GUARDIANS

D2.2.6 Report on sensors for navigation, localisation, and mapping

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Abstract.
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The aim of this document is to survey the available sensors for robotic localisation, navigation, and mapping.
Keyword list: sensors, navigation, localisation, mapping.

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Executive Summary

The aim of this document is to survey the available sensors for mobile robots in the context of navigation, localisation and mapping. Specifications of sensors will be presented and compared, based on their integration in the algorithms methods used in the literature to solve such problems. The collection of sensors discussed in this report has been chosen based on the needs of the Guardians platform, the goals of the project, and the current availability.

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Chapter 1

Introduction

Nowadays mobile robotics and more specifically autonomous mobile robotics is a very active topic all over the world. It is difficult to find any medium-to-large research institution that does not have an special division devoted to this topic. Algorithms for localisation, autonomous navigation, obstacle avoidance, path planning, map building, and other important issues are available. Also new techniques are being developed while classical approaches are being refined every day. But to make them work, autonomous mobile robots need to collect environmental and self-state data. The availability and accuracy of sensor data is crucial and fully constrains the algorithms and techniques according to the platform and the environment. We find often a tight relationship between the algorithms developed and the robotic platforms used, and specifically the types of sensors employed, up to the point that countless times the algorithms only work with an specific model of sensors and even with a specific configuration. This could give us an eye-shot of the crucial importance the sensors have. In this report we will try to report an insight on the sensor capabilities commonly found or at least available for mobile platforms. We draw special attention on the limitations each type of sensors and techniques have. Since this study lays within the context of the GUARDIANS European project we have several constrains due to the dynamic and hazardous unstructured and unknown environment.

1.1 The Navigation, Localisation, and Mapping problem

When a robot needs to move ”repeatably” though an environment about which it has little or no prior knowledge, calculating ego-motion using just odometry is not sufficient as estimates based solely on such measurements of relative motion will have errors which over time will drop the system to an state where it thinks it is far from where it really is.

It has been traditionally necessary that the robot uses environment perception to identify landmarks in the surroundings, and then, use measurements of relative positions of these landmarks from future points on its movement path, to lock down its localisation estimates. Essentially it must ”make a map” of features in the scene and then estimate its location relative to this map.

Anything whose relative location to a robot can be repeatably measured using a sensor can be used as a feature in the map.

A combination of sensors making measurements of various feature types can be used together in map-building, and so, contributing to locate the robot. It is really important to highlight that not a single sensor will be able to cope this task alone in every environment, and furthermore, no sensor will give perfect data, so we have to think on sensors as a measure units with an associated uncertainty. This fact makes us use this data in a probabilistic way.

In robot applications there is often not available pre-mapping of the environment the robot will be required to visit, and therefore we must consider the challenging problem of ”sequential” navigation (avoiding obstacles), localisation (using the part of the environment known, and all relative movement data available), and map-building (having in mind the possible computational power and memory limitations the robot could have, given the fact that each loop must integrate new data in the map in a way the map continues to be ”usable” and at the same time not consuming too much time as new data will be arriving soon).

Sequential map-building is therefore the process of propagating through time a probabilistic estimate of the current ”state” of a map and the robot’s location relative to it.

The most common approaches taken in sequential map-building uses Extended Kalman Filters, Particle filters, and such kind of probabilistic methods.

Chapter 2

Odometry

The word odometry is composed from the Greek words hodos (meaning “travel”, “journey”) and metron (meaning “measure”).

Odometry [htte] [SK08] is the study of position estimation during vehicle navigation. The term is also sometimes used to describe the distance travelled by a vehicle. Odometry is used by robots to estimate (not determine) their position relative to a starting location. Basically odometry is the use of data from the movement of actuators to estimate change in position over time. This method is very sensitive to error. Rapid and accurate data collection, equipment calibration, and processing are required for odometry to be used effectively.

Suppose a robot has rotary encoders on its wheels. It drives forward for some time and then would like to know how far it has travelled. It can measure how far the wheels have rotated, and if it knows the circumference of its wheels, compute the distance.

But there is a big issue here: slippery. When moving, and specially when turning, the robot wheels tend to slip slightly and slide on the floor, and so the encoders are not going to measure the real robot displacement but the number of turns of the wheels. This also occurs when going forward and backwards, and even more when breaking and accelerating. All these errors accumulate over time and, if we don’t apply any kind of contingency to this error (mostly through the use of other sensing systems) the the odometry readings will become increasingly unreliable.

Chapter 3

Inertial

An inertial measurement unit, or IMU [httb] [SK08] works by detecting the current rate of acceleration, as well as changes in rotational attributes. This data is then fed into a controller, which calculates the current speed and position, given a known initial speed and position, by integrating the accelerations.

Some IMU units also provide compass information, usually with a magnetic device. This compass information can be useful in some cases but we have to take care, as is very sensitive to magnetic fields.

In figure 3.1 we can see the variation of the measures of the IMU device mounted on the back of a walking person. The IMU device used in this experiment was an XSens MTx [1]. The MTx is a small and accurate 2DOF Orientation Tracker. It provides drift-free 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn (rate gyro) and 3D earth-magnetic field. The MTx uses 3 rate gyros to track rapidly changing orientations in 3D and it measures the directions of gravity and magnetic north to provide stable reference. The systems real-time algorithm fuses the sensor information to calculate accurate 3D orientation, with highly dynamic response and stable over time.

The device was attached to the body of the walking person through the use of back rubber band as shown in figure 3.2. The experiment consisted of a simple walk and back, turning 180 degrees at the end of the walking line, and going back. The length was about 15 meters. The walk was performed indoors, for more realistic readings in terms of electromagnetic interference.

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[1] http://www.xsens.com/en/products/human_motion/mtx.php?

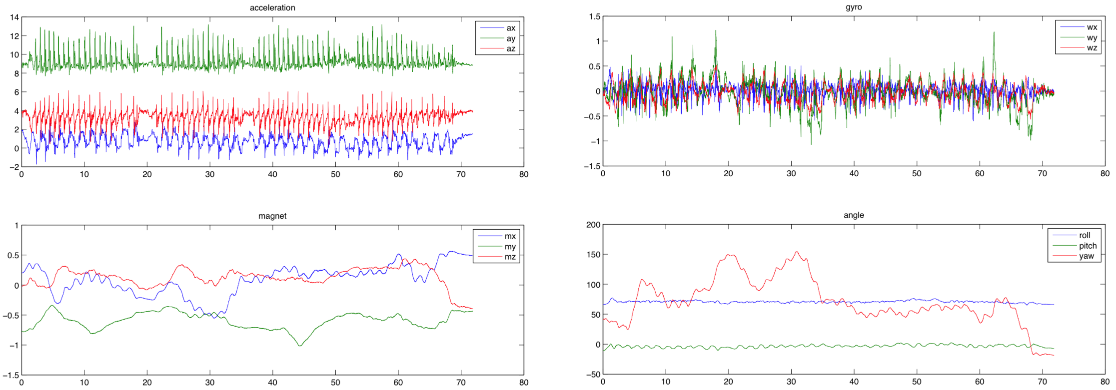

Figure 3.1: IMU readings from an XSens device on a walking person

Figure 3.2: IMU XSens MTx device on a back rubber band

The data provided by this IMU device can also be used for user information purposes in a Human Robot Interaction scheme. This way we can use a simple GUI application as shown in figure 3.3 or a more elaborated system like the device presented in figure 3.4.

