

A Baby Monitoring Mat based on Fiber Optic Sensor

Field of Invention

This patent invention relates to a Baby Monitoring Mat that utilizes Optic Sensing system for the detection of presence of baby, as well as movement and
5 breath count thereof.

Background

Currently, there are products in the consumer market that can detect baby-breathing movement using different sensing technology.

One method is based on piezoresistive pressure sensor pads that are placed
10 beneath the mattress for detecting movements. This type of pressure sensor pad consists of a micro-machined silicon diaphragm with piezoresistive strain gauges diffused into it, fused to a silicon or glass backplate. Pressure induced strain increases the value of the radial resistance. This resistance change can be high as 30%. The resistors are connected as a Wheatstone Bridge Circuit, the output of
15 which is directly proportional to the pressure applied to the pressure sensor pads.

The pressure sensor pads detect every movement of the baby sleeping on the mattress, including breathing action by baby. But such sensor often provides false alarm that arises from high sensitivity of the pressure sensor pad to any surrounding vibrations transmitted to the pressure sensor through the bed frame structure.
20 Further, such pressure pad would not work properly on a "spring-based" mattress. In addition, although such pressure sensor pad is also able to pick up breathing action, but it does not provide any breath count because it is not able to differentiate the type of movements occurring on the bed.

There exists another sensor that is based on the properties of piezo film (strip
25 of piezoelectric PVDF polymer film) as a dynamic strain sensor to detect the breathing rate of an infant. Such sensor uses a PVDF-monitor device clipped to the waistband of the baby's diaper. When the baby breathes, its stomach movement causes strain to the piezo film materials, which generates the signal for detecting

breathing movements. Such sensor, however, also provides false alarm arising from bad contact between diaper or nappy and body of baby, especially if the baby body circumference is small or the diaper or nappy is too large or too loose for the baby. Further, such sensor is also not able to provide any breath count; only detects for no
5 breath movement.

Summary

In one aspect of the present invention, there is provided, a Baby Monitoring Mat that comprises of a sensor mat having a top mesh layer, a bottom mesh layer, and two flexible sheets and an optical cable, wherein the optical cable is routed
10 across and sandwiched in between the top mesh layer and the bottom mesh layer, and the flexible sheets further sandwiched the top mesh layer and the bottom mesh layer in between forming sensing area across the flexible sheet surface; a light source for feeding light from one side of the optical cable; a photodiode for detecting light attenuation at the other end of the optical cable; a printed circuit board having a
15 processor connected to the light source and the photodiode, wherein the processor operationally receives signals from the photodiode, the signals are processed to determine movements and breath counts. The signals are generated based on the light attenuation changes along the optical fiber cable detected by photodiode, the light attenuation changes are operationally caused by the optical fiber bending lost
20 caused by the movements and breath.

In one embodiment, the light source is a light emitting diode. The flexible sheets may be latex sheets. It is desired that the optical fiber cable maybe a multimode optical fiber cable. Further, the top and bottom mesh layer may comprise grid patterns adapted to guide and protect the multimode optical fiber cable routed in
25 a symmetrical manner across the sensor mat. The optical fiber cable may be spaced at least about 20mm apart. In another embodiment, the top and bottom layer of mesh comprises symmetrical grid pattern spaced at least about 5mm and less than about 8 mm apart with fiber turning hooks with spacing of about 20mm apart to guide the multimode optical fiber across the sensor mat.

In a further embodiment, the Baby Monitoring Mat may further comprise a flexible bridge for connecting two sandwiched mesh layers for allowing the Baby Monitoring Mat to be foldable.

In another embodiment, the Baby Monitoring Mat may further comprise a wireless transceiver on the printed circuit board, wherein the wireless transceiver operably transmits status information such as baby presence, movement and breath counts, to a remote display unit, such that the movements on the sensor mat can be monitored there through.

Yet, the Baby Monitoring Mat may further comprise a baby wake up sock electrically connected to the printed circuit board, the wake up sock is wearable on a baby's leg, wherein the wake up sock vibrates when the sensor detects zero breath count when a baby is presence on the sensor mat.

