FRONT-FACING CAMERA AND MAXIMIZED DISPLAY SCREEN OF A MOBILE DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to unpublished U.S. design application Ser. No. 29/539,390, filed September 14, 2015, titled "Mobile electronic device" and unpublished U.S. design application Ser. No. 29/546,466, filed November 23, 2015, titled "Wearable electronic device."

TECHNICAL FIELD

The present invention relates to mobile electronic devices and, in particular, to methods and systems that maximize the display screen of mobile electronic devices while providing a high quality, front-facing camera.

BACKGROUND OF THE INVENTION

Common smartphones, phablets, tablet computers, or comparable mobile electronic devices contain a front-facing camera placed on the front side of the mobile electronic devices. The front side of the mobile electronic devices also contains a display screen, using a display technology such as liquid-crystal display (LCD) or active-matrix organic light-emitting diode (AMOLED). Typically, the display screen does not occupy the full front side of the mobile electronic devices, because a wide border is required at the top and/or at the bottom of the front side to accommodate the lens of the front-facing camera and also to accommodate other optical or acoustic sensors and emitters. As a result, the size of the display screen is reduced.

The front-facing camera of mobile electronic devices may be used for video telephony or to take a self-portrait photograph, commonly known as a "selfie." In recent years, the resolution of the front-facing camera has increased, and it is likely that the resolution will continue to increase in the future (e.g., from 8 megapixels to 13 megapixels) to be able to take "selfies" of the highest quality and to record high quality 4K videos. Therefore, high quality camera lenses for the front-facing camera and an undisturbed light path are essential.

Patent applications US2017/0123454 A1, US2017/0123453 A1, and US2017/0123452 A1, titled "Camera integrated into a display," patent application US2017/0123575 A1, titled "Optical sensors disposed beneath the display of an electronic device," patent application US2017/0124933 A1, titled "Mobile device with display overlaid with at least a light sensor," patent applications US2017/0126979 A1 and US2017/0126937 A1, titled "Apparatus and method to maximize the display area of a mobile device," and patent application US2015/0271392 A1, titled "System and method for coordinating image capture in a camera hidden behind a display device" suggest disposing the front-facing camera beneath the display screen of mobile electronic devices. However, depending on the display technology of the screen (e.g., LCD, OLED, Micro-LED, etc.), small opaque or semi-transparent structures that may be necessary for the operation of the display screen may blur or cloud the resulting picture of the front-facing camera, because the light path must pass through the display screen. Furthermore, LCD panels often also require removing a diffuser layer to adapt them for use as transparent displays, and the polarizing filters of the LCD panels inherently limit the transmission efficiency of unpolarized light. This may reduce the light sensitivity of a front-facing camera located beneath the display screen, especially in low light conditions. The disclosure of the above-mentioned patent applications is hereby incorporated by reference in its entirety.

SUMMARY OF THE INVENTION

The present invention is directed to mobile electronic devices with a display screen and at least one front-facing camera, optical sensor, and/or emitter, such as smartphones, phablets, tablet computers, smartwatches, subnotebooks, or laptops. In one embodiment, a smartphone has very thin or curved borders at the left- and right-hand edges as well as at the top edge of the device's display panel. To accommodate a front-facing camera in spite of an upper border that is too thin for a camera module and lens, at least one upper corner of the display panel is cut out. The cutout has a convex shape, thereby maximizing the remaining screen area. The lens of the front-facing camera is disposed at the location of the cutout. Optionally, the camera module (or the lens) fills the void at the level of the display panel at least in part.

To compensate for invisible screen content in the region of the cutout, the layout of the screen content is changed or rearranged, as long as the invisible screen content is essential. For this purpose, the elements displayed on the screen are categorized by relevance.

The aforementioned and many further aspects, variants, objectives, and advantages of the invention will be comprehensible to those skilled in the art after reading detailed descriptions of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features, advantages, and potential applications will be apparent from the drawings. All described and/or illustrated features, alone or in any combination, independent of the synopsis in individual claims, constitute the subject matter of the invention.

FIG. 1 shows a conventional smartphone.
FIG. 2 is a diagrammatic representation of the computer system of the smartphone.
FIG. 3 is a top plan view of a first embodiment (upper part of the casing).

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a conventional smartphone 100 as an example of a mobile electronic device. The drawing illustrates display screen 101 with touchscreen functionality, lens 102 of a front-facing camera, earpiece 103 (speaker for telephone calls), a combined proximity and light sensor 104, and LED indicator 105 (e.g., on/off state of smartphone 100, charging of battery). Graphics sub-system 108 (integrated into the device 100 and shown in dotted lines in FIG. 1) is responsible for generating the screen content displayed on display screen 101.

As can be seen in FIG. 1, conventional smartphones 100 typically feature a thin border 106 at the left edge of the display screen 101 and a thin border 107 at the right edge of the display screen 101. It can also be seen that in the example of FIG. 1, a wide border is required at least at the top of the front side of smartphones 100 to accommodate lens 102 (front camera), earpiece 103 (for the ear speaker), proximity/light sensor 104, and LED indicator 105.

FIG. 2 is a diagrammatic representation of the computer system 200 of smartphone 100 or a similar device (e.g., tablet computer, smartwatch, or game console). Computer system 200 may consist of processor 201 (CPU), main memory 202 (RAM), at least one non-volatile memory 203 (e.g., flash memory, SSD, or memory card), I/O interface 204, including network interface and sensors (e.g., WiFi, mobile communications, and accelerometer), and other familiar devices. The components of computer system 200 can be coupled together via bus system 205 or through some other known or convenient devices.

Instructions 206 for the execution on processor 201 and data (e.g., text data, vector data, and bitmap image data) may be stored in main memory 202 and/or non-volatile memory 203. For example, processor 201 may execute instructions 206 (stored in main memory 202 and/or non-volatile memory 203) to process bitmap image data (also stored in main memory 202 and/or non-volatile memory 203) that is displayed on display screen 101 via the graphics sub-system 108.

The computer system 200, as per FIG. 2, is intended to illustrate a hardware platform on which any of the subsequent embodiments (and any other components described in this specification) can be implemented. It is to be expressly noted that the computer system 200 integrated into the mobile electronic device (e.g., smartphone 100) can be of any applicable known or convenient type.

FIG. 3 through FIG. 6 show a first embodiment in accordance with the present invention. FIG. 3 shows a top plan view of the upper part of smartphone 100. FIG. 4 shows a sectional view of the smartphone 100 taken at the sectioning plane and in the direction indicated by section lines 4–4 (in FIG. 3). Another sectional view of the smartphone 100 is shown in FIG. 5: this sectional view is taken at the sectioning plane indicated by section lines 5–5. FIG. 6 is a top plan view showing further aspects of the first embodiment; as indicated by curved break lines, smartphone 100 and display screen 101 can have a different, e.g., larger, aspect ratio. For instance, display screen 101 may have an aspect ratio of 16:9, 21:9, 2:1, 3:1, etc.

Referring to the sectional views shown in FIG. 4 and FIG. 5, smartphone 100 may consist of several layers: the front side of the casing of smartphone 100 may consist of cover glass 405. A rectangular display panel 401 may be disposed beneath cover glass 405, and a printed circuit board 404 (PCB) equipped with ICs may be disposed beneath display panel 401. Optionally, a transparent touchscreen panel (e.g., capacitive touchscreen) may be disposed between cover glass 405 and display panel 401, or the layer that detects touch may be integrated into display panel 401, rather than overlaid on top of it. As illustrated in FIG. 4 and FIG. 5, printed circuit board 404 may be equipped, inter alia, with graphics sub-system 108 (e.g., GPU), front camera module 402, proximity/light sensor 104, LED 105, and ear speaker 403. Ear speaker 403 may be of any applicable known or convenient type, including piezoelectric speakers.

In FIG. 4 and FIG. 5, the remaining casing of smartphone 100 (e.g., lower part, bottom side) is indicated as a dotted line. More information about the assembly of a smartphone 100 may be found in patent application US2014/0135071 A1, titled "Mobile terminal." More information about a camera module may be found in patent application US2015/0077629 A1, titled "Camera module." More information about a proximity sensor may be found in patent US8996082 B2, titled "Proximity sensor arrangement having a cold mirror in a mobile device." The disclosure of these patents and patent applications is hereby incorporated by reference in its entirety.