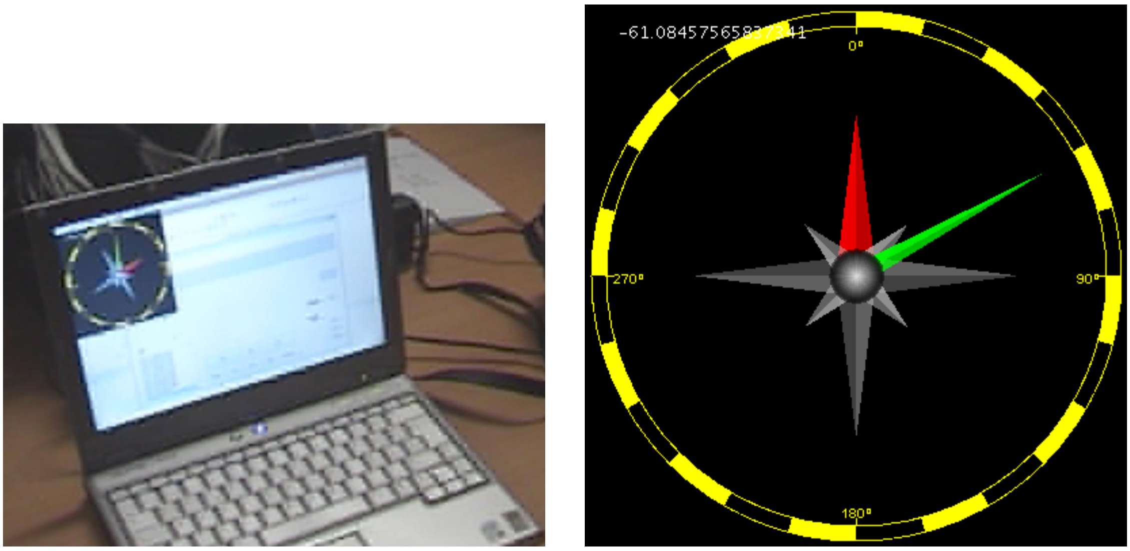

Figure 3.3: IMU data presented in a GUI application

Figure 3.4: IMU data fused with other inputs for HRI presentation

A major disadvantage of IMUs is that they typically suffer from accumulated error. Because the guidance system is continually adding detected changes to its previously-calculated positions (see dead reckoning), any errors in measurement, however small, are accumulated from point to point. This leads to ’drift’, or an ever-increasing difference between where the system thinks it is located, and the actual location.

Chapter 4

Vision

Although vision is usually an "Environment-Perception" mechanism, here we describe some techniques to estimate "Ego-Motion" information from vision data.

4.1 Visual Odometry

When traditional odometry techniques cannot be applied to robots due to non-standard locomotion methods, or simply because of the odometry universal precision problems, we have to find other ways of getting this data.

Visual odometry [httj] is the process of determining equivalent odometry information using only camera images. Compared to traditional odometry techniques, visual odometry is not restricted to a particular locomotion method, and can be utilized on any robot with a sufficiently high quality camera. Most existing approaches to visual odometry are based on the following stages.

1. Acquire input images: using either single cameras, stereo cameras, or omnidirectional cameras [Sca08] [CSS04]
2. Image correction: apply image processing techniques for lens distortion removal, etc
3. Feature detection: define interest operators, and match features across frames and construct optical flow field.
    (a) Use correlation to establish correspondence of two images, and no long term feature tracking.
    (b) Feature extraction and correlation (Lucas-Kanade method).
    (c) Construct optical flow field.
4. Check flow field vectors for potential tracking errors and remove outliers [CSNP04]
5. Estimation of the camera motion of the camera from the optical flow [SKLP05] [KAB$^+$06] [CMM06]

    (a) Choice 1: Kalman filter for state estimate distribution maintenance.
    (b) Choice 2: find the geometric and 3D properties of the features that minimize a cost function based on the re-projection error between two adjacent images. This can be done by mathematical minimization or random sampling.

6. Periodic repopulation of trackpoints to maintain coverage across the image.

4.2 Optical flow

The optical flow [httf] is the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer (an eye or a camera) and the scene [BR78] [WS85]

Optical flow techniques such as motion detection, object segmentation, time-to-collision and focus of expansion calculations, motion compensated encoding, and stereo disparity measurement utilize this motion of the objects surfaces, and edges [KRTA08] [SSB95]

The application of optical flow includes the problem of inferring not only the motion of the observer and objects in the scene, but also the structure of objects and the environment. Since awareness of motion and the generation of mental maps of the structure of our environment are critical components of animal (and human) vision, the conversion of this innate ability to a computer capability is similarly crucial in the field of machine vision [Bro87]

A two-dimensional image motion is the projection of the three-dimensional motion of objects, relative to the observer, onto its image plane. Sequences of ordered images allow the estimation of projected two-dimensional image motion as either instantaneous image velocities or discrete image displacements. These are usually called the optical flow field or the image velocity field [SSB95]

Fleet and Weiss provide a tutorial introduction to gradient based optical flow [FW06]

John L. Barron, David J. Fleet, and Steven Beauchimen provides a performance analysis of a number of optical flow techniques. It emphasizes the accuracy and density of measurements [JLBB94]

Optical flow was used by robotics researchers in many areas such as: object detection and tracking, image dominant plane extraction, movement detection, robot navigation and visual odometry [KRTA08]

Chapter 5

Infrared

Infrared light has been used for years in a wide range of topics[httc]. From thermographycal cameras and night vision cameras, to communications devices, meteorology, health care, etc.

5.1 Basic principles

The basic idea is this: a pulse of IR light is emitted by the emitter. This light travels out in the field of view and either hits an object or just keeps on going. In the case of no object, the light is never reflected and the reading shows no object. If the light reflects off an object, it returns to the detector and creates a triangle between the point of reflection, the emitter, and the detector, as shown in figure 5.1.

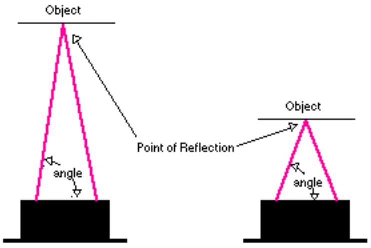

Figure 5.1: Different Angles with Different Distances

The angles in this triangle vary based on the distance to the object. The receiver portion of the detectors[1] is actually a precision lens that transmits the reflected light onto various portions of the enclosed linear CCD array based on the angle of the triangle described above. The CCD array can then determine what angle the reflected light came back at and therefore, it can calculate the distance to the object.

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[1] http://www.acroname.com/robotics/info/articles/sharp/sharp.html

Chapter 6

Ultrasound

6.1 What is Sonar?

Sonar[Mar05][Fra96] is a method of finding the distance to an object by measuring the time it takes for a pulse of sound (usually ultrasound) to make the round trip back to the transmitter after bouncing off the object. At sea level, in air, sound travels at about 344 metres per second (1130 feet per second). In practical terms this means 2.5 cm are covered in about 74 microseconds. These sorts of numbers are easily managed by a simple microcontroller system. In principle, all you do is send a burst of ultrasound from a suitable transmitter, setting a clock or timer running at the same time. When the receiver picks up the reflected signal or “echo”, the clock is stopped and the elapsed time is proportional to the distance. Although it seems to be simple, there are some practical problems that need to be addressed.

6.2 Transducer Characteristics

An ultrasonic transducer is basically a miniature loudspeaker tuned to emit or receive a single frequency, usually 40 kHz. The sound does not emerge from the front of the device in a nice pencil-shaped beam, but has a shape like that in Figure 6.1.

