GAISS - Live Asset Tracking and Statistical Modelling in Missing Person Search

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***Abstract*—The GAISS project provided a system for integrating live over-the-air automatic positional reports, recorded GPS data, and statistical models of missing person behaviour in an effort to aid the tasks of search planning and recording in missing person searches. This paper gives an overview of the aims of GAISS, describes the user requirements gathering with a primary response agency, integration between their PMR network both between the software and an existing position reporting system (APRS), and finally describes a field trial of the system, and the information gained from this.**

I. Introduction

This paper describes the genesis, implementation and results of the Enterprise Ireland funded GAISS (Geographically-Aware Information Support System) project. The GAISS project is intended as an aid for search management, and an illustration of the broader application of using live and recorded positioning data as input to statistical models.

II. Background

The GAISS project aimed to provide an integrated solution for search management that remains viable in situations where commercial data communications infrastructure is unreliable or not available.

In order to properly assess the concepts behind GAISS, the project group secured the co-operation of the South Eastern Mountain Rescue Association (SEMRA) [2] and the Search and Rescue Dog Association of Ireland (SARDA) [3], both specialised Search and Rescue (SAR) organisations operating in the Southeast of Ireland.

Initially, it was proposed that the software would automatically assign search assets (teams, vehicles, etc.) based on mathematical model of the search scene. However, after consultation with the user group, it was decided that rather than directly allocating teams to particular areas, the software should instead visually suggest the areas most likely to contain the target (those to which it would have allocated teams), but allow the search manager to have final decision on the matter.

The two major tasks undertaken by the GAISS software were:

- Provide a live display of search team positions
- Produce Probability of Area (POA) calculations for the Incident Commander.

In order to properly assess the concepts behind GAISS, a live field trial formed part of the project plan.

III. PMR Equipment Integration

To provide a live position display of team member, the GAISS system made use of Global Positioning System (GPS) receivers connected via low-bandwidth radio data communications to an Incident Command Post (ICP). At the ICP, the search co-ordinator would use the GAISS software for visualisation of search team progress, and for search planning.

A. Interfacing with PMR system

Like all other member associations of the Irish Mountain Rescue Association [1], the SEMRA and SARDA memebers are equipped with Simoco model SRP-9130 PMR handsets. These are capable of determining their position using a GPS-equipped microphone, and relaying this position over the air.

Position reports are transferred using MAP27, the user-data protocol for the MPT1327 trunked radio system [7]. The use of this protocol required a complete Data-Link layer protocol to be implemented on the GAISS host system.

An interface library was provided by the radio manufacturer, but this exhibited very poor reliability, was only available on the Microsoft Windows platform, and then as a binary with no source code supplied.

Apart from the need to fix the pre-existing bugs in this library, it was desirable to provide the ability to interface with MAP27 equipment to software on multiple platforms in order to broaden any future applications of the software. As no suitable implementation of the MAP27 protocol existed for the Unix platform used by the GAISS software, this had to be written, starting from the protocol specification.

As a result, the project team produced a fully-functioning software library that would enable solutions providers to easily extract status information from MAP27 radio equipment. Despite being used initially for position gathering only, this library should be be usable for any type of message exchange with MAP27-compliant equipment, as it implements the full MAP27 data link layer protocols.

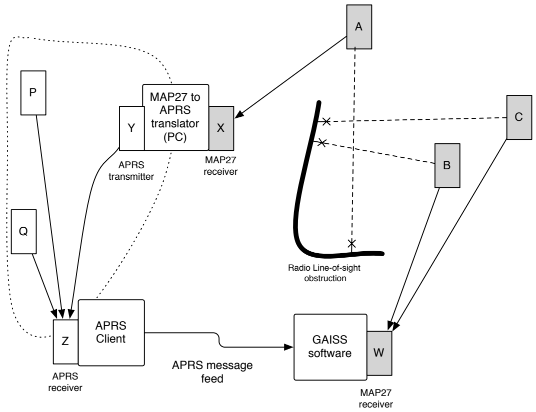


Fig. 1. Use of APRS relaying allows position information for radio A, which cannot be seen by receiver W, to be carried over the complementary APRS network.

B. Interoperation with the APRS system

The site of the testbed in Southern Ireland is covered by a pre-existing packet data network used and maintained by radio experimenters. Normally, use of this network is restricted to radio amateurs alone. However, under the Irish Government's major emergency plan [14], radio experimenters must, if required, make this infrastructure available to assist in emergency operations.