Display panel 401 (shown in FIG. 4 through FIG. 6) forms images by receiving electric signals (e.g., from graphics sub-system 108). The images generated by display panel 401 are visible on display screen 101. It is to be expressly noted that display panel 401 can be of any applicable known or convenient type, including, but not limited to, liquid-crystal displays, micro-LED displays, and organic light-emitting devices.

For example, display panel 401 may be an LC panel. The LC panel may include a thin film transistor (TFT) substrate, a color filter substrate, and LC molecules injected between the TFT substrate and the color filter substrate. The TFT substrate may include gate lines and data lines implemented as matrices. Thin film transistors (TFT) may be formed at crossing points of the gate lines and the data lines. A signal voltage is applied to a common electrode disposed between a pixel electrode and the color filter substrate. Liquid crystal molecules are aligned between the pixel electrode and the common electrode according to the signal voltage, thereby controlling light transmittance. The color filter substrate may include a color filter and a common electrode, the color filter having red, green, and blue filters repeatedly formed in a state where black matrices are disposed therebetween. The common electrode may be formed of a transparent conductive material such as indium tin oxide (ITO) or indium zinc oxide (IZO).

A pair of polarizers may be arranged on the upper and lower surfaces of the LC panel. The polarizers may be arranged to cross each other. The polarizer disposed under the LC panel serves to polarize light incident onto the LC panel, and the polarizer formed on the LC panel serves as an analyzer. A backlight unit may be disposed beneath the LC panel. The backlight unit may include a diffusion sheet, a reflection sheet, and a prism sheet.

Referring to FIG. 3, the housing of smartphone 100 is characterized by a thin edging or border 301, 106, 107 at the upper edge, left edge, and right edge of display screen 101. In particular, the border 301 at the top of the display screen 101 is very thin. The benefits are, inter alia, a bigger screen and/or smaller phone dimensions. For example, borders 301, 106, 107 may have a width of 2mm, 1.5mm, 1mm, 0.5mm, or less. The first embodiment features an earpiece 103 (for ear speaker 403 shown in FIG. 4) that is a long, narrow gap. For example, the gap of earpiece 103 may have a width of 0.5mm or less.

In order to accommodate optical sensors/emitters and the lens 102 of the front-facing camera – in spite of the very thin border 301 at the top of display screen 101 – the upper left-hand and right-hand corners of the display panel 401 are cut out. This is illustrated in FIG. 6: Cutout 601 at the top left-hand corner and cutout 601 at the top right-hand corner have been removed from display panel 401. Cutout 601 of display panel 401 has a convex shape as opposed to a conventional display screen with rounded corners, which has a concave cutout. The convex cutout 601 of the first embodiment as per FIG. 6 may be advantageous, because it maximizes the remaining area of the display panel 401 while still accommodating the lens 102 of the front-facing camera (or other sensors/emitters). For illustrative purposes, display panel 401, as shown in FIG. 6, is emphasized by means of standard drafting symbol patterns. The color "dark gray" of display panel 401 could represent the display screen 101 in the switched-off state.

Referring to FIG. 4, which shows the sectioning plane 4–4 at the top of display screen 101, the front camera module 402 and affiliated lens 102 are disposed beneath cover glass 405 at the location of cutout 601 (on the left), such that front camera module 402 and lens 102 fill the void at the level of display panel 401. Dotted line 406 shows the light path of front camera module 402, which must only pass through cover glass 405. As a result, the camera system (camera module 402 and lens 102) may use the entire height of the casing of smartphone 100. This may be advantageous, because, compared to disposing the front-facing camera beneath display panel 401 (as suggested in the prior art) , the length of the lens system of camera module 402 can be maximized. The length of a lens system can be a limiting factor for taking high quality pictures, and disposing the front-facing camera beneath display panel 401 may reduce the maximum length of the lens system by the thickness of display panel 401.

With continued reference to FIG. 4, proximity/light sensor 104 and LED indicator 105 are also disposed beneath cover glass 405 at the location of cutout 601 (on the right), such that they fill the void at the level of display panel 401, at least partially. Dotted lines 406 show the light path of proximity/light sensor 104 and LED indicator 105.

Both, display panel 401 and the optical sensors/emitters (lens 102, proximity/light sensor 104, LED indicator 105) may be covered by a continuous transparent material, such as transparent plastic or glass 405, as shown in FIG. 4 and FIG. 5 and indicated in FIG. 3 by means of shading lines slanted at an angle of 45 degrees.

Comparing the sectional views shown in FIG. 4 and FIG. 5, it can be seen that the width of display panel 401 is reduced at the locations of the cutouts 601. This is indicated by dot-dash projection lines. Optionally, in other embodiments, only opaque and/or semi-transparent layers of display panel 401 may be cut out, that is, transparent layers of display panel 401 may remain. This may depend on the technology used by display panel 401 (e.g., LC panel or AMOLED).

The front-facing camera (front camera module 402 and lens 102) and other optical or acoustic sensors and emitters (e.g., proximity/light sensor 104, LED indicator 105, flashlight, IR or UV sensor, fingerprint sensor, iris scanner, or sensor(s) for face recognition, face tracking, or eye tracking) may be located in all four corners of the casing of the smartphone 100, in the two upper corners, in the two lower corners, in the corners on the left or right side of the casing, in diagonally located corners, or in one corner only. Also, cutout 601 and the casing of smartphone 100 may have different shapes. The convex shape of cutout 601 may vary between a quarter circle (as shown in FIG. 6) and a square or rectangle. For example, cutout 601 may have the shape of a square with rounded edges. The following drawings illustrate different sensor locations and different convex shapes of cutout 601.

FIG. 7 shows a perspective view of a second embodiment. The second embodiment corresponds to the first embodiment, except that there is a second front-facing camera to support self-portrait photographs ("selfies") taken in stereoscopic 3D as well as videos recorded in stereoscopic 3D. Lens 701 of the second front-facing camera is located in the upper right-hand corners of display screen 101. The width of the casing of smartphone 100 is suitable for the interaxial separation between the two lenses 102, 701. Interaxial separation refers to the distance between the centers of two camera lenses. The interocular separation or interpupillary distance technically refers to the distance between the centers of human eyes.

In other embodiments, lens 701 (of the second front-facing camera) may be the lens of an iris scanner used for unlocking the smartphone 100.

FIG. 8 shows a top plan view of a third embodiment. Exemplary screen content is shown in dotted lines. Compared to the first embodiment, the lens 102 of the front-facing camera is located in the upper right-hand corner of display screen 101. Instead, an electronic flash unit 801 is disposed in the upper left-hand corner of display screen 101. Electronic flash unit 801 may be a flash LED or an electronic flashlamp to support taking "selfies" in low light conditions. An LED flash can also be used for illumination of video recordings or as an autofocus assist lamp in low light conditions.

In other embodiments, a warning light, caution lamp, or anti-theft alert signal may be disposed at the location of cutout 601 in the upper left-hand corner (or any other corner) of display screen 101.

FIG. 9 shows a top plan view of a fourth embodiment featuring a front-facing camera (lens 102) in the upper left-hand corner, a light guide 901 (which combines several optical sensors and emitters) in the upper right-hand corner, an ultraviolet (UV) sensor 902 in the lower left-hand corner, and a fingerprint sensor 903 in the lower right-hand corner of display panel 401.

Many technologies are known in the prior art for capturing a live scan of the fingerprint pattern including optical, capacitive, RF, thermal, piezoresistive, ultrasonic, or piezoelectric fingerprint sensors. For example, fingerprint sensor 903 may be an optical, ultrasonic, or capacitance fingerprint sensor.