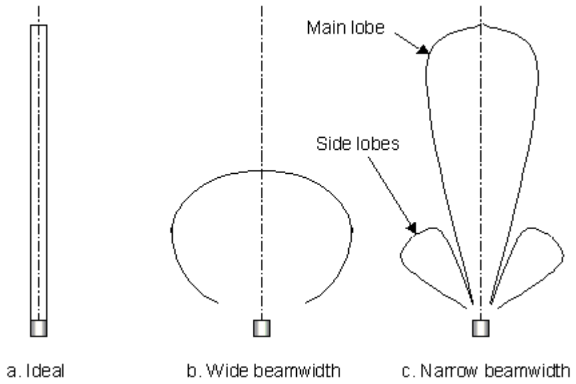


Figure 6.1: Transducer beam/sensitivity patterns

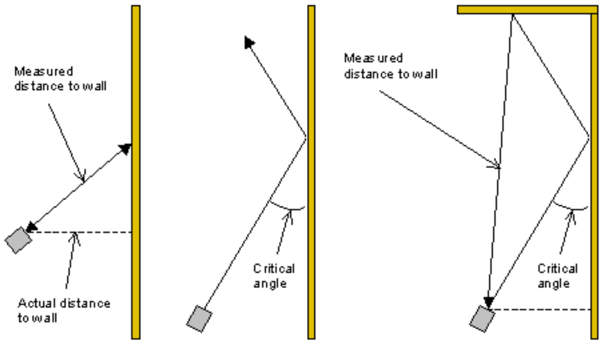
We should have in mind that these shapes are three-dimensional, so Figure 6.1a would be a cylinder shape. The wide beam transducer puts out a lot of energy sideways, and if the receiver sensitivity has the same shape then we may have problems with the "direct" signal. In other words the receiver picks up the transmitted pulse not just the echo. This is known as "cross-talking" between sonar transceivers.

6.3 Electronics

The transmitter transducer can be driven directly from common microcontrollers. The piezoelectric device resonates at its natural frequency. A single pulse applied to the terminals will make it "ring" at 40 kHz for a number of cycles. The receiver transducer output will be very small, so an amplification circuit is necessary to bring it up to a sensible level. The clock or timer necessary for measuring the signal "time of flight" is also usually found built-in in most microcontrollers.

6.4 Reflection Problems

When the waves are incident on an object, part of their energy is reflected. In many practical cases, the ultrasonic energy is reflected in a diffuse manner. That is regardless of the direction where the energy comes from, it is reflected almost uniformly within a wide solid angle, wich may approach 180 degrees. If targets were always at right-angles to the axis of the beam, distance measurements would be reliable and accurate. Unfortunately they seldom are, and to make it worse the target material may be such that no signal is bounced back at all. Figure 6.2 illustrates some problematic situations. For simplicity, the signal path is shown as a single line. If an object moves, the frequency of the reflected waves sill differ from the transmitted waves. This is called the Doppler effect



a. Triangle error b. Specular reflection c. Corner error

Figure 6.2: Sources of error

If the robot is heading towards the wall at an angle, then you can see from Figure 6.2a that the measured distance will be too long. A strange effect occurs when the angle with the wall becomes shallower as in Figure 6.2b. At a certain critical angle, Specular Reflection takes place and all the signal is reflected away from the robot. In other words, the wall disappears because there is no echo. This critical angle depends on the wall material and its surface: a very smooth gloss finish on a skirting board can lead to specular reflection. Slightly rough surface materials, such as cardboard cause the signal to be scattered in all directions, so at least some makes it back to the receiver. Figure 6.2c shows how specular reflection in a corner can fool the sonar into making a very large error indeed.

The hardness of the target material is also an important factor. A skirting board will reflect most of the energy, absorbing very little, but soft furnishings will do the reverse. This means that the maximum detection range is large for the walls, but soft objects may not be "seen" until the robot is nearly on touching them. Note that this does not affect the accuracy of distance measurements, only the maximum range at which a particular object can be detected.

6.5 Noise Interference

The sonar signal is a short burst of ultrasound at 40 kHz, way above frequencies humans can hear. Bats use sonar at these and higher frequencies. The transducers are tuned piezo-electric devices so the transmitter only emits the one frequency, and the receiver is very insensitive to frequencies away from 40 kHz. Most extraneous noise from other robot parts will thus be ignored. However motor vibration fed to the transducer through the robot body will cause trouble. Sharp mechanical shocks can also provide a false echo. That is why transducers are usually mounted in foam rubber. Only the receiver transducer needs this treatment however. An alternative would be to mount the motor/gearbox assemblies on foam rubber instead.

6.6 New wide-beam approach

Recently, a new wide-beam [1] based approach has been introduced in contra position to the narrow-beam classical approach. Using several wide-beam sensors and firing them in the correct order we can be able to detect small objects, and even to get the correct relative position of them. This is accomplished through the use of techniques like “Different Time of Arrival”. The principle is that knowing the geometrical distribution of sensors and the order of firing, the different readings in each sensor will give us an approximation of the position of the obstacle by triangulation.

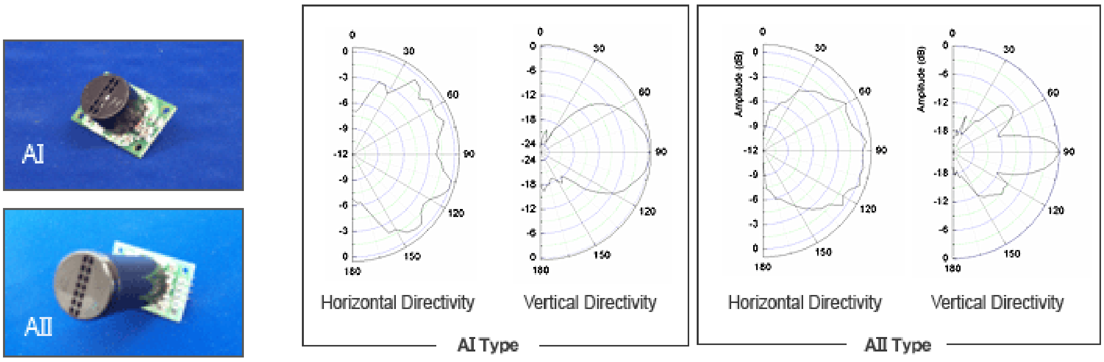


Figure 6.3: AniBat Wide-Beam sonar sensors

Using this new devices we have performed a set of tests for the problem of the estimation of the distance by using ultrasound waves. From this study we can say that the use of ultrasound signals can be used as a feasible alternative to node localisation.

The experiment consists in the estimation of distances by measuring the time of propagation of ultrasonic waves. To achieve this purpose we have used two ultrasonic transmitters and receivers from Hagisonic (Figure 6.3).

Two different models of sensors are intended to be used in the future for implementing Time Difference of Arrival (TDoA) in order to derive position information. Those sensors (HG-M40DAI and HG-M40DAII) are ultrasonic object detectors and range finders that offer very short- to medium-range detection. The AII model offers a special narrow directional response, 25 30 degrees in vertical direction to minimize the reflection of unwanted sound waves.

The configuration includes an ultrasound transmitter, emitting pulses that the receiver will detect at different distances from the emitte (Figure 6.4).

