the sensor when the

5　　writing instrument is not being used for writing.

1　　101.　　A method comprising

2　　　　　　receiving light from a moving writing instrument at a light

3　　sensor having an array of sensitive pixel elements,

4   determining the location in the array at which the

5   maximum intensity of light has been received from the writing

6   instrument, the location being determined with sub-pixel accuracy.

7   102.   The method of claim 101 in which the sub-pixel location is

8   determined by

9   determining the integer pixel location that is closest to the

10   subpixel location, and

11   finding a fractional center of gravity of a subarray that is

12   centered on the integer pixel location.

13   103.   A method comprising

14   indicating locations on a non-electronic surface that

15   correspond to inputs to an electronic device,

16   detecting the locations and inputting them into the

17   electronic device.

18   104.   Apparatus comprising

19   a sensor configured to detect light from a moving writing

20   instrument, and

21   a clip for clipping paper on which the writing instrument is

22   to be moved to the sensor.

23   105.   The apparatus of claim 104 in which the mechanism

24   comprises part of a clipboard or a notebook.

25   106.   The apparatus of claim 104 in which the clip includes a

26   mechanism for enabling a user to cause the clip to grip or to

27   release the paper.

28   107.   The apparatus of claim 106 in in which the mechanism

29   comprises an activation button and a spring.

30   108.   The apparatus of claim 107 in which the mechanism

31   includes a lever operated by the button.

32   109.   The apparatus of claim 108 in which the lever is configured

33   to rotate in response to the button.

34   110.   The apparatus of claim 107 in which the button is

35   configured to be pushed.

36   111.   The apparatus of claim 107 in which the button is

37   configured to be pulled.

