Ασύρματα Δίκτυα Αισθητήρων

Πέππας Κωνσταντίνος

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Πολλές οι εφαρμογές των WSN. Κάποιες είναι φουτουριστκές ενώ ένας μεγάλος αριθμός είναι πρακτικά χρήσιμος
- Παραδείγματα: – environment monitoring, target tracking, pipeline (water, oil, gas) monitoring, structural health monitoring, precision agriculture, health care, supply chain management, active volcano monitoring, transportation, human activity monitoring, and underground mining
- Θα συζητήσουμε κάποιες εφαρμογές ενώ άλλες τις περιγράφουμε με λεπτομέρεια

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Στις 2 Αυγούστου 2007, μια γέφυρα κατάρρευσε στην πόλη της Minnesota μέσα στο Μισισσιπή σκοτώνοντας 9 ανθρώπους.
- Η επιτροπή δεν μπόρεσε να προσδιορίσει την αιτία του ατυχήματος όμως έδωσε τρείς πιθανές αιτίες: Φθορά λόγω χρήσης, κακές καιρικές συνθήκες και επίδραση μιας κατασκευαστικής εργασίας που πραγματοποιούνταν κοντά στην περιοχή. Λόγω της κατασκευής οι 4 από τις οκτώ λωρίδες κυκλοφορίας είχαν κλείσει όταν συνέβη το ατύχημα
- Δύο εβδομάδες αργότερα – στις 14 Αυγούστου 2007 – κατάρρευσε μια άλλη γέφυρα σε ένα δημοφιλές τουριστικό κέντρο στην Κίνα, στην Fenghuang, σκοτώνοντας 86 ανθρώπους. Την ίδια μέρα, το BBC ανέφερε ότι η Κίνα ταυτοποίησε περισσότερες από 6000 γέφυρες ως επικίνδυνες.
- Κατά τη διάρκεια αυτών των γεγονότων, το Associated Press (3 August 2007) και το *Time* (10 August 2007), δημοσίευε άρθρα τα οποία ζητούσαν τη χρήση WSNs για την παρακολούθηση γεφυρών και άλλων κατασκευών.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Οι γέφυρες παρακολουθούνται σε διαφορετικές φάσεις και σε διαφορετικά επίπεδα (Koh and Dyke 2007):
  1. Οπτική παρακολούθηση η οποία πραγματοποιείται carried απο τεχνικούς συντήρησης δρόμων, συνήθως κάθε μέρα.
  2. Βασική παρακολούθηση η οποία πραγματοποιείται τουλάχιστον μια φορά το χρόνο από τους τοπικούς ελεγκτές της γέφυρας.
  3. Λεπτομερής παρακολούθηση, τουλάχιστον κάθε πέντε χρόνια από περιφεριακούς ελεγκτές γεφυρών
  4. Ειδικοί έλεγχου από υψηλά εξειδικευμένο προσωπικό και ερευνητές ανάλογα με τα αποτελέσματα της λεπτομερούς παρακολούθησης

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Η πρώτη φάση απαιτεί έντονη χειρωνακτική εργασία είναι ασυνεπής και υποκειμενική (Koh and Dyke 2007), ενώ οι υπόλοιπες απαιτούν εξειδικευμένα εργαλεία τα οποία είναι συνήθως ακριβά, ογκώδη και καταναλώνουν μεγάλα ποσά ενέργειας.
- Συνεπώς η ανάπτυξη αυτοματοποιημένων, αποδοτικών και φθηνών τεχνικών παρακολούθησης είναι μια ενεργή ερευνητική περιοχή
- Οι τεχνικές παρακολούθησης βασισμένες σε εργαλεία (tool based inspection techniques) μπορούν χονδρικά να κατηγοριοποιηθούν σε τοπικές (local) και σε καθολικές (global) (Chintalapudi *et al.* 2006)
- Οί τοπικές τεχνικές εστιάζουν στην ανίχνευση ανεπαίσθητων σφαλμάτων σε μια πολύ εξειδικευμένη περιοχή της κατσκευής. Αυτές οι τεχνικές χρησιμοποιούν υπερήχους, θερμικές τεχνικές, ακτίνες Χ, μαγνητικές και οπτικές τεχνικές αλλά απαιτούν πολύ χρόνο και τη διακοπή της κανονικής λειτουργίας της κατασκευής

- Οι καθολικές τεχνικές παρακολούθησης ανιχνεύουν ζημιά ή ελάττωμα το οποίο είναι αρκετά μεγάλο ωστε να επηρεάσει όλη την κατασκευή
- Εμφανείς αλλαγες στις κινήσεις των στηριγμάτων, κιγκλιδωμάτων, φραγμάτων, πύργων, συνδέσμων κλπ
- Οι τεχνικές αυτές θεωρούνται ως ένα αντίστροφο πρόβλημα, δηλαδή η κατάσταση της δομής καθορίζεται στη βάση της απόκρισης σε ένα εξωτερικό ερέθισμα.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Τέτοια ερεθίσματα μπορεί να είναι άμεσα, πχ ένας σεισμός ή ισχυρός άνεμος ή εξαναγκασμένα, πχ ένα ερέθισμα που προέρχεται από το χτύπημα ενός σφυριού.
  Σε κάθε περίπτωση, παράμετροι όπως οι φυσικές συχνότητες, συντελεστές απόσβεσης, τρόποι ταλάντωσης χρησιμοποιούνται για τον καθρισμό της ζημιάς η οποία μπορεί να οφείλεται σε διαστολές, αποκολλήσεις, διαβρώσεις, ραγίσματα κλπ
- Οι παράμετροι των μοντέλων καθορίζονται από διάφορους παράγοντες όπως το μέγεθος και η διάρκεια του ερεθισμού, το υλικό της κατασκευής, το μέγεθος της κατασκευής, τους τεχνικούς περιορισμούς, την ηλικία, κλπ.
- Πρόσφατα, οι ερευνητές ανέπτυξαν και δοκίμασαν WSNs σαν μέρος των μηχανισμών καθολικής παρακολούθησης.
- Τρεία πράγματα τα καθιστούν κατάλληλα για αυτή τη διαδικασία:
  1. Οι κόμβοι μπορούν να τοποθετηθούν σε περιοχές μή προσβάσιμες σε καλωδιωμένες και ογκώδεις συσκευές
  2. Εγκαθιστώντας ένα μεγάλο αριθμό κόμβων μπορούμε να συσχετίσουμε (correlate) διαφορετικές μετρήσεις
  3. Ιδανικά, η εγκατάσταση και η διαχείριση του δικτύου δεν παρεμβάλλεται στην ομαλή λειτουργία της κατασκευής

