Natural Disaster Indicators
Use of sensors in geotextiles

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Abstract
In this paper, the authors emphasise the importance of incorporation of sensors in geotextiles and present applications for prevention of natural calamities. The authors first explain the advantages of nanosensors and their use in textiles. Benefits due to compactness of the system are also mentioned.

- The various types of sensors which will be useful for applications in these areas are then discussed. There are three types of optical sensors: Extrinsic Fabry-Perot Interferometer, Fibre-Bragg Grating and Long Period Grating.
- The method of incorporation of these sensors within the fabric structure is also covered.
- The use of each sensor for application to which natural calamity is stated for identification and efficient usage of the sensor.
Furthermore, various types of geosynthetics are explained. These are fibre structures and are employed in different areas. Geosynthetics can be woven, non-woven or knitted. However, easy sensor incorporation is provided best with warp-knitting technique.

Optical fibres are also incorporated into woven structures. Two such woven structures are discussed namely Bedford and Layered fabric designs. All three types of optical sensors were woven in the back of the fabric. Due to this, the sensors can make direct body contact, increasing the efficiency of the sensor yet are not seen by the face of the fabric.

The topic ‘Application’ discusses the use of these sensors embedded in geosynthetics for easy detection, monitoring and prevention of natural disasters (like earthquakes, floods, landslides and thunderstorms/rainstorms).

The paper blends the benefits of smart geosynthetics, optical sensors and intelligent weaving. Pressure and humidity sensors are used for prediction of storms, temperature sensors for prediction of volcanoes and a pressure and strain sensors for prediction of landslides, earthquakes etc. The use of these novel techniques will lead to increased disaster management programmes. It will also provide efficient warning systems for better adaptation and mitigation.

Keywords – Fibre Optical Sensors, Geotextiles, Natural Hazard Detection, Nanosensors, Electronic Textiles, Sensor Integrated Fabric.

INTRODUCTION:
Integration of electronic components into fibre circuitry is an emerging topic and finds its applications in nearly all realms of daily life. One such field is geotextiles. Geotextiles is a sub-division of textiles which deals with the association of textiles with earth. These fabrics can be laid down on the soil for various purposes such as: prevention of soil erosion, filtration, prevention of landslides etc. These fibres have high abrasion resistance and are very durable to withstand the harsh climatic conditions.

With advancements in geotextiles, a new arena named as Multifunctional Geotextiles has opened up. Multifunctional Geotextiles (MFG) incorporate electrical and electronic applications within the fibre structure to create a smart fabric. Multifunctional geotextiles have a wide range of applications such as: sensor integrated geotextiles for prevention of failure of railway embankments, dams and bridges, soil stabilisation and subsidence protection as well as various monitoring functions.
This direction of study has also come of great use in protection of historic buildings whose structure may have weakened over time. These structures are highly vulnerable because they were initially constructed for vertical gravity loads and may not withstand the dynamic horizontal loads of a strong earthquake.\cite{5}

Sensors used in association with geotextiles can also be used to monitor rainstorm, landfill leakage, NPS Pollution and water run-off.\cite{6}

Geotextiles are permeable textile materials and may be woven, non-woven or knitted. However, the use of warp knitting in geotextiles, provides a way for construction of reinforcements with easy sensor incorporation.

Fabric sensors have lately come in the limelight as they are lightweight, flexible and can be easily integrated in the fibre structure.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image1.png}
\caption{Use of sensor embedded geotextiles for prevention and monitoring of landslides}
\end{figure}

\textbf{Nanosensors:} \begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image2.png}
\caption{Integration of nanosensors in textile material}
\end{figure}
Nano particles are an arrangement of molecules and atoms that when combined together creates stable building blocks that can be made into larger, more complex materials and structures.

For instance, the outer walls of the red blood cell are stabilized by a flexible mesh like protein skeleton. The bars and connectors that make up this mesh are considered part of a nanomaterial. Without these reinforcing nano structures, the cell would be much more fragile and not nearly as flexible.\(^1\)

Nanosensors are sensory points which are used to convey the information of the nanoparticles to the macroscopic world.

