Accurate Localisation in Tough Environments: Fire Fighters

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Omnisense
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Introduction

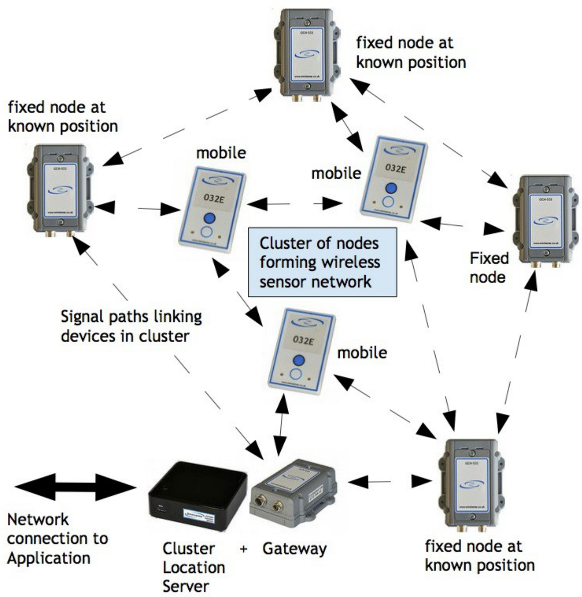
Emergency Services and First Responders, Fire Fighters in particular, present one of the most demanding set of requirements for accurate localisation, positioning and tracking. Their most challenging requirements include:

- the system needs to be deployed and operational within minutes at arbitrary unknown locations that cannot be prepared ahead of time;
- performance demands are very high: one metre or better accuracy with continuous tracking with 3D position updates up to several times per second;
- the deployed environment may be hostile: high temperatures, deep indoors or underground and challenging for radio signals;
- position output needs to be at both fire fighter and to the incident commander and/or other command personnel;
- orientation is an essential part of the navigation solution so that fire fighters can be guided in particular directions;
- the system should not fail, or if it does performance should degrade as gracefully as possible.

Traditional solutions that are available today do not meet all of these requirements. GPS fails indoors and does not yield the requisite accuracy (except when operating outdoors in RTK mode) and provides poor height accuracy. Dead reckoning solutions drift over time and require frequent recalibration.

The Omnisense Series 500 system provides a suite of unique capabilities. GPS and inertial navigation (dead reckoning) are combined with the Omnisense cluster positioning techniques that use Time-of-Arrival (ToA) measurements of radio signals between devices in the network to compute real-time high accuracy position and orientation data.

By using a combination of techniques and smart fusion of the measurements within the Omnisense Joint Timing and Location Engine (JTLE) algorithms the creation of positioning and navigation solutions for tough environments, such as for fire fighters becomes possible.



Series 500 System Architecture

The figure above illustrates the backbone of the Omnisense Series 500 system. A number of nodes are linked to one another forming a mesh network that allows data to be routed through one or more gateways to a CLS (Cluster Location Server) that provides high level APIs using TCP/IP for user applications. This mesh network has a dual purpose: it transports data between nodes and wider networks; and measurements of the radio signals are used for accurate relative positioning of nodes.

Each node may also be part of a personal area network linking different sensors and devices within the context of the object being tracked – for example the fire fighter.

Through a fusion of different measurements from different sources and different sensors the system is able to deliver robust high-quality high-precision position and localisation information.

Component Technologies in the Node

Key to making the solution work for this demanding application are the component technologies and measurements available to compute position and localisation information.

The Series 500 geolocation nodes include the following capabilities:

- 2.4 GHz radio using the IEEE 802.15.4a PHY (CSS) which forms the backbone of the mesh network and which provides ToA measurement good for positioning at the 1 to 2 metre level of accuracy over medium distances.

- UWB radio based on IEEE 802.15.4f which allows extremely high accuracy ToA measurements for positioning at the 0.3 metre level of accuracy over short distances.
- Bluetooth Low Energy radio used for PAN (personal area network) communications with auxiliary sensor devices, UI devices and other nearby resources.
- A suite of motion sensors including tri-axial accelerometer, gyroscope and magnetometer an a precision barometer, used for dead-reckoning and inertial navigation.
- Optional GPS module (multi-GNSS capable) for wide-area outdoor positioning at medium accuracy. On the GCN534 (larger industrial node) the GPS can provide raw pseudo-range measurements which can be used for enhanced positioning when only partial GPS coverage is available (Omnisense IPR).
- Optional sub-GHz long-range narrow-band telemetry link to provide communications into areas beyond the reach of the 2.4GHz or UWB radio networks.
- On the GCN534 (industrial node) an optional Wi-Fi radio provides high capacity connectivity to WLAN networks at the node level.
- The GCN534 also includes optional RS485 and CAN bus interfaces (in addition to standard USB and RS232 interfaces) for connectivity to other local infrastructure.
- The advanced mesh networking protocol (omniMesh) is optimised for mobility to ensure proper operation of highly mobile nodes within the network without compromising their ability to act as routers, parents or children in the network.