In another aspect of the present invention, there is also provided, a method of detecting movements and breath counts of a baby on a mat. The method comprises providing an optical cable for routing across and sandwiched between the mats; and detecting movements on the mat through acquiring light attenuation changes along the optical fiber cable, wherein the light attenuation changes are operationally caused by the optical fiber bending lost caused by movements and breath on the mat.

There is yet another aspect of the present invention, that is, a method for monitoring a baby's movement and breath counts on a Baby Monitoring Mat according to the aforesaid method, wherein a Baby Monitoring Mat is configured according to the aforesaid specifications.

Brief Description of the Drawings

The invention is described by way of non-limiting embodiments with reference to the accompanying FIGURES, in which:

FIGURE 1 is an overall system of a Baby Monitoring Mat in accordance with one embodiment of the present invention;

FIGURE 2 is the Exploded View of a Baby Monitoring Mat in one embodiment of the present invention;

FIGURE 3 is the Schematic Block diagram of a Baby Monitoring Mat in a further embodiment of the present invention;

5 FIGURE 4 is the cross section of a sensor mat of FIGURE 2;

FIGURE 5 is the exploded view of the flexible bridge connection to the mesh structure and the optical cable;

FIGURE 6 shows the flexible bridge design together with the optical fiber before and after bending

10 FIGURE 7 is a bottom layer mesh of the sensor mat in yet another embodiment of the present invention;

FIGURE 8 shows the locking mechanism between the top layer mesh and bottom layer mesh;

15 FIGURE 9 is an Optical Fiber Cable assembly in an embodiment of the present invention;

FIGURE 10 is an Optical sensor assembly in an embodiment of the present invention;

20 FIGURE 11 shows an Optical Fiber Cable assembly of FIGURE 9 and an Optical Sensor assembly of FIGURE 10 that are assembled for coupling to each other;

FIGURE 12 is an illustration of Baby Monitoring Mat when used in a baby cot;

FIGURE 13 exemplifies signal patterns for Baby presence detection;

FIGURE 14 exemplifies signal patterns for Baby movement detection;

FIGURE 15 exemplifies signal patterns for Baby Breath count detection; and

25 FIGURE 16 exemplifies signal patterns for Baby Apneic Episode.

Detailed Description

The following descriptions of a number of specific and alternative embodiments are provided to understand the inventive features of the present invention. It shall be apparent to one skilled in the art, however that this invention may be practiced without such specific details. Some of the details may not be described in length so as to not obscure the invention. For ease of reference, common reference numerals will be used throughout the figures when referring to same or similar features common to the figures.

The present invention discloses an optic fiber sensor embedded to a baby mat in accordance with one embodiment of the present invention. The fiber cable is routed within a sandwiched structure inside the baby mat. Non-coherent light source is coupled into the fiber cable for operationally emitting light for travelling along the length of the fiber cable. Baby breathing movement on top of the mat will cause light lost due to internal reflections from the macro bending lost caused by the sandwiched structure. These reflections will create distinct light attenuation pattern when measured with a light detector. By processing the light attenuation signal pattern detected through the light detector, detection of movement, breath count and presence of the baby on the mat can be differentiated. Figure 13 to 16 illustrates all the signal patterns generated by the mat for the purposes of detecting Baby presence, movement, breath count and apneic episodes. Figure 15 shows the signal of breathing movement which is characterized by a periodic sine wave of certain constant amplitude and duration. The duration determines the breath/minute measurements. Figure 16 shows the phenomena of an apneic episode whereby there are no breath cycles in between. An apneic episode that will generate an alarm is classified as 15 seconds of no breath cycles. Figure 14 shows movement disturbances in between breathing cycles. A movement event is determined when the amplitude of the signal changes at least 6 times of the amplitude of normal breath cycles for a period of 5 seconds. Figure 13 shows the event of out of mat detection. An amplitude drop of at least 8000 in value signifies an out of mat event.

The optic fiber sensor of the above embodiment, provides an improved mechanical coupling whereby the full weight of the baby comes into direct contact with the mat without a mattress in between which can cause unnecessary

interference to the accuracy of the sensing. Further, the sensitivity of the fiber sensor has improved over the conventional pressure sensor or the like because it is based on macro bending of light passing through the fiber. It advantageously provides the capability of measuring baby breath count, movement and presence accurately. In accordance with the present invention, the present baby mat can be light in weight and portable to be used in different environments.