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Η σεισμική απόκριση σε μεγάλες δομές είναι μεταβατική από τη φύση της και εμπεριέχει συχνότητες κάτω από μερικές δεκάδες Hz
- Η απόκριση σε σεισμό μπορεί να παρακολουθηθεί χρησιμοποιώντας αισθητήρες επιταχύνσεως, αισθητήρες κλίσης (tilt), και πιεζοηλεκτρικούς αισθητήτρς
- Πρέπει να γίνει υπερδειγματοληψία σε υψηλές συχνότητες για αντιστάθμιση του θορύβου και ατελούς τοποθέτησης
- Προκλήσεις για την ανάλυση των δεδομένων:
- (α) περιορισμοί που αφορούν στα χαρακτηριστικά των διεγέρσεων
- (β) θόρυβος
- (γ) σφάλμα στο μοντέλο
- (δ) περιβαλλοντικοί περιορισμοί

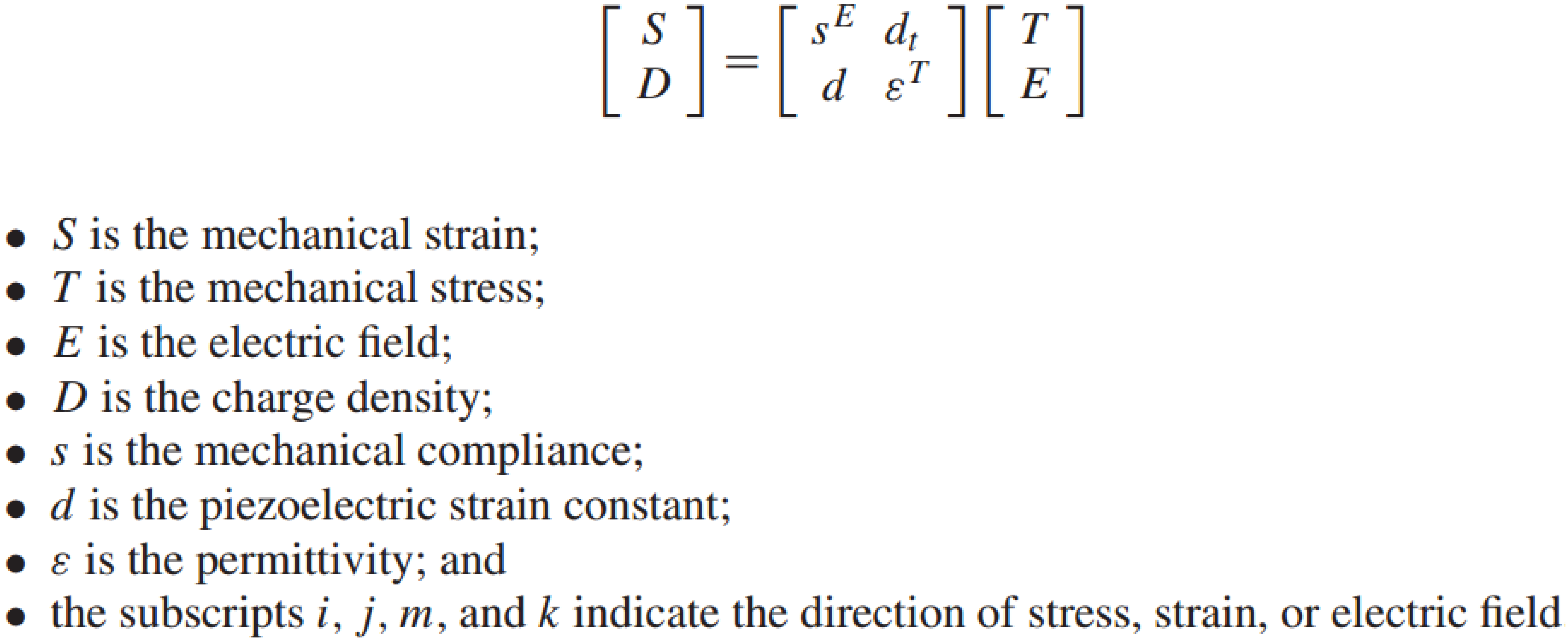
Εφαρμογές ασύρματων δικτύων αισθητήρων

- Οι είσοδοι για τις τεχνικές ανίχνευσης ζημιών αποκτώνται από αισθητήρες επιτάχυνσης ή από αισθητήρες κλίσης (tilt.)
- Μπορούμε να χρησιμοποιήσουμε πιεζοηλεκτρικά υλικά για να συλλάβουμε την απόκριση σε σεισμό.
- ¨Όταν μια μηχανική καταπόνηση εφαρμόζεται σε πιεζοηλεκτρικό υλικό γεννά ένα ηλεκτρικό φορτίο. Όταν ένα ηλεκτρικό πεδίο εφαρμόζεται σε πιεζοηλεκτρικό υλικό οι διαστάσεις του αλλάζουν ανάλογα με το πεδίο.
- Οι ιδιότητες αυτές καθιστούν τα πιεζοηλεκτρικά υλικά κατάλληλα για sensing και για actuation
- Η σχέση ανάμεσα σε μηχανικές και ηλεκτρικές παραμέτρους ενός πιεζοηλεκτρικού υλικού μπορούν να περιγραφούν ως εξής (Park *et al*. 2000):

$$S_i = S_{ij}^{E} T_j + d_{mi} E_m$$

$$D_m = d_{mi} T_i + \varepsilon_{mk}^{T}$$

Εφαρμογές ασύρματων δικτύων αισθητήρων



$$\begin{bmatrix} S \\ D \end{bmatrix} = \begin{bmatrix} s^E & d_t \\ d & \varepsilon^T \end{bmatrix} \begin{bmatrix} T \\ E \end{bmatrix}$$