38   112.   The apparatus of claim 46 in which a light guide delivers

39   light to the tip of the pen and conveys it outwardly in a disk-like
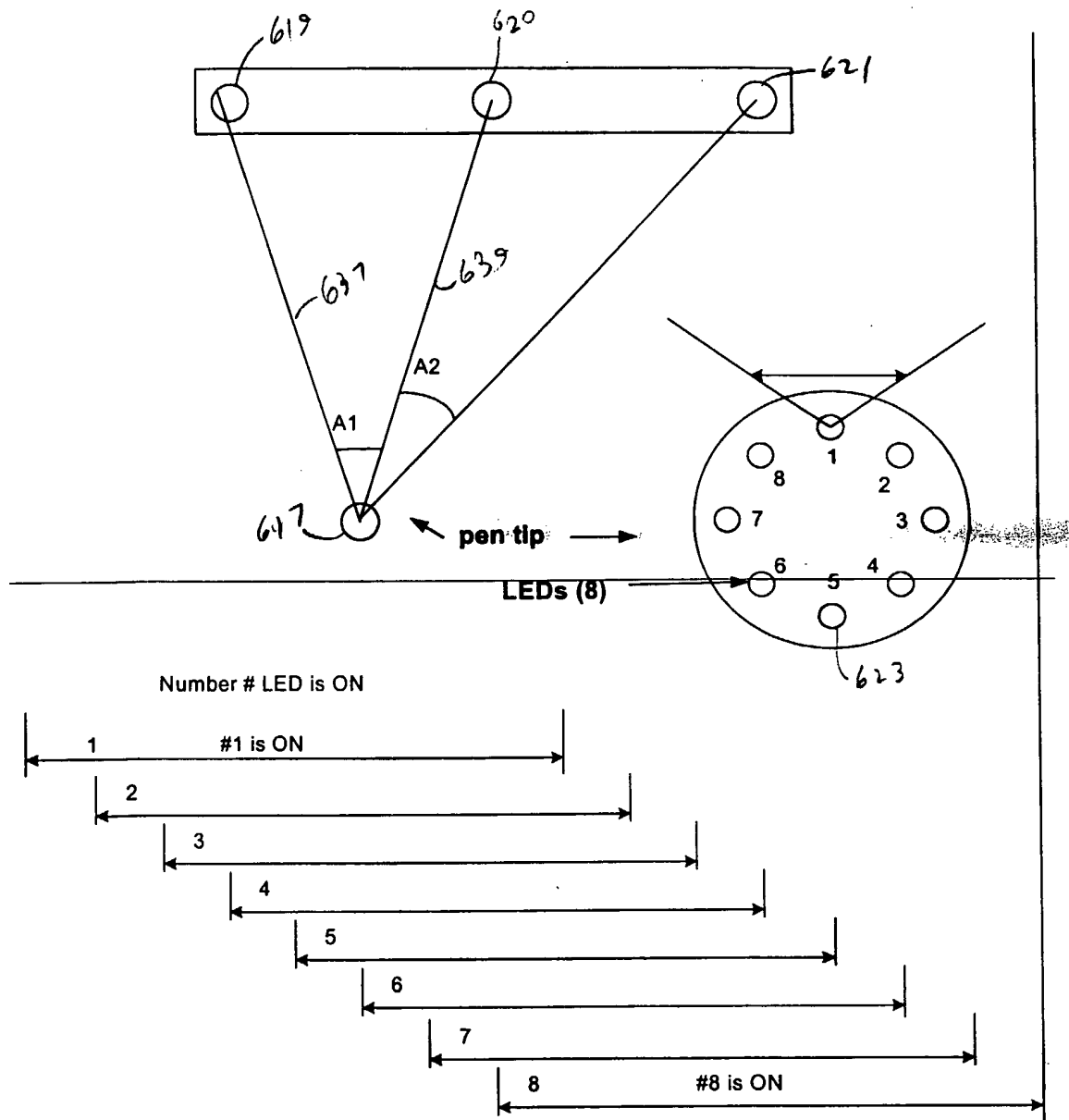
40   pattern.
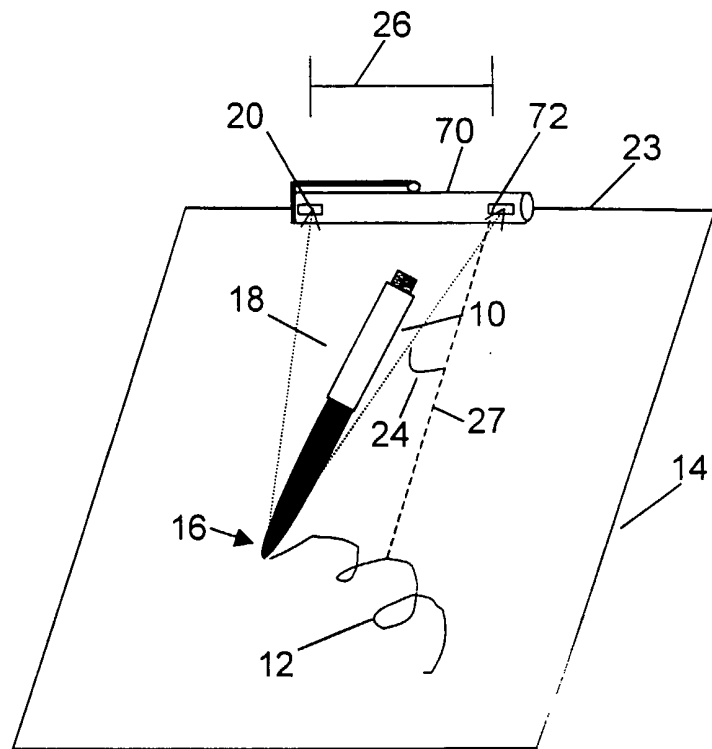
Figure 1
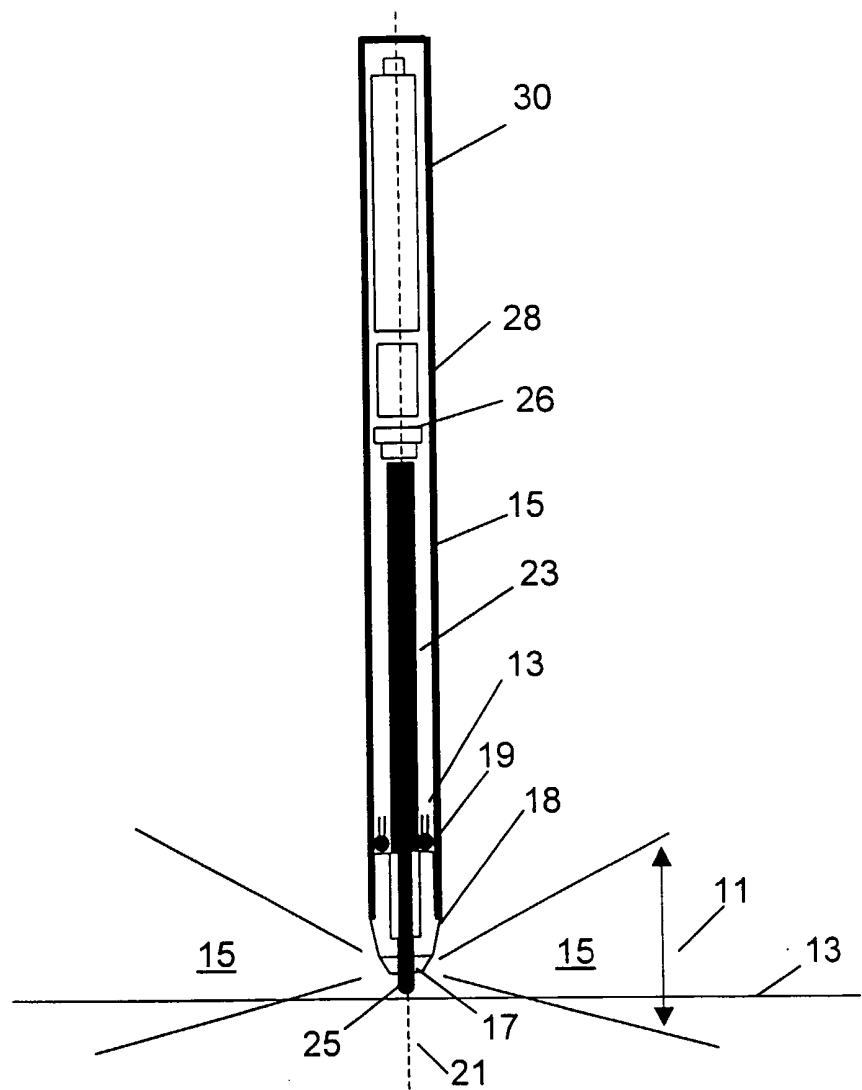
Figure 2
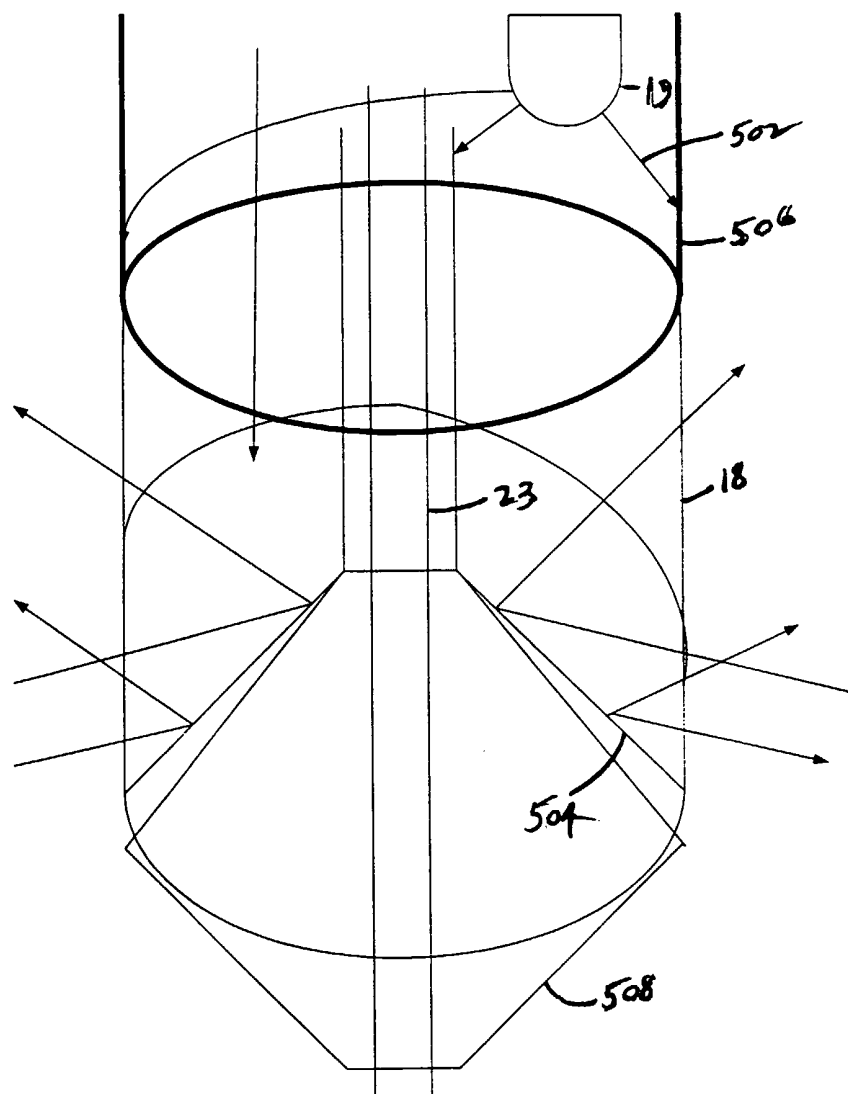
FIGURE 3
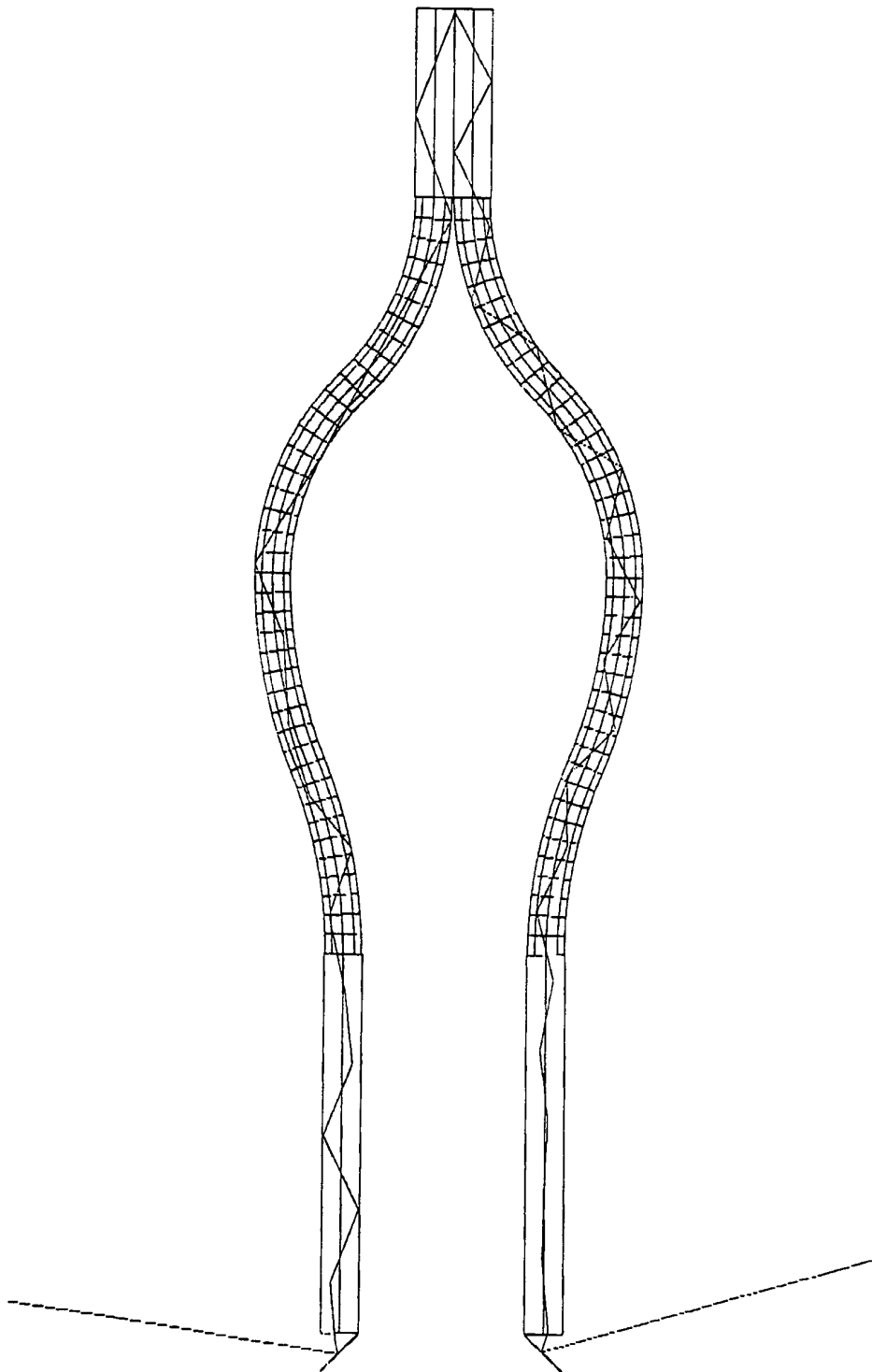
FIGURE 4
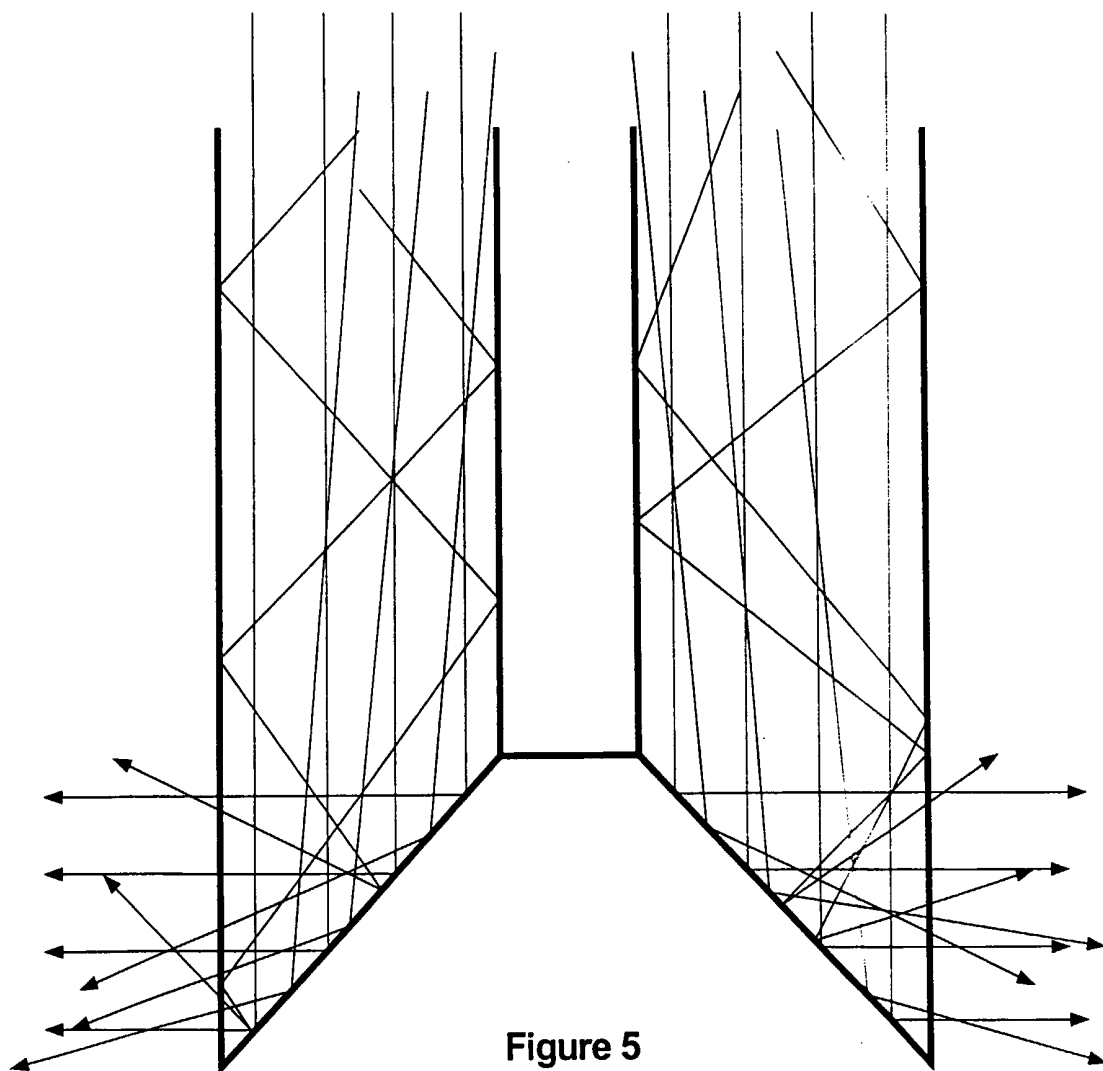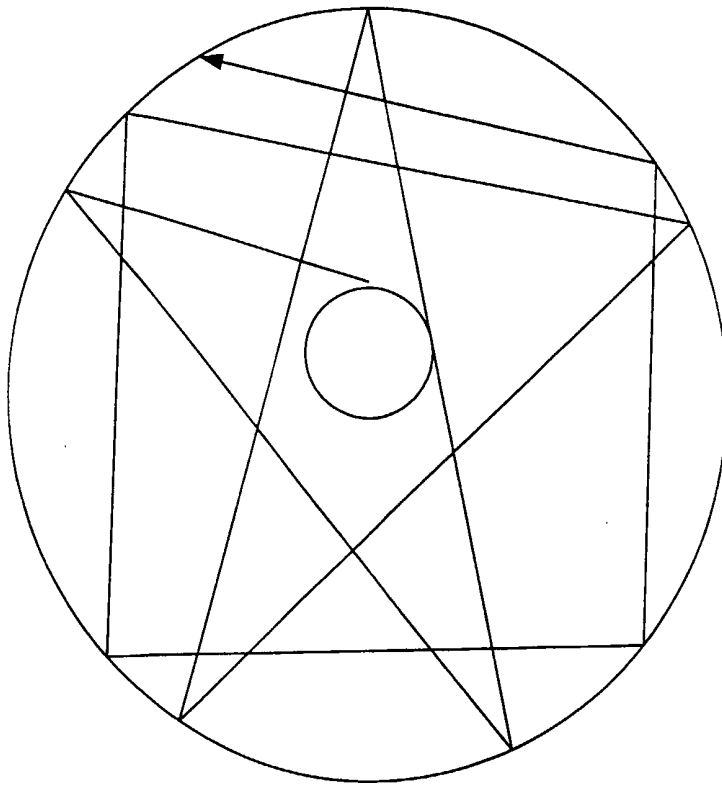
Figure 5

