



## Investigating ultra-wideband location positioning as a guidance system for mobile robotics

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### ABSTRACT

The ability to track the real-time location and movement of robots offers a range of useful applications in areas such as safety, security and the supply chain. Real-time Ultra Wide Band Location determination is a technology that uses Ultra-wideband (UWB) and aims at delivering high positional accuracy in harsh industrial environments that previously caused problems for traditional location systems due to electromagnetic interference. Ultra Wide Band systems can calculate the location of tags which are designed to be mounted on assets or worn by a person. They transmit UWB signals that are received by sensors which contain an array of antenna and ultra-wideband radio receivers. The data from these sensors combined with dedicated software uses algorithms to work out the angle of arrival (AOA) of the UWB signal from the tag which is then compared to the time difference of arrival (TDOA). This information is determined between pairs of sensors connected by timing cables. The combination of AOA and TDOA measurement technologies delivers a precise three dimensional location system that is powerful, reliable, and robust for harsh industrial environments. This research examines the use of ultra wide band technology in tracking items such as mobile robots.

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### Introduction

Location systems can be divided into two types. There are outdoor and indoor location systems. The overall principle upon which these systems operate is to locate an object accurately. There are various types of location systems some wireless, others based on Video imaging and digital location systems but they all have their advantages and disadvantages. Outdoor location systems are costly to implement. The infrastructure required for these types of systems include satellites and receivers. Their performance can be affected by weather conditions and other atmospheric conditions and the accuracy which they deliver is not as accurate as that of indoor location systems. Indoor location devices still have some problems such as the ability to locate objects exactly. This can be caused by a number of factors depending on the system being used. Each system has its advantages and its disadvantages. Some can provide a high degree of accuracy but are not suitable for manufacturing applications as they do not perform well in these conditions due in part to interference caused by other machinery. The cost of some of these systems is also a factor as they can be very expensive to implement. Scalability is another issue that requires investigation. However in order to evaluate these systems we must look at how the different systems operate. The benefits of being able to track objects accurately cannot be underestimated. Industry has longed to be able to effectively track objects, components, assets and people. Ultra Wide Band technologies are often described as the next generation of real time location positioning systems. In the world today industry is becoming more competitive and any technology which can provide a competitive edge is welcomed and much sought after. However not all technologies live up to their claims which can prove very costly to industry. Therefore this research

investigates the use of a real time indoor positioning system to guide robots in performing various tasks. The aim is to evaluate and test the accuracy, precision and robustness of a location detection system in a small geographical area in order to ascertain how beneficial an indoor UWB location detection system could be in the field of robotics and how industry could benefit from this technology [1]. The adoption of radio frequency is simpler than face-recognition using vision, guarantees a higher success rate and allows the identification of each robot regardless of its morphology. There might be similar robots of the same shape or colour. As wireless networks have become omnipresent, we plan to examine positioning solutions that would allow robots to locate themselves by listening for radio beacons such as 802.11 access points.

### Location Positioning

Indoor location systems are required to provide more accurate location detection than outdoor systems and they often have to work in harsher environments. Often RF signals are interfered with because of electromagnetic discharge from other sources. Therefore indoor location systems still have problems to overcome regarding the accuracy location detection. Ultra-wideband employs sonic detection methods that help overcome many of the difficulties that other indoor location systems suffer from. Ultra-wideband location detection systems combine sensors and transmitting tags to provide coverage of an area referred to as intelligent space which is where accurate information can be obtained about location of objects. Indoor Positioning Systems (IPS) track objects in buildings. These may be pre-tagged objects, or discovered objects. Examples of tagged objects are patients or equipment in a hospital. Examples of discovered objects are people in burning buildings or soldiers on a battlefield. An IPS uses other radio technology, infrared, or

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ultrasound, to overcome this limitation. Infrared and ultrasound are useful in environments where wireless radio frequencies may interfere with critical equipment. The robotics industry can also benefit from advanced location detection systems. Using a combination of sensors and taking accurate measurements of a tagged robots location, one can accurately predict, with better accuracy, the position of a robot in relation to its surroundings. Mobile robots will then be able to operate autonomously in their environment, with accurate prediction of location paths and navigation direction, making them more productive and reliable.