- S is the mechanical strain;
- T is the mechanical stress;
- E is the electric field;
- D is the charge density;
- s is the mechanical compliance;
- d is the piezoelectric strain constant;
- ε is the permittivity; and
- the subscripts i, j, m, and k indicate the direction of stress, strain, or electric field

Εφαρμογές ασύρματων δικτύων αισθητήρων

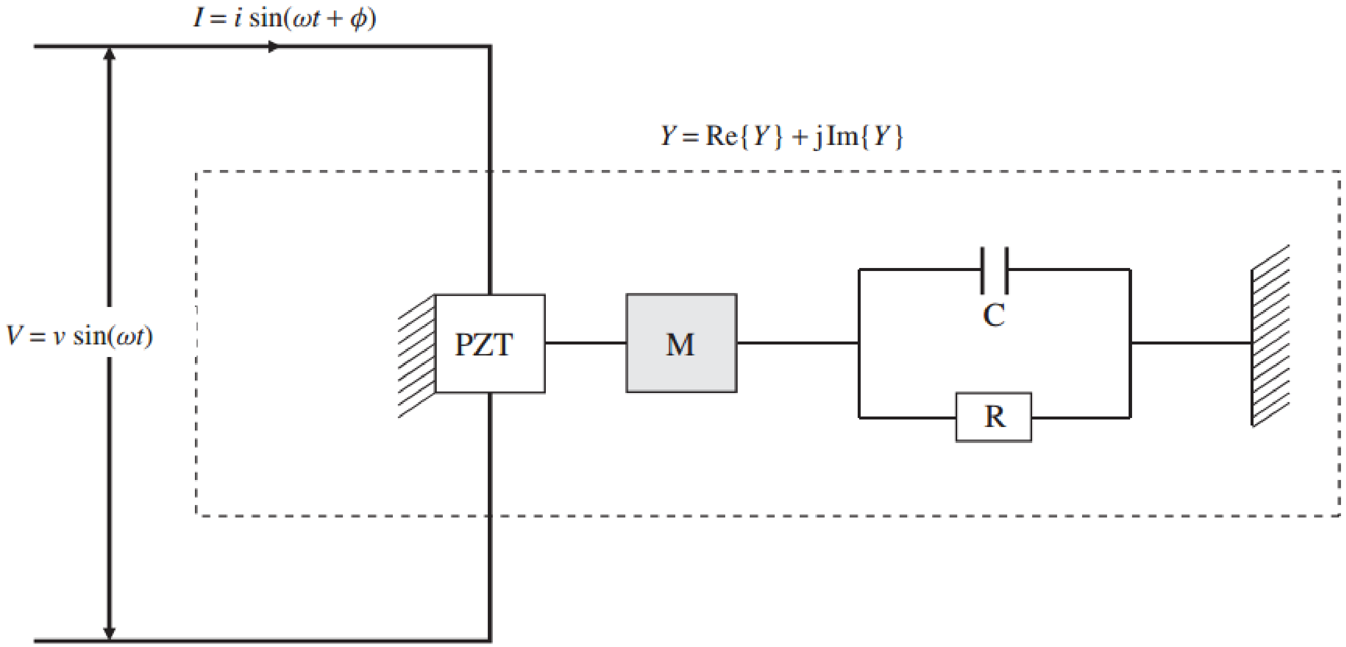
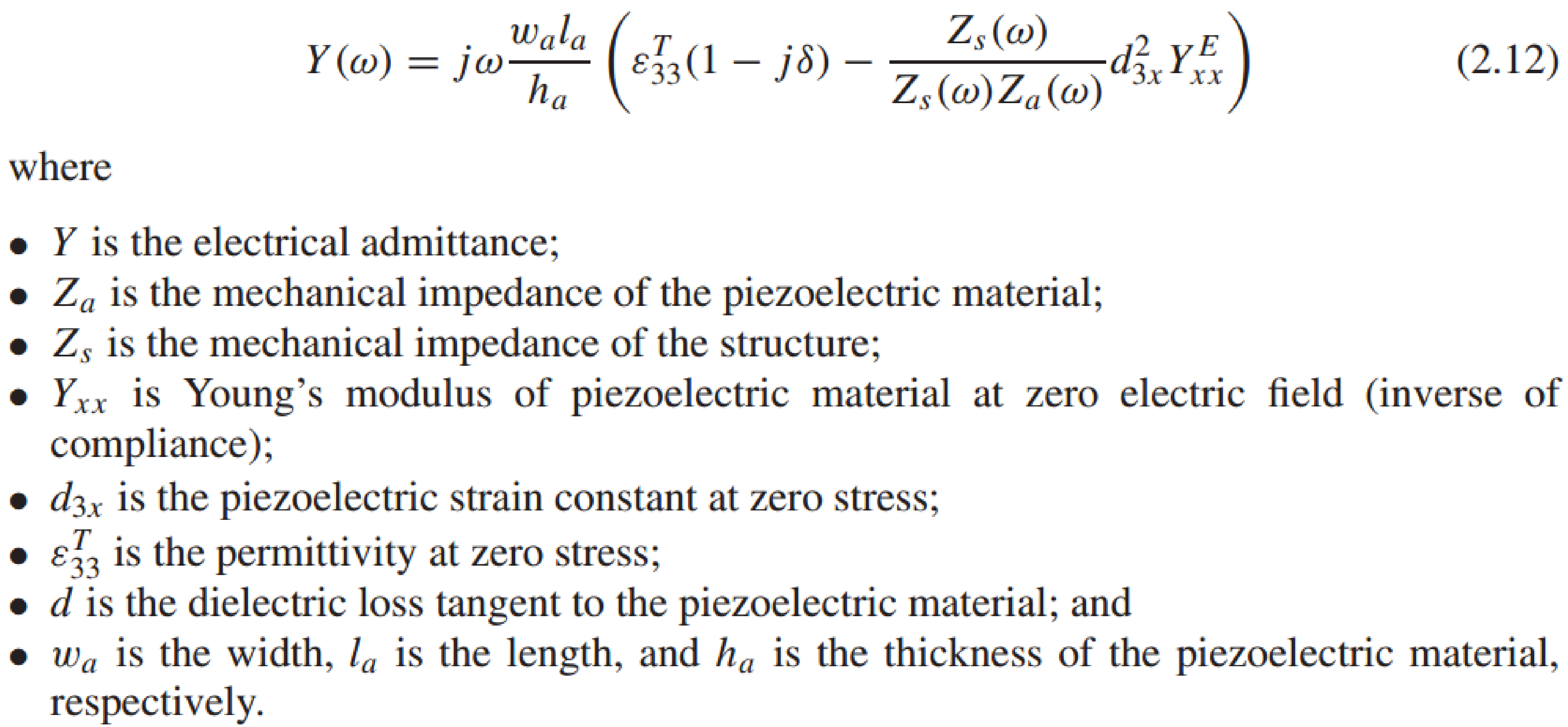