Figure 6

Figure 7

Figure 8

9/33
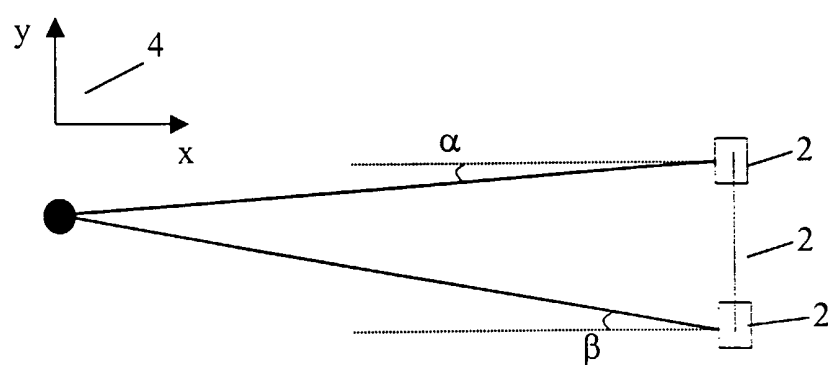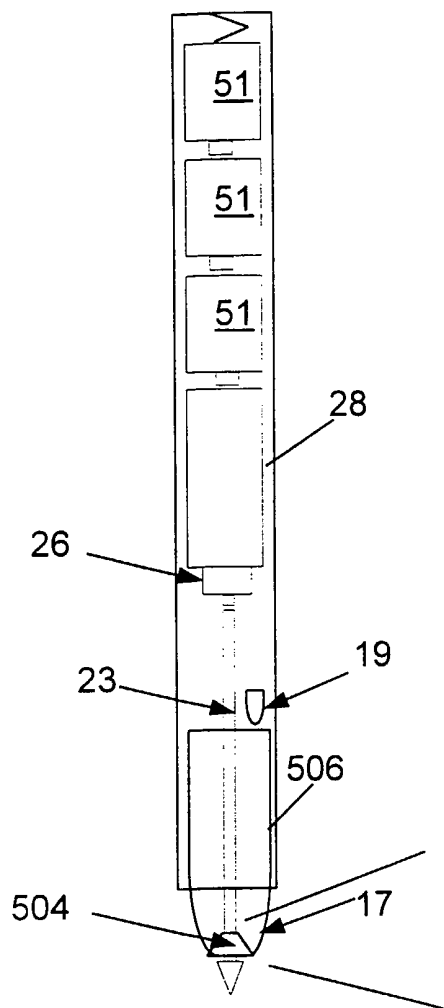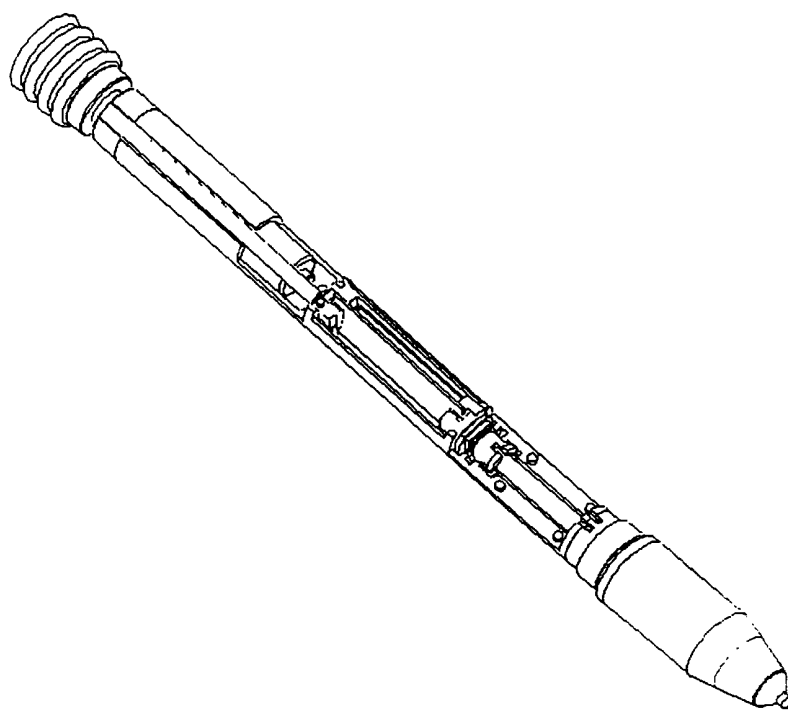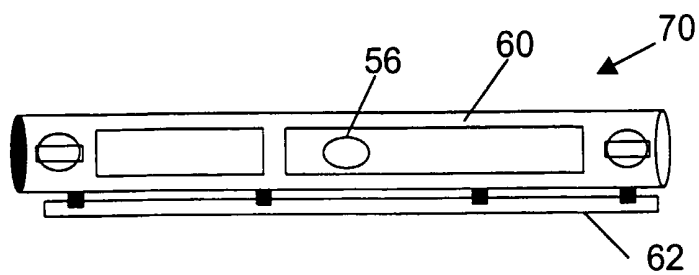
Figure 9