#### **Wi-Fi (802.11) Based Indoor Positioning**

Sound navigation and ranging is a technique that uses sound propagation (usually underwater) to navigate, communicate with or detect other vessels. Sonar may be used as a means of acoustic location. Acoustic location in air was used before the introduction of radar. Radio Detection and Ranging, early systems were used to detect metallic ships in dense fog but not its distance. During the Second World War Britain exploited this technology as a defense system against German aircraft attack to great effect. Radar was able to identify the range, altitude direction, or speed of both moving and fixed objects such as aircraft, ships, motor vehicles, weather formations, and terrain. The Radar system works by using a transmitter to emit radio waves that are reflected back by the object that one is trying to locate. Wi-Fi positioning algorithms can analyse signal strength. One commercial implementation is from Ekahau. The Ekahau RTLS system uses software based location tracking to accurately track assets and people over any existing Wi-Fi network. It does this by using algorithms to compute the location of tags which have the Ekahau location protocol built in and use 2-way Wi-Fi signals to deliver the required accuracy across a geographical area, without the need to install any software or hardware in remote sites.

The Place Lab architecture is an example of an indoor positioning system. It is made up of three elements: radio beacons in the environment; databases holding beacon location information and Place Lab clients that estimate the location from these data [2]. Place Lab uses open source software developed by Intel's research center in Seattle and an 802.11 interface which combine to predict location positions. It uses known positions that are stored in a database combined with 802.11 signals to establish a user's location. However when tested to find a users position in a relatively small geographical area like a University Campus, it does not achieve very good accuracy.

#### **Camera Based Indoor Positioning**

Vicon is a digital optical and video based motion tracking system that allows for a better understanding of movement. By being able to track and analyse movement it offers solutions to real life problems. This advanced optical motion capture system consists of cameras, controlling hardware and software that is able to analyse data and output in a meaningful way. Vicon offers high speed, high resolution, interference-free, real-time tracking for engineering related studies. This system is designed to be expandable and allow easy integration into the working environment. The system allows for the accurate tracking of objects by use of cameras, triangulation and software that allows users to analyse the data. A benefit of this system is that it does not use radio frequency (RF) which is sometimes prone to metallic interference. It claims to be able to provide a positional accuracy of better than 1 mm. However the Vicon system is very expensive and involves the installation of many cameras.

#### **Ultra-Wideband**

Ubisense Ultra-wideband (UWB) is a radio technology that can be used at very low energy levels for short-range high-bandwidth communications using a large portion of the radio spectrum. Ultra wideband has gained in popularity as a new technology and has been the focus of much research and development. It offers solutions to applications, such as see-through-the-wall, security applications, family communications and supervision of children, search and rescue, medical imaging, control of home appliances, which make UWB an ideal candidate for wireless home network [3]. It is essential to investigate and identify real world needs where location awareness technology can make a difference. Ubisense provides a breakthrough in the field of accurate 3D positioning. It utilises ultra-wideband in the field of Radio Frequency (RF) to deliver accurate 3D positioning which is scalable and offers real time performance. This can be used over a large geographical area, especially for in-building locations.



**Fig 1: Ubisense compact tags, single sensors and series 7000 sensors**

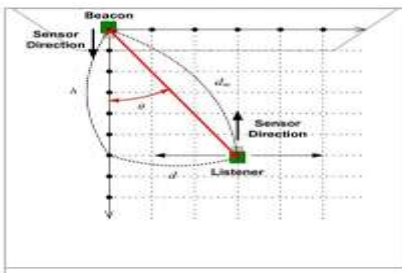
Ubisense is targeting its sensing and middleware technologies at a number of markets, including healthcare, security, workplace productivity and military training [4]. The development and deployment tools make the system easy to design, implement and maintain. Proprietary tags communicate with the series 7000 sensors (see Fig 1). Ultra-wideband is a technology based on radio frequency which has been used by to build real time systems that can provide a high degree of positional accuracy, in real time to within 15cm. It can work in very harsh and challenging environments where conventional RFID and Wi-Fi have experienced problems with interference.