Figure 2.1 A piezoelectric material for capturing mechanical impedance. The PZT is normally bonded directly to the surface of the structure by a high strength adhesive to ensure better mechanical interaction - this is indicated by the gray box, M. The broken line indicates the coupled electromechanical admittance Y (Park *et al* 2000).

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Η πρώτη σχέση περιγράφει την αλλαγή στις διαστάσεις ενός πιεζοηλεκτρικού υλικού σαν αποτέλεσμα της εφαρμογής ηλεκτρικού πεδίου
- Η δεύτερη σχέση περιγράφει το ηλεκτρικό πεδίο σαν αποτέλεσμα της αλλαγής των διαστάσεων του υλικού.
- Χρησιμοποιώντας ένα πιεζοηλεκτρικό υλικό είναι δυνατό να υπολογίσουμε μηχανική και ηλεκτρική σύνθετη αντίσταση, λαμβάνοντας πληροφορίες για μηχανικές κατασκευές από μετρήσεις της ηλεκτρικής αντίστασης.
- Μαθηματικά, η σχέση ανάμεσα στη μηχανική και στην ηλεκτρική αντίσταση δίνεται από την ακόλουθη σχέση:

Εφαρμογές ασύρματων δικτύων αισθητήρων



$$Y(\omega) = j\omega \frac{w_a l_a}{h_a}\left(\varepsilon_{33}^{T}(1 - j\delta) - \frac{Z_s(\omega)}{Z_s(\omega) Z_a(\omega)} d_{3x}^{2} Y_{xx}^{E}\right) \qquad (2.12)$$

where

- Y is the electrical admittance;
- Z_a is the mechanical impedance of the piezoelectric material;
- Z_s is the mechanical impedance of the structure;
- Y_{xx} is Young's modulus of piezoelectric material at zero electric field (inverse of compliance);
- d_{3x} is the piezoelectric strain constant at zero stress;
- ε_{33}^{T} is the permittivity at zero stress;
- d is the dielectric loss tangent to the piezoelectric material; and
- w_a is the width, l_a is the length, and h_a is the thickness of the piezoelectric material, respectively.