Figure 10

FIGURE 11

Figure 12

87   95   97   79   99

89   93   91   83   82   80
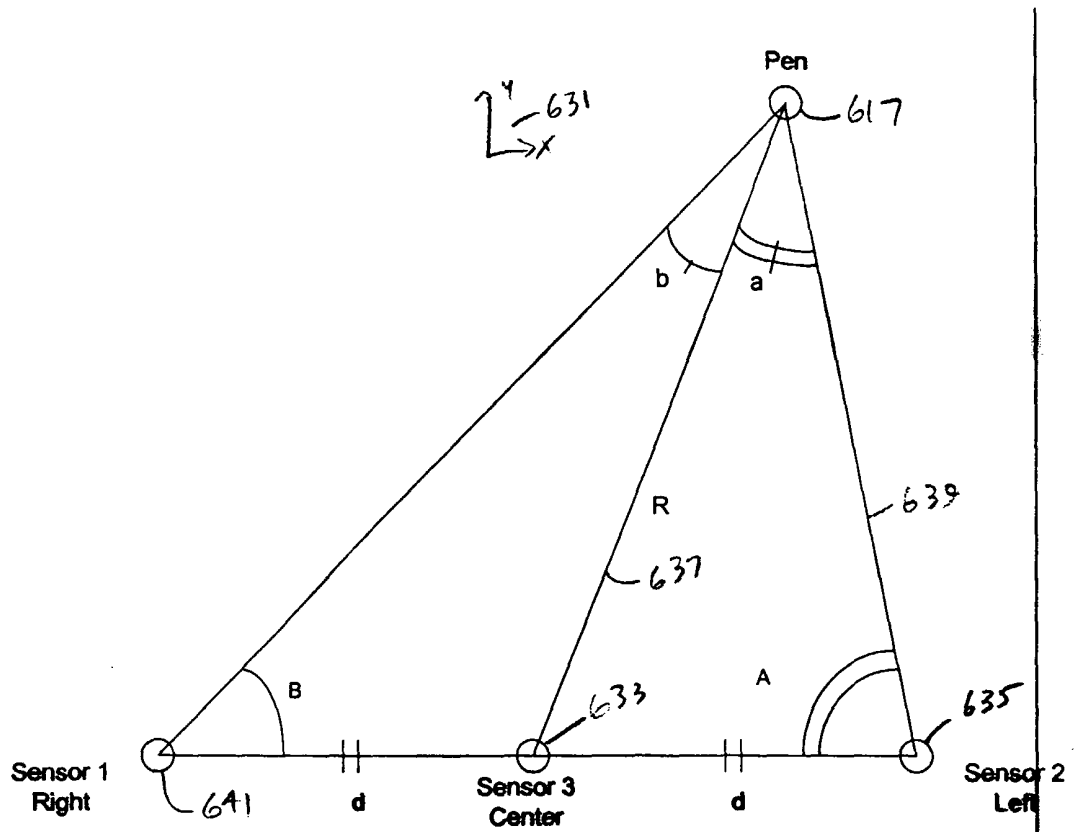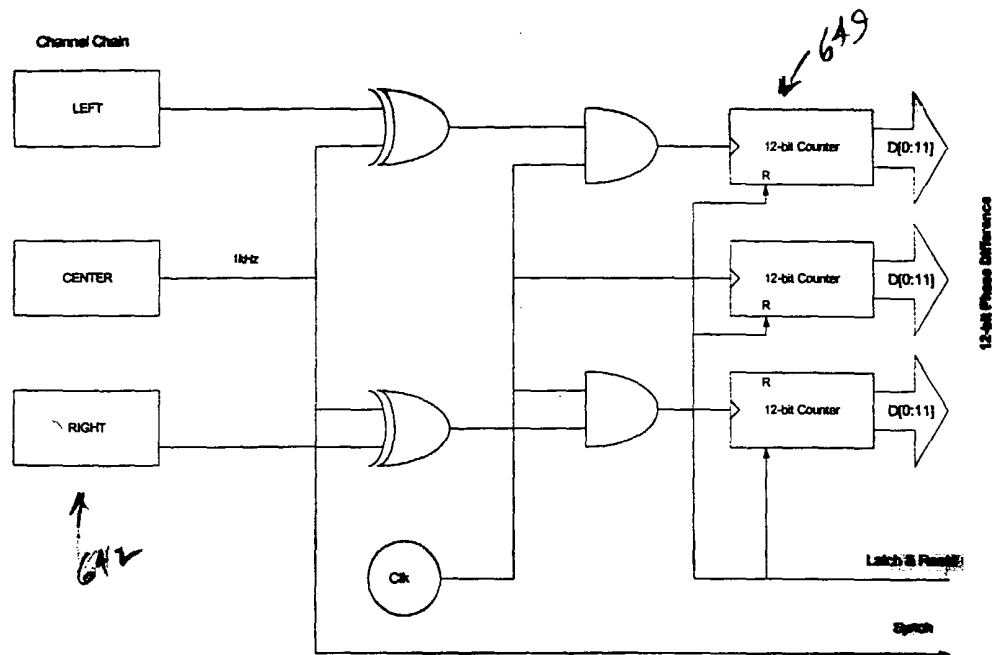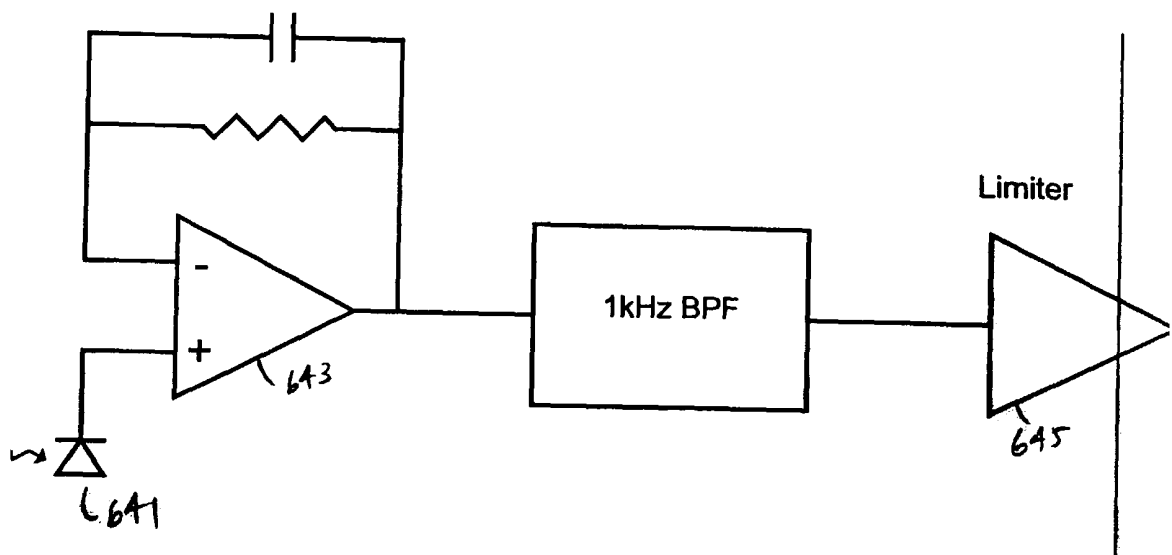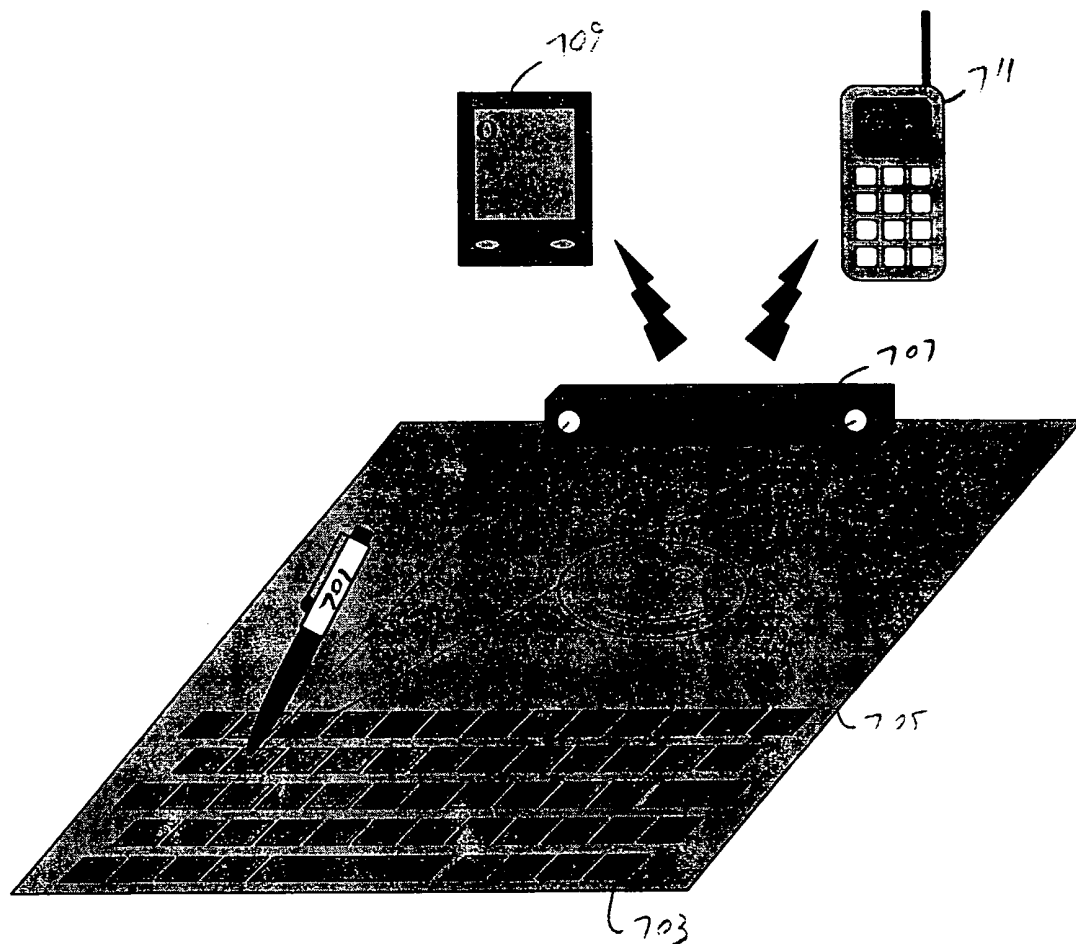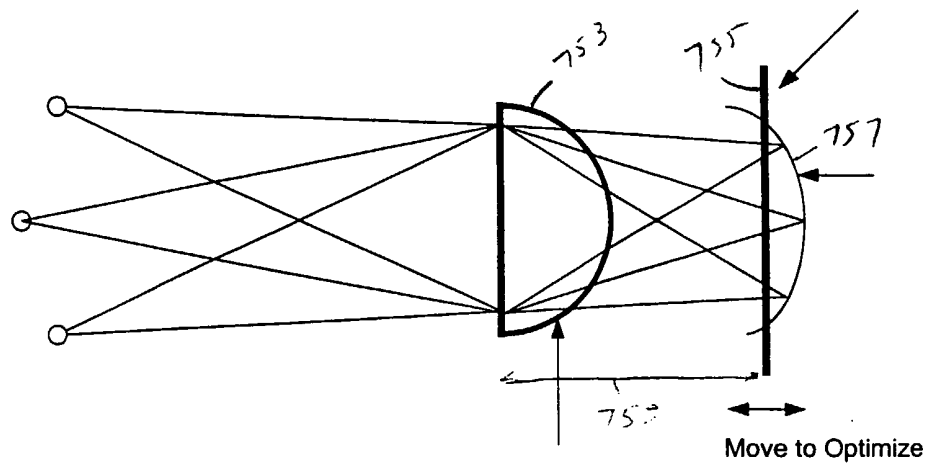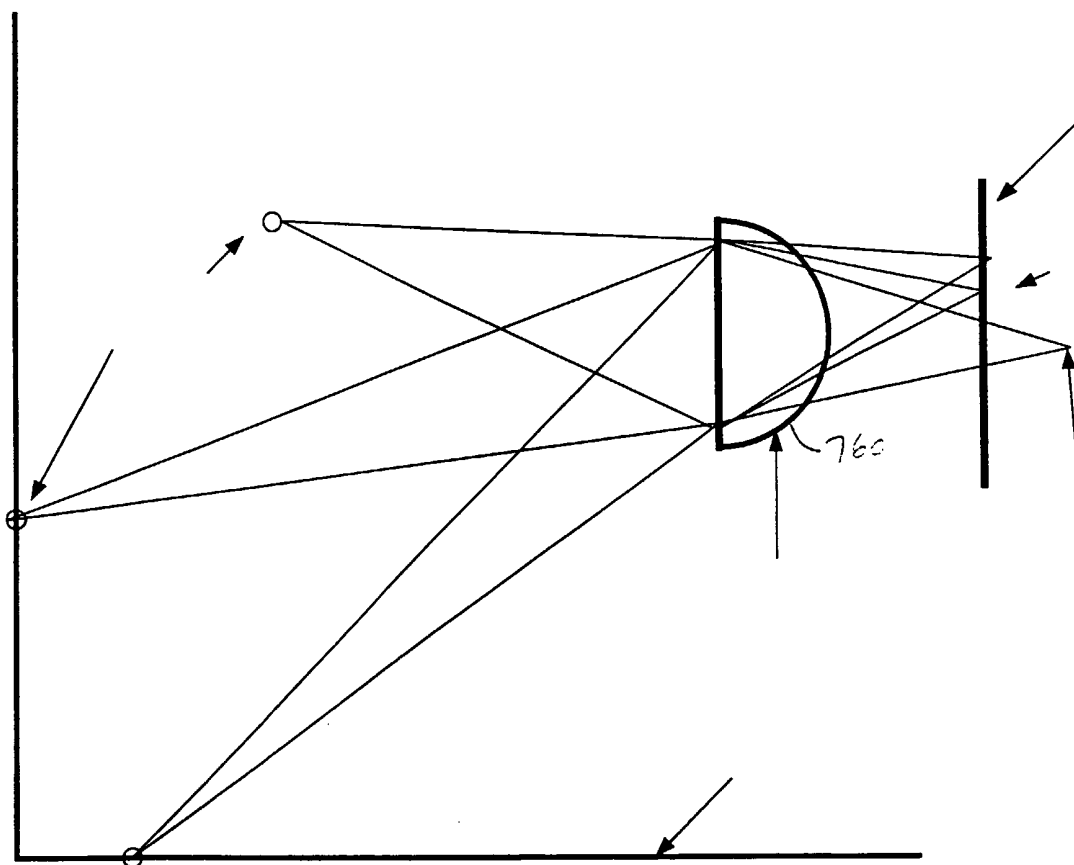
Figure 13