Nanosensors have gained increasing popularity for performing a large number of electrical applications in an abundantly compact area. They have also proven to be more efficient than their large sized counterparts. The application of nanosensors are manifold. Here are some of the examples:

1) For people who have mobility impairment, communication can be a grave issue. **Gesture recognition sensors** are therefore needed as an assistive technology for those affected either by spinal cord Injury (SCI), brain injury, strokes or degenerative diseases. The existing gesture recognition systems are intrusive and bulky. With the latest technology, capacitive plates and conductive threads can be sewn into the fabric structure. These sensors work on the principle that the capacitance of the plates changes when there is movement in the environment in close proximity to the plates. These sensors eliminate the use of touch based gesture recognitions.\(^7\)

2) Ammonia gas is a harmful gas which can cause respiratory problems and even death when exposed to large amounts. Ammonia gas is also responsible for climate change and it is therefore necessary to monitor amounts of ammonia released by industries into the environment. Nanotubes are employed as room temperature **ammonia sensors** since nanostructures have a larger surface area than their bulkier counterparts and act as efficient sensors.\(^10\)

3) Nanosensors have also proven effective in **temperature and humidity sensors**. These can be very important to detect slight changes in temperature where temperature constancy is of paramount importance. It can be used to monitor vital signs of critical care patients. It can also be incorporated in weather forecast systems and assessing the air quality in areas such as schools, hospitals etc. Temperature sensors are also used for sensing volcanoes.\(^14\)

4) **Pressure sensors** also employ the use of nanosensors to assess variation in pressure in the environment. They are incorporated in the fibre structure by the intarsia knitting technique. Pressure sensors use very thin piezo-electric or piezo-resistive polymer films in between two conductive plates. Piezo-electric polymers convert an applied force to an output voltage. Piezo-resistive polymers convert an
applied force into a change in its electrical resistance. Pressure sensors are used in aircrafts, rockets and satellites as well as in submarines and deep sea diver suit.

Fig. 3. Changes in colour of fabric when subjected to atmospheric pressure variation\cite{12}
The aim of the authors is to describe such applications of sensors in the field of geotextiles for the prediction and monitoring of natural calamities.

- **TYPES OF SENSORS**[^6]

Two broad categories of sensors are being used in the integration into textiles:

1) **Fibre Optic Sensors:** There are three main types of optical sensors extensively used with geotextiles, namely:

**Extrinsic Fabry-Perot Interferometer (EFPI):**

An interferometer is an instrument in which the interference of two beams of light is employed to make precise measurements. **Extrinsic sensors** are sensors that use optical fibre as a means of relaying signals from a remote sensor to the electronics that process the signals. The sensors are fabricated individually and then spliced (joined or connected by interweaving the strands at the ends) into fibres.

![Fig. 4. Schematic Diagram of a Spliced Fibre][6]

**Fibre Bragg Grating (FBG):**

Fibre Bragg Grating is a type of distributed Bragg reflector which is embedded in a segment of optical fibre; it reflects certain wavelengths of light and transmits the others. These sensors are useful for monitoring temperature and strain of a material. The construction of this grating consists of alternating material of varying refractive index. When a strain is introduced in the sensor, the reflected spectrum deviates from the original case and the strain is thereby measured. Temperature, pressure, acceleration and displacement changes can also be similarly sensed using FBG. The wavelengths of light reflected and transmitted is a fundamental function of the refractive index.

![Fig. 5. Schematic Diagram of FBG][6]
**Long Period Grating (LPG):**
In LPG, the germina-doped fused-silica glass is photosensitive and its refractive index varies periodically. When exposed to a periodic variation, the LPG behaves in a similar manner to a Fibre Bragg Grating (FBG).

2) **Sensing Fibres:** These fibres are manufactured by using nanoparticles/nanosensors in coatings or by integrating it into the base of the fibre.