The Baby Monitoring Mat is typically placed in the baby cot on top of the mattress. The mat can be powered by battery or AC/DC adaptor connected to the mat. When powered by battery, the mat is portable and can be brought out to monitor the baby outside of the baby cot.

With reference to FIGURE 1, a Baby Monitoring Mat comprises a Sensor Mat **210**, an Electronic Box **410** and a Parent Control Unit **310**. The entire area of the Sensor Mat has optical fiber cable embedded in between to enable detection of baby presence, movement and breath count when baby is placed on it. The Electronic Box **410** can be powered by an external AC/DC adaptor **510** and/or with battery installed inside the Electronic Box **410**. An external alarm device **710** can be connected to the mat to provide additional notification of critical events detected by the Sensor Mat **210**. A stimulation device in the form of a wake up sock **610**, for example, can also be attached to the electronic box **410**. The wake up sock **610** is integrated with a built-in vibrator, which will jolt the baby's feet when zero breath count or any predetermined condition is detected. The wake up sock **610** attempts to agitate the baby to resume normal breathing pattern while the caregiver is being notified to response to the baby's need via the Parent Control Unit **310**. The Parent Control Unit **310** is operationally communicating with the Electronic Box **410** wirelessly. It has a display to indicate events such as Baby out of mat/presence, Baby movement and Baby Breath count continuously. Alarm of events detected by the sensor mat **210** is indicated with an audible alarm or vibration of the Parent Control Unit **310** working within the wireless range. When Parent Control Unit **310** is outside the wireless range of the Baby Monitoring Mat, an out of range alarm will be sounded.

FIGURE 2 shows the exploded view of the Baby Monitoring Mat **210** in accordance with one embodiment of the present invention. The central portion is made up of the sensor which consists of optical fiber cable **217** winded in a

symmetrical manner with top layer meshes **220,224** and bottom layer meshes **221,225** acting as the optical cable guide to sandwich and secure the optical fiber **217** in place. In the middle of the bottom layer meshes **221,225** and the top layer meshes **220,224**, there is a flexible bridge **222** which acts as a hinge which binds all the four portions of the top layer meshes **220,224** and the bottom layer meshes **221,225** together. Besides binding the four meshes together, the main function of the flexible bridge **222** is to enable the Baby Monitoring Mat **210** be foldable so that the Baby Monitoring Mat can be more compact for storage and portable for carrying along with the baby. At the folding edge, the flexible bridge **222** guides the optical fiber cable **217** such that it is not bend at an acute angle that will break the optical fiber cable **217**. The top layer mesh **220,224** and bottom layer mesh **221,225** together with the flexible bridge **222** form the mechanism to secure and lock the optical fiber cable **217** in place with the routing pattern defined. The top layer latex **241** and bottom layer latex **242** together with the protective cover **240** is provided to sandwich the meshes with the optical fiber cable **217** embedded to form the sensor mat **210**. The sensor mat **210** is attached in place on the Electronic box top housing **911** and Electronic box bottom housing **913**. The Electronic box **410** consists of a sensor box assembly **800** and an electronic printed circuit board **912**. The optical fiber cable **217** is connected to the sensor box assembly **800**, which is the brain that controls the whole Baby Monitoring Mat **210**. The electronic printed circuit board **912** housed the power on/off push button, external connections to AC/DC adaptor, alarm and Power LED indication. Electronic box bottom housing **913** also housed compartment enclosure for installation of 4 pieces AA battery.

FIGURE 3 illustrates a block diagram of the Baby Monitoring Mat **210** in accordance with another embodiment of the present invention. As shown in FIGURE 3, the optical fiber **217** sandwiched within the Baby Monitoring Mat **210** as shown in FIGURE 2 is connected to a sensor box assembly **800**. This is the sensor from which all critical events are derived. The basic principle of the sensor is based on measurement of light attenuation loss generated by macro bending effect of the optical fiber cable during baby breathing movements. A multimode fiber is used to channel light through relatively tight bends. From a long term mechanical reliability standpoint and to limit light attenuation from bend losses, the bending diameter of the fiber may be limited to be greater than about 20mm. An optical sensor assembly

