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WIRELESS CONNECTIVITY STUDY

Wireless Connectivity of the Structural and Environmental Sensor Devices

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ABSTRACT

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The aim of this master’s thesis was to study a selection of environmental and infrastructural monitoring devices and their wireless connectivity. The company Haltian Ltd. was interested in studying the possibility of using the device they were developing, with the measurement devices available for those areas, and to find out if the connectivity of the developed device was already suitable for the usage with the devices on the market.

The technical information of the wireless sensors was searched from the product manufacturer's web pages. Detail information of the sensors was found out in books and on web pages. Basic knowledge for the study topic comes from the bachelor's degrees in both civil engineering and information technology.

The result of the study was that measurement devices that would have been easily connectable wirelessly to the developed device were not found. Hence, the conclusion was that the test phase was not executed. Anyway, several devices and manufacturers were studied and overall picture of the devices and the technologies used in environmental and infrastructural monitoring was gained. It came out that in many cases manufacturers are developing their monitoring systems with proprietary wireless protocols. On the other hand, sensor devices could be used with a wired analog connectivity method. This could be considered in the future device development.

Keywords: wireless, sensor, structural, environmental, monitoring

PREFACE

The interest for the topic of this thesis work came from the fact that, in addition to a degree in information technology, embedded software, the author also has a Bachelor's degree and work experience in civil engineering. In the past five years this has given an idea if the experience of these two fields could be somehow combined. When Haltian Ltd, a company based in Oulu, Finland, was also interested in investigating the possibility of using the device they were developing with the measurement devices developed for the field of environmental and infrastructural monitoring, the mutually interesting and beneficial topic for the thesis was found.

Oulu, 30.11.2015

Jussi-Pekka Leinonen

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SYMBOLS AND ABBREVIATIONS

2G	2nd generation of mobile telecommunications technology
3G	3rd generation of mobile telecommunications technology
A-GPS	Assisted-GPS
API	Application Programming Interface
ARM	Acorn RISC Machine
BLE	Bluetooth Low Energy
BR	Basic Rate
BSD	Berkeley Software Distribution
DC	Direct Current
EDR	Enhanced Data Rate
GLONASS	Global Navigation Satellite System
GPRS	General packet radio service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HART	Highway Addressable Remote Transducer Protocol
HW	Hardware
ID	Identification
IEEE	Institute of Electrical and Electronics Engineering
ISM	Industrial, Scientific and Medical
JSON	JavaScript Object Notation
LOS	Line Of Sight
MEMS	Micro-Electro-Mechanical Systems
NAND	Negated AND logic gate
OS	Operating System
RTOS	Real-Time Operating System
REST	Representational State Transfer
RF	Radio Frequency
SAW	Surface Acoustic Wave
SD	Secure Digital
SDK	Software development kit
SIG	Special Interest Group

SW	Software
Thingsee	Device / system developed by Haltian Ltd.
UI	User Interface
USB	Universal Serial Bus
UART	Universal Asynchronous Receiver Transmitter
VOC	Volatile Organic Compound
Wi-Fi	Wi-Fi Alliance Trademark
WLAN	Wireless Local Area Network
XML	Extensible Markup Language

1 INTRODUCTION

The main aim of this thesis was to study a selection of environmental and infrastructural monitoring devices available and their wireless connectivity. The company Haltian Ltd. was developing a wireless device, called Thingsee, which also has a short range wireless connectivity integrated in it. The purpose was to find out if the current connectivity of the developed device was already suitable to be used with the devices on the market. Another aspect was to find out if the new use cases and markets for the developed wireless device and the whole system can be found.

The technical properties that were gone through in the found measurement devices are, for example, a wireless communication radio and protocol information, an overview of the used sensors, and the applications that the sensor devices are used for. The infrastructural measurement devices monitor, for example bridges, roads and railways. The parameters measured by the environmental devices are for example temperature, pressure, carbon dioxide (CO_2) and liquid level.

In the study where the product offering must be studied, the most obvious source of information is nowadays the product manufacturer's web pages. This way a lot of information is easily accessible, but on the other hand, this is also a problem. It is difficult to quickly identify good sources and even more difficult and time consuming to find the needed information from the numerous pages. Often, the data is also organized differently.

In the beginning of the document the device hardware and the device software of the Thingsee device are shortly explained. Also, the overview of the web server usage and the functionality is covered. The structural and environmental sensor devices are gone through separately in the chapters 5 and 6. The data is organized differently in these two chapters. Firstly, because there are not that many parameters that the structural devices monitor, the examples are sorted by the measurement parameter types, like a strain and an inclination. On the other hand, there are so many parameters that can be measured in environmental devices, that few examples are selected from the selection of two manufacturers to give a general view.

2 TERMINOLOGY

Wireless measurement devices are discussed in this thesis. Often there can be varying meanings, for example, for a system or a sensor. Based on a person's background, a sensor may mean one component measuring one parameter or it may mean a whole device including wireless connectivity and different kinds of sensing components measuring several physical parameters. A sensor in this thesis means a single sensor component. Usually, a sensor measures one physical parameter (for example acceleration), but sensors can also measure more than one parameter, like temperature and humidity. A sensor device or a measurement device can contain several sensors, and it can have some data processing capabilities. It can also provide an interface to read and write data separately from each sensor or a fusion of data of many sensors. One very commonly used sensor fusion example is a digital compass, which combines the data from a magnetometer and an accelerometer. An interface to communicate with a sensor device can be wireless or wired.

The system developed by Haltian is called Thingsee. The system was initially targeted for the tracking of valuable shipments, for example containers, but its usage is not limited only to that. In this thesis, the system contains a battery powered device with cellular mobile data and a short range wireless connectivity, and a server implementation where the data sent by the device can be manipulated and shown to a user. A more detailed description of the system will be presented. The Thingsee device can also be considered as a wireless gateway: it is able to receive data wirelessly from remote sensors and send it to the server with an integrated wireless modem. A wireless device does not always mean that a device is really wireless and portable. In some cases even though the data delivery and communication happens wirelessly, powering might need cabling. In this thesis the wireless device, Thingsee in particular, means a battery powered portable device with wireless communication capabilities.