Incorporation of sensors in textiles has many more advantages than the conventional case, nanosensor embedded textiles are compact, provide reliable measurements due to minimal changes in the surrounding environment (i.e. fabric structure) and make possible easy installation of sensors in areas where it would be extremely difficult to place a standard sensor.

![Fig. 6. Schematic of Integration of Sensors into Textiles](image)

- **GEOSYNTHETICS**
These are extremely beneficial for the prediction and prevention of soil erosion and landslides and finds its use in hydraulic engineering projects.
Geosynthetic is a generic term which includes:

**Geotextiles:** These are permeable fabrics which can be woven, non-woven or knitted. While warp knitted fabrics provide for easy sensor incorporation, non-woven fabrics provide better filtration and drainage properties as they have high porosity.

**Geogrids:** Used primarily for soil reinforcement, these are planar structures with aperture sizes big enough to interlock in soil particles and rocks. There are two types of geogrids: Uniaxially oriented and Biaxially oriented.

![Geogrids](image)

(a) Uniaxially-oriented geogrid  (b) Biaxially-oriented geogrid

*Fig. 8. Geogrids* 

**Geomembranes:** These are continuous membranes of materials with low permeability to control fluid migration.

**Geocomposites:** When the above three types of geosynthetics are combined for the protection of landslides, erosion, bank protection etc., they are termed as geocomposites.
Geonets and other products, geomats, geomeshes and geowebs: These are similar to geogrids but with much lower tensile strength. They are used in hydraulic applications and landfills.

- SENSOR EMBEDMENT INTO FIBRE STRUCTURE[6]

The two main weave structures which were used to incorporate optical fibers into woven fabric were:

1) Bedford
2) Layered

The Bedford fabric used 20/2 polyester spun yarn with a construction of 44 ends/inch and 30 picks/inch. Mostly Bedford cords had a plain weave as the face in which 5 warp ends and a cutting end were contained by the cord. A separate warp beam was then used to introduce wadding yarns (with sensors). This structure within which the sensors were placed was efficient because the sensors were not visible and also were well protected inside.
The Layered (double cloth) fabric used 2 warp beams and 2:1 as the face to back ratio. The 1/1 plain weave can be used to weave the front and back layers of the fabric out of which the back layer includes the sensor filaments. A float of more than 18 picks can help avoid frequent interlacement. Such structures can allow direct contact of the sensors with the body to collect data; however without being visible from the face side of the fabric.
Fig. 13. Layered Fabric (Face)\textsuperscript{[6]}

Fig. 14. Layered Fabric (Back)\textsuperscript{[6]}
Fig. 15. 3-Dimensional Structure of Layered Fabric[6]

Fabric Testing and Results[6]

For measuring the power losses connectors were attached to a spliced fibre (back side) in case of layered fabric and to optical fibre in case of Bedford fabric. Around 1.98 dBs power losses were recorded for Bedford and 1.74 for layered fabric. The EFPI sensors had similarity in geometry to splices. The insertion of 2 ends was secured with epoxy. The length of the gap left between two fibres was measured by the sensors. The reflected spectra of the EFPI sensor fabric connected to a light source were interrogated for studying the interference peaks. The location of interference peaks were found to depend on the sensor gap. Physical properties like temperature, strain and pressure can be measured by configuring the sensors.

The incorporation of Bragg grating sensors into the fabric was done by splicing a grating strand into the fibre. The FBG distributed strain sensors were used to check the proper functioning of sensors after embedment.

Multiplexed LPG sensors can be simulated using stripped fibres where the weak areas are the stripped areas. These areas are weak because of the removed polymer buffer coating leaving the optical fibre core and cladding unprotected. Therefore these sensors easily break when woven into fabric.

- APPLICATIONS

In this paper, the correlation between the importance of sensors in geotextiles for prevention and monitoring of Natural Hazards is emphasized.