Whilst all of these component technologies are available in the node hardware, the firmware and software to fully exploit them is still under development.

Radio Communications Challenge

In order to achieve the scale and coverage required for fire fighters, including tough indoor and underground environments the right choice of radio communications is essential. In order to achieve long range and effective building penetration lower frequency signals (sub-GHz) and narrow-band channels are necessary. Such signals don't typically provide enough information to be used for positioning using ToA techniques.

This leads to two possible solutions for the fire fighter localisation problem:

1. Use a custom radio operating at sub-GHz frequencies which has a channel bandwidth of at least 6 MHz and which includes the capability to make accurate ToA measurements of the received signals; OR
2. Use a pure telemetry link operating in one of the sub-GHz bands and develop smart techniques and algorithms for making the best use of signals from the other radios, GPS and inertial sensors in order to compute estimated positions.

The first approach could lead to a powerful and generalised solution for localisation at an accuracy level of 3 to 5 metres but it has a number of drawbacks: radio spectrum availability is uncertain and geographically fragmented; cost of the radio is significant; and although the most appropriate frequencies are used the wider bandwidth (6 MHz compared with narrowband channels of, say 25 kHz) means that penetration is still not as good as the pure telemetry solution.

Therefore, Omnisense is working toward intelligent solutions (second approach) in which smart algorithms built around the nodes' rich sensor and measurement palette provide robust ubiquitous localisation.

Localisation techniques

The following techniques and methods are, or will be, used for localisation with Series 500:

- GPS as a guide or constraint or when off the mesh network will give outdoor performance in the metres to tens of metres accuracy range.
- The “4a” mesh network gives relative positioning at the 1 to 2 metre accuracy level with link ranges up to around 400 metres under clear radio conditions.
- The “4f” network give high accuracy (0.3 metre) positioning when radio ranges are tens of metres up to about 100 metres under clear radio conditions.
- The motion sensors (accelerometer, magnetometer and gyroscope) give excellent short term positioning; the radio network positions and/or GPS positions are used to continually calibrate out sensor drifts in the inertial sensors.
- Combining GPS and mesh radio measurements enhances the performance of

both systems; especially for nodes which have access to raw GPS pseudo-range measurements (Omnisense IPR).

- Measurements are sent back to the CLS which computes optimal positions for command staff and applications.
- The node may be linked to a local computation device and UI using the BLE PAN (or local physical connection) allowing navigation information to be supplied locally to the fire fighter.
- In the event that both GPS and the mesh network become unavailable the inertial sensors continue to supply positioning information based on inertial measurements alone.
- For pairs or groups of nodes separated from the mesh network, they can still exchange measurements with one another allowing relative distances separating them to be determined and these measurements combined with inertial sensor measurements from both local and neighbour nodes can provide improved relative and absolute positioning through joint signal processing.
- If required additional sensors can be worn and linked via the BLE PAN; for example the fire fighter may wear additional motion sensors (accelerometer and gyroscope) attached to each boot – the node combines the measurements from these different motion sensors to provide optimal fire fighter position and orientation making use of zero velocity re-calibration that is possible for foot worn sensors.
- As long as the long-range telemetry radio link is still operational the fire fighter node can exchange data with the command network, even though this telemetry link itself does not aid with localisation.

Vision for Fire Fighters

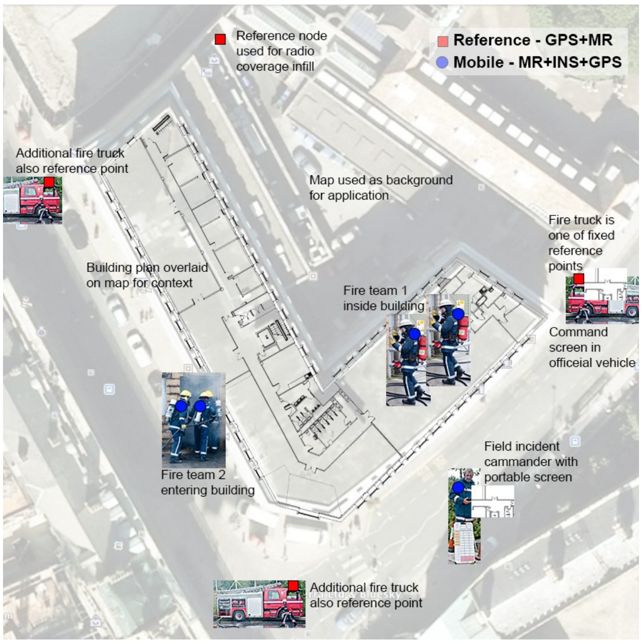
Equipping fire fighters with advanced Series 500 nodes containing both “4a” and “4f” radios, inertial motion sensors, BLE, GPS and the optional long-range narrow-band sub-GHz telemetry radio link will allow advanced navigation and positioning systems for almost all operational scenarios to be developed.