#### **Robotics and Location Determination**

Different sensors are used to extract meaningful information and measurements that can help provide information about the robots environment [5]. For an autonomous mobile robot to operate successfully it requires three things: perception of its environment, decision making capabilities and a way to execute information received in a meaningful manner (for example path planning and navigation to execute a goal i.e. moving from one position to another efficiently, safely and successfully avoiding objects). This requires problem solving skills and strategic planning together with navigational capabilities. Many different types of systems are currently on offer for outdoor and indoor location detection systems. Exteroceptive sensors are used to obtain information from the external environment.

Robots can obtain information from their environment using cameras that allow the robot to distinguish shapes and recognise objects. Proprioceptive Sensors measure the robots internal workings, for example the battery voltage level or it can measure the rotation of the robots wheels to measure distance travelled. The advantages of mobility cannot be fully exploited without the capability of navigating [6]. Sensors can provide lots of data that can be processed to provide meaningful information. However without being able to accurately predict the robots exact location at a given time then this data received would be unreliable and lead to errors. The goal for any location system is to be able to provide accurate positioning information within a

coordinate system. This will allow a robot to move autonomously (see **Error! Reference source not found.2**).

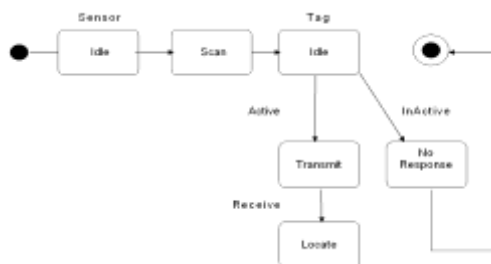


**Fig 2: Beacon aided navigation for Robots**

Ultra wideband claims to be able to accurately locate a transmitting RF tag to within 6cm in intelligent space. This paper investigates the accuracy of these claims and how this technology could be combined with the field of robotics' to accurately determine in real time a robots location in relation to its environment. A robots environment can include many different geometric obstacles and terrain conditions. In order to make accurate decisions not only does a robot require sensors to detect obstacles for path planning but it also needs to know its exact location, in order to benefit from the data it receives. Using Ultra wideband we explore how this location accuracy can be achieved and how it can be applied to the field of robotics. The Robots environment representation can range from a continuous geometric description to a decomposition-based geometric map or even a topological map. The first step of path planning system is to transform this possible continuous environmental model into a discrete map suitable for the chosen path-planning algorithm. Location information can also be derived from analysis of data such as video images, as in the MITSmart Rooms project [7]. Accurate object locations can be determined in this way using relatively cheap hardware, but large amounts of computer processing are required. Furthermore, current image analysis techniques can only deal with simple scenes in which extensive features are tracked, making them unsuitable for locating many objects in cluttered indoor environments.

#### Location Determination Prototype Development

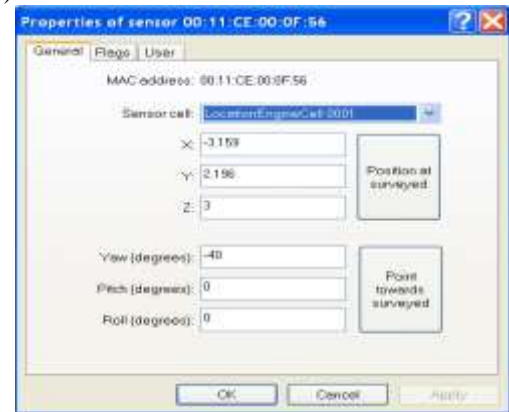
The aim of this investigation is to develop and test the accuracy of ultra wide-band location detection systems and their ability to track in real-time the location and movement over a small geographical area. The system uses battery powered radio tags and a cellular locating system to detect the location of the tags. The hardware used was that of Ubisense.



**Fig 3: State diagram for the Location Detection System**

The cellular locating system emits precisely timed short bursts of RF energy to provide accurate triangulation of the position of the transmitting tag. **Error! Reference source not found.3** shows a representation of the processes involved in a RF tag being located and tracked. When the software for the system initially loads the user is presented with the Platform Control which informs the user that connection to the Ubisense

Core server has been initialized and is up and running. The Sensor properties interface gives the user information relating to the location of the sensor about the X, Y and Z axis. The Yaw is the directional degrees at which the Sensor is tilted towards the Fuducial Calibration Point (see **Error! Reference source not found.4**).