3 THINGSEE SYSTEM

Today there is a trend that devices need to be able to connect wirelessly to the Internet. The Thingsee system has been developed to address this trend and demand, while being also an important reference of the technical expertise in the company. One important principle is to be able to offer the whole system, including the web server. With the integrated short range radio connectivity, also wireless devices from other manufacturers can be connected to the Thingsee device to provide the data if required.

3.1 Device hardware

A block diagram of the Thingsee hardware can be seen in the figure 1. A wireless short range connectivity is handled with Bluetooth low energy (BLE) and a wireless local area network (WLAN). A mobile data connection is taken care of by GSM/GPRS cellular network modem. Thingsee has also an internal GPS/GLONASS hardware for positioning applications, like tracking. The assisted-GPS (A-GPS) is also supported. The assistance data is provided by a module vendor. The device is battery powered and charging can be done through a micro USB connector. A charger recognition and charging management functionality is handled by a power management (PM). For possible data logging needs, there is a mass memory available: a reader for a removable microSD card. Like previously mentioned, the first target application for Thingsee is planned to be the tracking of valuable shipments. In this kind of usage the most important thing is to monitor constantly the conditions of a shipment. For this purpose, there are internal sensors in the device. A low power accelerometer can be configured to be always-on to detect possible hits and fall overs. A pressure, temperature and humidity information can be monitored more seldom, for example once every ten minutes. If needed, a display is also available to show the important status information of the device.

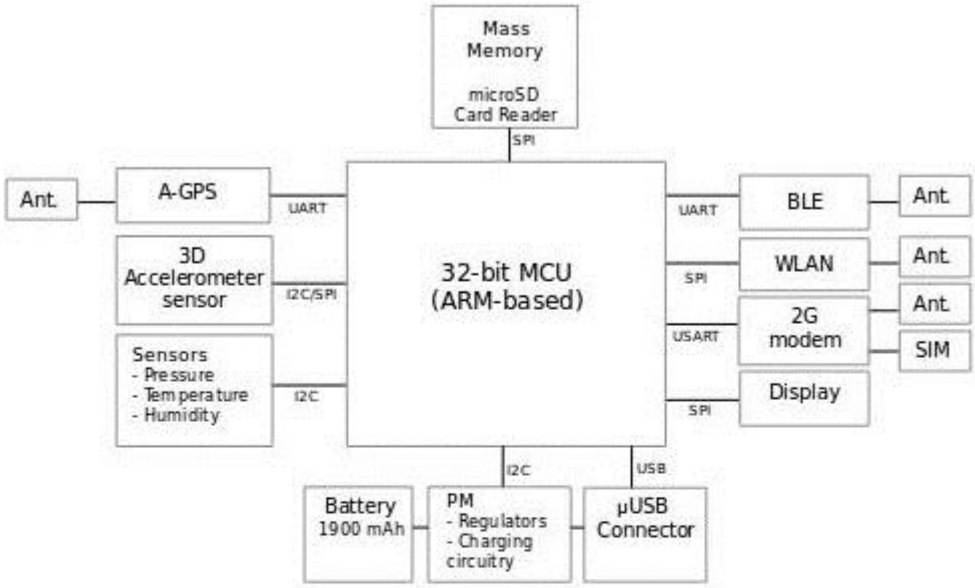

FIGURE 1. Thingsee HW block diagram.

3.2 Device Software

NuttX real time operating system (RTOS) was selected as a basis of the Thingsee device software development. The NuttX RTOS was released by Gregory Nutt in 2007 under the BSD License [1]. As an important note relating to embedded devices, to be able to enable the usage of different power states of target hardwares, the power management (PM) sub-system implementation was introduced in 2013 [2, p.1-2].

The BSD Licenses are very liberal licenses setting minimal restrictions on a redistributed software. NuttX uses a so called 3-clause license. If a user distributes modified or unmodified software, either in a source code or binary form, one must include the original copyright notice, a disclaimer of warranty and a list of these three clauses setting the restrictions. One of these clauses also tells not to use a company or contributer names without a permission when promoting new products derived from a software. [3] [4]

The NuttX RTOS source code provides a set of drivers for several hardware families, for example, for the very popular ARM and Atmel AVR devices. In the case of the Thingsee hardware, drivers can be found for example for the I^2C and SPI buses but a configuration and small changes had to be implemented. From the Thingsee point of view the important parts of the NuttX software structure are: nuttx and apps. A NuttX folder contains the kernel and all the device drivers, when the actual functionality and the usage logic is built in the applications (apps) folder. NuttX also provides the graphical user interface called NXWidgets, but this is not taken in use because of the Thingsee hardware memory limitation.

3.3 Web server

A web server consists of a back-end server, a front-end server and a data storage database. From feature point of view, the back-end handles the data storing and a manipulation and the front-end handles showing the data to a user.