Light guide 901 may transmit a light beam between the environment outside and the sensors and emitters inside smartphone 100. By this means, light guide 901 may combine, by way of example, a proximity sensor, a light sensor, an LED indicator (on/off/charging), and a flash LED. The proximity sensor and/or the light sensor may be deactivated or ignored for the short period of time during which the flash LED brightly lights up. A light guide 901 may have the advantage that the visual impression of the upper left-hand corner (lens 102) and of the upper right-hand corner (light guide 901) appear similar to the user, because there is only one round optical element in each corner. More information about light guides may be found in patent applications US2017/0126868 A1 and US2017/0124377 A1, titled "System and method for reducing the number of ports associated with a mobile device," the disclosure of which is hereby incorporated by reference in its entirety.

With continued reference to FIG. 9, a tweeter 905 (a loudspeaker designed to reproduce high frequencies) is disposed beneath narrow gap 904 at the upper border of smartphone 100, such that tweeter 905 is close to narrow gap 904 (as far as possible). Furthermore, a woofer or midrange speaker 906 (a loudspeaker designed to reproduce lower frequencies) is disposed beneath display panel 401, such that woofer or midrange speaker 906 is close to tweeter 905. An audio crossover or frequency crossover may be used to connect tweeter 905 and woofer 906 (or midrange speaker) to I/O interface 204 as per FIG. 2. The audio crossover may split up an audio signal into two (or more) frequency ranges, so that the signals can be sent to loudspeakers that are designed for these frequency ranges.

Compared to earpiece 103 as per FIG. 3, narrow gap 904 may be even smaller, because only high frequencies must pass through this opening. For example, a few small holes (instead of a gap) may be sufficient. No opening is required for the lower frequencies produced by woofer or midrange speaker 906.

Optionally, a second pair of tweeter 905 and midrange speaker 906 may be disposed close to a second narrow gap 904 at the lower border of smartphone 100. This may allow for playing audio in stereo if the user holds smartphone 100 horizontally, e.g., while playing a movie in the horizontal format (landscape mode).

FIG. 10 shows a top plan view of a fifth embodiment characterized by a fully symmetric smartphone 100, that is, a front-facing camera (lens 102) is located both in the upper left-hand corner and the lower right-hand corner of display screen 101. Furthermore, an infrared (IR) LED 1001 is located both in the upper right-hand corner and the lower left-hand corner of display screen 101. The infrared LEDs 1001 may illuminate the face of the user in low light conditions, e.g., to support face recognition, face tracking, or eye tracking by means of the front-facing cameras (lens 102).

Due to the symmetry, the user can rotate the smartphone 100 by 180 degrees, and a front-facing camera is still available in the upper left-hand corner. (A front-facing camera at the top of smartphone 100 typically is the preferred location for taking a "selfie" or for video telephony.) An orientation sensor or accelerometer, connected to I/O interface 204 (as per FIG. 2), may measure the direction of gravity. By determining the current orientation of smartphone 100, computer system 200 may activate the presently upper front-facing camera for capturing images.

The exemplary screen content displayed on display screen 101 (shown in dotted lines in FIG. 10) is for illustrative purposes only. The screen content may be rotated by 180 degrees as soon as the user rotates the symmetric smartphone 100 by approximately 180 degrees.

FIG. 11 is a bottom view of the symmetric smartphone 100 as per FIG. 10. Two main/rear cameras (lens 1101) may be located close to the upper and lower edges of the underside of smartphone 100, as shown in FIG. 11. The upper camera may be the active camera, or both cameras may be used to take stereoscopic 3D images in landscape mode. Alternatively, a single main camera may be located at the center, as indicated by lens 1102 (shown in dotted lines).

FIG. 12 shows a rear view, FIG. 13 shows a front view, and FIG. 14 shows a left side view of the (nearly) symmetric smartphone 100 in accordance with the fifth embodiment. Instead of a flat display screen 101, as shown in FIG. 7, all embodiments may be designed with a slightly curved display screen 101, as shown in FIG. 14. Loudspeakers (e.g., tweeters 905 and midrange speakers 906) may be implemented similar to the fourth embodiment, as per FIG. 9. The slightly curved display screen 101 may focus the sound or may direct the sound of several tweeters 905 over a suitable distance to the ear.

FIG. 15 is a top plan view of a sixth embodiment. A front-facing camera (lens 102) is located in the upper left-hand corner, a proximity/light sensor 104 is located in the upper right-hand corner, an LED indicator 105 (on/off/charging) is located in the lower left-hand corner, and a fingerprint sensor 903 is located in the lower right-hand corner of display screen 101. The occupied space of these sensors and/or emitters at the corners of display screen 101 may additionally be used as touch keys for navigation functions of an user interface, thereby gaining additional space on display screen 101 for other applications ("apps"). The user interface may be part of an operating system running on computer system 200 of smartphone 100.

A conventional smartphone may display a navigation bar with soft keys (e.g., "Home," "Back," "Recent apps") at the bottom of the touchscreen display – similar to the example shown in dotted lines in FIG. 10. As can be seen by comparing FIG. 10 with FIG. 15, the space needed for the navigation bar now is available for other screen content (such as the exemplary speech bubbles of a chat or messenger app).

The touch keys, as per FIG. 15, located on sensors/emitters 104, 105, 903, may operate using the touchscreen functionality of the regular display screen 101. For example, as soon as a touch or tap gesture is detected at a corner of the touchscreen – on the location of a sensor/emitter 104, 105, 903 – this is interpreted as an input for the dedicated touch keys "Home," "Back," or "Recent apps." For this purpose, a transparent touchscreen panel that extends to the entire front side of smartphone 100 may be disposed between cover glass 405 and display panel 401.

Alternatively, in other embodiments, each touch key (located on the optical sensors and/or emitters 104, 105, 903) may have its own, dedicated touch sensor. The dedicated touch sensors may be connected to I/O interface 204 (as per FIG. 2) and may be realized as transparent capacitive touch sensors, as transparent resistive touch sensors, or may work by means of optical imaging. In the case of optical imaging, the existing optical sensors (e.g., front camera 102, light sensor 104, fingerprint sensor 903) may be repurposed as touch sensors for the touch keys; for example, proximity/light sensor 104, which can measure the distance of a finger, can be repurposed as a touch sensor for the "Recent apps" touch key.

Printed symbols 1501, 1502, 1503 for the navigation functions of the user interface or operating system may surround the optical sensors and emitters 104, 105, 903, as shown in FIG. 15: printed symbol 1501 (schematic house) for "Home key," i.e, exit application and go back to homescreen; printed symbol 1502 (schematic arrow) for "Back key," i.e., go back to the previous screen; printed symbol 1503 (square) for "Recent apps key," i.e., recently used applications and favorites. Printed symbols 1501, 1502, 1503 may surround optical sensors/emitters 104, 105, 903 entirely, as shown in FIG. 15, or only partially. For example, instead of schematic arrow 1502, which surrounds LED indicator 105 entirely, a U-turn arrow may be printed that surrounds LED indicator 105 only in part.

Printed symbols 1501, 1502, 1503 may be printed (e.g., in white color) on the top surface of cover glass 405 or preferably back-to-front on the inside of cover glass 405. Alternatively, printed symbols 1501, 1502, 1503 may be printed on a transparent layer that is disposed beneath cover glass 405; e.g., a transparent touchscreen panel or a dedicated layer such as a plastic film.

Printed symbols 1501, 1502, 1503 should have a suitable shape and position, such that the light path of the optical sensors and emitters 102, 104, 105, 903 is not blocked. For instance, a gear icon consisting of the outer shape of the gear may represent a setup screen or setup function of the operating system. Furthermore, printed symbols 1501, 1502, 1503 should not hide a part of the active screen area of display panel 401 (next to cutout 601). It is to be expressly noted that printed symbols 1501, 1502, 1503 are not displayed by display panel 401 to maximize the available space on the display screen 101 for other screen content.

Display panel 401 may be implemented as an active-matrix OLED display consisting of several layers, e.g., cathode layer, organic active layers, thin-film transistor (TFT) array, and substrate. An active matrix of OLED pixels generates light (luminescence) upon electrical activation. The active matrix of OLED pixels may be deposited or integrated onto the thin-film transistor (TFT) array, which functions as a series of switches to control the current flowing to each individual pixel. Known TFT backplane technologies, such as polycrystalline silicon (poly-Si) and amorphous silicon (a-Si), may be used. Optionally, display panel 401 may have an in-cell touch panel that integrates a capacitive sensor array.