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[1] http://www.hagisonic.com/

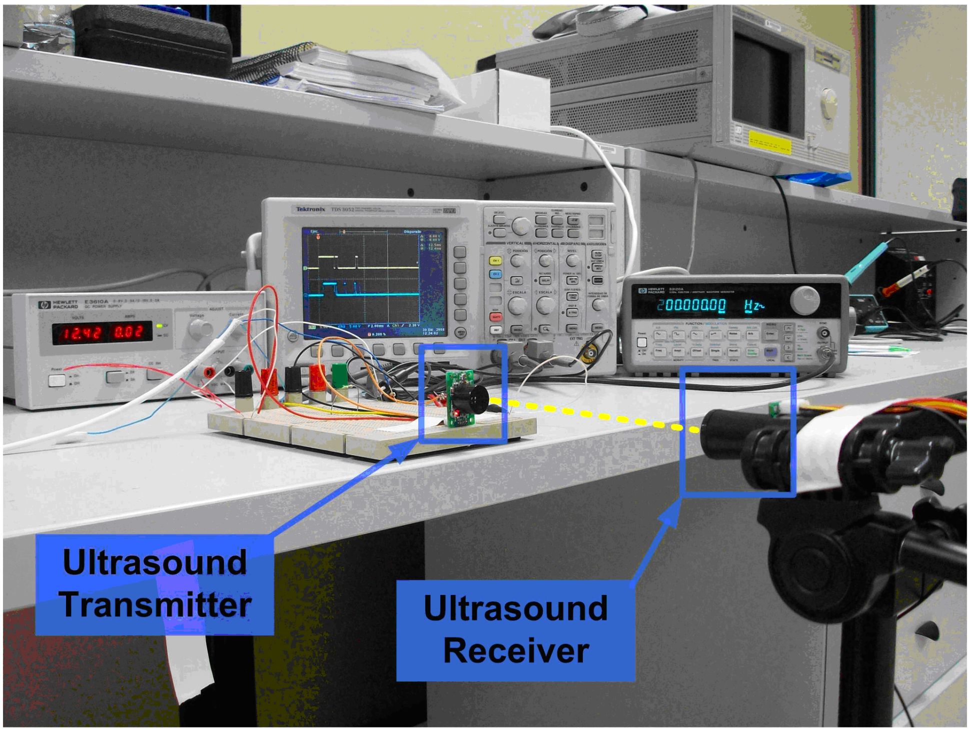


Figure 6.4: Experimental setup

In the receptor, several pulses can be received, due to the echoes produced by reflections. The first impulse can be considered as the reception of ultrasound waves in straight line from the emitter (see Figure 6.5). A time delay appears between transmission and reception, fact that will be used to estimate de distance from transmitter to receiver.

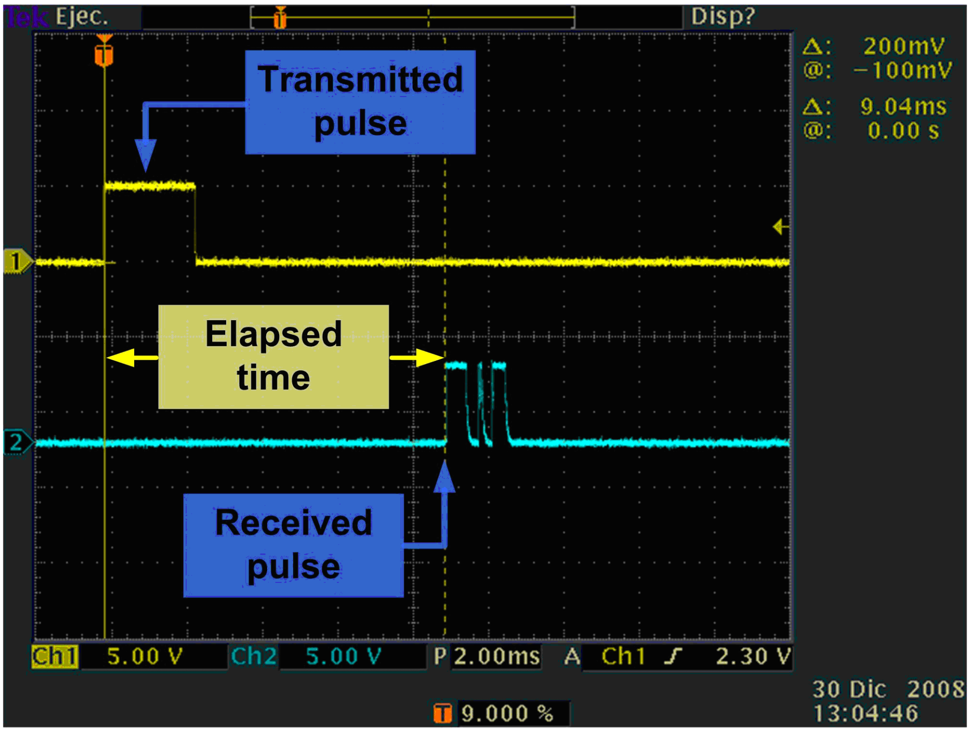


Figure 6.5: Time delay between transmission and reception

In order to analyze the feasibility of using ultrasound waves to estimate the distance, several measurements have been taken in steps of 50 cm, ranging from 0 to 4 meters (see Figure 6.6).

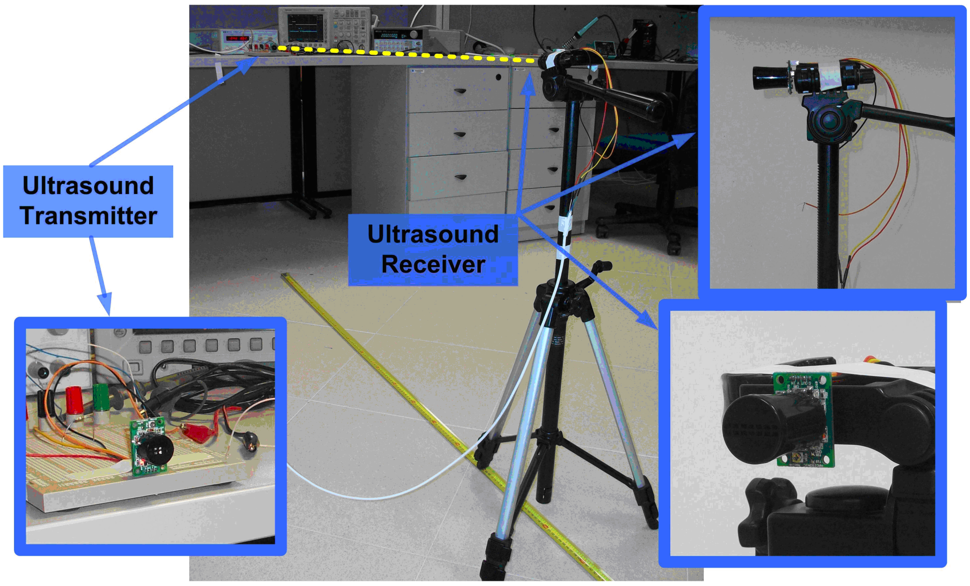
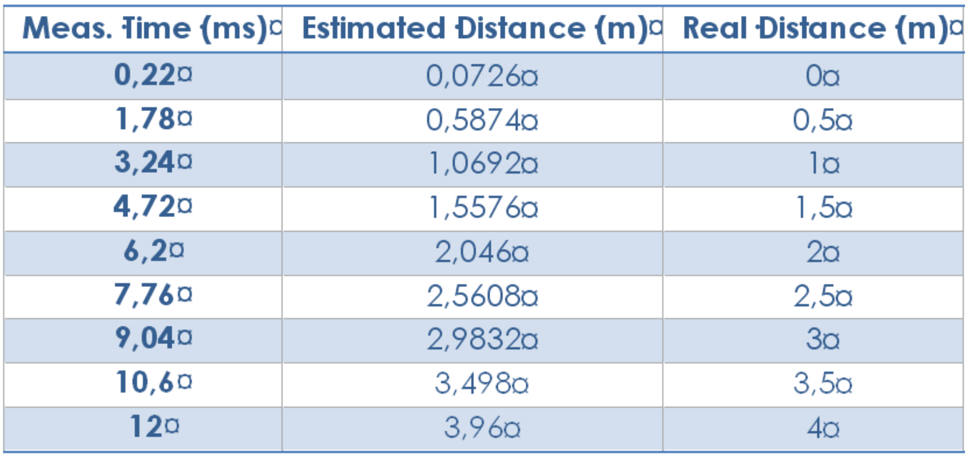


Figure 6.6: Distance measurements

The time measurements for each increasing distance are showed in Figure 6.7. The estimation of the distance has been done considering a sound propagation speed of 330 m/s.