811 is adapted for channeling light from a light source **813** as well as detecting light using a light sensor **812** attached at the tail end of the optical fiber. The construction of the light coupling assembly structure enables a standard LED and Photodiode to be embedded such that the optical fiber can be connected to the structure using standard SC connectors **820**. **814** illustrates the processor unit, which is the brain behind the differentiation of the signal channeled through the fiber. The reference light source **813** sent into the fiber sensor structure will be modulated by the bending losses created by baby movement which causes light attenuation losses of the light received by the light sensor **812** at the tail end of the optic fiber. The processor analyses the attenuation losses to determine events such as baby presence, movement and breath count. When such events are detected by the processor, it will initiate alarm **816** directly and send the notification wirelessly via the RF transceiver **815** to a Parent Control Unit **310** for alerting the caregiver.

FIGURE 4 illustrates the cross section of the sensor mat **210**. The optic fiber **822** is routed in a symmetrical manner space at least about 20mm apart and sandwiched between two layers of mesh network **220,224,221,225**. The mesh network **220,224,221,225** is responsible for generating the bending losses to light passing through the optic fiber caused by the baby's chest movement during sleep. The mesh network **220,221** is sandwiched by latex sheets **241,242** to mask the hardness of the mesh material to allow comfortable feel during baby sleep. The outer layer **240** includes a protective sleeve that uses material that is waterproof, anti-bacterial, cooling and easy to de-sanitize. This allows baby to directly sleep on top of the mat.

FIGURE 5 is the exploded view of the flexible bridge connection to the mesh structure and the optical cable in accordance with one embodiment of the present invention. The flexible bridge **222** is made of soft stretchable material such as silicone rubber or similar elastic materials. The flexible bridge **222** is adapted with means to secure the four sides of the mesh **220,224,221,225** together such that the sensor mat **210** is foldable. The other major function of the flexible bridge **222** is to control the bending angle of the fiber cable assembly **217** at the folding area such that the folding angle does not cause any breakage to the fiber cable. FIGURE 6 highlights the optical fiber before and after it has been folded. As illustrated, the fiber

cable bending angle is controlled by the flexible bridge **222** such that the fiber cable does not break when it is folded.

FIGURE 7 shows the design of the bottom layer mesh **221,225** that is used to generate macro bending losses to the optic fiber in one embodiment of the present invention. The grid pattern **226** has a spacing of at least about 5 mm and no less than about 8mm to generate the macro bending effect. The grid pattern **226** exists on the top layer meshes **220,224** and bottom layer meshes **221,225** such that when the optic fiber cable **217** is sandwiched between them, bending losses occurs as the grid edge comes in contact with the fiber cable. The fiber turning hook **223** is used to guide and secure the optical fiber cable as it is laid across the bottom mesh layers **221,225**. The fiber turning hook **223** is present at spacing of about 20 mm at both sides of the mesh. This enables optical fiber cable to be easily routed across the entire mesh layer using the fiber turning hook **223** to fix the position of the optic fiber cable **217** pattern. In the middle of the bottom layer meshes **221,225**, a flexible bridge **222** is used to secure the two halves of the mesh layers together. The flexible bridge **222** is made of soft material to enable the two halves of the mesh to be folded together.

FIGURE 8 shows the means **250** for securing a top layer mesh with a bottom layer mesh in accordance with one embodiment of the present invention. Both top and bottom layer meshes are provided with coupling through holes along the respective side edge of the meshes **220,224,221,225**. The means are adapted with male **252** and female **251** mesh lock stubs that act as the locking mechanism to secure the top layer mesh to the bottom layer mesh through the through holes.

FIGURE 9 shows the Optical fiber cable assembly **217**. The fiber cable **822** is terminated with SC connectors **820**. One side of the SC connector **820** pipes the light source into the fiber cable **822** while the other end of the fiber cable **822** is terminated with SC connector **820** that has a light sensor which detects the attenuation losses of light channeling through the fiber cable **822**. A Fiber protection sleeve **821** covers a short length from the SC connectors to protect the fiber cable **822** from breaking at the connection point of the fiber cable to the SC connectors.