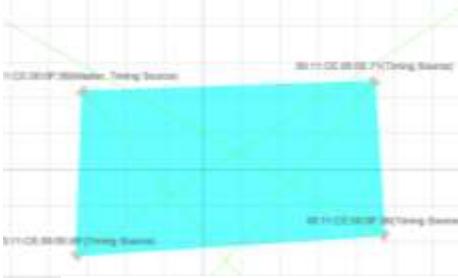
**Fig 4: Properties of the master sensor location.**

Users will utilize battery powered radio tags to be mounted on a robot or worn by a person. These tags when activated will transmit RF energy to provide accurate data that allows the location of the tag to be identified through the use of triangulation. The Location engine includes software required for the sensors to track battery powered tags, in real time. The system was mounted at a recommended height of 3 meters above the floor level. The sensors were attached to the wall using brackets and were then maneuvered to point to a central location in the middle of the floor at approximately 45 degree angle ensuring a good line of sight. All four sensors were connected to an Ethernet switch using cat 5 network cables and one of the sensors was configured to be the Master and the other sensors slaves. A timing cable was connected from each slave to a cable port on the master sensor. The cables were connected via a switch to a laptop. Identification of the sensors was achieved and their location established on a grid matrix. This allowed calibration of the sensors in relation to the space which they monitored.

Tags are located by accurately computing the time difference of arrival (TDOA) of a signal transmitted from the tag to the four receivers mounted at each corner of the room. Locating a Tag by measuring the TDOA of a signal transmitted from the tag and received by the synchronized sensors allows for the accurate location of the tag to be identified accurately in real time. A plan was created for the area covered by the sensors and the identification numbers of each sensor. Master sensor ID 00:11:CE:0F:56 controls the timing for the other sensors which are connected to it. The sensors are calibrated to a central fuducial point on the floor; this reference point is used to verify that the system is correctly set up. Addresses from each sensor are relayed via the master sensor to the location platform software which is installed on the laptop.

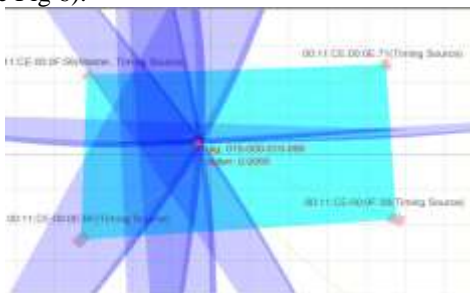
The software then constructs a grid diagram showing the location of the sensors in relation to the space which they monitor. Each sensor had to be individually calibrated to ensure that background noise was eliminated. The calibration process allowed the thresholds to be set for each sensor in order to reduce interference. Fig 5 shows results of running the software after calibration to ensure that the timing signals from the sensors were operating correctly and that the area to be covered could be scanned. This was performed before introducing the

Tags in order to reduce interference.



**Fig 5: Sensors scanning area to be covered**

As can be seen from Fig 6, each sensor is scanning the area plan searching for a Transmitting tag. The master sensor coordinates the timing signals of the scans to ensure synchronisation accuracy. When a radio tag is introduced it will transmit a signal back to the sensors located at each corner of the room. Algorithms are used to work out the difference between the timing signals and the radio transmitted signal from the tags which are picked up by the sensors. In this way the system accurately works out the location of the Tags to a degree of accuracy claimed to be within 6 cm. Factors that may affect the accuracy of the readings could be the temperature of the room or the humidity of the room. Other factors may be reflection from objects within the room or attenuation loss from the tags. Testing of the systems performance under various conditions will allow the location accuracy claims made by the manufacturers to be examined. Movement of the tags at various speeds will be tested to see how fast the location data can be retrieved by the system and the accuracy of that data. Tests involved running the system in real-time, with tag number 010-000-015-099 located at the centre of the area plan. The location of the Tag is indicated by the red dot at the junction of the blue waves (see Fig 6).