Meas. Time (ms)	Estimated Distance (m)	Real Distance (m)
0,22	0,0726	0
1,78	0,5874	0,5
3,24	1,0692	1
4,72	1,5576	1,5
6,2	2,046	2
7,76	2,5608	2,5
9,04	2,9832	3
10,6	3,498	3,5
12	3,96	4

Figure 6.7: Experimental vs. theoretical values

As can be seen in Figure 6.8, the estimated distances closely approach to the real measurements.

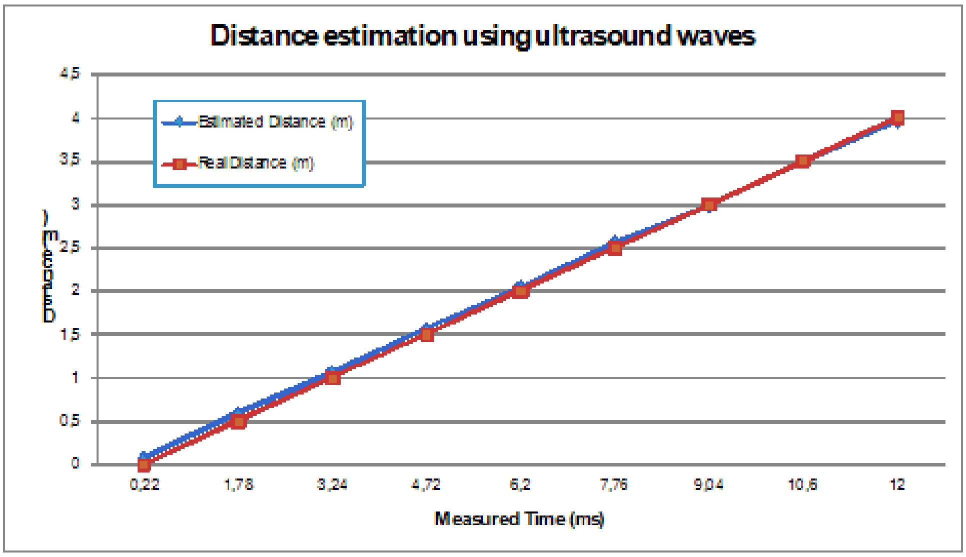


Figure 6.8: Graphical representation of estimated distances

In conclusion we can say that the estimation of distances by measuring the time of propagation of ultrasonic waves can be useful for several localisation methods based on the knowledge of some distances. The experiments show a good performance of the sensors for distances up to 4 meters. As a future work, we are planning to use synchronization radio signals in order to estimate distances between two independent nodes.

Chapter 7

Optoelectronic range finder

7.1 Optical sensors

Optical sensors are nowadays probably the most popular for measuring distances, and so for position and displacement measures also. Their main advantages are, among others, simplicity, relatively long operating distances, accuracy, and insensitivity to magnetic fields and electrostatic interferences, which makes them quire suitable for many sensitive applications. They usually require at least three essential components: a light source, a photodetector, and light guidance devices, which may include lenses, mirrors, optical fibbers, etc, as shown in figure 7.1. Light is guided towards a target and is diverted back to detectors. The light emitted from an optoelectronic sensor is usually polarised light [Jud], which enhances the sensing capabilities and the immunity to interferences.

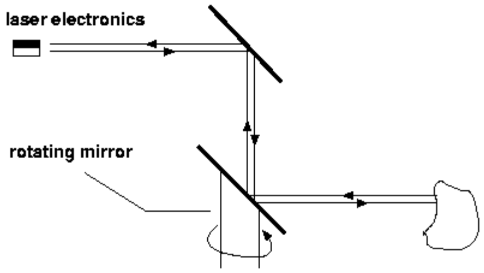


Figure 7.1: Laser range finder schematics

7.2 Laser range finders

Laser range finders are also known as LIDAR (Light Detection and Ranging) devices. LIDAR [httd] is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves instead of light, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. LIDAR technology has application in archaeology, geography, geology, geomorphology, seismology, remote sensing and atmospheric physics [CH07].

A laser typically has a very narrow beam which allows the mapping of physical features with very high resolution compared with radar. In addition, many chemical compounds interact more strongly at visible wavelengths than at microwaves, resulting in a stronger image of these materials. Suitable combinations of lasers can allow for remote mapping of atmospheric contents by looking for wavelength-dependent changes in the intensity of the returned signal.

The beam densities and coherency are excellent. Moreover the wavelengths are much smaller than can be achieved with radio systems, and range from about 10 micrometers to the UV (ca. 250 nm). At such wavelengths, the waves are ”reflected” very well from small objects. This type of reflection is called backscattering. Different types of scattering are used for different lidar applications, most common are Rayleigh scattering, Mie scattering and Raman scattering as well as fluorescence. The wavelengths are ideal for making measurements of smoke and other airborne particles (aerosols), clouds, and air molecules [CH07].

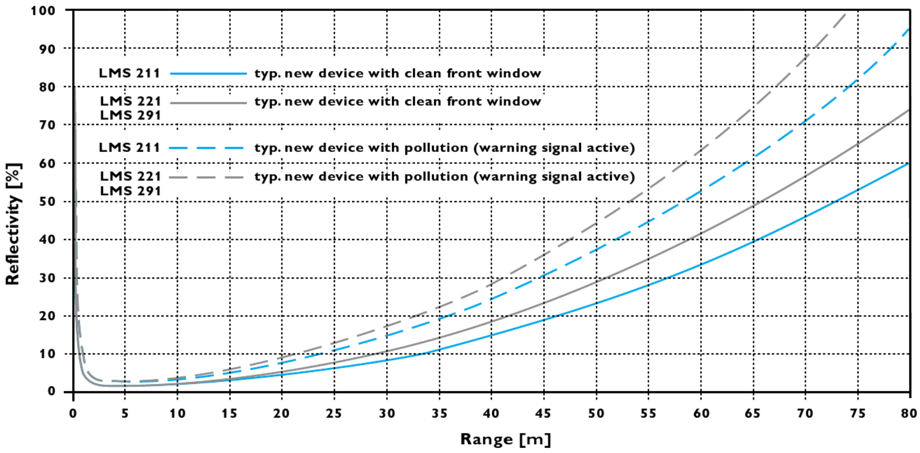


Figure 7.2: Sick LMS 211, LMS 221, LMS 291, relationship between reflectivity and range with good visibility[rr03]

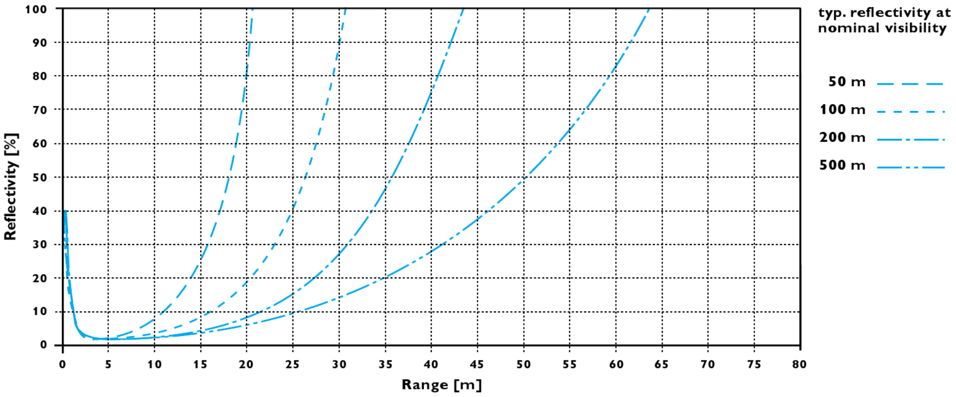


Figure 7.3: Sick LMS 211 - relationship between reflectivity and range in fog[rr03]