Εφαρμογές ασύρματων δικτύων αισθητήρων

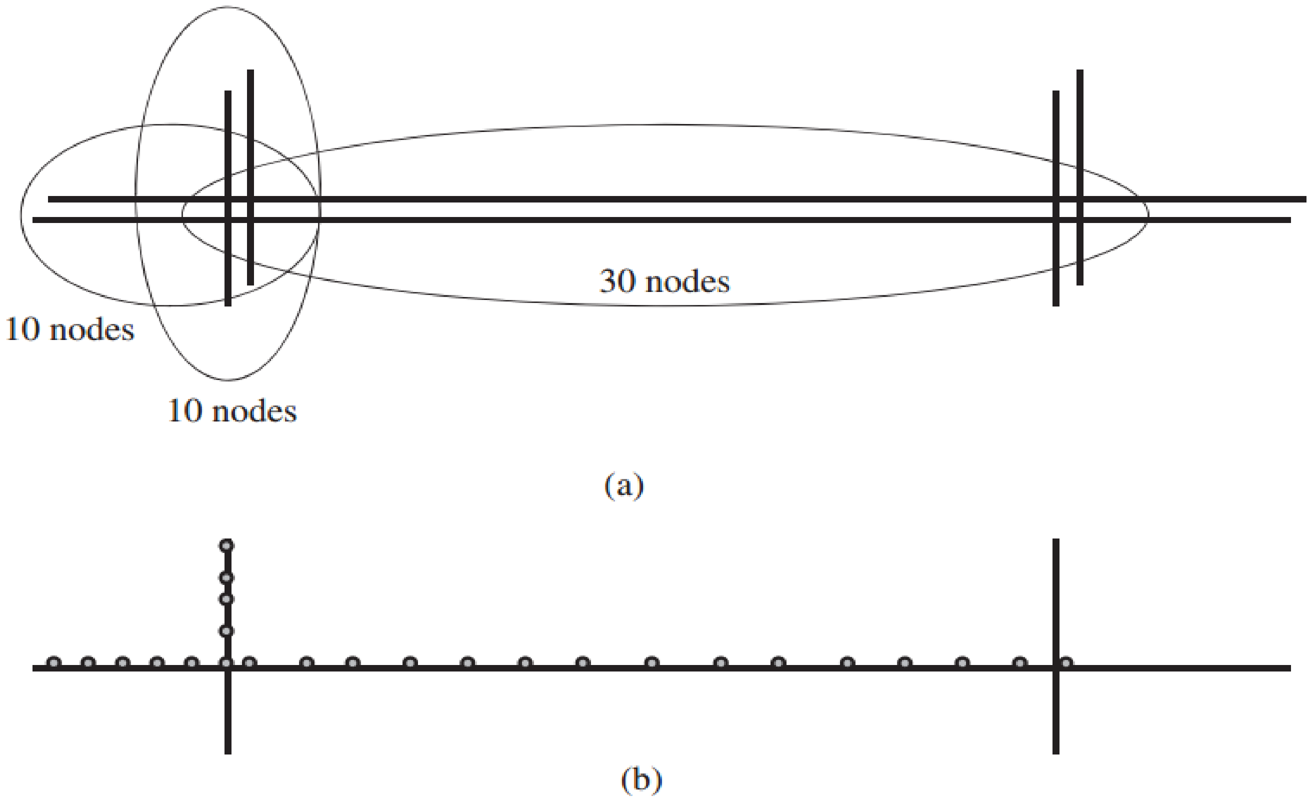


Figure 2.2 The deployment scenario of on the Golden Gate Bridge. (a) The nodes are deployed on both side of the span. (b) A two-dimensional view of the placement of nodes on the bridge.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Ground transportation is a vital and complex socioeconomic infrastructure.
- Operationally, it is linked with and provides support for a variety of systems, such as supply-chain, emergency response, and public health. In urban areas, this results in potential congestion.
- The 2009 Urban Mobility Report, issued by the Texas Transportation Institute, reveals that in 2007, congestion caused urban Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of fuel.
- The total congestion cost is estimated to be $87.2 billion – an increase of more than 50% over the previous decade. Unfortunately, building new roads is not a feasible solution for many cities of the world owing to the lack of free space and the high cost of demolition of old roads (streets).
- Many consider better regulation of transportation systems as the only sustainable solution to road congestion.
- One approach to dealing with congestions is to put in place distributed sensing systems that reduce congestion. These systems gather information about the density, sizes, and speed of vehicles on roads; infer congestions; and suggest to drivers some alternative routes and emergency exits.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- A large number of devices are used in traffic control systems. These include video, sonar, radar, inductive loops, magnetometers, microloop probes, pneumatic road tubes, piezoelectric cables, PVDF wire, and pneumatic treadle.
- Video and sonar-based sensing systems need to be installed on poles, while inductive loops, magnetometers, and pneumatic treadles can be embedded into the transportation infrastructure. Camera-based systems involve human operators to process images, identify incidents, and assign speed rankings.
- Apparently, this technique is costly and can only be employed in selected streets, such as those that are frequently traveled.
- Another way is to fully automate congestion recognition. There are several approaches to do this. For example, automated camera-based systems use machine vision to count and classify vehicles.
- Alternatively, they target the license numbers of passing vehicles and associate driving history as a means of estimating congestion causes. These approaches are well suited as long as the data from the cameras is reliable. In the presence of fog, smog, dust, snow, or rain, however, roadside cameras are unreliable.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- More recently, in-road sensing devices have been developed as complementary systems
- These devices are interesting because they are unaffected by weather and provide direct information with very little ambiguity.
- One of the most common in-road traffic sensors is the inductive loop (Knaian 2000). This is a coil of wire several meters in diameter and can be buried under the road and connected to a roadside control box that passes an electric current through the coil.
- By establishing relationship between the current, the magnetic field strength that is induced as a result of the current, and the speed and size of the passing vehicles, it is possible to infer traffic flow.
- The exact relationship between the current and a vehicle can be defined by using Faraday’s induction law. According to Faraday’s law, when an electric current passes through a conductor, it produces a magnetic field around the conductor.
- The direction of the field is normal to the direction of the current flow. The strength and density of the magnetic field depends on the length and cross-sectional area of the conductor as well as the material from which the conductor is made, that is, the permeability of the conductor, μ.
- The ratio of the magnetic flux, to the current I is called inductance, L, which is defined as $L = \Phi/I$:

Εφαρμογές ασύρματων δικτύων αισθητήρων

- If, instead of a straight conductor, the current passes through a solenoid (a long, thin coil, with a length much greater than the diameter of the loop) of *N* turns and length *l*, the magnetic flux density, **B**, induced in it is expressed as:

$$\mathbf{B} = \mu_0 \frac{Ni}{l}$$

- μ_0 is the permeability of free space; N is the number of turns; I is the current; and l is the length of the coil.
- The magnetic flux through the coil is obtained by multiplying the flux density **B** by the cross-sectional area, *A* and the number of turns, *N*:

$$\Phi = \mu_0 N^2 i \frac{A}{l}$$

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Reformulating this equation will yield:

$$L = \mu_0 N^2 \frac{A}{l}$$

- The inductance of a solenoid changes when vehicles drive on the road, disturbing the induced magnetic flux.
- The magnitude of the change depends on the vehicle’s speed and size. To determine the speed of the vehicle, two loops separated by a distance, *d*, of known length are sufficient.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Measuring the change in voltage or current is easier than measuring the change in magnetic field strength or magnetic flux.
- The induced electromotive force in a closed loop is directly proportional to the rate of change of magnetic flux through the loop. This can be better explained by moving a conductor through a magnetic field, which induces a voltage in that conductor.
- The induced voltage is proportional to the speed of movement, the length and cross-sectional area of the conductor, and the strength of the magnetic field.
- If the conductor forms a solenoid, the number of turns of the conductor influences the induced voltage.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- The magnetic field, the direction of movement, and the voltage are all orthogonal to each other.
- To determine their exact direction, Fleming's right-hand rule can be applied.
- Alternatively, it is also possible to keep the conductor stationary and vary the magnitude and direction of the magnetic field to induce a voltage in a conductor.
- Mathematically, this is expressed as:

$$\varepsilon = -N\frac{\mathrm{d}\Phi_B}{\mathrm{d}t}$$

Εφαρμογές ασύρματων δικτύων αισθητήρων

- *ε* is the electromotive force (emf) in volts; *N* is the number of turns of wire; *B* is the magnetic flux inWeber that passes through a single loop.
- The negative sign in this Equation indicates that the direction of the electromotive force is opposite to the direction of the magnetic flux.
- The magnetic flux is a function of the cross-sectional area of the conductorand the magnetic field strength, which is normal to the conductor.
- Lenz’s law can be applied to determine the direction of the induced electromotive force (emf) and current resulting from electromagnetic induction

Εφαρμογές ασύρματων δικτύων αισθητήρων

- More generally, the relation between the rate of change of the magnetic flux through a surface *S* enclosed by a contour *C* and the electric field along the contour is expressed as:

$$\oint_C E \cdot \mathrm{d}l = -\frac{\mathrm{d}}{\mathrm{d}t} \int_S \mathbf{B} \cdot \mathrm{d}\mathbf{A}$$