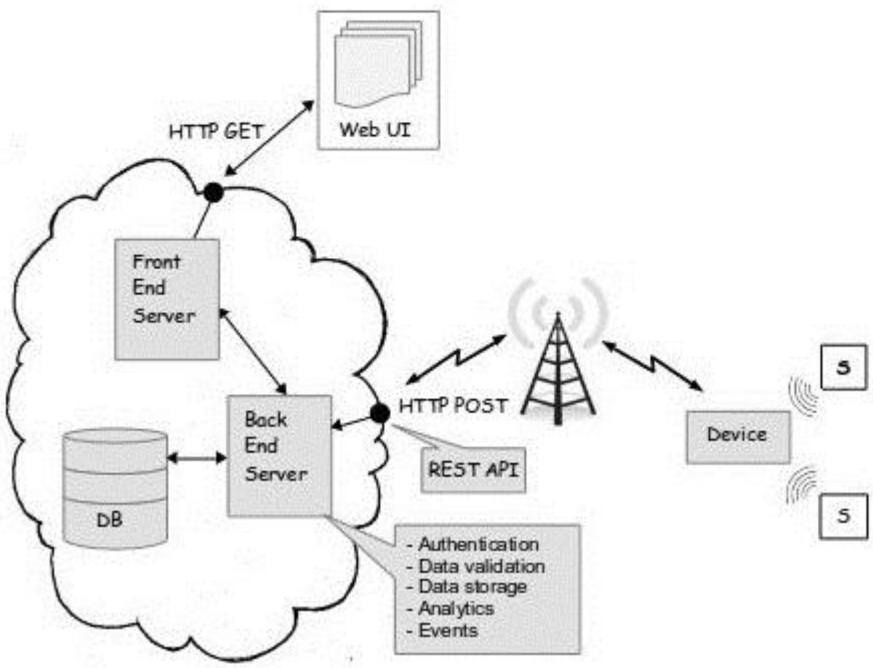

FIGURE 2. Thingsee system diagram.

In the case of the Thingsee device, the data can be generated by the device itself or the data can be received from a sensor (in figure 2 marked as 'S') connected wirelessly to the Thingsee device. Figure 2 illustrates how Thingsee can send the data to a selected server with a mobile connection but the wireless LAN is also an option.

The device sends the data to the web server with the HTTP POST message. The data is in the REST API format. The pre-defined device ID must be used in the message. The message can also contain the pre-defined data fields of, for example, a GPS location, temperature, humidity or the information about a device orientation, including a time stamp. The back-end checks the validity of the data and stores it to the database. Further data processing and data checks against limits can be done later on in the back-end for the incoming data, but in some use cases also immediate analytics can be done. The limit values are maintained in the back-end. Based on the data analysis, events telling for example about the exceeded limits can be generated and saved to the database. Another feature of the back-end server is to maintain the user information and check the user validity.

The REST API in the Thingsee system contains a set of data and functions for sending data to the server. It also contains functions to be used in the front-end server when inquiring the data from the back-end to be shown in a web UI. REST is an architectural style, not being a standard anyway, used to design modern web services and a web API following the REST guidelines is the REST API. [5, p.5] [6] A REST architectural style was originally defined in parallel with the HTTP protocol, but it is not limited to it. Simple HTTP methods like POST and GET can be used in a service, like it is done also in Thingsee [7]. Among many other Internet media types, JSON and XML can be used to define a data format.

The Thingsee web server front-end pulls the information from the back-end and shows it to the user. Based on the user and the selected device identification, the GPS location data is shown on the map. Also, the saved events, which usually are a result of abnormal events, are listed in the UI to highlight them to the user. All the device related data that is saved to the database can be viewed by the user over a selected time period, for example one day or a week. In the UI the user can also change the back-end maintained limits for logged parameters.

4 MEASUREMENT SYSTEMS IN GENERAL

Based on the data collection from device and system manufacturers' web pages, measurement devices are very often divided roughly into the following categories based on their end usage environment: environmental, structural, industrial and home environments. In some usage environments, especially in an industrial one, certain data connection interfaces and standards seem to be dominant. On the other hand, in many areas, for example in structural and environmental fields, there seem to be more variation, and wireless communication interfaces are not that well standardized. Hence, interoperability between different manufacturers' devices is not possible. This can be, of course, an outcome of a marketing strategy because the companies are willing to sell the whole systems, not only certain parts of them. One point favoring the manufacturer specific wireless interfaces over the general interfaces is that in such way the connection of the wireless devices can be made as easy as possible for the end user.

All different kinds of integration levels can be found in the device and system offering. In one end everything is basically integrated to one device, meaning that a single device contains both a measuring sensor and a modem, like a Moog Crossbow ILC2000 device [8], which communicates data to a server through the mobile network. In the other end a system can be very modular. In these measurement systems a sensor device, a short range radio adapter, a data logger and a modem can be separate devices. Figure 3 below illustrates system modularity of one manufacturer. Here sensors are connected to the wireless short range adapters, which are sending data to a data logger / wireless gateway. The gateway is then able to send the data wirelessly to the Internet cloud service for a further analysis.

FIGURE 3. Wireless sensor device modularity presented by LORD MicroStrain [9].

In the following chapters some of the devices and sensors are listed. All the manufacturers are not providing a wireless option for a communication but some wired sensors are also presented to give an idea about an overall offering of different types of sensor devices.

5 STRUCTURAL MEASUREMENT DEVICES

Structural measurement devices are the devices used to detect changes in the structures like bridges, buildings, roads and rail roads. Walls in mines, different kinds of slopes in a landscape and foundations can also be considered as structures that are under a stress causing changes. Measured parameters are, for example a tilt of a pillar, a strain in a beam of a bridge, a load in a cable of a suspension bridge, a vibration of a building and a displacement of a crack in a building, in a soil or in a rock.

5.1 Connectivity

Structural measurement devices are designed to be very modular; to enable a wireless data link from a sensor device to a wireless gateway or a data logger, the user very often has to connect a wireless adapter to a sensor device. Some devices exist in which a wireless connectivity has been integrated but mostly solutions are modular. One example which includes an integrated wireless connectivity is a wireless inclinometer by a company Sherborne Sensors (see figure 11 and table 7). The radio interface it offers is 2.4 GHz proprietary, hence data can be received with the Sherborne base station or the hand held devices only.

In the most common solution, which includes a separate wireless adapter, several interfaces are used to deliver data from sensor devices to wireless adapters. These interfaces are for example a 4-20mA analog current loop (for example a Sherborne inclinometer), a 0-10V DC voltage (for example a HBM strain-gauge) and a resistance (for example a Kyowa strain-gauge). In the wireless adapters the radio interface is also proprietary in some vendors' solutions, like in the Campbell Scientific devices. They offer the wireless adapters with 868 MHz (Europe), 900 MHz (US and Canada) and 922 MHz (Australia and New Zealand) radios. In some product datasheets a radio protocol is only informed to be IEEE 802.15.4. In these cases the wireless connection can be assumed to be proprietary, because more specific upper layer standards like ZigBee are not specified. Also, more common options are offered like WLAN (802.11b/g/n) in the STS4 node product from Bridge Diagnostics Inc. and ZigBee in the AvidSmartNode [51] device by the company AvidWireless.