Display panel 401 may be a flexible display, which enables the display panel to be bent, rolled, or curved at the edges. For example, a flexible OLED-based display may comprise a flexible substrate on which the electroluminescent organic semiconductor is deposited.

Design patent USD775597 S, titled "Electronic device," shows a smartphone with a curved display panel at the left- and right-hand edges of the display screen. In the prior art, it may cause problems to bend a flat display panel at more than two edges, i.e., the left and right edges. Bending a flat display panel at the top edge – in addition to the left and right edges – may crumple, crease, or kink the display panel at the corners or may cause problems with the lamination process.

FIG. 16 is a perspective view of a seventh embodiment of smartphone 100. A front-facing camera (lens 102) is located in the upper right-hand corner, and a light guide 901 that combines several optical sensors and emitters (e.g., proximity/light sensor) is located in the upper left-hand corner. FIG. 17 shows a sectional view of the smartphone 100 taken at the sectioning plane and in the direction indicated by section lines 17–17 (in FIG. 16).

As can be seen in the drawings, display screen 1601, or rather display panel 1702, has a curved edge on the left, a curved edge 1602 on the right, and a curved edge 1603 at the top. To avoid that display panel 1702 gets crumpled, creased, or kinked at the corners, the upper corners are cut out in a convex shape, e.g., an oval shape or a quarter circle; see convex cutout 601 in FIG. 6. Instead, lens 102 and light guide 901 are disposed at the locations of cutout 601. This effectively prevents the problems described above: the convex cutout 601 allows the display panel 1702 to be bent at two orthogonal edges 1602, 1603 at the same time.

Referring to FIG. 17, which shows sectioning plane 17–17, a flexible display panel 1702 (e.g., a flexible OLED-based display) is disposed beneath cover glass 1701. As can be seen in the sectional view, cover glass 1701 has a curved edge 1603 at the top, and display panel 1702 is bent at the upper edge. Optionally, a piezoelectric speaker 1703 (e.g., piezo film speaker with piezo actuator) may be disposed beneath display panel 1702. Piezoelectric speaker 1703 may serve as an earpiece for telephone calls. In FIG. 17, the remaining casing of smartphone 100 (e.g., lower part, bottom side) is indicated as a dotted line.

FIG. 18 is a perspective view of an eighth embodiment. The eighth embodiment corresponds to the seventh embodiment (as per FIG. 16 and FIG. 17), except that, instead of piezoelectric speaker 1703, two ear speakers 1802, 1803 are disposed beneath (or close to) the convex cutouts 601 in the upper left and right corners, i.e., close to light guide 901 and lens 102. As shown in the drawing, the earpiece for each ear speaker 1802, 1803 (on the left and right) may consist of a plurality of small holes or openings 1801 that partially surround light guide 901 on the left and lens 102 on the right and that are still located in the areas of the two convex cutouts 601 of display panel 1702, such that the sound waves are not blocked by the adjacent display panel 1702. The small holes or openings 1801 may have any suitable shape. For example, instead of a plurality of small holes 1801, each opening (on the left and on the right) may consist of a single curvilinear slot or slit.

In effect, smartphone 100, as per FIG. 18, features two earpieces for telephone calls: one earpiece 1801 in the top, left corner and one earpiece 1801 in the top, right corner of display screen 1601. During a telephone call, while holding the smartphone 100 to the ear, the user may use the upper earpiece 1801 of smartphone 100. In this context, "upper earpiece 1801" means the earpiece 1801 with a higher position while holding the smartphone 100 like a telephone receiver. Expressed differently, for convenient use, the user may hold or press the upper corner of smartphone 100 to his/her ear, while the lower corner of smartphone 100 is at the level of the neck.

Depending on whether the user holds the smartphone 100 to the left or right ear, the smartphone corner with light guide 901 (on the left in FIG. 18) or the smartphone corner with lens 102 (on the right in FIG. 18) may be the location of the upper ear speaker, and, since the user holds the upper ear speaker to his/her ear, the lower ear speaker (at the level of the neck) may be switched off.

An orientation sensor or accelerometer 1804 may be used to determine the current orientation of smartphone 100. The accelerometer 1804 may be connected to I/O interface 204 (as per FIG. 2) and may measure the direction of gravity. For example, if the gravity primarily points into the positive direction of the X-axis of coordinate system 1805, ear speaker 1803 (close to lens 102 on the right) may be switched off. If the gravity primarily points into the negative direction of the X-axis, ear speaker 1802 (close to light guide 901 on the left) may be switched off. Optionally, in other embodiments, both ear speakers 1802, 1803 (on the left and right) may operate simultaneously and may focus the sound to the ear.

FIG. 19 shows a top plan view of a ninth embodiment, namely a smartwatch 1900 as a further example of a mobile electronic device. Smartwatch 1900 and display screen 101 can have any suitable aspect ratio, as indicated by curved break lines. In this example, display screen 101 (or rather display panel 401) has a convex cutout 601 in the upper right-hand corner and a convex cutout 601 in the lower left-hand corner. Accordingly, a lens 102 of a front-facing camera is located in the upper right-hand corner and an LED flashlight 1991 is located in the lower left-hand corner. Alternatively, the two cutouts 601 and sensors/emitters 102, 1991 may be located in the upper left-hand corner and lower right-hand corner. LED flashlight 1991 may serve as an emergency flashlight, pocket torch, or pocket lamp. The front-facing camera (lens 102) may be used to take a "selfie" – exemplary screen content is shown in dotted lines.

Optionally, the two convex cutouts 601 (for lens 102 and LED flashlight 1991), shown in FIG. 19, may additionally serve as touch keys for functions of the smartwatch 1900, as described above with reference to the sixth embodiment (FIG. 15).

The embodiments shown in FIG. 3 through FIG. 19 maximize the effective area of display screen 101, 1601 or display panel 401, 1702, respectively. However, if a conventional user interface or a conventional application ("app") that is running on computer system 200 displays screen content in full screen (full height/width), parts of the screen content may be invisible due to cutout 601 (as per FIG. 6). To avoid this, embodiments of the present invention may use the flowcharts shown in FIG. 20, FIG. 21, and FIG. 22. The flowcharts may be implemented as a hardware circuit or as software running on computer system 200. A hardware implementation may be realized as field programmable gate array (FPGA) or as application specific integrated circuit (ASIC). A software solution may run on processor 201 and/or graphics sub-system 108, as per FIG. 2; e.g., a CPU with integrated graphics processing unit (GPU).

The screen content rendered by graphics sub-system 108 and displayed on display screen 101, 1601 by means of display panel 401, 1702 may consist of screen objects or graphic objects, referred to herein as "objects." A coordinate system (X, Y) may be used to position objects on the screen 101 and to scale the size of objects. Objects used by the user interface of an application and/or operating system, running on computer system 200, may comprise, inter alia, picture elements, icons, buttons, text lines, bars and boxes, etc. Screen objects or graphic objects may derive from conventional applications ("apps") that are not optimized for cutout 601.

Flowchart 2000, shown in FIG. 20, may be used to handle invisible parts of screen objects or graphic objects due to cutout 601 – before the objects are rendered by graphics sub-system 108. In step 2001, it is checked whether the object in question is affected by cutout 601. For example, by comparing the X and Y coordinates of the outer shape of the object with the corresponding X and Y coordinates of the outer shape of cutout 601, it can be determined whether the object and cutout 601 are overlapping or "colliding." If the object and cutout 601 are not overlapping, the object can be rendered without any changes by graphics sub-system 108 (i.e., position and size as originally intended). This is done in step 2002.

Otherwise, if the object and cutout 601 are overlapping, the object type or category is determined in step 2003. The objects used by the user interface and/or by applications may be categorized depending on their properties, such as purpose, size, relevance, etc. For example, there may be a category of essential elements that are required for user interaction, such as icons, buttons, checkboxes, drop-down boxes, sliders, and other control elements. Furthermore, there may be, for instance, a category of ornamental or portioning elements, such as frames, bars, background color, dialog boxes and balloons, etc.

Optionally, a configuration menu or setup option may allow the user to configure the relevance or the importance level of object types or categories as a personal preference. In this way, the user can decide for himself/herself which screen objects (pictures, text, etc.) are considered to be essential or important. This option applies to all subsequent cases.