89   93   91   80

Figure 14

80

86
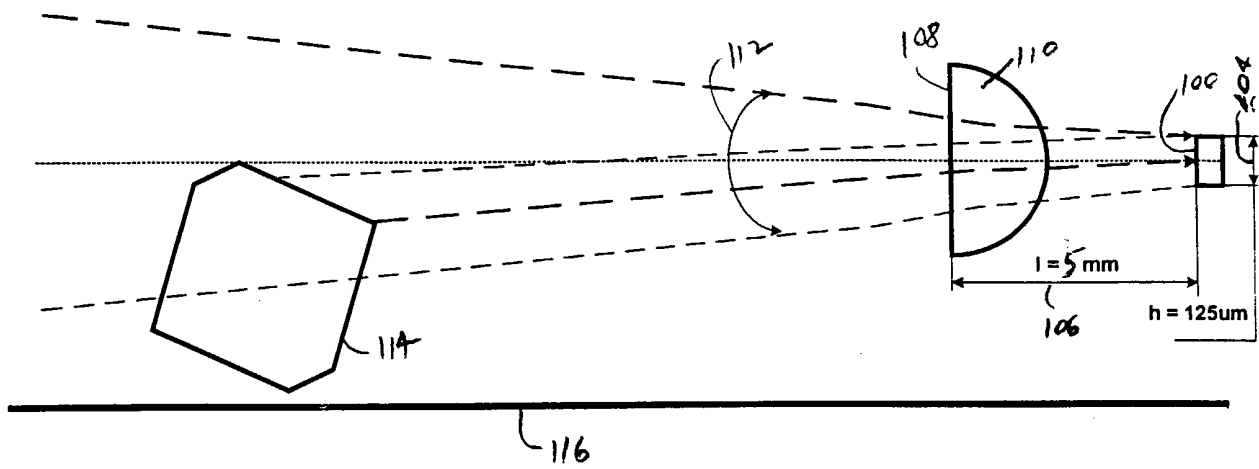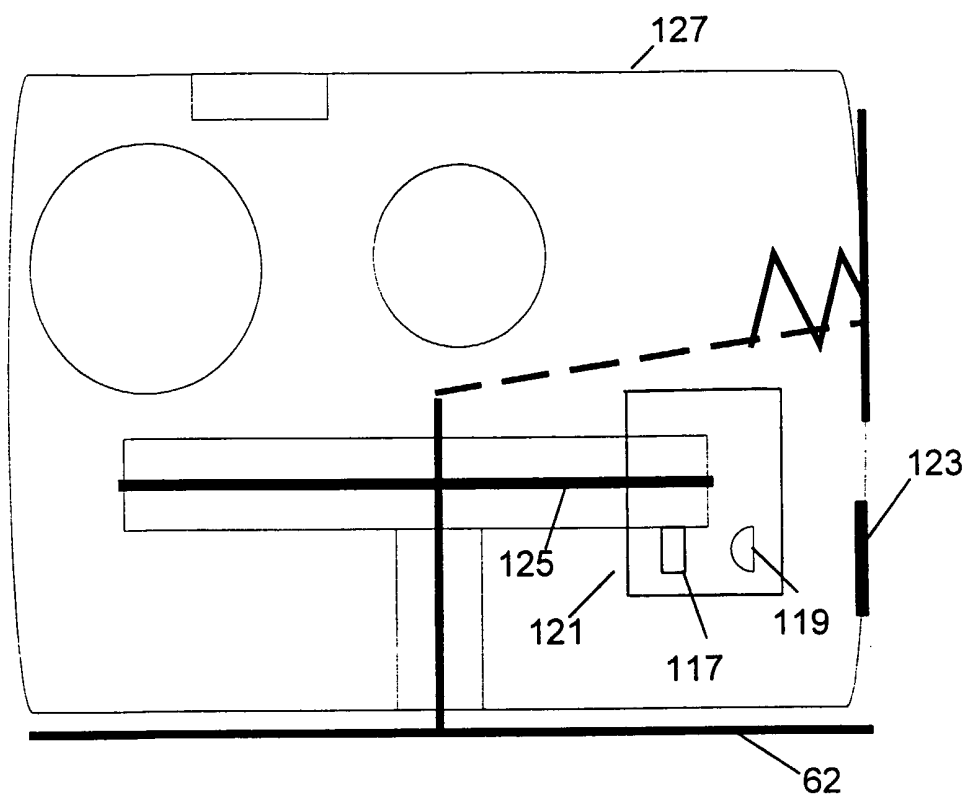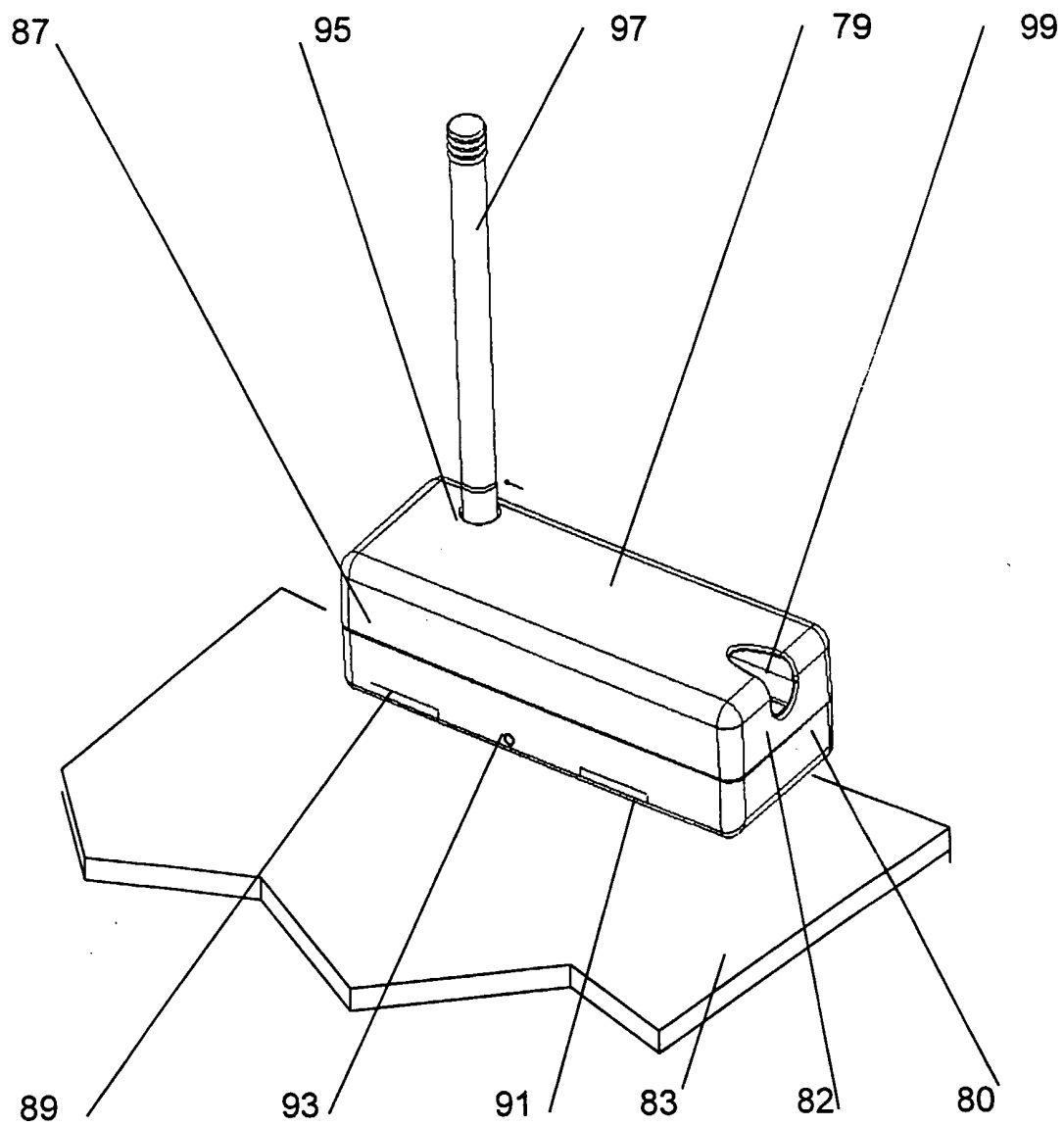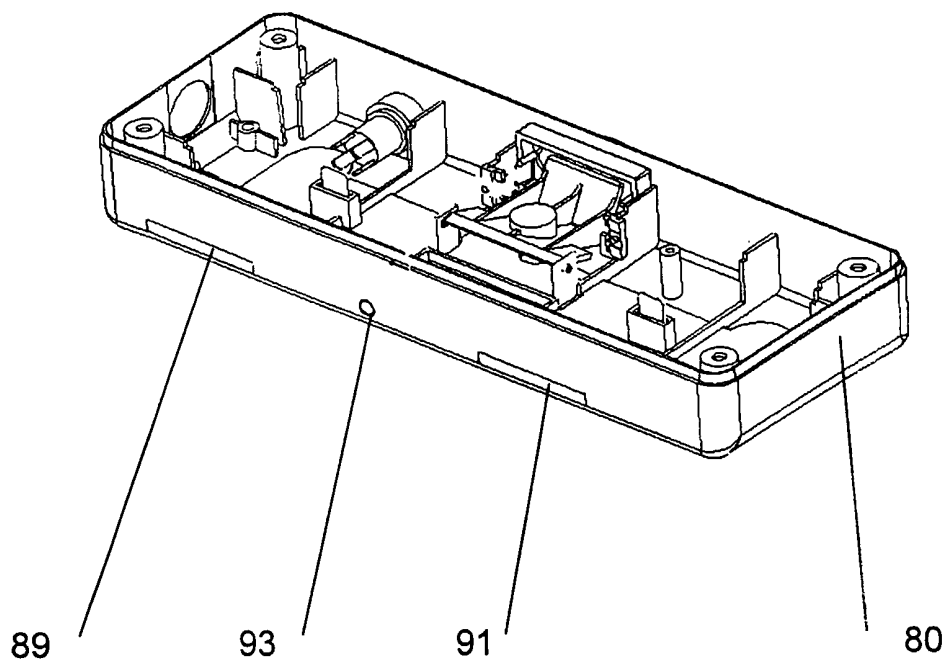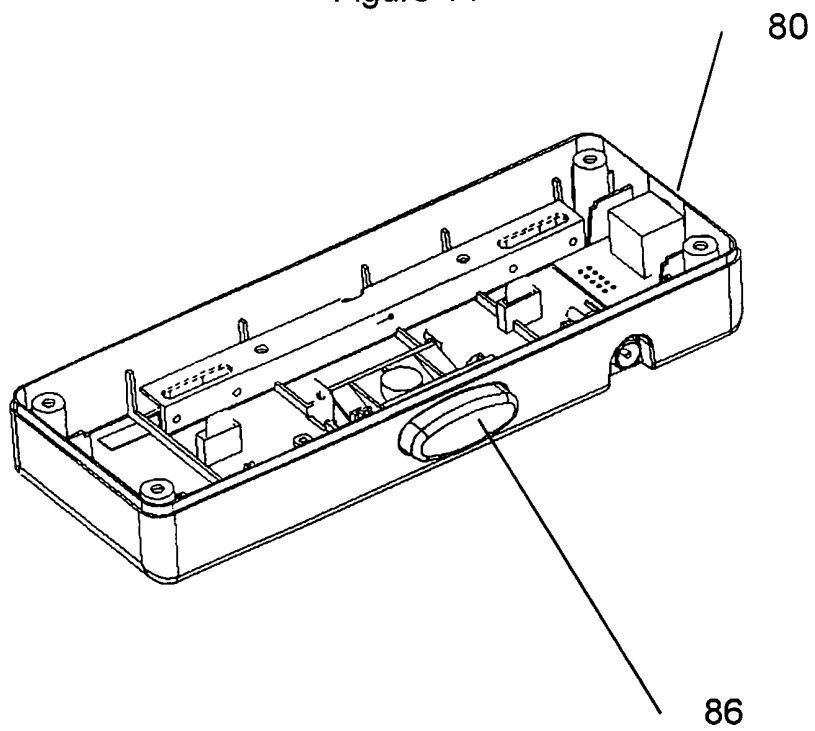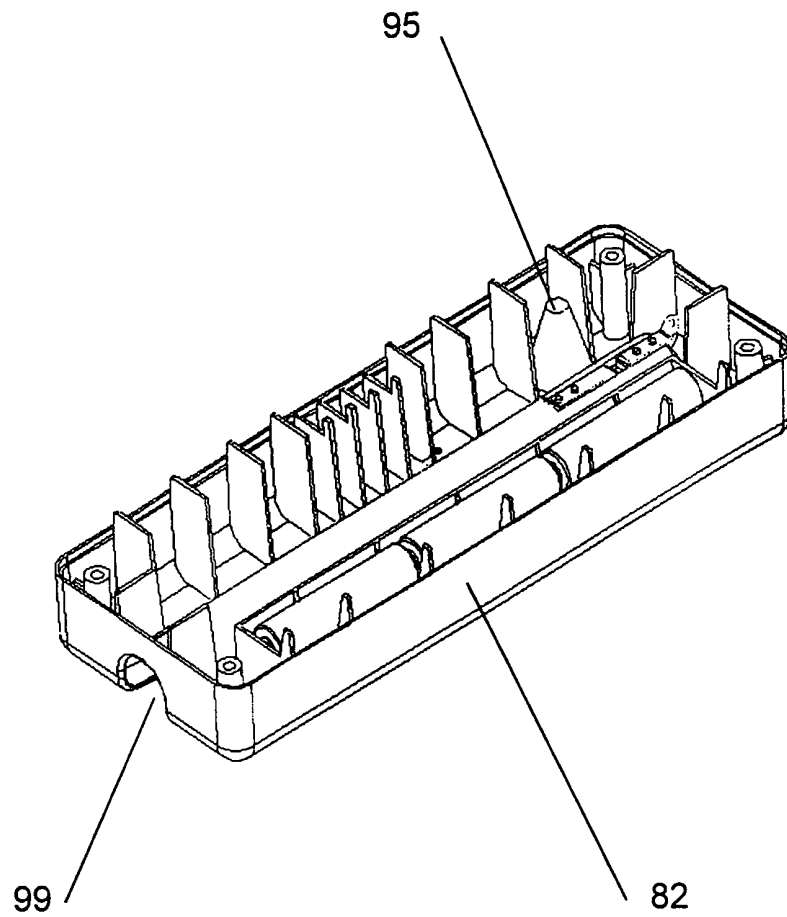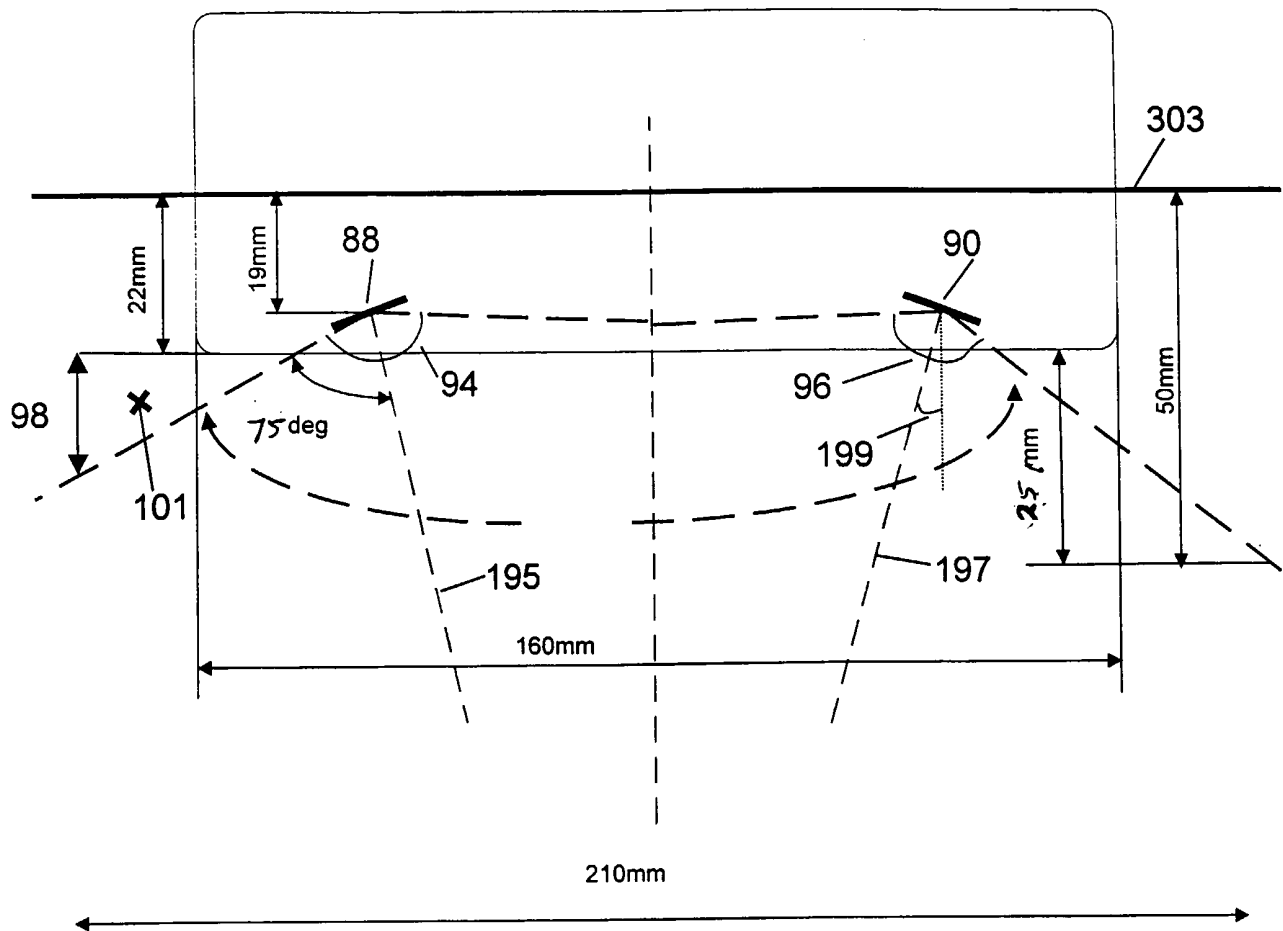
Figure 15