5.2 Sensors

5.2.1 Strain gauge

A strain in an object or in a structure can be measured with a strain gauge. A bridge deflection is one of the parameters which can be calculated based on the strain. A deflection is a parameter that measures a displacement of a structure under a load. A displacement can be a distance or an angle [10]. In a building the construction deflection is in a very important role when selecting a beam material.

The most common strain gauge type is a metallic foil pattern with a flexible insulating backing. The strain gauge is attached to an object with adhesive. A principle of an operation is that when the foil pattern gets under a tension and a wire area narrows, the resistance increases. When the foil pattern gets under a compression, the wire area thickens, and a resistance decreases. [11] Strain gauges, which output the resistance, can be used with the devices that internally use the Wheatstone bridge to read the resistance, for example with the National Instruments's WSN-3214 Strain/Bridge Completion Node (see table 1).

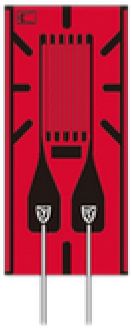

FIGURE 4. General purpose foil strain gauge by Kyowa [12].

FIGURE 5. Strain/bridge completion wireless node by National Instruments. [13]

TABLE 1. Data about strain/bridge completion wireless node by National Instruments [14]

Manufacturer	National Instruments (NI)	
Device	WSN-3214	
Type	Wireless node for strain gages	
Power	4 x 1.5V AA	
Input	20bit ADC; excitation voltage 2V, max 6.4mA,	
Radio	2.4 GHz	
Protocol	IEEE 802.15.4	
Power [dBm]	max 10dBm (international)	max 17dBm (North America)
Range [m]	150	300
Power consumption	Sleep 1mW, 4mW at 12V (60 sec interval)	

A transducer is a device converting one physical signal to a signal in another physical form [15, p.1]. The table 2 shows the data about two strain transducers from the company Hottinger Baldwin Messtechnik Gmb (HBM). The products utilize the strain gauge technology, and the output signal is the current loop or the voltage, as it can also be seen in table 2 below.

FIGURE 6. Strain transducer by HBM [16].

TABLE 2. Data about strain transducers by HBM [17].

Manufacturer	HBM (Hottinger Baldwin Messtechnik Gmb)	
Component	SLB700A/06VA1	SLB700A/06VA2
Type	Strain transducer	Strain transducer
Power	19-30 V	19-30 V
Output	0-10 V	4-20 mA
Meas range [um/m]	0-500	0-500
Max current consumption [mA]	20	20

An interesting finding is a passive wireless surface acoustic (SAW) strain gauge sensor, which does not need a battery or energy harvesting. The sensor can be wirelessly interrogated by the radio frequency transceiver (WRE010 by SENSeOR, see table 3), which sends an electromagnetic pulse to the sensor (SSE E015 by SENSeOR). On the sensor, the pulse is converted into the surface acoustic wave, modified based on the sensed physical parameter, and sent back to the transceiver. In transceiver the acoustic wave is translated and the result can be read from a digital output. [18] [19] [20, p.1]

FIGURE 7. Wireless Passive SAW Temperature Sensor Evaluation Kit by SENSeOR [21].

TABLE 3. Data about wireless SAW strain gauge by SENSeOR. [19] [20]

Manufacturer	SENSeOR	
Component	SSE E015	WR E010
Type	Wireless SAW strain gauge sensor	RF transceiver for wireless SAW sensors
Meas range	+/- 500 um/m	
Power	No battery needed	USB port
Radio	434 MHz ISM band	434 MHz ISM band
Protocol	-	-
Power [dBm]		Max +10dBm
Range [m]		0.3m, 2.0m (application dependent)
Power consumption		85mA at 5V
Meas frequency		20 Hz

5.2.2 Displacement sensor devices

In a literature a position transducer and displacement transducers are separated. A displacement is considered as a relative difference between the initial and final position of a point. On the other hand, a position is the distance between a reference point and a target. The displacement and the position can be linear or angular. [15, p 4, p 8]

The picture and the information about one example of the displacement transducer and the wireless adapter is presented in figure 8 and in table 4. LVDT is an abbreviation from a linear variable differential transformer. In the LVDT transducer there is a mechanically moved core inside a cylindrical element, and two coils that are not contacting physically the core. The movement of the core changes the coupling between the primary and the secondary coils and hence the output voltage. The LVDT is able to provide the direction and the magnitude of the displacement. [22, p. 288]

FIGURE 8. LVDT displacement transducer and wireless adapter STS4 by BDI. [23]

TABLE 4. Data about displacement transducer and wireless adapter by BDI. [24][25]

Manufacturer	Bridge Diagnostics Inc. (BDI)	
Component	LVDT	STS4
Type	Displacement transducer	Wireless adapter for sensors
Measurement Range	+/- 25mm	
Resolution	< 0.0025mm	
Power	+5V to +18V DC excitation, 100mA typical	+10.8 VDC (Nominal) Li-Ion, 6.2Ah
Input		+/-5 Vdc
Output	+/- 2 V	
Frequency band		2.4GHz
Protocol		802.11b/g/n
Power [dBm]		
Range [m]		
Power consumption	Typical: 2.5mW, max 75mW,	Sleep:<10mW , Base: 0.7W, typical 1.5W
Meas frequency	Settlement time ~0.75 seconds	Max 1000 Hz

Vibrating wire (VW) instruments are used to monitor displacements in slopes, dams, mines, rock and other geotechnical environments. A wire can be tens of meters long in total and is embedded in a soil to be monitored. A force targeting to an instrument changes the tension and therefore a vibration frequency of the wire converts to a relative displacement. [51] In table 5 can be seen the data about the wireless node targeted for vibrating wire instruments.