- where *E* is the electric field; d*l* is an infinitesimal element of the contour *C*; and **B** is the magnetic field strength. The directions of the contour *C* and d**A** are assumed to be related by the right-hand rule.
- Equivalently, the differential form of Faraday's law can be employed

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Εφαρμογές ασύρματων δικτύων αισθητήρων

- The only limitation of inductive loops is their physical size.
- First, deployment requires the complete dismantlement of an entire cross-section of a road. Second, it is difficult to distinguish vehicles in bumper-to-bumper traffic, since two vehicles may cross the loop at the same time.
- The presence, direction, and speed of a vehicle can be determined by employing magnetic sensors.
- The technique requires a magnetic field of known strength and direction. A moving vehicle can disturb the distribution of the magnetic field either by producing its own magnetic field or simply by cutting across it.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- As the magnitude and direction of the disturbance depends on the speed, size, density, and permeability of the vehicle, it is possible to use magnetic sensors to quantify the disturbance.
- Magnetic sensors can be classified into low-field, medium-field, and high-field sensors, according to the range of the strength of the magnetic field they measure (Caruso and Withanawasam 1999).
- Low-field sensors measure magnetic field strength below 1 µG medium-field sensors measure between 1 µG and 10 G; high-field sensors can measure above 10 G. The Earth’s magnetic field is found in the medium field.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Magnetic fields are set up by the motion of electrical charges. For instance, the magnetic field of a bar magnet is created by the motion of negatively charged electrons within iron atoms.
- The cause of the Earth’s magnetic field is not completely understood, but it is believed to be associated with electrical currents produced by the coupling of convective effects and rotations in the spinning liquid metallic outer core of iron and nickel.
- It has a uniform distribution over a wide area (several kilometers). It was first measured by Carl Friedrich Gauss in 1835 and has been repeatedly measured since then, showing a relative decay of about 5% over the last 150 years.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Sensors that can measure the Earth’s magnetic field comprise an alloy of nickel and iron. Typical examples are anisotropic magnetoresistive (AMR) sensors whose resistive property changes according to the Earth’s magnetic field strength.
- AMR sensors can measure both linear and angular positions and displacement in the Earth’s magnetic field.
- Almost all road vehicles, including those with polymer body panels, contain a large mass of steel. Since the magnetic permeability of steel is much higher than the surrounding air, it has the capacity to concentrate the flux lines of the Earth’s magnetic field.
- The concentration of magnetic flux (disturbance) at a particular location varies as the vehicle moves and can be detected from a distance of up to 15m (Weaver 2003).
- Figure demonstrates how an AMR sensor can be used to measure the disturbance in the Earth’s magnetic field caused by a moving vehicle.

Εφαρμογές ασύρματων δικτύων αισθητήρων

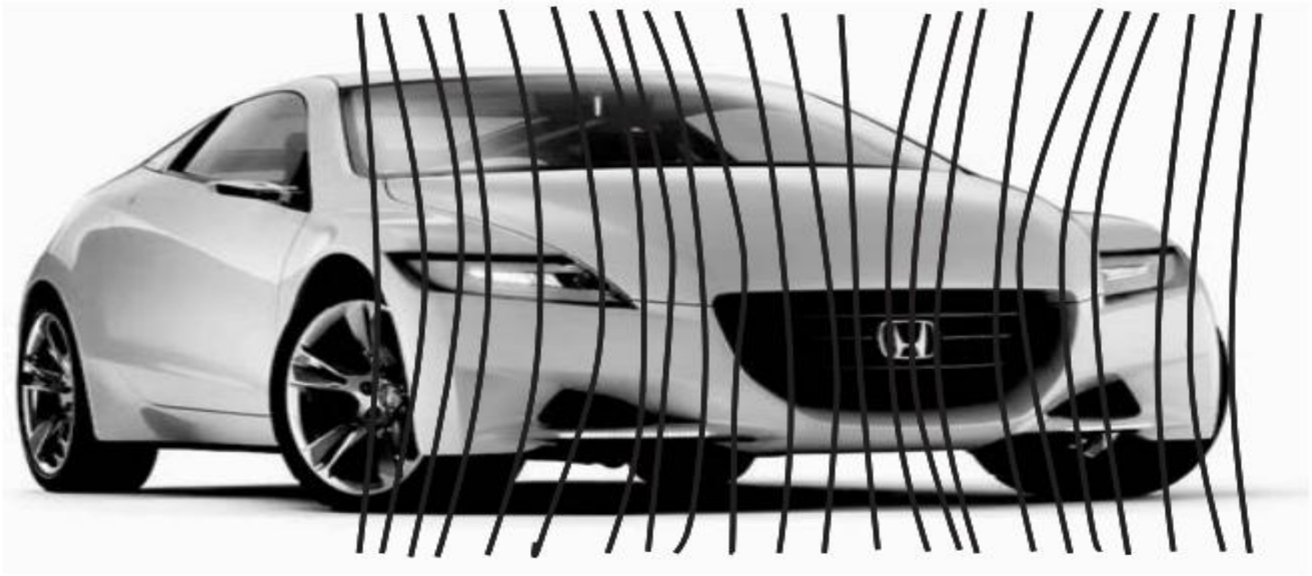


Figure 2.3 Detection of a moving vehicle with an AMR magnetic sensor (Caruso and Withanawasam 1999).

Εφαρμογές ασύρματων δικτύων αισθητήρων

- It is possible to distinguish between different types of vehicles (car, bus, minibus, truck, etc.) by modeling a vehicle as a composition of many dipole magnets (Caruso and Withanawasam 1999).
- These dipoles have north–south orientations that cause distortions in the Earth’s magnetic field. The extent of the distortions of the dipoles depends on, among other things, the permeability of the dipoles.
- For example, the engine and wheel areas exert stronger distortions than the other parts of a vehicle, and for each vehicle class of interest, it is possible to produce a unique model.
- When a vehicle passes close to a magnetic sensor, or drives over it, the sensor can detect the different dipole moments of the various parts of the vehicle. The field variation reveals a detailed magnetic signature.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Knaian (2000) proposes the use of wireless sensor networks for traffic monitoring in urban areas.
- A prototype was deployed in Vassar Street, Cambridge, Massachusetts. The wireless sensor node consists of two AMR magnetic sensors for detecting vehicular activities and a temperature sensor for monitoring road condition (snow, ice, or water).
- The movement and speed of a vehicle is captured by observing the disturbance it creates in the Earth’s magnetic field.