Head mounted nodes provide accurate information about the position and orientation of the fire fighter's head.

For improved positioning fidelity, especially when operation beyond the range of the mesh network occurs and GPS is unavailable additional boot worn motion sensors provide slave data to the Series 500 node which can be used to improve dead reckoning performance.

When local navigation and position output is needed by the fire fighter this is supplied using a computation device (for example small android or embedded Linux platform) and appropriate UI. The computation device is linked to the Series 500 node using the BLE PAN eliminating the need for on-body cabling.

With the small size (45 g) and relatively low cost of the Series 500 node a very cost effective and modular positioning and navigation solution is achieved.



Supplemental System Techniques

In some deployments it may be desirable and advantageous for the mesh network to be extended into the more difficult-to-reach areas. One technique for this is to use temporary in-fill nodes. These could be standard GCN534 industrial nodes which are rapidly deployed on tripods or by attaching to pre-existing infrastructural elements (such as walls). In this case their internal GPS is used to provide automatic configuration linking them to (approximate) geographic positions.

Pre-conditions for good positioning

The Omnisense JTLE is able to compute positions of nodes relative to one another even when there is no absolute position reference available. However, for positions to be computed using a particular ground-fixed coordinate reference frame (such as WGS84) it is necessary to link a minimum of four nodes (for 3D positioning) to known positions.

It is envisaged that these “infrastructure nodes” would be permanently attached to equipment such as vehicles, or as rapidly deployed nodes. Their positions would be automatically determined using

GPS, although configuration tools on the CLS provide the means for an operator to correct or set their positions manually.

Although a minimum of four infrastructure nodes is required, the best performance is achieved by using more than the minimum – 6 or more being recommended for small areas, and more for large areas depending on the nature of the radio environment.

Data Processing Techniques

The CLS includes sophisticated data processing algorithms. In addition to basic position computation (in three dimensions) orientation and velocity are also computed and output, along with position quality estimates and other status information.

Positions can be delivered using the coordinate system of choice by the application and they may be delivered as coordinates or as localities such as zone (e.g. room) or nearby landmark.

Position and navigation information may be managed according to go and no-go areas or based on routes and waypoints.

All measurements are logged and applications can access position and location information in flexible rich ways.

Current state-of-the-art

Present Series 500 systems can do positioning using the radio mesh network. Inertial measurement data is used in simple ways to deliver 3D position, velocity and orientation. Position and navigation information is available at the CLS. GPS integration is available at a basic level.

Right now Series 500 is not able to deliver local navigation output at the node; the companion algorithms for the local computing device are not yet available although the JTLE has been designed to allow it to be ported to the distributed embedded envinronment and the local node APIs are available in prototype form.

Fully-fledged inertial navigation is not yet released.

The BLE PAN is not yet released, although hardware support is included in the node.

The optional long-range sub-GHz radio has not been developed yet, but the node includes an expansion connector to allow this feature to be added as a plug-in module inside the node.

Routes, navigation guidance and restricted areas are not yet supported on the CLS.

Auxiliary sensor devices such as the boot-mounted motion sensor have not yet been built.

Conclusions

Series 500 provides an excellent platform on which fully-featured rich positioning and localisation solutions for fire fighters can be built. The hardware already supports most of the technologies that when used together can provide this solution. The hardware includes generous memory and computing resources (ARM cortex CPU) which will allow the sophisticated algorithms required to be developed and deployed.

This solution, which combines GPS, inertial measurements and relative radio positioning using two different radio modes on top of the mobility optimised omniMesh networking protocol will provide a far superior solution to those relying on GPS and/or inertial sensors whether separately or together.

About Omnisense

Omnisense Limited is a Cambridge UK based technology business specialising in positioning assets: people, animals and other objects.

Omnisense owns IPR relating to its Cluster positioning systems and JTLE, including patents, designs and know-how.

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