FIGURE 9. Wireless node for VW instruments by Newtrax Technologies. [26]

TABLE 5. Data about wireless adapter by Newtrax Technologies.[26]

Manufacturer	Newtrax Technologies Inc.
Component	NTX-WN-RTU-VW-100
Type	Wireless node for vibrating wire instruments
Power	Replaceable battery pack
Output	4-pin RS-232 serial for e.g. gateway, Modbus
Frequency band	902-928MHz
Protocol	(Mesh topology)
TX Power [mW]	1 mW to 25 mW
Sensitivity	-100 dBm
Range [m]	Mines: 50-150m, on surface: 50-600m

As one example of the vibrating wire transducer, which can be used with the Newtrax technologies wireless node, is the Mine Design technologies' (MDT) SMART MPBX (Multi-Point Borehole eXtensometer). It can be used for example in underground excavations or in open-pit mines. The MDT SMART MPBX instrument has six anchor points that are at user specified distances along the length of a maximum 60 meter instrument. Each six anchor nodes are connected with fiberglass rods to the instrument head, which containing the electronics, converts displacements to the voltages. [27] [28]

5.2.3 Inclination / tilt sensor devices

So called gravitational sensors that are measuring the angle between the direction of the gravitation force, which is pointing to the center of the earth, and the sensor's internal axis, are called inclinometers. The inclinometers are also called as tilt sensors or inclination sensors. [22, p.349] Common implementations of inclinometers are MEMS and electrolytic sensors. Like the name MEMS implies, there are micro electrical and mechanical parts in the sensor. [22, p.626] When the inclinometer is tilted, a micro mechanical part in the sensor moves and produces a change in a signal.

In an electrolytic sensor there is a small tube, which is partly filled with a conductive electrolyte. When the sensor is tilted, an air bubble moves in a tube. Electrodes that are built in the tube are sensing an electrical resistance increasing and decreasing along with the movement. With the electrolytic sensors very high resolution angular displacements can be measured. [22, p.350] Sensors with a variety of measurement ranges can also be found. One example of a manufacturer providing the electrolytic sensors is Fredericks Company. In the tables 6, 7 and 8 can be seen examples of the electrolytic tiltmeter sensor and the wireless node for it, the MEMS inclinometer with an integrated wireless connectivity and the MEMS tilt beam.

FIGURE 10. Electrolytic tiltmeter by BDI. [29]

TABLE 6. Data about electrolytic tiltmeter and wireless adapter by BDI. [30][25]

Manufacturer	Bridge Diagnostics Inc. (BDI)	
Component	T500-100	STS4
Type	Electrolytic tiltmeter	Wireless node for sensors
Meas Range	+/- 10 arc degrees	
Resolution	<.0005 arc degrees	
Power	+5 to +15 VDC excitation voltage	+10.8 VDC (Nominal) Li-Ion, 6.2Ah
Input		+/-5 Vdc
Radio		2.4GHz
Protocol		802.11b/g/n
Power [dBm]		
Range [m]		
Power consumption	Typical: 2.5mW, max 75mW,	Sleep:<10mW , Base: 0.7W, typical 1.5W
Meas frequency	Settlement time ~0.75 seconds	Max 1000 Hz

FIGURE 11. Wireless MEMS inclinometer by Sherborne. [31]

TABLE 7. Data about wireless MEMS inclinometer by company Sherborne. [31]

Manufacturer	Sherborne
Component	WTS inclinometer
Type	Wireless MEMS inclinometer
Measurement range	+/-15 degrees (available +/-5 - +/-60)
Resolution	0.003 degrees
Power	2 x AA, Li-Ion rechargeable
Frequency band	2.4GHz
Protocol	802.15.4 proprietary
Power [dBm]	
Range [m]	100
Power consumption	
Meas frequency	5 Hz

In a tilt beam concept, there is a tilt sensor in a beam body often having the length of approximately one meter. This way a tilting or for example a deflection can be detected from a longer distance of a structure. Often beams can be attached together in their ends to get a longer beam.(see table 8)

FIGURE 12. MEMS tilt beam by Geokon. [32]

TABLE 8. Data about MEMS tilt beam by Geokon. [32]

Manufacturer	Geokon
Component	model 6165
Type	MEMS tilt beam
Beam length	1029 mm
Measurement range	+/- 15 deg
Resolution	+/- 0.01 mm/m (+/- 2 arc seconds)
Power	8-15 VDC
Output	280 mV/degree

A tilt sensor can be used in infrastructural measurements, for example to measure a bridge beam tilting during the loading of a bridge. This is one way of measuring a bridge deflection. One example of such experiments is studied in the conference paper: Bridge deflection measurement using wireless MEMS inclination sensor systems [33, p.38-57].

Structural measurement devices gone through in previous paragraphs are to some extent obvious findings, for example a tilt meter application is commonly used in embedded devices, also in phones. A couple of very interesting technologies, which are based on a laser beam and on video image processing methods, were also found. In the following two chapters these are shortly discussed.

5.2.4 Laser beam

A laser beam can be used to monitor a structure deflection and displacement. One way is to use a rotating leveling laser and an active detector sensor(s) in a measurable target (product Deflection Multimeter), for example in a bridge. Another way is to use a tachymeter and reflecting prisms. One company using these two methods in their measurement devices is Dimense Oy. In the active detector, there is a possibility for a battery and solar panel powering. A wireless connectivity can be taken care of by the WLAN connectivity or with a 3G mobile network. The tachymeter product can feed data to an Internet service through an Ethernet. The advantage of using the prisms is that they don't need a supply power. [34] [35]

5.2.5 Video gauge

One company offering a video gauge technology is Imetrum Limited. A video of a target is taken with a camera that can have a 2-, 5- or 12-megapixel resolution. The video gauge usage is based on a real time pattern recognition and on a sub-pixel interpolation. The Imetrum system can perform up to 1600 measurements per second in real time. In practice, this could mean 100 monitoring points at the rate of 16 Hz or for example 4 points at the rate of 400Hz. It is also possible to do the analysis and produce a report afterwards based on the own digital video material. The technology can be used for a non-contact monitoring of a strain, rotation and displacements in structures like bridges. [36] [37] [38]