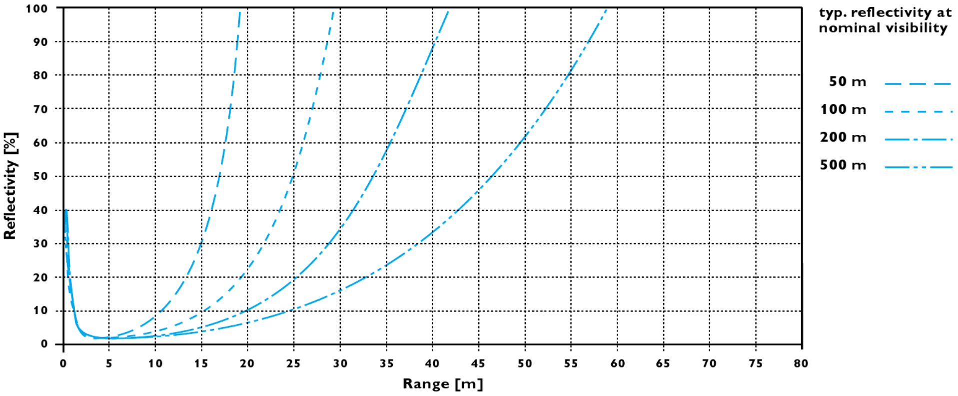


Figure 7.4: Sick LMS 221/LMS 291 - relationship between reflectivity and range in fog[rr03]

Although is the most accurate system we can use by now, in the field of the GUARDIANS project is almost useless, as we face environments full of smoke [PMdA08] were it is proved that typical laser range finder devices commonly available are useless from a density of smoke on, and for a small distance on.

In the sequence of images 7.5 we can briefly see how the laser range finder is blinded when a high density of smoke is reached. The smoke was inserted using standard smoke machines like the ones used in Discos. At a low smoke density, the laser range finder has no problem, but from a point on, it starts having scattered readings more and more often as the density increases, up to the point that the laser is completely blinded for distances bigger than a few centimetres.

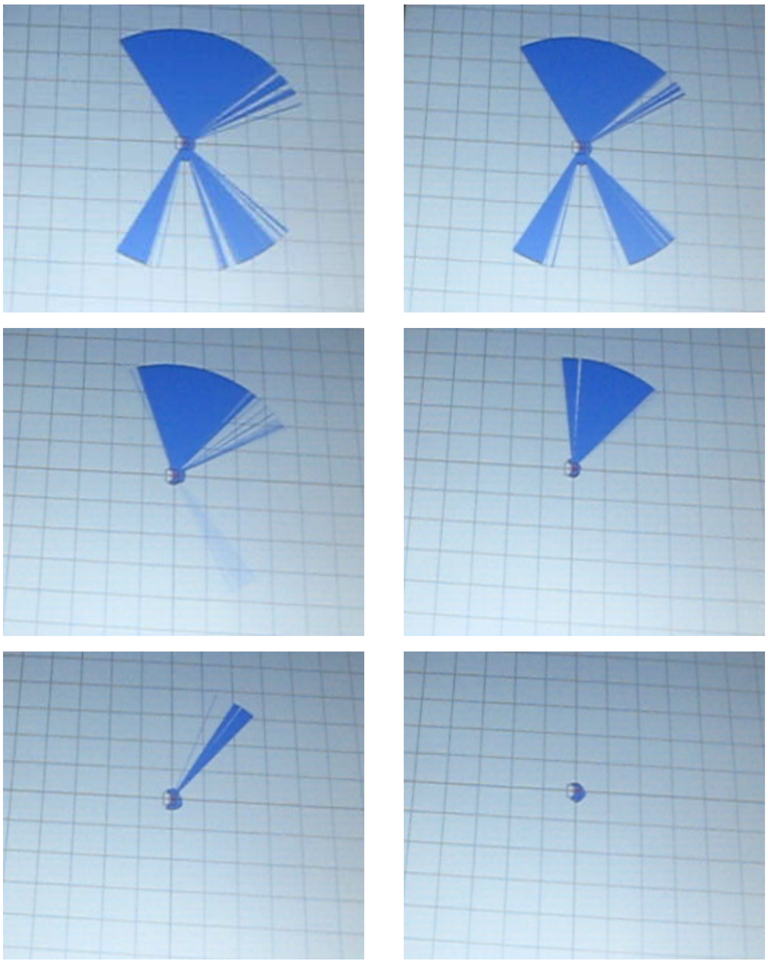


Figure 7.5: Sequence of laser range finder readings while inserting smoke

Using Laser Range Finder technology we developed a basic human leg following behaviour. The system uses the ranging data and the last relative position of the legs to detect were the legs are at each moment. The system needs the starting human relative position with respect to the robot to start tracking the legs. We can also provide a range parameter that will determine the distance the robot will try to maintain with respect to the human at each time. By default it is set to 1 meter. Using the detected relative position of the human with respect to the robot we compute a velocity control in terms of angular an linear speed that provides this following behaviour. When the human moves fast, the robot also speeds up. When it reaches a point where the human is near it moves slowly. The transition is completely smooth between fast ans slow motion as it depends on the distance of the human. Some stills from a demonstration video [1] can be seen in figure 7.6.

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[1] http://www3.uji.es/ nomdedeu/HumanFollow_007_Custom.mov

Figure 7.6: Sequence of stills from the following behaviour video

Chapter 8

Micro and Millimeter wave Radar

The basic principle [httl] [httg] of operation of primary radar is simple to understand. However, the theory can be quite complex. An understanding of the theory is essential in order to be able to specify and operate primary radar systems correctly. The implementation and operation of primary radars systems involve a wide range of disciplines such as building works, heavy mechanical and electrical engineering, high power microwave engineering, and advanced high speed signal and data processing techniques. Some laws of nature have a greater importance here.

8.1 Basic principles

Radar measurement of range, or distance, is made possible because of the properties of radiated electromagnetic energy.

The electromagnetic waves are reflected if they meet an electrically leading surface. If these reflected waves are received again at the place of their origin, then that means an obstacle is in the propagation direction.

The primary difference between lidar and radar is that with lidar, much shorter wavelengths of the electromagnetic spectrum are used, typically in the ultraviolet, visible, or near infrared. In general it is possible to image a feature or object only about the same size as the wavelength, or larger. Thus lidar is highly sensitive to aerosols and cloud particles as well as smoke [CH07]. In the other hand, radar has less accuracy.

An object needs to produce a dielectric discontinuity in order to reflect the transmitted wave. At radar (microwave or radio) frequencies, a metallic object produces a significant reflection. However non-metallic objects, such as rain and rocks produce weaker reflections and some materials may produce no detectable reflection at all, meaning some objects or features are effectively invisible at radar frequencies. This is especially true for very small objects (such as single molecules and aerosols) [CH07].