In step 2004, it is checked whether the object in question belongs to the type of ornamental or portioning elements (e.g., frames, bars, background color, dialog boxes, balloons, etc.). If this is the case, the object is rendered without any changes in step 2005 by graphics sub-system 108 (original position, etc.), because it is assumed that the screen content is still intelligible even if, by way of example, a line of a frame or dialog box is interrupted by cutout 601.

In step 2006, it is checked whether the object in question is flowing text (continuous text comprising several lines and wordwraps). If applicable, the flowing text is reformatted depending on the location of cutout 601. This is done in step 2007. If cutout 601 is located in the upper, left corner, reformatting is done by indenting the uppermost line(s), and if cutout 601 is located in the lower, left corner, reformatting is done by indenting the lowermost line(s), such that the flowing text and cutout 601 no longer overlap. If cutout 601 is located in the upper or lower, right-hand corner, reformatting is done by moving the position of the word wrap to the left, such that the last word(s) of the affected uppermost or lowermost line(s) no longer overlap with cutout 601; i.e., after reformatting, the affected line(s) are shorter. The number of lines that are shortened depends on the font size and the height of cutout 601.

In step 2008, it is checked whether the object in question is a full screen video or full screen 3D graphics, referred to herein as full screen objects. Full screen objects may extend to the entire height and/or width of display screen 101. If applicable, full screen objects are handled by the separate flowchart 2100 shown in FIG. 21 and described below (subroutine call in step 2009).

Next, since the object in question is not a "special case" (like the exemplary portioning elements, full screen objects, or flowing text), it is checked in step 2010 whether it is possible to move the position of the object. This may depend on neighboring objects and the gaps between the elements. See FIG. 22 through FIG. 25 and the corresponding description below. If it is possible to move the object, the object (and possibly adjacent objects) are moved away from cutout 601 in step 2011, such that the object and cutout 601 no longer overlap. Typically, this involves shifting the object (and possibly adjacent objects) horizontally, vertically, or slightly to the center of display screen 101.

If it is not possible to move the position of the object for some reason (e.g., neighboring objects cannot be moved either), special actions must be performed depending on the object type. This is done in the subsequent steps, starting at step 2012.

If the object in question is a single text line, such as a title, a caption, or a headline, and since it is not possible to move this text line, the font size of the text line is reduced in step 2013, such that the text line and cutout 601 no longer overlap.

Referring to step 2014, if the object in question is an essential element that is required for user interaction (e.g., an icon, button, checkbox, drop-down box, slider, or other control element) it may not be appropriate to reduce the size of this object significantly, because this may hinder the usability. Instead, the size of other, less important or less relevant objects may be reduced. Essential objects are handled by the separate flowchart 2200 shown in FIG. 22 and described below (subroutine call in step 2015).

In other embodiments, the entire screen content may be resized to a smaller size in step 2015, such that the essential element and cutout 601 no longer overlap, and, in exchange, a margin (e.g. in black) is added to the left, right, top, and/or bottom area of display screen 101, depending on the location of cutout 601. As a result, the essential element is reduced far less in size because all other objects on the screen are slightly reduced in size as well. Optionally, the width and the height may be scaled independently.

Alternatively, with continued reference to step 2015, the operating system may announce a different, e.g., lower, screen resolution of the display panel 401, 1702. For example, if the width in pixels of a display panel is 1080 pixels, the height of the display panel is 1920 pixels, and the height of cutouts 601 at the top left and right corners is 200 pixels, then the operating system may announce a screen resolution of 1080 pixels (width) x 1720 pixels (height) to applications ("apps") running on the operating system. The coordinate origin of the screen is assumed to be in the upper, left corner, as is common practice. As a result, the screen content generated by the "apps" will not be hidden by the cutouts 601 at the top left- and right-hand corners if the operating system virtually moves the coordinate origin of the screen to a lower location, namely 200 pixels lower, such that the screen content of the "apps" starts in pixel line 200. Optionally, in this example, the upper 199 pixel lines may be used to display a status bar with useful information and icons as shown and described further below with reference to FIG. 30.

In step 2016, it is checked whether the object in question is a picture element. The picture element may be a bitmap image stored in a known file format such as BMP, JPG, GIF, or PNG. If the object is a picture element, a text recognition may be performed in step 2017, that is, the bitmap content of the picture element may be analyzed by means of optical character recognition (OCR). Any known techniques may be used for the OCR process, including (but not limited to) line and word detection, character isolation or segmentation, character recognition using matrix matching, and/or feature extraction.

Next, in step 2018, if the OCR process does not detect any (or any relevant) text, words, numbers, characters, logo designs, or other symbols that overlap with cutout(s) 601 in the corner(s) of display screen 101, the picture element can be rendered by graphics sub-system 108 without any changes (position and size as originally intended, step 2019 in the flowchart), because it is assumed that picture sections without characters or symbols are less important for the user. It is to be expressly noted that the picture element may contain text or characters at other locations that are not hidden by cutout 601. In such a case (e.g., a symbol or text near the center of the picture), the position and size of the picture element still remain unchanged.

Otherwise, if relevant symbols or characters (e.g., the beginning of a word) are found at the location of cutout 601, the picture element may be scaled to a smaller size in step 2020. Thanks to the smaller size, the picture element may now be moved away from cutout 601 (to some extent), such that relevant symbols or characters in the picture are no longer hidden by cutout 601.

Alternatively, instead of scaling the picture element to a smaller size, the relevant but (partially) invisible symbol(s) or text message found at a corner of the image may be copied to an other location within the image (i.e., less close to the corner). This can be done by means of image processing and/or picture manipulation; for example, by means of copy operations applied to the bitmap image. The new location for the symbol(s) or text message is preferably chosen in such a way that no important picture areas are hidden or affected by the moved symbol(s) or text message. The symbol(s) or text message may be moved as a block including the background or may be extracted from the picture background, e.g., by means of object recognition and/or OCR, such that the picture background at the new location remains partially visible.

Finally, in step 2021 of flowchart 2000, if the object in question does not belong to any of the exemplary categories listed above, the (unknown) object may be scaled to a smaller size and may be moved slightly, such that the object and cutout 601 no longer overlap.

In other embodiments, support for additional object types may be implemented. For example, support for vector graphics and/or graphical primitives (e.g., ellipse, circle, rectangle, or polygon) may be added. The lines and/or branching points of the vector graphics or graphical primitives may be categorized by relevance, and the vector graphics or graphical primitives may be scaled accordingly so that only less important parts (e.g., a continuous line) are hidden by cutout 601.

If display panel 401, 1702 has more than one cutout 601, for instance, cutouts 601 in the upper left- and right-hand corners, the procedure described in flowchart 2000 (as per FIG. 20) may be executed for each cutout 601.

Flowchart 2100, shown in FIG. 21, may be used to handle full screen videos and full screen 3D graphics, i.e., full screen objects. Full screen objects may extend to the entire height and/or width of display screen 101. In step 2101, the object type or category of the full screen object may be determined. Full screen objects may be categorized by purpose or relevance.

In step 2102, it is checked whether the object type is "3D graphics," for example, a computer game. Typically, the graphics of a computer game, generated by a 3D engine, consists of two parts: the 3D scene (with objects like landscape, buildings, vehicles, humans, and animals) and an overlay layer (with overlaid objects such as a score, a speedometer, a status message, or a text overlay).

With regard to step 2103, overlaid objects may be moved separately and may be managed using flowchart 2000, as per FIG. 20. See "single text line" and "picture element" in step 2012, step 2013, and steps 2016 through 2020. The 3D scene may be rendered without changes by graphics sub-system 108. (In this non-limiting example, it is assumed that overlaid objects like a score are essential, while the 3D scene is still intelligible even if a few regions at the edges of display screen 101 are invisible due to the cutouts 601.)

In step 2104, it is checked whether the object type is "full screen video," for example, a live-stream or the playback of a video file. The video file may be stored in a known format, such as MP4 or AVI. In this non-limiting example, the full screen video is displayed in "landscape mode," that is, the user holds the smartphone 100 horizontally.