Figure 16

Figure 17
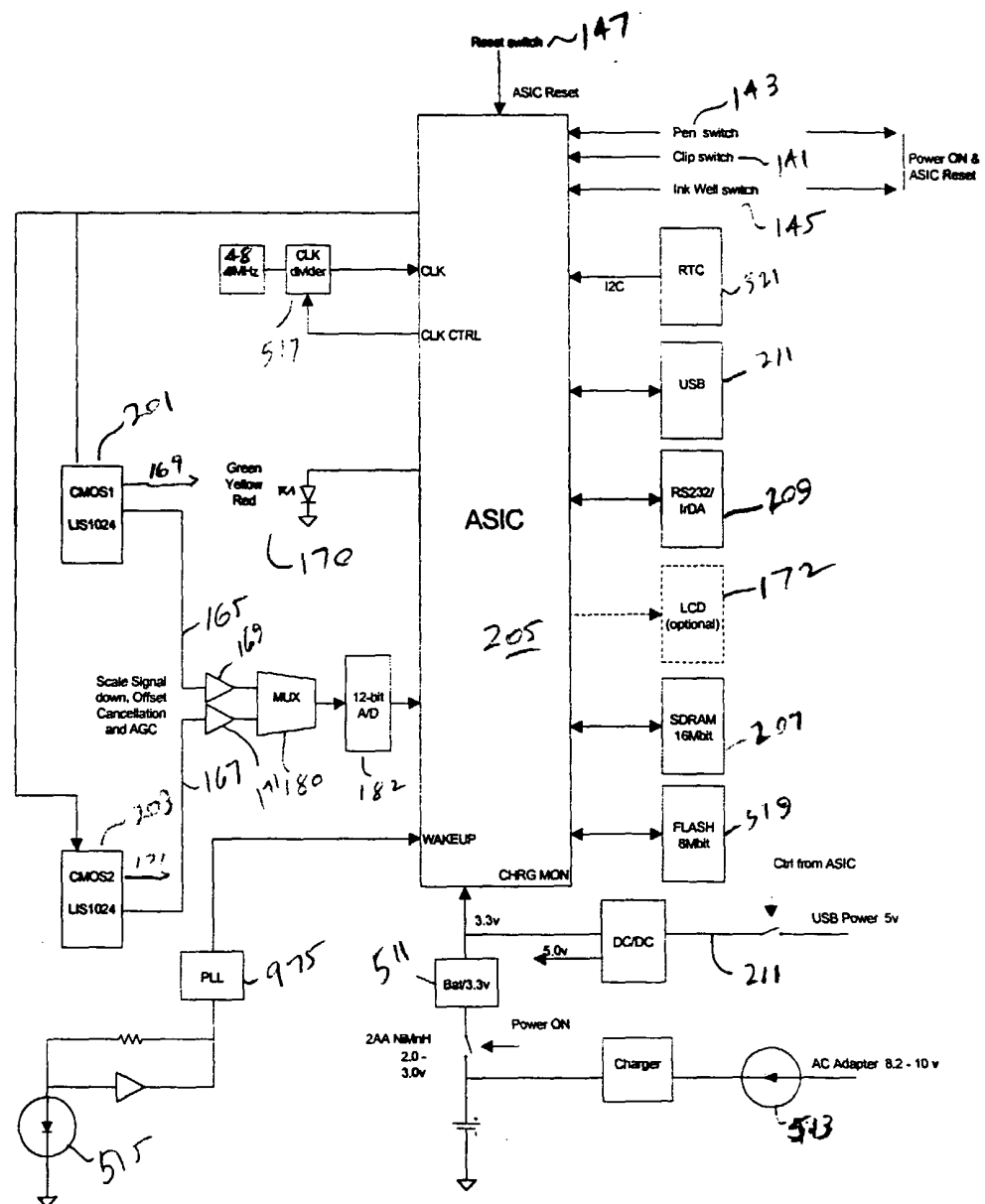
FIGURE 18

FIGURE 19

FIGURE 20

601

FRAME RATES

1200 Hz

600Hz

300 Hz

1	2	3	4	5	6	7	8	9	10	11	12

100Hz

LED ON

LED OFF

FIGURE 21

B

X

(0,0)