Εφαρμογές ασύρματων δικτύων αισθητήρων

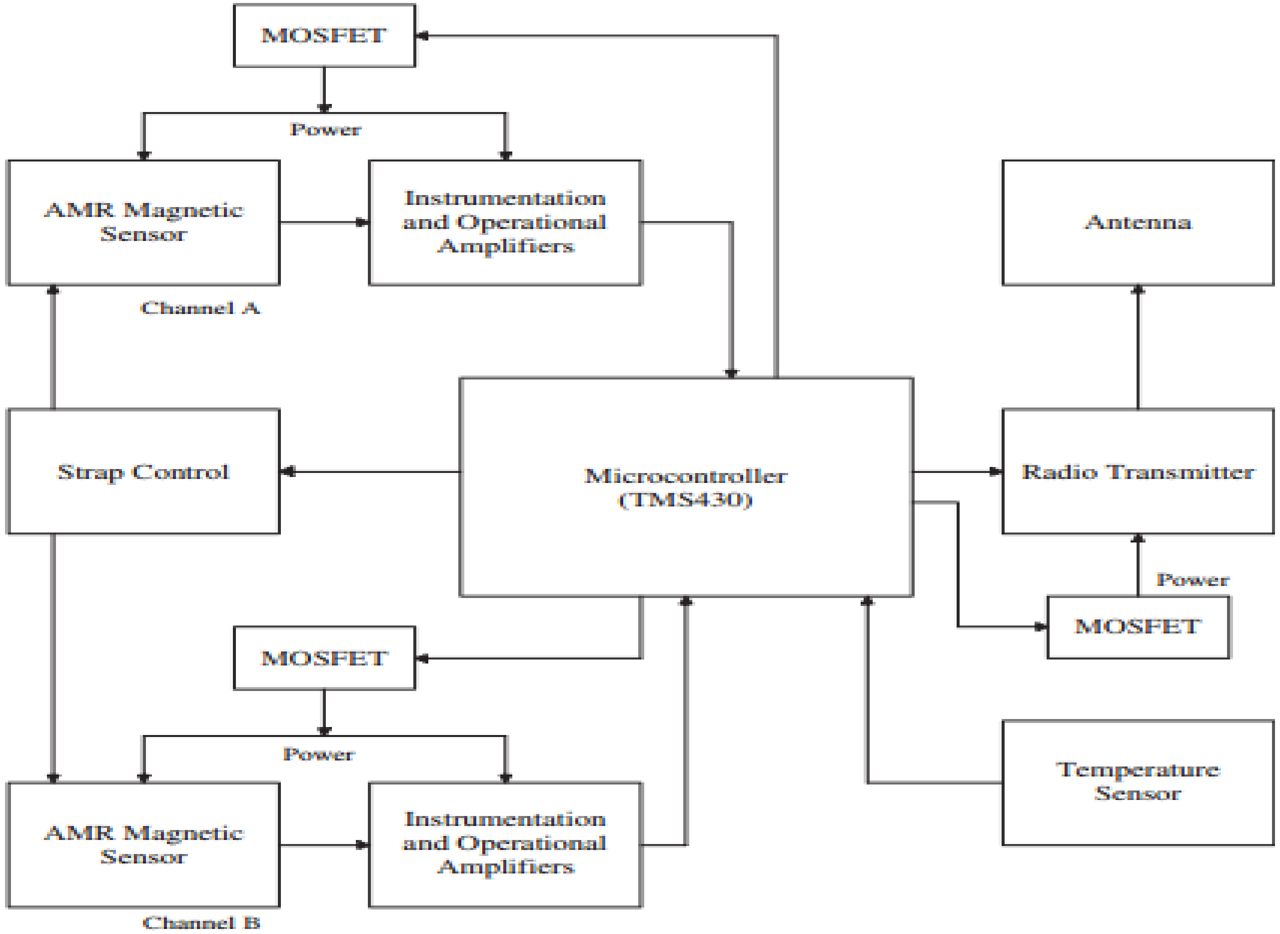


Figure 2.4 Block diagram of the MIT node for traffic monitoring (Knaian 2000).

Εφαρμογές ασύρματων δικτύων αισθητήρων

- A wide range of health care applications have been proposed for wireless sensor networks
- include monitoring patients with Parkinson’s Disease, epilepsy, heart patients, patients rehabilitating from stroke or heart attack, and elderly people.
- Unlike other types of applications discussed so far, health care applications do not function as stand-alone systems.
- Rather, they are integral parts of a comprehensive and complex health and rescue system

Εφαρμογές ασύρματων δικτύων αισθητήρων

- comprehensible solution that involves the following tasks:
- building pervasive systems that provide patients with rich information about diseases and their prevention mechanisms;
- seamless integration of health infrastructures with emergency and rescue operations as well as transportation systems;
- developing reliable and unobtrusive health-monitoring systems that can be worn by patients to reduce the responsibilities and presence of medical personnel;
- alerting nurses and doctors when medical intervention is necessary;
- reducing inconvenient and costly checkup visits by creating reliable links between autonomous health-monitoring systems and health institutions.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- pulse oxygen saturation sensors: they measure the percentage of hemoglobin (Hb) saturated with oxygen (SpO2) and heart rate (HR);
- blood pressure sensors;
- electrocardiogram (ECG);
- electromyogram (EMG) for measuring muscle activities;
- temperature sensors – both for core body temperature and skin temperature;
- respiration sensors;
- blood flow sensors;
- blood oxygen level sensor (oximeter) for measuring cardiovascular exertion (distress).