If the present object is a full screen video, the aspect ratio of the full screen video is checked in step 2105. Next, in step 2106, if the aspect ratio of the full screen video and the aspect ratio of display panel 401, 1702 are approximately equal, the output of the video may be scaled to a slightly smaller size, such that the corners of the video are somewhat more visible. This is referred to as "windowboxing." For example, if both the full screen video and the display panel 401, 1702 have an aspect ratio of 16:9, the video may be slightly reduced in size while maintaining the original aspect ratio of the video. As a result, smaller regions of the corners of the video are hidden by cutouts 601. (Optionally, the user may be able to activate or deactivate this behavior as a preference.)

In step 2107, it is checked whether the full screen video has an aspect ratio that is wider, i.e., greater, than the aspect ratio of display panel 401, 1702 ("widescreen aspect ratio"). For example, this would be answered in the affirmative if the full screen video is a feature film in the Panavision® or CinemaScope® format 2.35:1, while the display panel 401, 1702 has an aspect ratio of 1.78:1, better known as 16:9.

In step 2108, if the aspect ratio of the full screen video is greater than the aspect ratio of display panel 401, 1702, the full screen video is displayed in a mode referred to as "letterboxing." Bars, typically black bars, are added at the top and/or at the bottom of the full screen video (displayed in landscape mode) such that the cutouts 601 of display panel 401, 1702 are located in the region of the (black) bars. As a result, no parts (or at least fewer parts) of the full screen video are hidden by the cutouts 601.

Otherwise, in step 2109, if the aspect ratio of the full screen video is smaller than the aspect ratio of display panel 401, 1702, the full screen video is displayed in a mode referred to as "pillarboxing." For example, the full screen video may have a classic aspect ratio of 4:3 and the display panel 401, 1702 may have an aspect ratio of 16:9. In another example, the full screen video has a 16:9 aspect ratio and the display panel 401, 1702 has an aspect ratio of 21:9. In these cases, vertical bars (e.g., in black) are added at the left and/or right side of the full screen video (displayed in landscape mode) such that the cutouts 601 of display panel 401, 1702 are located in the region of the vertical bars. As a result, no parts (or at least fewer parts) of the full screen video are hidden by the cutouts 601.

Finally, in step 2110, if the full screen object in question does not belong to the exemplary categories discussed above, the (unknown) full screen object may be scaled to a smaller size and, if applicable, may be moved slightly, such that the full screen object and the cutouts 601 no longer overlap. In other embodiments, support for additional object types may be implemented.

In step 2011 of FIG. 20, it is mentioned that the possibility of moving an object may depend on neighboring objects that may block the necessary shift of the object. (If no consideration would be taken of neighboring objects, the shifted object and neighboring objects would overlap.) The exemplary flowchart 2200, shown in FIG. 22, handles such a situation.

In step 2201 of flowchart 2200, it is checked whether adjacent object(s) get in the way when repositioning the current object away from cutout 601. If no objects are blocking the shift, the current object is moved in step 2202, such that no parts of the object are concealed by cutout 601. The object may be moved horizontally, vertically, diagonally, or in any suitable direction.

Otherwise, in the case that adjacent object(s) are blocking the shift of the current object, it is checked in step 2203 whether the adjacent object(s) can be moved. If applicable, the adjacent object(s) are moved where necessary so that the current object can be moved as well (away from cutout 601). This is done in step 2204. Since the adjacent object(s), in turn, may be blocked by other neighboring objects, a recursive algorithm may be used for this purpose. Depending on the arrangement, it may not be necessary to move all adjacent objects.

If it is not possible to make the necessary changes in position, that is, if at least one adjacent object cannot be moved for any reason, it is checked in step 2205 whether the current object is more important than the inflexible adjacent object(s). For this purpose, the objects may be categorized by relevance, purpose, size, etc. For example, there may be essential objects with high relevance (e.g., a button, a checkbox, a drop-down box, or a slider) and ornamental objects with low relevance (e.g., a frame or a picture). Categorizing by purpose may involve distinguishing between interactive elements and static elements, and, eventually, it may be less problematic to reduce the size of a large object.

If the current object (e.g., a button) is more important than each inflexible adjacent object (e.g., pictures), then the adjacent object(s) are scaled to a smaller size in step 2206, and the gained space is used to move the current object away from cutout 601 to make it fully visible. Otherwise, if the current object is less important than the adjacent object(s), the size of the current object is reduced in step 2207, so that (thanks to the smaller size) the current object can be moved away from cutout 601, at least slightly.

Optionally, a list with all participating objects on the screen may be sorted by relevance. In this way, the least important objects are known. The least important objects may be preferred candidates for a reduction in size.

FIG. 23 shows exemplary graphic objects of a conventional application ("app") that is not optimized for the four cutouts 601 at the corners of display screen 101. A medium-sized picture element 2301, e.g., a logo, symbol, or other design, is located in the upper, left-hand corner of display screen 101. In this example, the upper part of the letter "L" is invisible due to cutout 601. Four small icons 2302 through 2305 are located on the right next to picture element 2301. In this example, the icons are essential elements of the user interface and must be visible. Yet, the last icon 2305 is largely concealed by cutout 601 in the upper, right-hand corner, which makes icon 2305 practically unrecognizable and/or inoperable. The exemplary screen content in the lower area of display screen 101 consists of a large picture element 2306 with a photograph, e.g., a JPG image file. The text in the lower, right-hand corner of picture element 2306 is part of the bitmap data of the image (and not a separate text string). As can be seen, the name after "Photo taken by ..." has been truncated by cutout 601 (and hence is unrecognizable).

The operating system, on which the conventional app is running, may adjust the size and the position of the graphic objects using the approach outlined in flowchart 2000 (FIG. 20) and flowchart 2200 (FIG. 22), such that all relevant or substantial elements are visible. The exemplary solution shown in FIG. 24 is based on the directive to move objects horizontally.

An analysis of the relevance of icon 2305 (step 2003 in flowchart 2000) indicates that icon 2305 is essential and must be moved to the left horizontally. This shift is blocked by adjacent icons 2302, 2303, 2304, which are also essential and too small to reduce their size, such that, by means of flowchart 2200, it is determined that all four icons must be moved to the left (e.g., recursive algorithm). Medium-sized picture element 2301 has a lower level of importance and is large enough such that a reduction of its size is acceptable. See step 2203 and step 2205 in flowchart 2200.

Optionally, optical character recognition (OCR) may be applied on medium-sized picture element 2301. The analysis may show that the letters in "LOGO" are big and that it is acceptable that a part of the letter "L" remains invisible. Hence, picture element 2301 is reduced in size but only shifted slightly to the right.

With continued reference to FIG. 24, optical character recognition (OCR) at the corners of the large picture element 2306 (photo) will discover the small text at the lower, right-hand corner; see step 2017 in flowchart 2000. As a result, and in accordance with step 2020, picture element 2306 is scaled to a smaller size and is moved horizontally to the left, such that the name "Alice" becomes visible. Since no relevant symbols or characters have been found (by OCR) in the lower, left-hand corner of picture element 2306, it is acceptable that this corner of the photo is hidden by cutout 601. Alternatively, as shown in FIG. 25, a directive to move the objects diagonally towards the center of display screen 101 may be applied as indicated by means of arrows 2501.

Optionally, advanced methods, such as a trained neural network, may be used to improve rearranging the graphic objects on the screen. Neural networks may be trained to distinguish important objects from less important objects and they may be trained with a set of preferable layouts that are both visually appealing and user-friendly while avoiding the cutouts 601 as needed. The system may recognize recurring applications ("apps") and may remember the best layout for these "apps." Moreover, neural networks may learn from the user behavior: for example, if the user deactivates the current layout (generated by a neural network), the layout may be unfavorable.

FIG. 26 through FIG. 30 show an HTML web page or the page of an e-book displayed on display screen 101. Depending on the embodiment, a web browser or a dedicated e-book reader app, running on smartphone 100, may be used. In the example as per FIG. 26, the flowing text 2601 is not optimized for the four cutouts 601 at the corners of display screen 101. As a result, a few words of the story ("Alice's Adventures in Wonderland," in the public domain) are truncated or missing at the corners. For example, the word "by" is completely hidden by cutout 601 in the upper, right-hand corner.