C

C

Y

FIGURE 22

FIGURE 23

22/33

Normal Mode -
during
Continuos
writing

Idle
mode

Sleep mode

Idle
mode

Periodic
Acquisition

Storage to Flash
memory

at 100Hz
sampling
frequency
and Filling up
available RAM

when page is full

Processor and on-pen
electronics are in
Standby mode

Wake up
processor on detection of
optical signal
and Start Data
Acquisition

End of Data
Acquisition -
Flash page
size is filled in
RAM

No data
acquisition;
no traces
made; no
interrupts

FIGURE 24

FIGURE 25

FIGURE 26

FIGURE 27

FIGURE 28

FIGURE 29

Move to Optimize

FIGURE 30

FIGURE 31

Top View

770

771

Side View

770

771

FIGURE 32

Step 1

Step 2

782

78°

784

785

783

Clip Unfolding

Step 3

788

787

786

788

Step 4

789

Step 5

Fig. 33

Front View
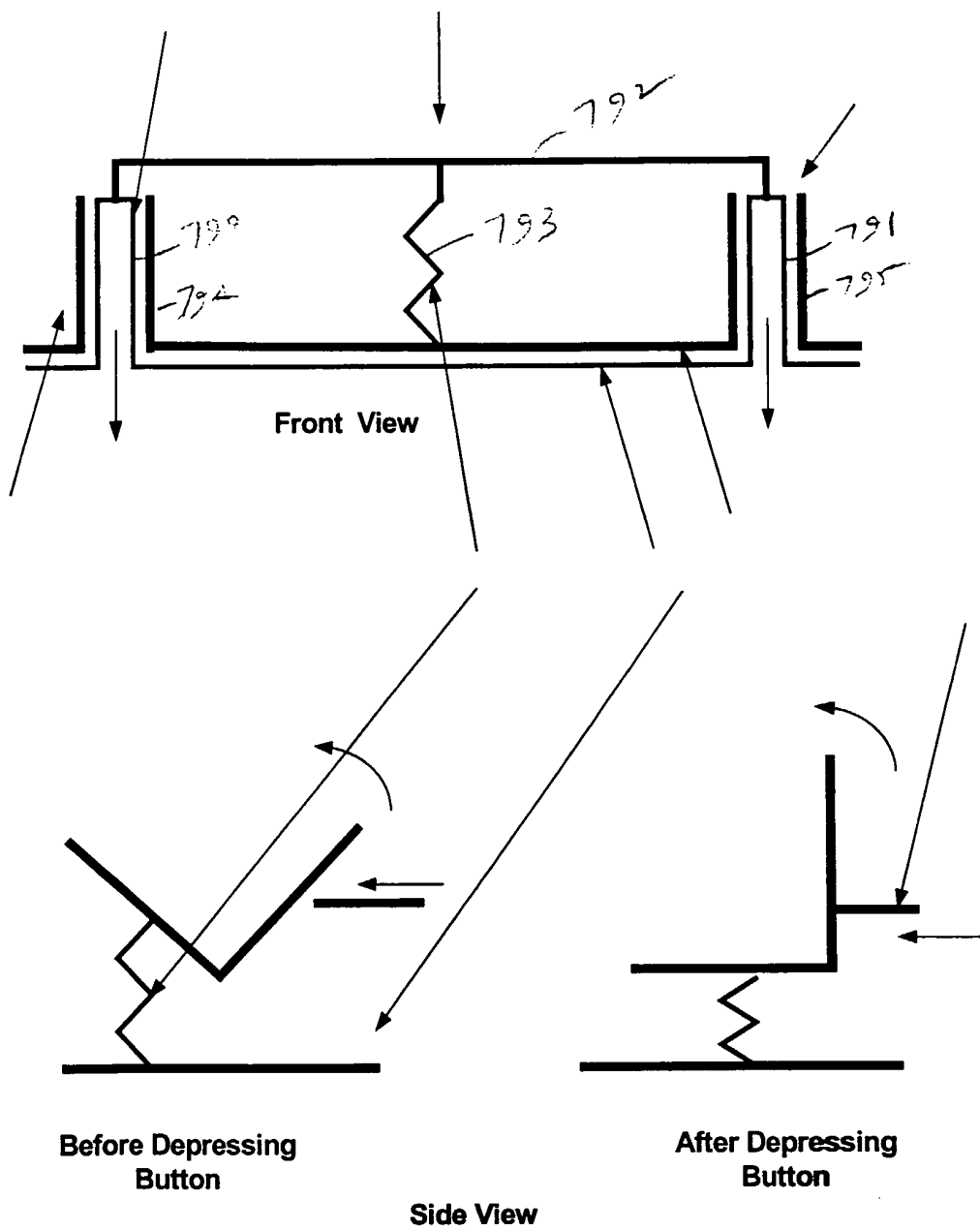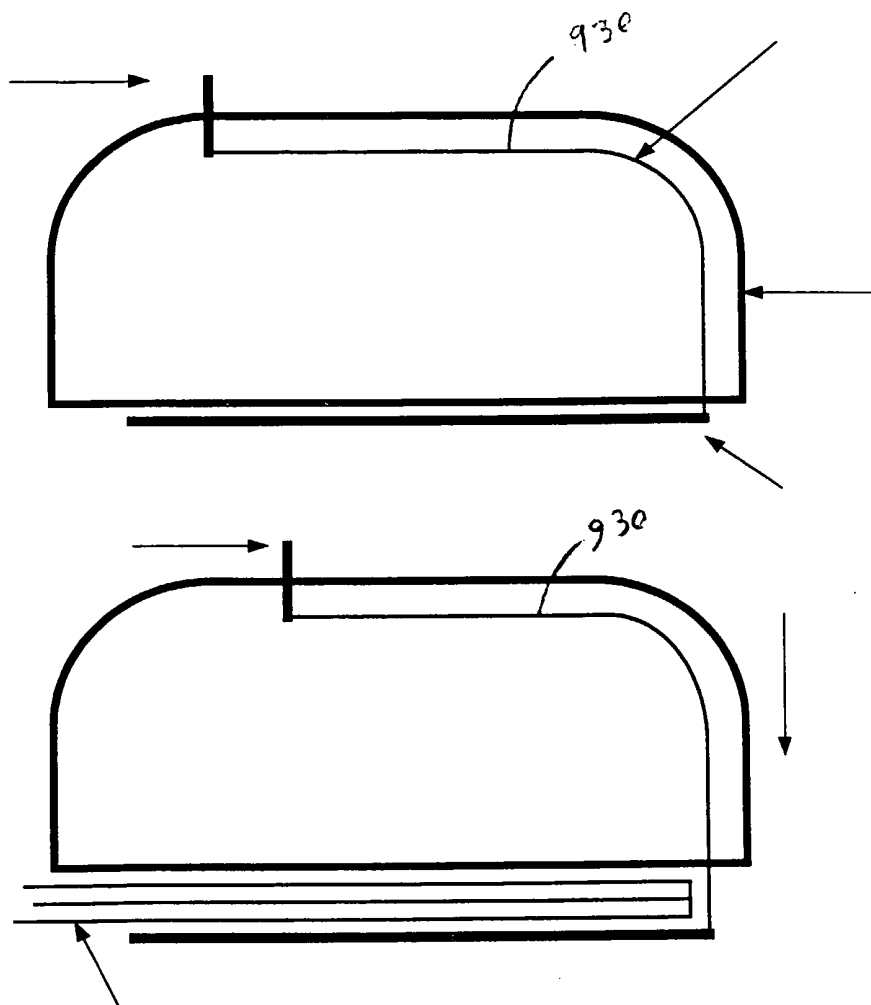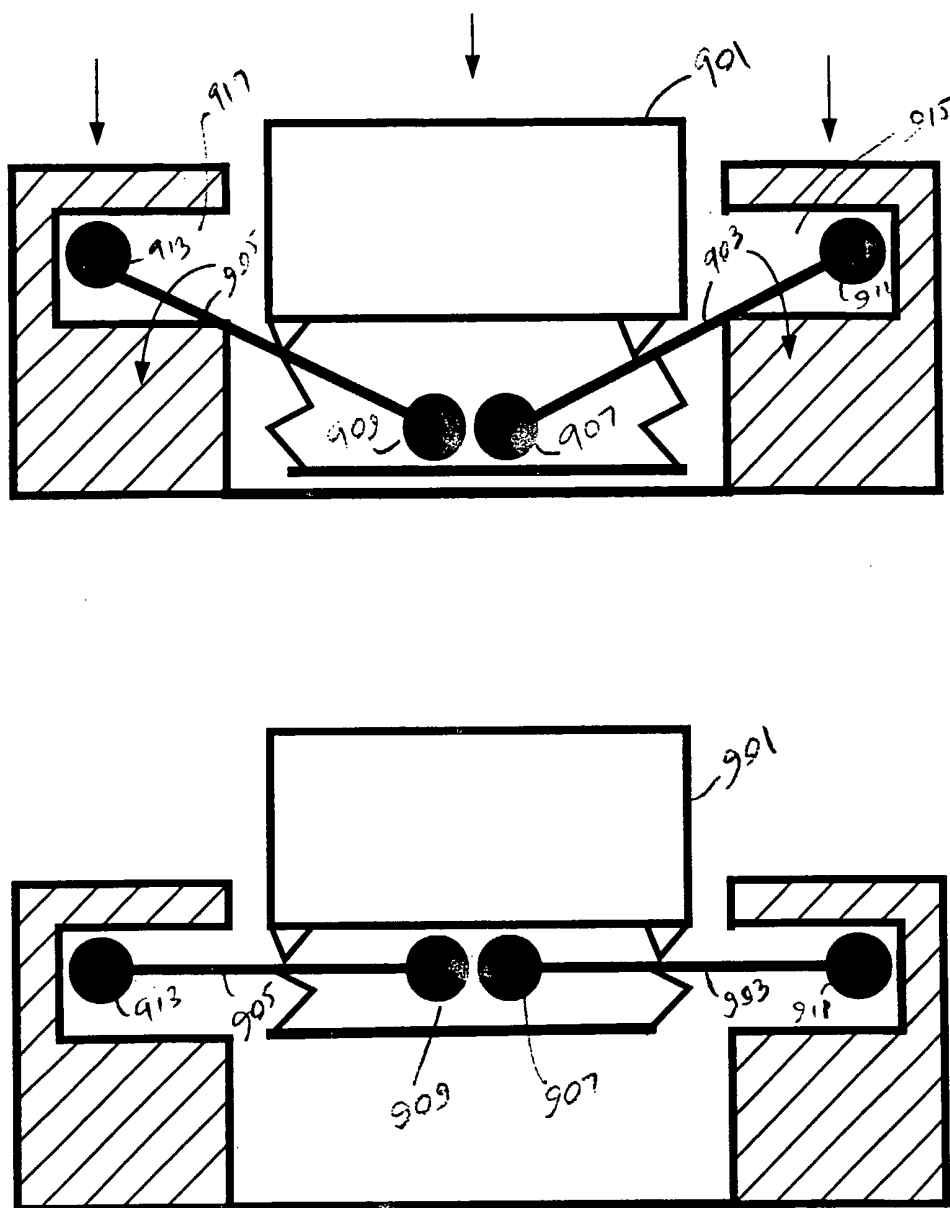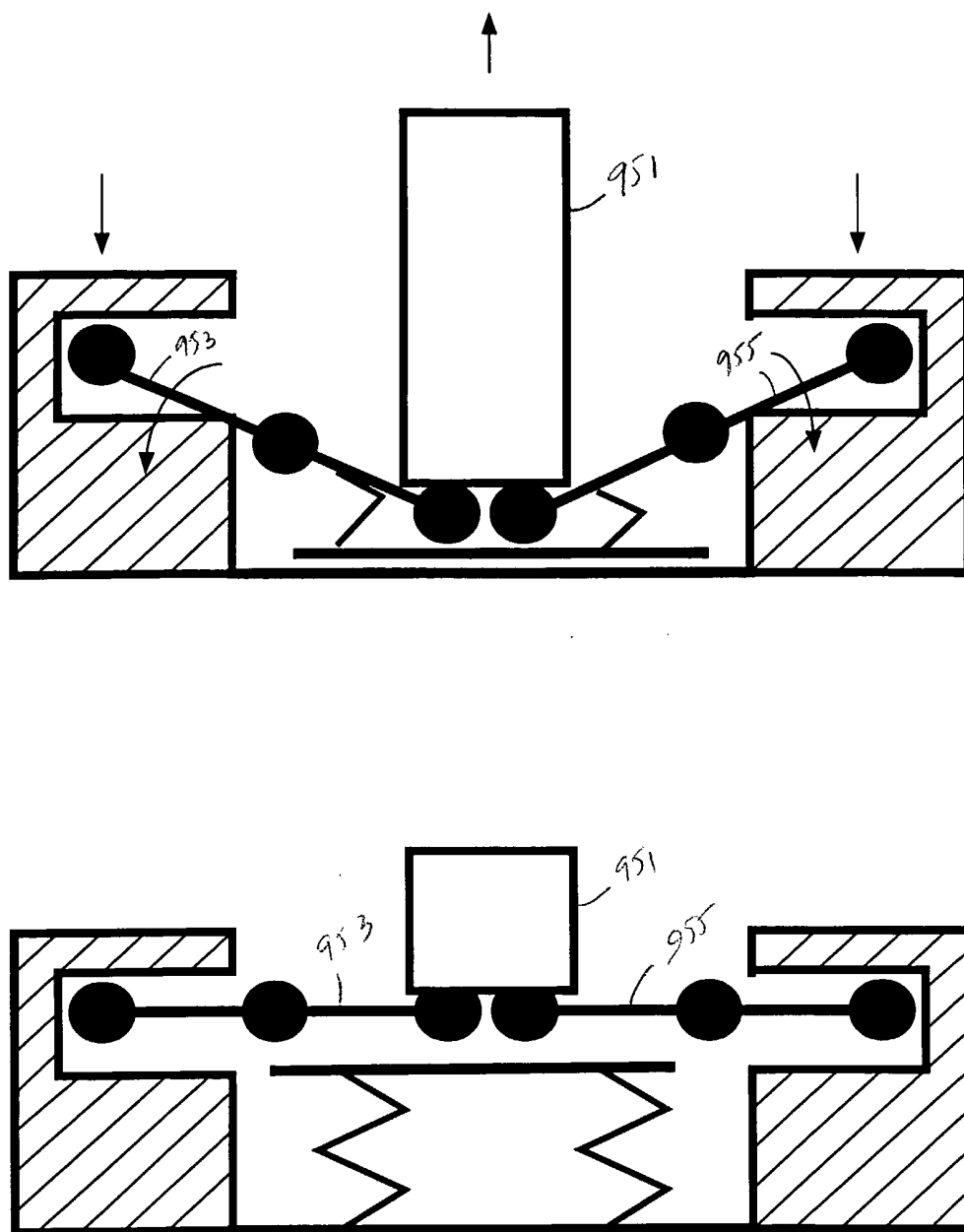
Before Depressing
Button