Electromagnetic energy travels through air at a constant speed, at approximately the speed of light, 300000 kilometers per second. This constand speed allows the determination of the distance between the reflecting objects (airplanes, ships or cars) and the radar site by measuring

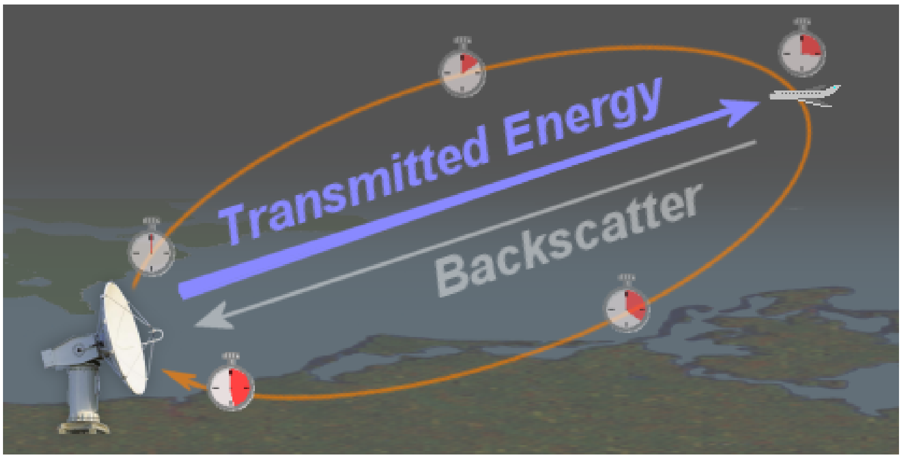

Figure 8.1: Radar principle: The measuring of a round trip time of a microwave

the running time of the transmitted pulses.

This energy normally travels through space in a straight line, and will vary only slightly because of atmospheric and weather conditions. By usind of special radar antennas this energy can be focused into a desired direction. Thus the direction and elevation of the reflecting objects can be measured.

These principles can basically be implemented in a radar system, and allow the determination of the distance, the direction and the height of the reflecting object.

Millimetre wave technologies have proved to work under the worst weather circumstances [VT86] and even with heavy dust. Therefore, it must been taken seriously as an option to ensure ranging capabilities in the field of the GUARDIANS project or environments alike.

A review of the use of millimetre wave radar for robotics is presented in [BBS01]. The paper also includes a brief overview of the different radar and scanner technologies.

8.2 Industrial radar sensors

8.2.1 Elva-1

Their Distance Sensor[1] is based on millimeter wave FMCW (frequency-modulated continuous wave) radar principles. It is free from laser, acoustic, and microwave radar shortcomings. It is characterized by a narrow beam that's good for enclosed areas like ore passes, because of 94 GHz FMCW radar operational frequency that is equivalent to 3mm wave length, the sensor provides an excellent penetration of dust and water vapour. The Distance Sensor works well even with a dust sticking on antenna. With a narrow beam, the Distance Sensor can build a precise surface profile at a hopper (mechanical scanning required). The operation range of Distance Sensor is 500m, that allowing using it at deep mines, where typical passes are up to 300m but rarely even longer.

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[1] http://www.elva-1.com/

The distance measurement system consists of radar (with external power supply), that measures the distance and controller that processes the radar signal, calculates the distance and presents the result to operator.

There is a prototype mounted on a rotary joint, for airport and defense applications. It consists of a WiFi module, thus it only needs +24VDC connection. Image 8.3 was obtained with a sectorial antenna (30dB gain, 600 mm, 0.5 degrees beam).

Figure 8.3 shows the results of a prototype. The system consists of a radar and a sectorial antenna, mounted on a rotary joint.

Figure 8.2: Prototype Radar mounting

8.2.2 NavTech radar

A radar would be the ideal sensor for our application. Companies like NavTech Inc. [2] are often asked to provide a solution when lasers prove to be unsuitable due to the environmental conditions. Particularly in environments where there is a lot of smoke or dust. The radar suffers almost no attenuation due to these conditions.

They would recommend their industrial radar sensor for this application. This unit weighs approximately 16Kg. This unit has a 2 degree beam width and an instrumented range up to 800m. In practice a useful maximum range is probably 300-500m depending on the size of the object we wish to look at. They also supply units with a limited maximum range for this type of application. E.g. 50-100m. This reduces the data rate and therefore reduces the bandwidth on the Ethernet interface. The interface to this unit is via a standard 100Mbit Ethernet connection and can therefore be connected directly to a PC or added to a network. It requires 24Volts at 1A.

The unit scans through 360 degrees. The scan rate can be from 1Hz to 5 Hz depending on the application. In most applications the radar takes 900 measurements per second although it may be possible to increase this depending on the maximum range we wish to see.

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[2] http://www.nav-tech.com/

Figure 8.3: Prototype Radar test

8.2.3 MaCom SRS radar

M/A-COM[3], a business unit of Tyco Electronics provides a new 24 GHz ultra wide band (UWB) short-range radar sensors for driver-assistance systems designed to improve safety and comfort functions in automotive applications by providing object detection and tracking to further support drivers.

This sensor is theoreticaly capable of:

- With a range of 1.8-meters, detect small objects in front of large objects and measure direction of arrival
- Scan out up to 30 meters to provide an advanced warning of an imminent collision.
- Detect and distinguish between objects as close as 15 centimeters from each other.

8.2.4 Call for input on short-range radar systems (SRR)

Radar technologies have caught the eye of politicians and car manufacturers as the technologies to enhance the security of drivers along Europe and specially short-range radar systems (SRR) [4]. The long term goal is to have short range radar systems available in a harmonised way on 1 July 2013. This will provide us, the research community, a new source of low cost market-ready reliable radar devices to work with.

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[3] http://www.macom.com/macom_prodnews.asp?ID=1094

[4] http://ec.europa.eu/information_society/newsroom/cf/itemdetail.cfm?item_id=4629

Chapter 9

Radio Frequence and Ultrasound position estimation

9.1 Wave-based Localisation. Common principles

Localization involves one question: Where is the robot now? Although a simple question, answering it isn't as easy, as the answer is different depending on the characteristics of your robot. Localization technics that work fine on an outdoor robot wouldn't work very good or even at all for an indoor robot.

All localization technics have to provide 2 pieces of information:

- what is the current position of the robot?

- where is it heading to?

The first could be in the form of Cartesian or Polar coordinates. The latter as compass headings.

The current position of a robot can be determined in several very different ways. Ones will work well outdoors (like GPS) while they are useless indoors.

In the GUARDIANS project we point to an indoors environment, so we will focus on indoor technologies rather than outdoors systems.

Most of the indoors technologies involve using some kind of signal spreading through the air. Measuring "Time of flight" or "Time of arrival" [htti], "Time Differece of Arrival" [htth] and "Angle of Arrival" [htta], and knowing the spreading speed of the specific signal as well as the geometrical position of the receivers, the position of the emitter can be determined with more or less accuracy depending on the technology, the number of beacons, the conditions of the environment, etc.

9.2 Wifi

In this case, common wifi ethernet devices are used. While packets are sent and received through the wireless network, we can also measure the "strength" of the signal for each packet. Doing some tests for each type of ethernet device we can build a regression table that will allow us in further experioments to estimate the distances the emitter is from us.

Using a trigonometric approach, with three or more network partners we can estimate a single plannar position were we are:

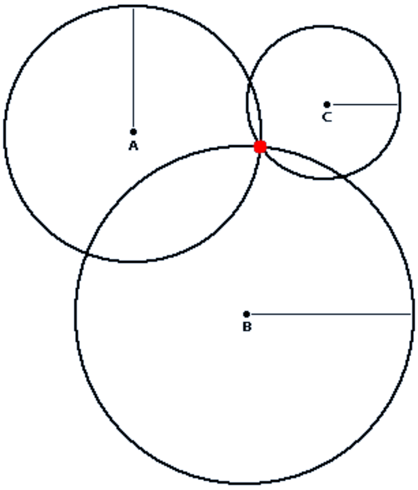

Figure 9.1: Trilateration

Multilateration, also known as hyperbolic positioning, is the process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from the object to three or more receivers. It also refers to the case of locating a receiver by measuring the TDOA of a signal transmitted from three or more synchronised transmitters.