Referring to FIG. 27, an embodiment is shown that indents the flowing text 2601 at the cutouts 601 on the left and that changes the position of the word wrap on the right, such that no part of the text is hidden by the cutouts 601; see step 2007 in flowchart 2000. Optionally, as shown in FIG. 27, the size of the indent and the position of the word wrap may vary from line to line to tailor the length of the lines to the convex shape of the cutouts 601.

As can be seen by comparing FIG. 27 with FIG. 26, the word wraps of the entire first paragraph of the story have changed; e.g., there is a new seventh line that reads: "conversations?'." If the text of the story were to be scrolled down, e.g., in a web browser, the word wraps of the uppermost paragraph would change permanently while scrolling, which may result in a poor user experience. Therefore, the embodiment as per FIG. 27 may be preferable if the pages are not scrollable; e.g., the user may turn the pages of an e-book by means of a swipe gesture (to the left or right) on the touchscreen.

The embodiment as per FIG. 28 and FIG. 29 is designed to scroll flowing text 2601 up and down without the above-described problem of permanently changing word wraps in the uppermost paragraph on the screen. This is achieved by changing the character width (also known as type width or font width) and/or the character spacing (also known as walking distance or tracking) dynamically.

Referring to FIG. 28, the character width of the first two lines and of the last two lines has been reduced such that all words of the original lines (as they would appear in FIG. 26 without the cutouts 601) fit into the reduced width between the cutouts 601; e.g., the words "sitting by" are still displayed in the first line and not in the second line (as per FIG. 27). At the top and/or bottom of display screen 101, the character width and/or character spacing may vary from line to line to tailor the length of the lines to the convex shape of the cutouts 601.

FIG. 29 shows the same flowing text 2601 scrolled down by one line. While the first line of the story now is invisible, the character width of the second and third line has been reduced as they become the upper lines (displayed on display screen 101). As can be seen by comparing FIG. 29 with FIG. 28, the word wraps (e.g., of the first paragraph of the story) have not changed, resulting in a good user experience while scrolling. Therefore, the embodiment as per FIG. 28 and FIG. 29 may be preferable for scrollable text, such as an HTML web page displayed in a web browser.

The embodiments disclosed in FIG. 20 through FIG. 29 handle the missing screen areas at the corners of display panel 401, 1702 by scaling and shifting graphic objects selectively; for instance, by reducing the size of a specific picture element or reducing the width of characters in a specific text line. However, instead of working on an object level (i.e., graphic objects), the entire screen content may be modified on a per pixel basis, as set forth in the following embodiments:

In one embodiment, all horizontal lines of pixels on the height of cutouts 601 (i.e., all lines of pixels that are located at the top and/or bottom of display screen 101) are scaled down individually to a shorter width, such that the width of each line of pixels is tailored to the convex shape of the cutouts 601. The result is screen content with distortions near each cutout 601, yet the entire screen content is visible – no parts are missing. For example, with reference to the partially comparable effect shown in FIG. 29, there would be significant distortions near the cutout 601 in the upper left-hand corner, almost no distortions in the middle, and significant distortions near the cutout 601 in the upper right-hand corner. The extent of the distortions can be reduced by smoothing the transition and by leaving a small part of the screen unused (below the upper cutouts 601 and/or above the lower cutouts 601).

In another embodiment, vertical lines of pixels (at the left and right of display screen 101) that are affected by cutouts 601 are scaled down to a shorter length, such that the height of each line of pixels is tailored to the convex shape of the cutouts 601. Since, in this example, vertical lines are longer than horizontal lines, this may reduce distortions in many regions of the screen.

In yet another embodiment, especially when displaying photographs or other images, horizontal and vertical scaling may be combined. Optionally, the corners of the image may be faded to low contrast or may be blurred.

The approach outlined in flowchart 2000 (FIG. 20), flowchart 2100 (FIG. 21), and flowchart 2200 (FIG. 22) identifies essential elements and likewise screen areas of little importance and rearranges the screen layout accordingly. In other embodiments, the users may decide for themselves whether current content that is invisible due to the cutout(s) 601 at the corner(s) is essential.

For example, if a photograph is displayed in full screen (e.g., full width and height) on display screen 101, and if no essential parts of the photo are located at the corners (usually this is the case), it is acceptable that the corners of the photo are cut off, and, hence, there is no need for the user to change the current (e.g., default) display mode.

Otherwise, if the current content on the screen is, by way of example, the text of an e-book, as shown in FIG. 26, the user will notice that words are truncated or missing at the corners. Therefore, the user will make a defined user input that causes the operating system to move the entire screen content downward approximately by the height of cutout 601; see FIG. 30. As a result, the entire upper lines of the e-book are temporarily visible. The available space between the upper cutouts 601 (or next to a single cutout 601) may be used to display a status bar 3001 with useful information and/or icons, such as signal strength, time, and battery status. The status bar 3001 may have any suitable height. For example, status bar 3001 shown in FIG. 30 is slightly smaller than the height of cutout 601, and the status bar in FIG. 8 has approximately the same height as cutout 601. In other embodiments, the status bar 3001 may have a greater height than the height of cutout 601.

The user may switch between the "maximized view" as per FIG. 26, the "detail view" as per FIG. 30, and other layouts or views using any defined user input that is applicable. For example, a touchscreen gesture may be used, such as a "swipe-down" from the top of the display screen 101 (starting at the upper edge). In other embodiments, a novel "drag-along" or "drag-away" gesture may be used, as suggested in patent US9323340 B2, titled "Method for gesture control," the disclosure of which is hereby incorporated by reference in its entirety. To switch between "maximized view" and "detail view" using the novel "drag-along" or "drag-away" gesture, the user may touch the touchscreen at any location (not necessarily at the edge) and next, while keeping his/her finger unmoved, the user shifts the smartphone 100 below the unmoved finger, such that the unmoved finger slides on the touchscreen. As soon as the gesture is detected by the operating system, and depending on the direction of the shift movement (e.g., forward or backward), the system will switch between the views.

Moreover, a variety of motion-based gestures can be used to switch between "maximized view" and "detail view." For example, the user may tilt or rotate the smartphone 100 approximately around the X-axis of coordinate system 1805 in a fast forward and backward movement causing the operating system to switch between the views.

Alternatively, pressure sensitive sensors, connected to I/O interface 204, may be embedded within the frame of smartphone 100 such that a squeeze to the phone's frame can be detected. Squeezing the frame may cause a switch between "maximized view" and "detail view."

Other embodiments may use eye tracking to switch between the views. Eye tracking may be done using the optical sensors and emitters located at cutout 601. For example, if the current view is the "maximized view" as per FIG. 26, and if the user looks at an upper corner (with a cutout 601) for a defined period of time, this is recognized by the eye tracking system and the operating system will switch to the "detail view" as per FIG. 30. Subsequently, if the user ceases looking at an upper corner for a prolonged span of time, the operating system may switch back to the (preferred) "maximized view."

In some embodiments, the operating system automatically switches back from "detail view" (as per FIG. 30) to the default "maximized view" (as per FIG. 26) after a defined period of time, because it can be assumed that it takes only a short time for the user to recognize the (previously hidden) text or symbols in the corner. The defined period of time can be made adjustable as a preference in the setup. This solution can be implemented regardless of whether switching is done via a touchscreen gesture, motion control, pressure, or by means of eye tracking.

In at least one embodiment, a pop-up window or a variation of a screen magnifier may be used that displays and, if intended, magnifies the content hidden by cutout 601 in another area on display screen 101. The pop-up window or screen magnifier may be activated by the user via a "long press" at the corner of the touchscreen. Alternatively, a pressure-sensitive touchscreen can be used that distinguishes between different levels of force being applied to the surface.

Switching between views is not limited to the examples discussed above. In further embodiments, an associated input gesture may cause switching between an adjusted layout (as per FIG. 20, FIG. 22, and FIG. 24), a distorted layout (horizontal and/or vertical scaling at the pixel level), the original layout (as shown in FIG. 23 or FIG. 26), and a layout with a status bar (as per FIG. 30). Furthermore, a configuration menu or setup option may allow the user to define the preferred layout or view for each application ("app") installed on smartphone 100. The preferred layout or view can be activated automatically as soon as a known application is started.