After Depressing
Button

Side View
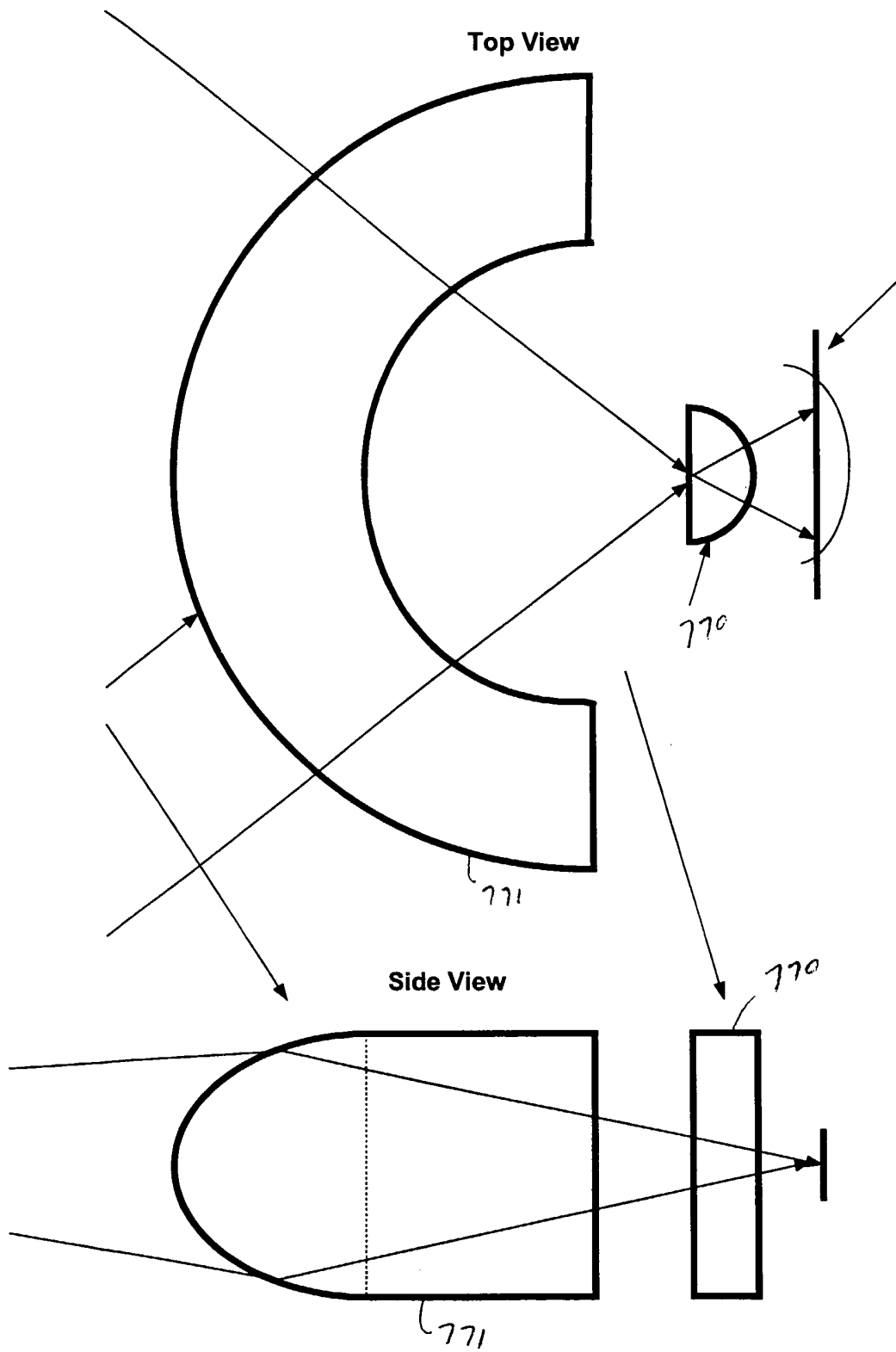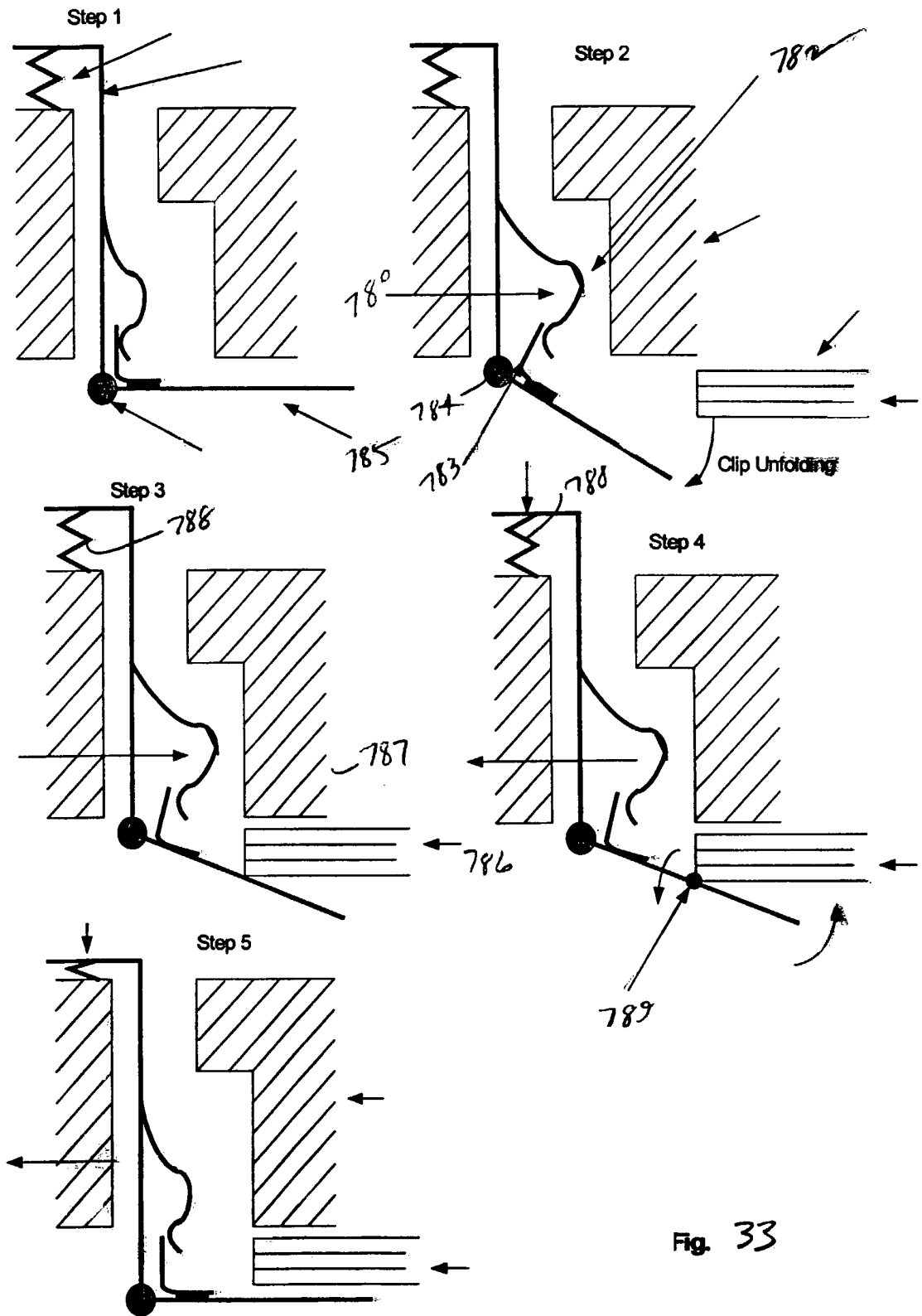
Fig. 34

Figure 35

Figure 36

Figure 37