The amateur packet radio network has the advantage of greater coverage than PMR, as well as an established network of relays. It was therefore of interest to the team to investigate how this existing network could be used for search management purposes.

The main technology of interest was APRS, the Automatic Packet Reporting System (formerly "Amateur Position Reporting System") [11]. APRS is the *de facto* standard for reporting positions on "amateur" experimenter radio networks.

The use of APRS has exploded in recent years, to the point where mainstream equipment manufacturers such as Kenwood and Yaesu have added support for the protocol to their products. [12] [13]

The GAISS software connects to an APRS server (a separate application, outside the scope of the GAISS system), which produces a "feed" of all packets received on a radio interface connected to that server, or from an IP-based "APRS backbone" network.

Figure 1 shows how this arrangement can improve the reception of MAP27-originated position reports. Of the three MAP27 equipped radios, only B and C can be received at the base-station (receiver W). However, unit A can be seen by a MAP27 to APRS relay: This PC receives MAP27 packet (receiver X), and converts it into an APRS message, which it broadcasts over its packet-radio connection (transmitter Y). This message is received by the APRS client (receiver Z), and relayed to the GAISS software.

IV. Visualisation and Scene Modelling

The visualisation system provides a means of overlaying the reported information onto a map of the scene. It is responsible for presenting both the team location information and the results of the statistical search modelling engine.

A. Projection and preservation of Geograhic information

Mapping used by Irish Search and Rescue teams in the field is almost exclusively the Ordnance Survey of Ireland [8] large-scale mapping series (1:50 000 scale), which uses the Irish Grid co-ordinate system [9]. This mapping is available digitally in raster format, and the Irish Mountain Rescue Association have secured a licence for use of this mapping by its constituent associations, so it was not necessary to digitise mapping for the project.

The geographic positions reported by the radio equipment, however, are encoded as Latitude and Longitude positions based on the WGS84 geodetic datum, an incompatible co-ordinate system to Irish Grid. A mathematical process exists which can convert these to Irish Grid co-ordinates, but there is some loss of precision in the process (of up to 5m on the ground, a significant distance when considered in relation to the width of a stream or crag, for example). More accurate conversion algorithms exist, but must be licenced at a cost from the respective mapping agencies, but the freely-published system was adequate for use in the trial. Nonetheless, the GAISS software was required to translate received positions from WGS84 latitude/longitude/height triples into Irish Grid.

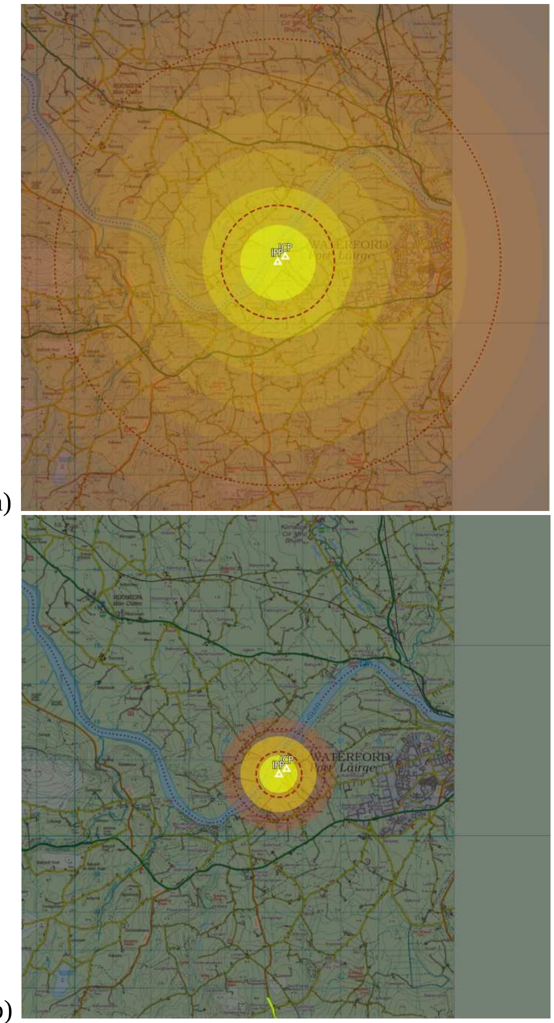
To further complicate matters, it is common for teams without automatic position reporting equipment to "radio in" their positions; these reports are invariably in Irish Grid. Thus, the data inputs to the GAISS system had to deal with GPS-originated co-ordinates (Latitude, Longitude, WGS84) and manually-entered positions (Irish Grid).