6 ENVIRONMENTAL MEASUREMENT DEVICES

An environment can be defined as the surroundings of someone or something. The environment also gives circumstances and conditions for health, growth and being. In practice we talk about air, water and soil, the quality, properties and level of which the environmental measurement devices monitor. [54]

Many different kinds of environmental parameters can be listed when studying an offering of the environmental measurement devices, so many that there is no point of going them all through in this context. On the other hand, not so many vendors seem to offer a whole variety of devices measuring all different parameters. The most commonly offered parameters are not so surprisingly the air temperature, humidity and pressure. More rarely offered devices are measuring air pollutant parameters like the hydrogen sulfide (H_2S) or methane (CH_4) and for example by utilizing a sonic noise, a snow depth and a water level.

6.1 Connectivity

From the companies offering a wide range of measurable parameters in their devices, two vendors can be mentioned as an example: Campbell Scientific Inc. and Libelium Comunicaciones Distribuidas S.L. Campbell Scientific also offers devices for structural measurements. Libelium mainly offers devices for environmental measurements. Because the offering of available parameters, for example from these two manufacturers is so wide, not all parameters are explained in the following chapters but the lists can be found in appendix 1 and in appendix 2.

According to Campbell Scientific company's web pages, all of their sensor devices can not be connected to their wireless node. Campbell Scientific has a couple of sensors with an integrated wireless connectivity, but mostly a wireless connectivity is handled with a wireless adapter. Sensors with an integrated radio are the infrared radiometer and the soil-water probe [39]. Other sensor types that are compatible with the wireless adapter are: the temperature, relative humidity, wind, rain, solar, water quality, leaf wetness sensor and the soil heat flux plate [40]. These both wireless sensor types cover

11 out of total 28. Radios that are used are 868 MHz, 900 MHz and 922 MHz with a proprietary protocol stack.

FIGURE 13. Wireless adapter by company Campbell Scientific.[39]

Libelium sensors can all be bought with a wireless connectivity and with several connectivity protocol options. A basis of the Libelium products is their modular platform called Waspmote. Modularity gives a possibility to use all the different radio modules in the sensor nodes. Radios that are available are mostly 2.4 GHz but also 868 MHz and 900 MHz radios are available.

When many companies prefer proprietary protocol stacks and therefore are not supporting the standard connectivity, Libelium seem to have a different approach when they also offer the standardized connectivity protocols in their devices. In addition to WLAN (IEEE 802.11), ZigBee PRO and Bluetooth 4.0 / Bluetooth low energy, Libelium offers a possibility for the Digi International Inc's proprietary Digimesh protocol [41]. Also the integrated 3G or GPRS cellular connectivity is available.

FIGURE 14. Wireless sensor node by Libelium [42]

As a side note it can be mentioned one choice of offering which is very close to Waspmote. This platform combines Libelium's hardware and IBM's Mote Runner SDK. This gives the possibility to use the 6LowPAN / IPv6 connectivity in the sensor nodes. [43]

Except the information about mobile data network connectivity, the characteristics of the wireless connectivity of the sensor nodes are shown in table 9. The full list of available Libelium sensor probes, 44 probes in total, can be found in appendix 2.

TABLE 9. Data about wireless nodes by company Libelium. [42]

Manufacturer	Libelium					
Type	Wireless sensor node					
Power	6600mAh rechargeable, 26Ah non-rechargeable					
Radio	2.4GHz	2.4GHz	2.4GHz	900 MHz	868 MHz (Europe)	2.4GHz
Protocol	802.15.4	ZigBee PRO	802.11b/g			Bluetooth 4.0/ BLE
TX Power	100 mW	50 mW	0-12 dBm	50 mW	315 mW	3 dBm
Range	7000 m	7000 m	50-500 m	10 km	12 km	100 m

6.2 Sensors

6.2.1 Campbell Scientific options

In the following tables can be seen examples of offerings from Campbell Scientific Inc. and Libelium. In the table 10 can be found the data about the combination of the solar radiation sensor and the wireless adapter. As it can be seen in the table, different radios in wireless adapters can be found for different continents. As a reference to the solar radiation sensor output, the full sunlight of 1000 W/m^2 will provide a signal of 200 mW.

FIGURE 15. Pyranometer (solar radiation) sensor device by Campbell Scientific. [44]

TABLE 10. Data about solar radiation sensor and wireless adapter by Campbell Scientific. [44] [45] [46]

Manufacturer	Campbell Scientific Inc.	
Component	CS300	CWS900E, CWS900, CWS900A
Type	Pyranometer (solar radiation)	Wireless node for sensors
Measurement range	0 to 1750 W/m^2	
Spectral range	360 to 1120 nanometers	
Power		2 x AA batteries
Input		-1 to 2.5 Vdc (0.3 uV resolution)
Output	0.2 mV per W/m^2	2.5 V, 3.3 V, 5.0 V excitation voltage; 20 mA max
Radio		868 MHz (Europe) 902 to 918 MHz (US/Canada) 920 to 928 MHz (Australia/New Zealand)
Protocol		Proprietary
Power [dBm]		14 dBm (25mW)
Range [m]		392 line of sight
Power consumption	-	Standby: 3 uA, transmitting: 45 mA Average: 300 µA (15 minute polling, depending on attached sensor)

As mentioned earlier, a couple of wireless sensor nodes can be found from the company Campbell Scientific. Below it can be seen a picture (figure 16) and the data (table 11) about the wireless infrared sensor node. The sensor node includes a thermopile and a thermistor. The thermopile measures a surface temperature without a physical contact. The thermistor measures a device body temperature as a reference temperature for a surface temperature. According to the company web pages, the device is suitable, for example for measurements of a road, soil, snow and water surfaces. [47] [48] [53]