**Fig 6: Tag moved 1/2 meter back from centre towards the master sensor**

Blue wave signals become more intense and concentrated as the tag moves away from the timing sensors 00:11: CE: 00: OE: 71 and 00:11: CE: 00: OF: 38. Location testing is crucial so that estimated results can be compared with the physical location of the transmitting tag. The floor area is accurately marked out to scale to allow accurate comparison of results on screen to the actual location of the tags position. The sensors locate the tags in three dimensional space from a particular point in space. The basic directions in which one can move are up/down, left/right, and forward/backward. Movement in any other direction can be expressed in terms of just these three definitions.

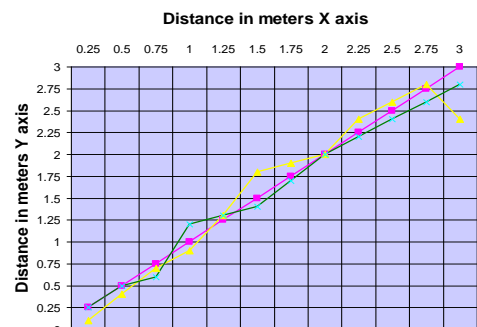
Errors can result from environmental factors such as false readings from reflective surfaces. In order to compensate for these environmental displacement errors it is important to calibrate the sensor thresholds. To do this it is important to set the "Disabled Radio" tag on the master of the cell and then calibrates the four sensors. This compensates for errors in the real environment, the perpendicular distance and the angle

between the sensors. The sensors measure distances with different sensitivities as the distance and the angle of transmitted tag signals varies. We can measure the distance error. Distance in this case is defined as the measurement from the wall mounted sensors to the transmitting tag. The error rate and time calculations using the position of the transmitting tag have shown that depending on the location of the tag the accuracy of the results can be influenced when deciding the exact location of the tag.

Trilateration is employed by the wall mounted sensors to locate the position of the transmitting tag. The drawbacks of using this method are that the scanning signals from the sensors do not always intersect at one point. Environmental factors can influence the readings through reflections of signals from surfaces. Humidity may also cause interference. Estimations of transmitting tag locations from the results supplied by the sensors compared with the real location of the tags position in relation to a measured grid map of the area covered by the sensors indicate some discrepancies. This is especially the case the further the transmitting tags are moved away from the centre of the area being scanned. There were areas beneath the sensors that are dead zones where signals from the sensors do not register.

### Evaluation

Here results of testing the Ubisense location determination system are presented. We evaluate how different materials may influence the accuracy of the transmitting tags location and how accurately the location system can track the movement and location of a tag moving from point A to point B in a room. The floor was mapped out in a one meter square grid. The Centre of the actual floor corresponds to Grid reference 1.5 on the Y axis and 2.5 on the X axis on. A number of readings were taken around the area covered by the sensors. This was done methodically starting at grid reference (0, 0 Y, axis - 0, 0 X, axis). Further readings were taken moving the tag to different locations where the grid lines meet finishing at grid ref reference (0,3Y, axis 0, 5 X, axis). This ensured that all cross references were covered. Fig 7 shows the results of a tag id 101-111-015-099 being paced at grid reference .25cm on the Y axis and .25 cm on the X axis. The results are then recorded and compared with the position where the sensors indicate that the tag is. The yellow line indicates where the sensors have located the tag on the Y axis and the green line indicates where the sensors have located the tag on the X axis. The chart shows that the level of error is greater along the Y axis than along the X axis.



**Fig 7: Location results for Tag id 101-111-015-999**

The purpose of the following experiments is to see how a liquid, in this case water, can effect and influence the location accuracy readings of the ultra wideband location detection systems (see Fig 8). Results indicate that water does cause interference with the location accuracy reading of the ultra

wideband location detection system - a positional change is recorded. These results above raise the question - if a person is wearing a transmitting tag how will their body (which contains 70% fluid) interfere with the accuracy readings.

The purpose of the following experiments is to see how different materials can effect and influence the operational accuracy readings of the ultra wideband location detection systems (see Fig 9). Materials lead and tin do cause interference to the accurate location of transmitting tag. Materials made from plastic or wood do not interfere with the capabilities of the ultra wideband location detection system. The four sensors were able to accurately locate and pinpoint the location of the tag.