To mitigate the effects of errors produced by co-ordinate conversions, the software was designed such that incoming position reports were projected onto Irish Grid for display purposes, but remained stored in their originally-received format (be that Latitude/Longitude or Irish Grid). This preservation of original data would be essential if the logs of the GAISS system were ever used as evidence in court: a co-ordinate projection error of 5m (typical) can be large enough to cast doubt on what side of a river was searched, or whether or not a particular path was taken.

B. Lost Person Behaviour and POA circles

The second aspect of the GAISS software was the automation of missing person searches. The method used is based on work done by the UK-based Centre for Search Research [4]. By statistical analysis of previous cases, the CSR have shown that it is possible to produce profiles of missing person behaviour that can be used to predict the behaviour of future missing persons.

A Lost Person Behaviour Profile is a summary of the data obtained from previous searches for a particular category of



(a) (b)

Fig. 2. Missing person projections overlaid on map, for a missing person matching two different profiles: (a) dementia (b) young child. Denser colours represent higher probability person being in that area. (The grey area to the right of each image is due to not having map data available; it has no other significance)

missing person. This profile gives statistical information such as:

- **Distance from IPP** How far the person was found from the search's Initial Planning Point (IPP). For example, those suffering from depressive illnesses (category "Despondent") tend to be found very close to the IPP, whereas hillwalkers and runners are found at a greater distance.
- **Condition when found** How often the missing person was found healthy, injured or deceased. This indicates how likely it is that the person can respond to searchers.
- **Terrain where found** Some categories of missing person tend to be found in particular types of terrain (for example, hillwalkers are most often found on open ground).
- **Other remarks** This includes observations made during previous searches, that could be useful in new operations (for example, persons in the "Despondent" category are often found in scenic locations).

Like any statistical technique, however, this profiling is only as good as the data that generates the profile. The Centre for Search Research in the UK provides statistical information for missing person cases, drawn from a database containing reports on 1,000 missing persons from incidents that have taken place in the UK and Ireland. This data set is extended continuously, and reports are published regularly with updated profiling information.

From this profiling data, it is possible to provide realistic predictions of the behaviour of missing persons; for some categories of missing persons (particularly sufferers from dementia), search outcomes are remarkably consistent.

The raw data which underlies the Lost Person Behaviour Profiles is available (with all personal identifying information removed) from CSR in machine-readable form for this purpose. Using this data, a prototype scene modeller was developed that uses historical missing person behaviour profiling to predict the likely distance of the missing person from the point where they were last seen. As an example, figure 2 shows the different predictions a missing patient with dementia, and a missing child.

"IPP" marks the Initial Planning Point for the search. In this case, the point last seen is used. "ICP" marks position of the Incident command post. The dashed red line shows the 30th percentile distance; the 70th percentile distance is shown as a dotted line.

As units return from the field, the path searched by them are used to modify the initial prediction, effectively "counting out" searched areas from the predicition (a searched area is less likely to still contain the missing person than an unsearched area).

V. Field Trial and End User Feedback

Over the weekend of 1–4 June, 2007, the Galtee Walking Festival took place in the Galtee Mountains. SEMRA and SARDA had a presence at this event, and also AREN [10] (an Amateur Radio voluntary emergency communications organisation) had members out providing communications for the event organisers. Some of these volunteers were carrying either APRS [11] trackers or MAP27 capable Radios, the data generated with these radios were gathered and processed by the GAISS application.

The initial plan was to situate a single "Base" at the Walk HQ (close to the base of the mountains), a MAP27 Protocol Interface on a high site north of the Galtees transferring MAP27 data back to the Walk HQ using a point to point WiFi connection. Initial surveys were carried out in February, with a second, shorter survey one month before the trial. On this second survey, it was discovered that due to increased foliage cover, the 802.11 wireless link between sites proved impossible.