FIGURE 16. Wireless infrared sensor node by company Campbell Scientific.[47]

TABLE 11. Data about wireless infrared temperature sensor node by Campbell Scientific. [45] [53]

Manufacturer	Campbell Scientific Inc.
Component	CWS220E
Type	Infrared temperature sensor
Measurement accuracy	±0.2°C @ -10° to +65°C ±0.5°C @ -40° to +70°C
Power	2 x AA batteries (solar charging)
Radio	868 MHz (Europe) (902 to 918 MHz in US/Canada, 920 to 928 MHz in Australia/New Zealand)
Protocol	Proprietary
Power [dBm]	14 dBm (25mW)
Range [m]	392 line of sight
Power consumption	Standby: 3 µA, transmitting: 45 mA, Average: 300 µA (15 minute polling)
Meas frequency	< 1 sec to changes in target temperature

6.2.2 Libelium options

In the company Libelium's offerings there are available few wireless node models, into which a certain combination of sensor probes can be connected directly. In practice the data from all the available sensors/nodes can be delivered wirelessly. The node hardware itself includes an internal temperature and accelerometer sensors. Also, when using the wireless node for a radiation measurement, the Geiger sensor is installed internally to the node. Below are presented few examples of the Libelium's sensor probe offerings. The full list of the Libelium probes can be found in an appendix 2.

The principle of operation in a leaf wetness sensor is that the humidity on the sensor surface, imitating the leaf, changes the resistance of the sensor. When the humidity on the sensor surface is absent, the resistance is high and when the sensor is submerged in water, the resistance is at its minimum. The leaf wetness sensors are used to monitor agricultural circumstances, when controlling for example the irrigation systems.

FIGURE 17. Infrared sensor probe by company Libelium. [49]

TABLE 12. Data about leaf wetness sensor probe by Libelium. [49]

Type	Leaf wetness sensor probe
Resistance range	5kΩ ->
Output voltage range	1 V ~ 3.3 V

An ultrasound distance probe can be used to detect a distance of an object from a sensor, or to detect, for example a water level or a liquid level in a tank. The sensor probe outputs the analog voltage proportional to a distance measured. According to the documentation on the Campbell Scientific web pages, these kinds of acoustic sensors are also suitable for a snow depth monitoring.

FIGURE 18. Ultrasound sensor probe by Libelium. [49]

TABLE 13. Data about ultrasound sensor probe by Libelium. [49]

Type	Ultrasound distance
Power	3.3 V – 5 V
Operation frequency	42 kHz
Max detection distance	600 cm (powered at 3.3 V), 700cm (powered at 5V)
Power consumption	Average: 2.1 mA peak: 50 mA (powered at 3.3V) Average: 3.2 mA peak: 100 mA (powered at 5V)

Libelium offers two different probes measuring air pollutants. The information about one of them is presented in table 14. Sensor model used in the probe is TGS 2602 from the company Figaro. When detectable gases are present, the gas concentrated in the air changes the conductivity of the sensor. A simple circuit can be used to convert conductivity changes in the sensor to an output signal corresponding to the gas concentration. TGS 2602 is sensitive to concentrations of the contaminant gases like Toluene ($C_6H_5CH_3$), Hydrogen Sulphide (H_2S), Ethanol (CH_3CH_2OH), Ammonia (NH_3) and Hydrogen (H_2). Ammonia and Hydrogen Sulphide are generated for example from waste in a home and in office environments. VOCs, i.e. organic chemicals, such as Toluene can emit from wood finishing and construction products. The sensor shows the resistance between 10 and 100 kΩ in the air without contaminants. A miniaturized sensing chip requires a heater current. Applications for the sensor are for example a ventilation control, air quality monitors and VOC monitors. [49] [50]


FIGURE 19. Data about air pollutant sensor probe by Libelium and sensor TGS 2602. [49] [50]

TABLE 14. Data air pollutant sensor probe by Libelium. [49]

Type	Air pollutants sensor probe
Gases	$C_6H_5CH_3$, H_2S, CH_3CH_2OH, NH_3, H_2
Measurement range	1 – 30 ppm
Power	5 ± 0.2V DC
Response time	30 sec
Power consumption	Average: 61 mA

7 CONCLUSION

When considering a practical usage of devices that are battery powered and communicate wirelessly, there are obvious limitations; they can not send the data very often, they can not use a lot of processor time for the data manipulation, and because of loss in a battery capacity, the usage of a radio and radio power has to be limited in cold temperatures. These limitations do not apply if a frequent charging of a battery is somehow taken care of, which on the other hand leads to a situation where a device is not anymore completely wireless. If a sensor device's battery capacity and power consumption are well in balance, wireless devices are the most suitable for cases where a quick installation of a system to an absent location is needed and the usage of a system is needed for limited time.

An overall technology development will advance the usability and the development of the wireless sensor devices. One example of an area, which most probably will advance the spreading of a wireless sensor device usage, is the energy harvesting technology development, which would decrease the maintenance need of the sensors in absent locations. The technology is already available in some manufacturers’ offering. There are also recent examples in a short range radio technology development that manufacturers have been able to halve the transmission peak currents, which directly improves the usage time and life time of the batteries and therefore, a device usage time, too. During the study a fast development could also be seen in the offered connectivity options when the company Libelium started to offer a Bluetooth low energy connectivity for their sensor devices. With examples like this, it can be speculated that wireless connectivities are evolving when new players are coming to the field and are having a different approach when it comes to a connectivity.

The target of the study was to go through the offerings of the wireless sensors that were targeted to measure environmental or structural parameters. The most important thing to find out was whether there were devices on the market whose wireless connectivity was suitable for the usage with the Thingsee device.