Fig 10 shows some other performance tests that were carried out on the transmitting tags and how the sensors were able to accurately locate the tags under different conditions. Performance test 1 showed that the location detection software was able to successfully track and locate a person wearing a transmitting tag walking in a straight line from one location to another location. Test 2 showed that when a transmitting tag was moved to different locations within the room, discrepancies arose with the location accuracy of the tags. Test 3 showed that areas directly below the sensors do not pick up the location of the transmitting tags with any degree of accuracy. There appears to be a correlation between the accuracy of locating the tags and their location directly beneath the location sensors.

Test 4 showed disturbance caused to the accuracy of the tags location when it was covered by water. The more water that covered the tag the greater the tags location signal was deflected and test 5 showed that when a transmitting tag was placed in the centre of the room which had been accurately mapped out – more accurate reading of the tags location occurred. In fact, the system was able to successfully pin point the tags location to 2 cm accuracy. This showed that in the centre of the room the accuracy of the location detection system was more reliable here than in other locations away from the centre.

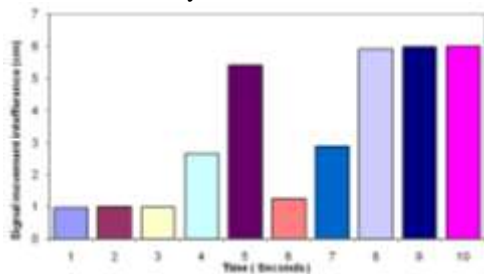


Fig 11: Disturbance caused to a transmitting tags signal.

Error! Reference source not found.11 shows the initial disturbance caused to the transmitting signal when a water obstacle is placed between the tag and sensors. **Error! Reference source not found.** shows the position of the transmitting tag as it is moved further away from the centre of the room.

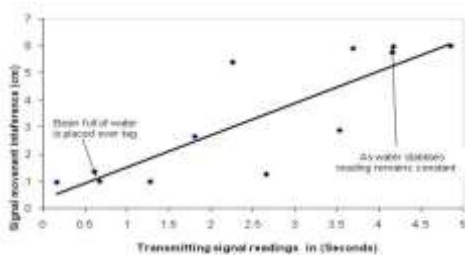


Fig 12: The influence of liquid on tag transmit performance

The reliability of the location detection system is affected by how far the transmitting tags are from the central position

covered by the sensors. Fig 13 shows how the error rate becomes more acute the further the tag is moved from the central position in the room.

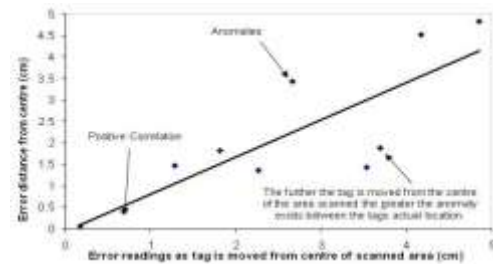


Fig 12: Position of the transmitting tag as it is moved further away from the centre of the room

Fig 13 shows the readings taken from a person wearing a transmitting tag walking from point A in the room to point B in a straight line.

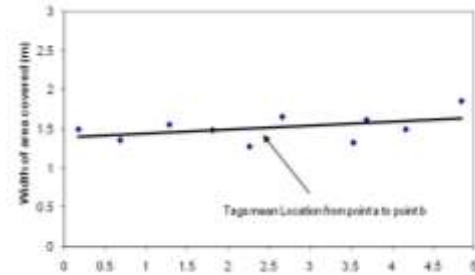


Fig 13: Person wearing a transmitting tag walking from point A to B

This research was concerned with the testing of an accuracy of an indoor location system utilising ultra wideband. The key to robot navigation is self localisation; this allows a robot to navigate between two points. By using a combination of map building and self localisation a robot will be able to successfully plan paths in relation to its surroundings in the real world. Determining the location of objects or people in a smart space is one of the prerequisites enabling smart applications. An Ultra wideband location detection system has the advantages of being able to carry out precision localisation and handle multi-path signals. Sensor network-based ultra wideband location detection system provides greater accuracy than other systems.