The sensors with utmost importance in these areas are as follows:

A. PRESSURE SENSORS

The sensors are developed of conductive yarns and a double layer piezo-resistive polymer as the detecting material. By utilizing intarsia weaving method, this sensor
can be vitally implanted in consistent cotton texture. Exploratory outcomes provide a direct detecting reaction over a wide weight territory up to 1000 kPa. Textile weight sensors have discovered critical applications in human services where strengths connected uniaxially by the human body on a texture surface of the sensor are to be measured. For instance, a material drive sensor whose capacitance changes with thoracic extensions is proposed for breath detecting, while piezo-electric weight sensors are utilized for heart-beat detecting in a cardiorespiratory checking application. Piezo-electric polymer changes over a connected drive into a yield voltage. Because of the high impedance of piezo-electric gadgets, this flag yield can be vulnerable to intemperate electrical impedance, and therefore low flag to-clamour proportion. Then again, piezo-resistive polymer changes over a connected constrain into an adjustment in its electrical resistance. Unlike piezo-electric polymers, piezo-resistive polymers are delicate to even static or low recurrence strains, for example, those instigated by powers declared by the human body. In addition, current piezo-resistive material weight sensors of comparable structure could just detect up to 800 kPa, which is inadequate for a few applications, for example, walk investigation that requires roughly 1,000 kPa.\[8\]

B. HUMIDITY AND TEMPERATURE SENSORS

The aim of manufacturing a temperature and a pressure sensor is for the joining into a keen material as detecting gadget that screens the room atmosphere. For this reason, a sensor framework on adaptable polyimide substrates containing a gold resistance temperature sensor (RTDs) and conductive polymer (PEDOT-PSS) pressure sensor was built. The sensor is woven into a material utilizing a business band weaving machine. The sensor framework is composed such that a solitary temperature and pressure sensor fit on a strip with a width of 1 mm. To interface the sensor framework with outside estimation set-ups, there are three contact pads on the stripe. Every sensor has an individual contact and both sensors share a contact as common ground. The design for the sensor plans comprises of a wind moulded resistor structure speaking to a temperature sensor and an interdigitated finger electrode structure representing a humidity sensor. The wind of the temperature sensor has a line width and division of 20 lm also, a general length of 22 mm. The stickiness sensors comprise of 40 fingers of a length of 1 mm with a dividing furthermore, width of 20 lm. A sensor framework on an adaptable polymer thwart comprising of a temperature and pressure sensor for the coordination into a material is developed. Cut sensor strips are woven into a material utilizing a business band weaving machine, what’s more, sensors withstand the mechanical effects happening amid the weaving procedure. The temperature sensors have a direct reaction to temperature with a temperature coefficient of 0.0028 ec-I. The moistness sensor has a direct dispersion till 60% RH and begins to immerse with higher moistness. The framework can quantify dampness and temperature and demonstrates its potential use in observing the room atmosphere. The associations inside the material are made utilizing conductive paste. By this technique just a solitary sensor unit can be measured. More sensor units must be associated in parallel and increment the unpredictability of the framework as more
conductive strings must be utilized. To defeat this issue an approach is to join the sensor framework with an ADC readout specifically on the strip. This would have the preferred standpoint, that the information of a few sensors can be transmitted carefully with just a single conductive string. Washing of the framework brings about corruption and delamination of the utilized conductive polymer PEDOT-PSS (AI 4083). To enhance launderability, security of the detecting layer with a semipermeable layer is a conceivable alternative.\cite{14}