FIGURE 10 shows the exploded view of the optical sensor assembly. The Optical sensor front housing **814** and Optical sensor rear housing **815** has been constructed to house the Light source **813** which is a standard Light Emitting Diode (LED) and a photodiode light sensor **812**. The Optical sensor front housing **814** was constructed to act as the male connector side such that the SC connectors **820** of the Optical fiber assembly **217** which is the female side can be plugged in to form the connection with the light source **813** and light sensor **812**. The Optical sensor rear housing **815** locks the light sensor **812** and light source **813** into place to form a compact unit that can be mounted into the sensor box assembly **800**. The main purpose of the optical sensor assembly is to house both the light source **813** and light sensor **812** such that the fiber cable assembly that uses standard SC connectors **820** can be mated seamlessly with minimal light coupling losses.

FIGURE 11 shows the Sensor box assembly **800**. The Sensor box assembly **800** consists of three parts. The Sensor box top casing **830** and the Sensor box bottom casing **832** and the Sensor box printed circuit **831**. The sensor box top casing **830** and the sensor box bottom casing **832** are adapted to mount the sensor box printed circuit **831** board assembly into place. The optical sensor assembly **811** is soldered to the Printed circuit board that contains the Processor **814**, RF Transceiver **815** and Alarm interface **816**. The Fiber cable assembly **217** is finally terminated at the Sensor box assembly **800**.

Optical fiber cable embedded within the mat is used for sensing movements utilizing a variety of scheme. The method used here is based on bending of non-coherent light source, which can be common light emitting diodes, coupled into multimode optical fiber travelling along the length of the fiber optic cable. When optical fiber cable is bent, there is light lost from the fiber due to internal reflections. The movement of the baby on top the mat will cause distinct light bending lost pattern. By measuring the light bending lost pattern at the receiver end of the optical fiber cable, detection of movement, breath count and presence can be differentiated.

The construction of a Baby Monitoring Mat with optical fiber embedded therein requires accounting few factors:

First, the optical fiber is brittle and will break when bend at an acute angle. Accordingly, the mesh layer is provided with grid patterns to guide and protect the optical fiber from any damage due to the bending. Further, the flexible bridge joining up the two separate mesh layer is also adapted to guide and protect the optical fiber damage even when the Baby Monitoring Mat is folded up.

Second, the sensitivity of the mat depends on how the optical fiber cable is routed and secured in the sensing mat. Considering the first factor, the grid patterns shall also be adapted properly to optimize the sensitivity as much as possible. As shown in FIGUREs 4 and 7, the optical cable is spaced at least about 20mm, for example, apart to prevent light loss at the bending corner, which will affect the sensitivity. Further, the mesh layer grid pattern has a gap of at least about 5mm and less than 8mm to ensure optimal light attenuation loss when the fiber comes in contact with the grid at regular intervals. Operationally, multiple bending of the optical cable would generate strong baby movement signal because the light attenuation loss is larger.

Third, the configuration of a sandwiched structure that creates bending effect for the optic fiber is critical to the sensitivity of the mat. Embodiments of the sandwiched structure are shown in FIGUREs 2 and 4. In these figures, the top and bottom mesh layer forms the main sandwiched structure where the latex layers offer comfort.

Fourth, the coupling of light for the transmitter and receiver is subject to coupling losses, which affect the signal strength at the receiver end. Accordingly, proper construction of the system and connections is necessary to avoid light loss. The coupling configurations are shown in FIGUREs 9 and 10.

And fifth, the sensing mat must be able to derive good signal strength for a light weight baby of minimum 1.5Kg in order to decipher the received data for event detection. The sensor box assembly also comprise an electronic sensor board mounted with a 16 bit low noise, high resolution ADC converter used to extract the necessary signals with sufficient Signal-to-Noise ratio to distinguish the different events, such as baby presence/absence, movement and breath count.

FIGURE 12 shows an application of the Baby Monitoring Mat **210** in one embodiment of the present invention. The current invention consists of a Baby Monitoring Mat **210** that acts as the sensor that continuously monitors the baby when he/she lies on top. A Parent Control Unit **310**, wirelessly connected with the Baby Monitoring Mat **210**, acts as an indicator that alarms the caregiver when the baby mat detects baby out of mat, baby wakes up from sleep and baby breath count is zero while on mat **210**. When zero baby breath count is detected, a stimulation device that is worn on one of the baby's feet will vibrate to jolt the baby to re-initiate its breathing pattern while parent is notified to tend to the baby.