**Conclusion**

Ultra wideband sonar location system is a new technology which aims to overcome many of the problems that affect other types of indoor location systems, especially in an industrial environment where interference from other mechanical and electrical devices can have an adverse effect on location detection devices. Ultra wideband location detection technology's unique characteristics make it a suitable solution for use in the tracking of robots in an indoor environment, offering acceptable positioning location although interference from obstacles in the line-of-sight of the sensors is one of the major causes of error. Line-of-sight obstacles degrade the accuracy of the time of arrival estimation of the direct path signal by making the multipath structure complex as was experienced when more than one tag was introduced to the area covered by the sensors.

This paper has showed that it is possible to setup and configure a location detection system that is capable of locating transmitting tags within a small geographical area. The field of robotics can benefit from this new technology in helping to accurately detect the location of robots. However the accuracy of the transmitting tags location detection can be influenced by many factors

including reflection from other surfaces and atmospheric conditions. The performance of the system to locate a single tags position was not as accurate as claimed by the manufacturer. When multiple transmitting tags were introduced into the area covered by the sensors, the systems performance became more unreliable which would influence the reliability and suitability of this system in the robotics field.

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**Fig 8: Water test results**

Water Test	Predicted Result	Actual Result	Movement Difference
Tag placed at central location in room under basin filled with water.	Expected displacement of tags location caused by water interfering with signals	Location of Tag did move. After two minutes only two of sensors were picking up tags location.	Discrepancies From original position. Y axis 6cm up X axis same
Tag placed at central location in room under a basin Half filled with water.	Expected less displacement of tags location caused by reduced water level interfering with signal	Scanning wave signals were less visible at tag location. Software indicated that Tags location had moved	Discrepancies From original position. Y axis 4cm up X axis same
Tag placed at central location in room under basin with 1 cm of water.	Expected little interference caused by water	All four sensors located Transmitting tag. Very slight deviation from tags original position	Discrepancies From original position. Y axis 2cm up X axis same
Tag placed beneath an empty basin.	Expected slight interference caused by basin	All four sensors located Transmitting tag. No noticeable interference caused to position of tag	Discrepancies From original position. None Y axis None X axis
Tag placed at central location in room	All Sensors to pick up signals from transmitting tag and be able to locate tag accurately	All sensors picked up transmitting tags signals. Location of tag was easily identifiable with ID number visible on screen	Discrepancies From original position. none

**Fig 9: Material test results**

Material Test	Predicted Result	Actual Result	Tag covered by material
Lead	Expected high degree of interference in accurately locating tag location.	Interference was caused to location of tag ID number 010-000-015-099 location.	High interference caused to accurately locating tags position
Tin.	Expected interference in accurately locating tag location	Interference to tag location. However not as much as lead experiment	Mild interference caused to accurately locating tags position
Wood	Expected some interference in accurately locating tag location	No Interference was caused to tag location	No interference caused to accurately locating tags position
Plastic	Expected some interference in accurately locating tag location	No Interference was caused to tag location	No interference caused to accurately locating tags position
Tag placed on table in same position for all experiments. No obstacles blocking line on sight	All Sensors to pick up signals from transmitting tag and be able to locate tag accurately	All sensors did pick up transmitting tags signals. Location of tag was easily identifiable with ID number visible on screen	Discrepancies From original position. None

**Fig 10: Other test results**

Performance Test	Predicted Result	Actual Result	Difference
Tag attached to an individual, walked in straight line from point A to Point B	Sensors to pick up signals from transmitting tag and be able to locate and update individuals movements as they walk	Sensors did pick up transmitting tags signals as individual walked in straight line. Location software was updated and individual's progress could be monitored.	Pass
Tag is moved to different position on floor	Sensor equipment is activated and locates new position of transmitting tag.	Scanning wave signals intersect to indicate location of tags new location	Pass but with discrepancies
Tag placed directly beneath sensors, at floor level	Other sensors should have picked up signal from transmitting tag	Sensors did not locate transmitting tag	Fail
Tag placed beneath basin of water	Sensors should pick up tags signal and location	Sensors did have difficulty picking up tags location. Introduction of water did have effect on results	Did locate tag with some discrepancies
Position Transmitting tag at centre point of all sensors at floor level.	Sensor location software from 4 sensors scan area to locate transmitting tag	Location of Tag by red dot on screen overlaid onto grid map of area covered. Tag identified by IP address	Passed for Y axis Error 2cm for X axis