Multilateration should not be confused with trilateration, which uses distances or absolute measurements of time-of-flight from three or more sites, or with triangulation, which uses a baseline and at least two angles measured e.g. with receiver antenna diversity and phase comparison.

This approaches can also be considered while using other communications technologies, like Bluetooth or ZigBee.

More in deep results can be found in our other work [SMN$^+$09].

9.3 Sonar

Ultrasounds do not suffer from electromagnetic interference with or from other equipment. In the other hand, ultrasounds can be "blinded" if they reach some specific materials, as the reflection vary depending on the characteristics of the materials.

The same techniques described in 9.2 can also be applied while using sonar [MDB96] as it also travels through the air with a known speed and attenuation. In addition, some of the techniques for ranging data based localisation, like the Monte Carlo localisation algorithms, will allow the use of sonar range data also, having in mind the different accuracy of this ranging data and laser based ranging data.

There are several companies that provides sonar based location systems, as for example, Sonitor[1]. They provide ultrasound real time location systems (RTLS) that automatically tracks the real-time location of movable equipment or people in complex indoors environments with high room-level, or zone-level accuracy (such as bed-level) within a room.

For this technique to work, it usually needs wireless detectors installed throughout the environment, and Tags attached to every item that we want to track. The motion activated Tag transmits its unique identification signal using ultrasound waves as the item moves throughout the environment area. Detectors transmit signals in digital format via the existing wireless LAN to a central computer unit that stores the information about the Tag's location and the time of the receipt of the Tag signal. This information enables to retrieve a Tag's position and/or movement and determine precisely by room where the item with that specific Tag is located.

The main problem with this approach is that a pre-setup of the environment is needed to be able to locate the robots, and so, robots will not be able to locate but in very specific buildings, and only if the electric power is working properly. It also need an infrastructure network what is an extra constraint.

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[1] http://www.sonitor.com/

Chapter 10

Ultra Wideband (UWB)

10.1 What is UWB?

Ultra Wideband (UWB) systems transmit signals across a much wider frequency than conventional systems and are usually very difficult to detect. The amount of spectrum occupied by a UWB signal, i.e. the bandwidth of the UWB signal is at least 25% of the center frequency. Thus, a UWB signal centered at 2 GHz would have a minimum bandwidth of 500 MHz and the minimum bandwidth of a UWB signal centered at 4 GHz would be 1 GHz. The most common technique for generating a UWB signal is to transmit pulses with durations less than 1 nanosecond [httk].

UltraWideBand (UWB) technology [SM04] [BG04] [hw] is a quite old born technology, but nowadays is a new trend in radio signal based technologies for mass data transfer mainly, but also for localisation and tracking of goods, materials, and any kind of item that can carry a tag. In fact, an european industrial driven project[1] has been created to carry on Ultra-Wideband Technology Research.

UWB is used as a part of location [SGG08] [FDMWry] systems and real time location systems. The precision capabilities combined with the very low power makes it ideal for certain radio frequency sensitive environments such as hospitals and healthcare. Another benefit of UWB is the short broadcast time which enables implementers of the technology to install orders of magnitude more transmitter tags in an environment relative to competitive technologies.

UWB[2] is also used in ”see-through-the-wall” precision radar imaging technology, precision locating and tracking (using distance measurements between radios), and precision time-of-arrival-based localization approaches [SKAK06].

We can find now several projects, companies, and research labs, working in this field to get a new high accuracy, high reliability, system. For example. the EUROPCOM[Har08] concept and project that aims to investigate in the UltraWideBand (UWB) technology and the positioning system fields.

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[1] EUWB (FP7-ICT-215669) http://www.euwb.eu/

[2] http://www.uwbforum.org/

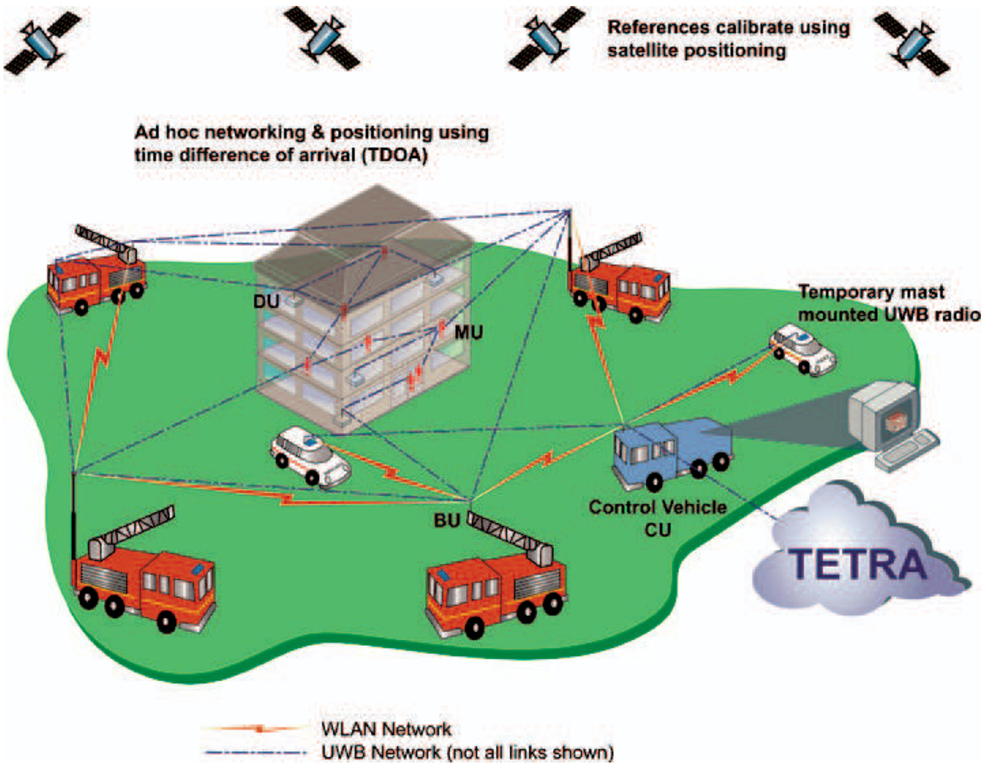

Figure 10.1: EUROPCOM concept

The Ubisense [3] precise real-time location system based on Ultra-Wideband technology (UWB) is able to locate, track, record and analyse the movements of goods and people to an accuracy of up to 15cm in 3D. As assured by the company staff.

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[3] http://www.ubisense.net/

Chapter 11

Conclusion

This work has been carried out within Task 2.2 *Sensor platform*. This task aims to develop the sensing capabilities of the robot platform.

In order to develop a full-functioning system it is clear that a very well designed integration is needed. Not only a single sensing technologies is able to solve every problem. Thus finding and using the strengths of each technology, will complement the weaknesses of the others, giving us a much more accurate and useful information of the environment, and so providing us with a base well informed layer to build new algorithms upon.

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[httb] http://en.wikipedia.org/wiki/Inertial_measurement_unit. Imu.

[httc] http://en.wikipedia.org/wiki/Infrared. Infrared.

[httd] http://en.wikipedia.org/wiki/LIDAR. Lidar.

[htte] http://en.wikipedia.org/wiki/Odometry. Odometry.

[httf] http://en.wikipedia.org/wiki/Optical_flow. Optical flow.

[httg] http://en.wikipedia.org/wiki/Radar. Radar.

[htth] http://en.wikipedia.org/wiki/Time_difference_of_arrival. Tdoa.

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