FIG. 31 shows a widescreen movie 3101 (illustrated in dotted lines) that is displayed in full screen on display screen 101. The user holds the smartphone 100 horizontally (landscape mode). The widescreen movie 3101 has an aspect ratio that is wider, i.e., greater, than the aspect ratio of display screen 101. Therefore, with reference to step 2108 in flowchart 2100, the widescreen movie is displayed in "letterbox" mode, such that the cutouts 601 of display screen 101 are located in the region of the horizontal bars at the top and bottom of the widescreen movie 3101. The widescreen movie 3101 is completely visible – no corners are hidden by the cutouts 601. The embodiment as per FIG. 31 is able to display the movie larger than a conventional smartphone (with the same dimensions of the casing).

When taking a self-portrait photograph ("selfie") or when recording a video with the front-facing camera (lens 102), the status of the front camera 402 may be indicated on display screen 101 by means of a quarter circle 3201 that surrounds lens 102 – as shown in FIG. 32. The graphic content displayed in quarter circle 3201 may be animated and may indicate operating states of the front camera 402, such as recording, ready, standby, inactive, flashlight required, etc. The animation of the graphics within quarter circle 3201 may involve a rotation wherein lens 102 constitutes the pivot point.

Optionally, when displaying a photograph or an other image in full screen (e.g., full width and height) on display screen 101, the corners of the photograph (as displayed on the screen) may be faded to black seamlessly – especially at corners with a cutout 601. In this way, the cutout(s) 601 may be less noticeable. The corner(s) of the photograph may also be faded to another color, for example, the color of the casing of smartphone 100.

In FIG. 4, the lens 102 of the front-facing camera is disposed beneath cover glass 405 at the location of cutout 601. However, in other embodiments, the cover glass 405 may have a small hole or opening at the location of the lens 102, and the lens 102 may be placed inside the hole, such that the lens 102 slightly protrudes from the cover glass 405. This may maximize the length of the lens system of camera module 402, as the length of a lens system can be a limiting factor for taking high quality pictures. Furthermore, the solutions described in this disclosure may allow the production of particularly thin smartphones 100.

It is to be expressly noted that the cutouts 601 at the corner of display panel 401, 1702 may accommodate optical and/or acoustic sensors and/or emitters of any applicable known or convenient type, including, but not limited to proximity sensors, light sensors, infrared sensors, ultraviolet sensors, LED indicators, flashlights, infrared LEDs, fingerprint sensors, iris scanners, sensors for face recognition, face tracking, or eye tracking, ultrasonic proximity sensors, or piezoelectric speakers. It should also be noted that the exemplary positions of the optical and/or acoustic sensors and/or emitters in the drawings can be swapped as needed.

The thin borders 106, 107, 301 at the right, left, top, and/or bottom edge of the display panel 401 may be extremely thin, such that, essentially, the borders 106, 107, 301 become nearly invisible and may be referred to as "borderless" in general language usage. Furthermore, display panel 401 with thin borders 106, 107, 301 may be referred to as "edge-to-edge display," and cover glass 405, 1701 may have edges known as a 2D, 2.5D, or 3D curved glass display.

Optionally, a conventional keyboard with mechanical keys may be integrated at the bottom of smartphone 100. While a mechanical keyboard may be beneficial for typing, the upper edge of display screen 101 may still feature a thin border 301 or a curved edge 1603, thereby maximizing the size of display screen 101; e.g., see FIG. 16 or FIG. 32. Moreover, due to the thin border 301 at the upper edge of display screen 101, it may be possible to combine a mechanical keyboard with a widescreen display panel 401, 1702 that has an advantageous aspect ratio, such as 16:9.

In the figures of the present disclosure, aspects of the invention are illustrated using a smartphone 100 and a smartwatch 1900. Yet, any other electronic device can be used, including, but not limited to, mobile phones, phablets, tablet computers, subnotebooks, laptops, game consoles, or wearable computers (also known as body-borne computers or wearables, e.g., a touchscreen device or display integrated into clothing). Furthermore, the electronic device may feature, by way of example, a folding display (e.g., foldable OLED screen) or collapsible display. Display panel 401, 1702 may be a flexible display, rollable display, elastic display, 3D display, holographic display, or of any other applicable known or convenient type.

The borders (or "thin borders," as used in the claims) that surround display screen 101 shall be defined as the distance between the outer housing frame of the mobile electronic device and the beginning of the active screen area (which displays the screen content).

The conjunction "or," as used in the claims, shall be interpreted as an alternative between two (or more) features, such as alternative method steps, and shall not be construed to specifically exclude any "non-selected" feature (such as an "XOR" operator). A list of features connected with an "or" that starts with the phrase "at least" or that ends with the phrase "a combination thereof" covers both single features from the list as well as any groups of features thereof. Furthermore, the conjunction "or," as used in the claims, shall not be construed as a logical "OR" operator of a computer program: even if a claim contains a condition, the conjunction "or" is intended to specify alternative features of the claim, such as alternative method steps.

LIST OF REFERENCE NUMERALS

100	Smartphone / Mobile electronic device
101	Display screen and touchscreen
102	Lens of front-facing camera
103	Earpiece (for ear speaker)
104	Proximity and light sensor
105	LED indicator
106	Thin border at the left edge of the display screen
107	Thin border at the right edge of the display screen
108	Graphics sub-system (e.g., GPU)
200	Computer system of smartphone
201	Processor (CPU)
202	Main Memory (RAM)
203	Non-volatile memory (e.g., flash memory, SSD, memory card)
204	I/O interface including network interface and sensors (e.g., WIFI, accelerometer)
205	Bus system / computer bus
206	Instructions for executing on the processor and data (e.g., bitmap image data)
301	Thin border at the top edge of the display screen
401	Display panel (e.g., LC panel, OLED panel)
402	Front camera module
403	Ear speaker (for earpiece)
404	PCB equipped with ICs
405	Cover glass (front side of casing of smartphone)
406	Light path of front-facing camera or optical sensor/emitter
601	Cutout at corner of display panel
701	Lens of second front-facing camera (3D)
801	Flash LED / Electronic flashlamp
901	Light guide combining optical sensors and emitters
902	Ultraviolet (UV) sensor
903	Fingerprint sensor
904	Narrow gap for tweeter
905	Tweeter (loudspeaker designed to reproduce high frequencies)
906	Woofer or midrange speaker (loudspeaker designed to reproduce lower frequencies)
1001	Infrared (IR) LED
1101	Lens of main camera or rear camera
1102	Main camera lens optionally located in the middle of the rear side
1501	Printed symbol for "Home key" (Exit application and go back to homescreen.)

1502 Printed symbol for "Back key" (Go back to the previous screen.)

1503 Printed symbol for "Recent apps key" (Recently used applications & favorites.)

1601 Display screen with curved edges

1602 Curved edge on the left and/or right side

1603 Curved edge at the top of the display screen

1701 Cover glass with curved edges (front side of casing of smartphone)

1702 Display panel with curved edges (e.g., flexible OLED panel)

1703 Piezoelectric speaker (e.g., piezo film speaker with piezo actuator)

1801 Earpiece: Plurality of small holes/openings

1802 Ear speaker on the left

1803 Ear speaker on the right

1804 Orientation sensor / Accelerometer

1805 Coordinate system

1900 Smartwatch / Mobile electronic device

1991 LED flashlight (emergency flashlight / pocket torch / pocket lamp)

2000 Flowchart

2001 - 2021 Steps of flowchart

2100 Flowchart

2101 - 2110 Steps of flowchart

2200 Flowchart

2201 - 2207 Steps of flowchart

2301 Medium-sized picture element (logo)

2302 - 2305 Small icons (essential user interface elements)

2306 Large picture element (photograph with text in lower, right corner)

2501 Directive to move objects diagonally (in the direction of the arrow)

2601 Flowing text (continuous text)

3001 Status bar

3101 Widescreen movie (letterboxing)

3201 Status indicator of front camera (quarter circle)