New interesting monitoring methods like the video and the real time pattern recognition were found, and also many devices with different sensor types were studied. However, quite surprisingly, at least for the author of this thesis, as a result of the study, it could be found out, that not too many manufacturers seem to offer sensor devices measuring environmental and structural parameters with a wireless connectivity that could be easily integrated as a part of the developed system and used with the device like Thingsee. Therefore, after the study it was concluded that because not easily connectable, interesting measurement devices were not found, Thingsee and the wireless sensor(s) testing phase, that was considered in the beginning of the study, was decided not to be done. On the other hand, the actualised implementation schedule of the device project and a system testing with wireless sensors would have been difficult to carry out in the pre-planned schedule.

The Thingsee device is able to produce the measurement data with the sensors it has in it, but it can be considered even more as a data gateway for wireless sensors designed for a specific purpose. The Thingsee device has a Bluetooth low energy short range radio, which could be used to connect wireless sensors, but BLE seems to be used as a connectivity more in consumer electronics, not in professional measurement systems. The company called Libelium, which has a wide variety of the sensors measuring many parameters, in an environmental monitoring in particular, offers the Bluetooth low energy connectivity though. Libelium also offers the mobile GPRS connectivity in their devices, which enables the connectivity to data servers directly.

As mentioned earlier, environmental and structural measurement device manufacturers use mostly a proprietary wireless connectivity. The reason for this might be that they are, of course, willing to sell and offer to their customers the whole system instead of selling only sensor devices, wireless nodes or gateway devices separately. That is most probably the marketing strategy they have selected. On the other hand, it is also a usability aspect. When devices in a system are advertising themselves and handling the connection procedure in a known, the proprietary way, new devices can be connected more easily, and less user interaction is needed.

Sensor devices themselves do not provide a wireless connectivity in many cases but they are designed to be connected with wired analog methods to manufacturers' wireless nodes. A connection from sensor devices to wireless nodes is often a voltage or a current loop. The Thingsee device has not been designed to serve such analog wired connection methods that these sensor devices offer but this could be considered in the future development. Examples of these wired methods are the analog current loop 4-20mA and the 0-10 V connection. Such an analog connection method is provided, for example, by the company HBM's strain transducer (see table 2) in the structural measurement devices. Even though industrial measurement sensors were not the target of the study, from the material could be found commonly used connection interfaces as the serial communication protocol Modbus and the digital industrial automation protocol HART (Highway Addressable Remote Transducer Protocol), which can operate over the 4-20 mA analog wiring [55] [56].

The Thingsee device has also the wireless LAN connectivity option, which some wireless nodes that can be connected to sensor devices are also providing. The Thingsee device, which also supports the cellular network GPRS connectivity, could be used as a gateway device in such systems, and hence sensor devices could also be easily connected with the data server that has been developed in the project at the same time with the wireless Thingsee device. Some companies have built their systems based on an idea that the data is sent from their wireless nodes, over the wireless LAN, directly to the PC to be analysed. For the companies like this, a mobile gateway and also a data server option would give more options for the system usage.

Even though sensor devices that are connected to the Internet are very much hot topic nowadays, it seems that real breakthrough, at least on consumer side, has not happened yet. Companies are of course trying to stay on the bar and trying to push the technology to market, but most probably all the applications that would benefit the most from a low power wireless communication have not been discovered yet. In a small scale, there are quite simple and reasonable applications in a home automation, and also in a monitoring of environment and structures, but as said, there must be potential for so much more. It remains to be seen if the connectivity methods which are very commonly used in consumer electronics, like BLE, will get more foothold and also become mainstream on the areas like environmental and structural monitoring, or do manufacturers keep developing their systems with a proprietary wireless connectivity also in the future.

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9 APPENDICES

Appendix 1 Campbell Scientific sensor types

Appendix 2 Libelium sensor probes

CAMPBELL SCIENTIFIC SENSOR TYPES

Precipitation - amount of rain
Conductivity - etc
Dissolved Oxygen
Distance
snow depths
water levels
Duff Moisture
Electrical Current
Electric Field
Evaporation
Freezing-Rain Detectors
Ice Detectors
Leaf Wetness
ORP
pH
Weather
Roadbed Water Content
Snow Water Equivalent
Snow Depth
Soil Heat Flux Sensors
Soil Temperature
Soil Volumetric Water Content
Soil Water Potential
Solar Radiation
Strain Gages
Surface Temperature
Turbidity
Visibility

LIBELIUM SENSOR PROBES

Temperature sensor probe
Humidity sensor probe
Atmospheric Pressure sensor probe
Carbon Monoxide (CO) sensor probe
Methane (CH_4) sensor probe
Ammonia (NH_3) sensor probe
LPG sensor probe - (CH_3CH_2OH, CH_4, C_4H_{10}, H_2)
Air Pollutants 1 sensor probe
Air pollutants 2 sensor probe
Solvent Vapors sensor probe
Carbon Dioxide (CO_2) sensor probe
Nitrogen Dioxide (NO_2) sensor probe
Ozone (O_3) sensor probe
VOC sensor probe
Oxygen (O_2) sensor probe
Temperature and Humidity sensor probe
Liquid Flow sensor probe
Presence sensor (PIR) probe
Liquid Level sensor probe
Liquid Presence sensor probe (Point)
Hall Effect sensor probe
Liquid Presence sensor probe (Line)
Soil/Water Temperature sensor (Pt1000) probe
Conductivity sensor probe
Dissolved Oxygen sensor probe
pH sensor probe
Oxidation-reduction potential sensor probe
Dissolved Ions sensors probes
Soil Temperature sensor (DS18B20) probe
Humidity sensor probe
Current sensor probe
Ultrasound sensor probe - Distance, e.g. liquid level
Noise sensor probe
Dust (PM-10 particles) sensor probe
Linear Displacement sensor probe
Smart parking node
Soil moisture sensor probe
Weather station WS-3000 probe
Leaf Wetness sensor probe
Solar Radiation sensor probe
Dendrometer sensor probe - Diameter
Luminosity sensor probe (LDR) - presence of the light
Luminosity sensor probe (Luxes accuracy) - exact quantity of the light in luxes
Radiation - internal Geiger sensor (Beta, Gamma [β, γ])