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Another area of application for wireless sensor networks is the monitoring of gas, water, and oil pipelines.
- The management of pipelines presents a formidable challenge.
- Their long length, high value, high risk, and often difficult access conditions require continuous and unobtrusive monitoring.
- Leakages can occur due to excessive deformations caused by earthquakes, landslides, or collisions with an external force; corrosion, wear, material flaws or even intentional damage to the structure.
- To detect leakages, it is vital to understand the characteristics of the substance the pipelines transport.
- For example, fluid pipelines generate a hot-spot at the location of the leak, whereas gas pipelines generate a cold-spot due to the gas pressure relaxation.
- Likewise, fluid travels at a higher propagation velocity in metal pipelines than in polyvinyl chloride (PVC). There are a large number of commercially available sensors (fiber optics, temperature sensors, and acoustic sensors) to detect and localize thermal anomalies.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- PipeNet is deployed in three different settings.
- In the first setting, pressure and pH sensors are installed on a 12 in. cast-iron pipe which supplies drinking water.
- Pressure data is collected every 5 min for a period of 5 s at a rate of 100 Hz.
- The wireless sensor node can locally compute minimum, maximum, average, and standard deviation values and communicate the results to a remote gateway.
- Likewise, pH data is collected every 5 min for a period of 10 s at a rate of 100 Hz. The sensor nodes use a Bluetooth transceiver for wireless communication.
- The pressure sensor is a modified version of the OEM piezoresistive silicon sensor. It has an error compensation mechanism to deal with the effects of nonlinearity and hysteresis.
- The sensor has a startup time of less than 20 ms and a fast dynamic response. It consumes less than 10mW. The pH sensor is a glass electrode with an *Ag/AgCl* reference cell.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- In the second setting, a pressure sensor is employed to measure the pressure in 8 in. cast iron pipe. The data is collected every 5 min for a period of 5 s at a sampling rate of 300 Hz.
- For this setting, local processing was not supported; instead, the raw data was transmitted to a remote gateway.
- Finally, in the third setting, the water level of a combined sewer outflow collector is monitored. Two pressure transducers were placed at the bottom of the collector and an ultrasonic sensor on the top. The pressure sensors are low-power devices and consume less than 10mW.
- The ultrasonic sensor is a high-power device and consumes 550mW. For efficient power consumption, the pressure sensors are employed for periodic monitoring while the ultrasonic sensor is required only to verify the readings from the pressure sensors when their difference exceeded a set threshold or when the water level exceeded the weir height.
- In this setting, data collection was carried out at a rate of 100Hz at 5 min intervals for a period of 10 s.
- Moreover, local data aggregation was performed to reduce the network traffic. The network supported remote configuration to increase the sampling rate up to 600 Hz.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Another interesting area where wireless sensor networks motivated a large number of researchers is precision agriculture.
- Traditionally, a large farm is taken as a homogeneous field in terms of resource distribution and its response to climate change, weeds, and pests.
- Accordingly, farmers administer fertilizers, pesticides, herbicides, and water resources.
- In reality, a large field exhibits wide spatial diversity in soil types, nutrient content, and other important factors. Therefore, treating it as a uniform field can cause inefficient use of resources and loss of productivity.
- Precision agriculture is a method of farm management that enables farmers to produce more efficiently through a frugal use of resources.
- This encompasses different aspects, such as micro-monitoring soil, crop, and climate change in a field, and providing a decision support system (DSS).
- Precision agriculture uses Geographic Information System management tools; GPS, radar, aerial images, etc., to accurately diagnose a field and apply vital farming resources.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- A large number of technologies have been developed over the last several years to facilitate and automate precision agriculture. Some of these are:
- *Yield monitors:* These are devices that use, among other things, mass flow sensors, moisture sensors, and a GPS receiver to monitor instantaneous yield based on time and distance. The sensors enable measurement of the mass or the volume of grain flow (grain flow sensors), separator speed, ground speed, grain moisture, and header height.
- *Yield mapping:* Couples GPS receivers with yield monitors to provide spatial coordinates for the yield monitor data.
- *Variable rate fertilizer:* Manages the application of liquid and gaseous fertilizer materials.
- *Weed mapping:* Enables a farmer to map weeds while combining, seeding, spraying, or field scouting.
- *Variable spraying:* By knowing weed locations from weed mapping, spot control can be implemented. This enables booms to be turned on and off electronically and alter the amount (and blend) of herbicide applied.

Εφαρμογές ασύρματων δικτύων αισθητήρων

- *Topography and boundaries:* Enable the production of very accurate topographic maps that can be used to interpret yield maps and weed maps as well as planning for grassed waterways and field divisions. Field boundaries, roads, yards, tree stands, and wetlands can all be accurately mapped to aid farm planning.
- *Salinity mapping:* This is used to map fields that are affected by salinity. Salinity mapping is valuable in interpreting yield maps and weed maps as well as tracking the change in salinity over time.
- *Guidance systems:* These are devices that can accurately position a moving vehicle within a 12 in. radius (or less). They are useful for spraying and seeding as well as field scouting.
- The main challenge in applying precision agriculture technologies is the need to collect amount of data over several days that is large enough to characterize the entire field. In this regard, wireless sensor networks can be excellent tools as large-scale sensing technologies

Εφαρμογές ασύρματων δικτύων αισθητήρων

- Monitoring active volcanoes is another application domain for wireless sensor networks (WSNs). Volcanoes occur when broken slabs of the Earth’s outermost shell, known as lithosphere,
- float on the hotter and softer layer in the Earth’s mantle. This phenomenon causes occasional collision between the lithosphere plates and is attributed to be the cause of most volcanoes.
- In most cases, the Earth’s volcanoes are hidden from view, occurring on the ocean floor along spreading ridges. Scientists attempt to capture and study the nature of active volcanoes by employing seismic and acoustic sensors and by collecting seismic and infrasonic signals.
- At present, typical active volcanoes are monitored by expensive devices that are difficult to move or require an external supply voltage. The deployment and maintenance of these devices require vehicle or helicopter assistance.
- Data storage is also a concern since, in typical scenarios, stations should log data to a Compact Flash card or a hard drive, which must be retrieved on a periodic basis.
- WSNs can be very useful for active volcano monitoring. First, a large number of small, cheap, and self-organizing nodes can be deployed to cover a vast field. In contrast to the expensive and bulky equipments presently used, the deployment of WSNs is fast and economical.
- Second, through a high density and wide coverage, it is possible to achieve high spatial diversity. Third, the networks can operate without requiring stringent maintenance routine