As shown in FIGURE 12, the Baby Monitoring Mat **210** is placed on top of a mattress **212** of a baby cot **214**. A bed sheet **216** may be placed beneath the Baby Monitoring Mat **210** to protect the mattress. When in used, the baby is placed on top on the Baby Monitoring Mat **210**.

FIGUREs 13 to 16 exemplify signals patterns that represent the various movements and breath counts.

The present invention is applicable towards the prevention or at least reduction of sudden infant death syndrome (SIDS) by monitoring baby's respiration and if the baby stops breathing, awaken the baby using external stimulation attached to baby's feet. The use of Fiber Optic Sensor enables a non intrusive way of detecting the baby's respiration without any cable/probes/sensor attached to the baby's skin. The Baby Monitoring Mat starts monitoring movement and respiratory sign when the baby sleeps on it.

The above description illustrates various embodiments of the present invention along with examples of how aspects of the present invention may be implemented. While specific embodiments have been described and illustrated it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the present invention. The above examples, embodiments, instructions semantics, and drawings should not be deemed to be the only embodiments, and are presented to illustrate the flexibility and advantages of the present invention as defined by the following claims.

CLAIMS:

1. A Baby Monitoring Mat, comprising:

a sensor mat having a top mesh layer, a bottom mesh layer, and two flexible sheets and an optical cable, wherein the optical cable is routed across and sandwiched in between the top mesh layer and the bottom mesh layer, and the flexible sheets further sandwiched the top mesh layer and the bottom mesh layer in between forming sensing area across the flexible sheet surface;

a light source for feeding light from one side of the optical cable;

a photodiode for detecting light attenuation at the other end of the optical cable;

a printed circuit board having a processor connected to the light source and the photodiode, wherein the processor operationally receives signals from the photodiode, the signals are processed to determine movements and breath counts,

wherein the signals are generated based on the light attenuation changes along the optical fiber cable detected by photodiode, the light attenuation changes are operationally caused by the optical fiber bending lost caused by the movements and breath.

2. The Baby Monitoring Mat according to claim 1, wherein the light source is a light emitting diode.

3. The Baby Monitoring Mat according to claim 1, wherein the flexible sheets are latex sheets.

4. The Baby Monitoring Mat according to claim 1, wherein the optical fiber cable is a multimode optical fiber cable.

5. The Baby Monitoring Mat according to claim 4, wherein the top and bottom mesh layer comprises grid patterns adapted to guide and protect the multimode optical fiber cable routed in a symmetrical manner across the sensor mat.

6. The Baby Monitoring Mat according to claim 5, wherein the optical fiber cable is spaced at least about 20mm apart.
7. The Baby Monitoring Mat according to claim 5, wherein top and bottom layer of mesh comprises symmetrical grid pattern spaced at least about 5mm and less than about 8 mm apart with fiber turning hooks with spacing of 20mm apart to guide the multimode optical fiber across the sensor mat.
8. The Baby Monitoring Mat according to claim 1, further comprises a flexible bridge for connecting two sandwiched mesh layers for allowing the Baby Monitoring Mat to be foldable.
9. The Baby Monitoring Mat according to claim 1, further comprising a wireless transceiver on the printed circuit board, wherein the wireless transceiver operably transmits status information such as baby presence, movement and breath counts, to a remote display unit, such that the movements on the sensor mat can be monitored there through.
10. The Baby Monitoring Mat according to claim 1, further comprising a baby wake up sock electrically connected to the printed circuit board, the wake up sock is wearable on a baby's leg, wherein the wake up sock vibrates when the sensor detects zero breath count when a baby is presence on the sensor mat.
11. A method of detecting movements and breath counts of a baby on a mat, the method comprising:
 - providing an optical cable for routing across and sandwiched between the mat; and
 - detecting movements on the mat through acquiring light attenuation changes along the optical fiber cable, wherein the light attenuation changes are operationally caused by the optical fiber bending lost caused by movements and breath on the mat.

12. A method for monitoring a baby movement including breath counts on a Baby Monitoring Mat according to claim 11, wherein the Baby Monitoring Mat is configured according to any one of claims 1-10.