C. STRAIN SENSORS

RFID-empowered strain sensors which give referenced readouts. The sensors depend on the backscatter readout system. The novel referenced readout is accomplished through the EM enhancement of a coupled two-label framework where one tag is made sensitive and one insensitive toward strain. The sensor and reference labels are both in view of dipole receiving wires with implanted inductive coordinating circles. Prolongation in the stretchable segment alters the EM properties of the tag and empowers the detecting usefulness. The stretchable and non-stretchable parts were associated utilizing a sewing machine and metal plated sewing string. The point was therefore to set up the sensor readout in light of the backscatter quality. In the genuine application condition, the reference tag enables the compensation of the conceivable contribution of multipath propagation from the strain readout since the signal from the peruser to the firmly dispersed tags travels around through a similar channel. Stretchable e-material empowers strain-sensitive radio wires i.e. antennas for uninvolved UHF RFID labels. By including a non-stretchable reference tag and improving the two-radio wire framework two remote strain sensors with incorporated references are achieved. They give strain readout normal unmodified RFID peruser equipment. Both sensors were confirmed for strain detecting up 30%. In the orthogonal arrangement, the sensor highlighted a profoundly direct reaction, however in correlation with the straight design, it possessed a bigger territory.\cite{17}

With these sensors the authors attempt to find useful applications in the case of following natural disasters:

I. EARTHQUAKE AND TSUNAMI HAZARDS:

Earthquake can be very hazardous even at a small scale, especially in populated areas or near a water body. Ergo, prediction of this natural calamity is of utmost importance. An early warning system can help in evacuating nearby localities, prepare the government for relief systems and prevent escalated danger by shutting down industries etc.

The sensor system consists of a highly sensitive 3-dimensional accelerometer, digital bandpass filter, a microcontroller, GPS module and GSM module. The extremely sensitive 3-dimensional accelerometer is put in use to convert the earth vibrations into electrical signals. These signals are then fed into computers and accurate predictions for the earthquake can be obtained.\cite{8}
For tsunami hazards, pressure sensors are placed in the seafloor where there is a possibility of earthquakes which could result in a tsunami. Furthermore, bottom pressure sensors should be established to measure water-surface elevation, wave directions, and seismic spectra characteristics. At present, the sensors are not placed in a location close to the source and therefore, detection and prevention of tsunamis are mediocre. Installing such sensors in geotextiles and when placed in the seabed will provide accurate and precise results well in advance and provide enough time for mitigation and relief systems to take place.

![Model of early warning system for earthquake](image)

**Fig. 16.** Model of early warning system for earthquake

II. LANDSLIDES:

Multifunctional geotextiles find its application in soil stabilization and monitoring of creeping and landslide slopes. For this particular application, strain sensors are incorporated within the multifunctional geotextile (MFG). In addition to the sensors acting as alert systems for potentially destructive landslides, the MFG can also contribute in supporting structures or preventing erosion of denuded slopes, thereby providing a collateral benefit. These sensors can help in providing early warnings by intimating us on tension cracks, before slip failures would occur. The sensor ends are enclosed in protection boxes so as to prevent its damage during the hazard and ensure its working for further usage.\[^4\]
III. **RAINSTORMS/HURRICANES:**

Storm prediction begins with monitoring the current weather conditions such as air temperature, air pressure and wind speed. This information is clubbed with measurement from humidity sensors at various altitudes which give us the location of clouds. All this data is further provided to a supercomputer which tells us about the atmospheric behaviour.\[14\]

**CONCLUSION:**

According to the Centre of Research on the Epidemiology of disasters (CRED) around 300-350 natural disasters occur worldwide in one year which causes a lot of destruction. Developments and research in natural disasters management are therefore very important for the world today.

Geosynthetics like geonets help in controlling, to an extent, the effects of a natural calamity. Further the incorporation of sensors in geotextiles not only controls the effect and aftermaths of the calamity but also helps predict, sense and measure the effect of calamity.
The possibilities offered by the integration of sensors in geotextiles enable a variety of applications. Major applications include the prevention of natural calamities. Monitoring rainstorm, landfill leakage, NPS Pollution and water run-off, protection of historic buildings, prevention of failure of railway embankments, dams and bridges, soil stabilisation and subsidence protection have also become possible now with the help of these sensor integrated textiles.

This review paper deals with different possible designs and weave structures of sensor embedded fabrics which can prove to be useful as an efficient disaster management solution and hence prevent heavy destructions.

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