At this point it was decided to use the pre-existing APRS infrastructure to transport MAP27 data. This was decided as it would only require a small modification to GAISS to receive position reports from the Protocol Interface (over multicast IPv6), and transmit them via the APRS protocol (which the

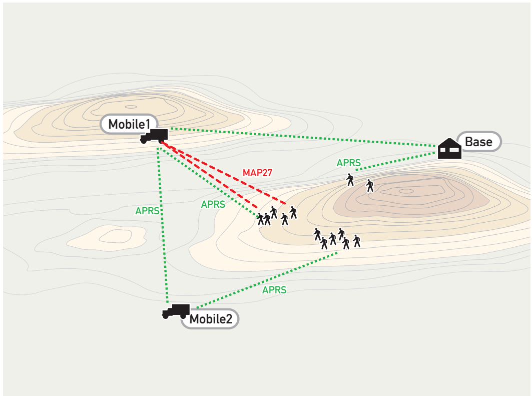


Fig. 3. Field trial setup

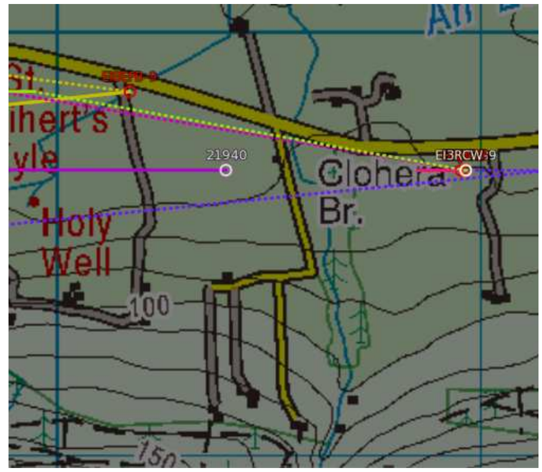


Fig. 4. Positioning errors due to lower precision of MAP27 reports carried as "APRS uncompressed position" packets. The track labelled 21940 is from a MAP27 radio, the holder of which was tavelling along the road approx. 20m to the north.

GAISS Visualisation system could already display).

Figure 3 shows the positioning of the three trial nodes.

The plan was updated and equipment prepared for deployment to various locations:

- Walk HQ
  - Visualisation Subsystem
  - VHF APRS Radio and Radio modem
  - APRS Decoder
  - Power Supplies, Cables, Aerials, Misc. Connectors
- Mobile 1
  - VHF MAP27 Radio
  - VHF APRS Radio
  - Car PC (MAP27 to APRS conversion)
  - Cables, Aerials, Misc. Connectors
- Mobile 2
  - VHF MAP27 Radio
  - VHF APRS Radio
  - Car PC (MAP27 to APRS conversion)
  - Cables, Aerials, Misc. Connectors

The equipment was set up on the day before the field trial. As the weather forecast for the weekend was poor, it was decided to set up one 'Mobile' MAP27 to APRS node at the team's accommodation which boasted a surprisingly good view of the North side of the Galtee Mountains. This afforded the team the possibility of having someone on hand to continuously monitor the node in relative comfort.

As the radio equipment had been little used by this point (delivery of the radios was significantly delayed), it was also decided to keep the second MAP27 radio at this location rather than send it out "mobile", so that in the event of a problem with one radio, which would have impacted on the trial results, the other could be quickly swapped in to replace it.

A. Results

1) Timeout in MAP27 protocol handler: Overall, the software worked as intended, with one small bug. The protocol interface had problems retaining synchronisation with the MAP27 radio. In real use, the MAP27 position reports were often several minutes apart, wheras in testing, the operators had sent two to three reports a minute (reports are sent by the radios after each voice communication). The longer interval exposed a timing error in the protocol interface which caused the software to lose connectivity with the radio transceiver after a number of minutes. To work around this problem for the duration of the trial, a simple script was written to re-start the the software module immediately after it lost synchronisation. The problem was properly addressed in a revised version of the software produced after the trial.

2) Loss of precision due to message format conversion: The second issue concerned the use of APRS as a 'transport' for the MAP27 position messages. As expected, some precision was lost, and this became very obvious when comparing against some more precise APRS position reports (originated in a format called Mic-E [11]). The loss of precision resulted from the APRS message format we chose ("uncompressed position report") being precise to only 0.01 minutes of an arc, compared with 0.001 arc minutes for GPS. (Figure 4).

B. User Observations

SEMRA made several observations regarding the trial results.

1) Interpolation of position reports: The first comment concerned the way that the visualisation system displayed the position reports it received from the field operatives.

Simply "Joining the dots" between position reporting points was not, in their opinion, the correct thing to do. The "tracks" thus formed can create a false visual impression that the person took a straight line path between two readings. In some cases, this was obvious, as in Figure 5 where consecutive readings received on opposite sides of a lake suggested that the searcher had walked on water!

2) Radio shadowing: Figure 5 also illustrates the problem of radio shadowing, a common and unavoidable problem when using line-of-sight radio communications in mountainous areas. This problem is exacerbated by the way the Simoco

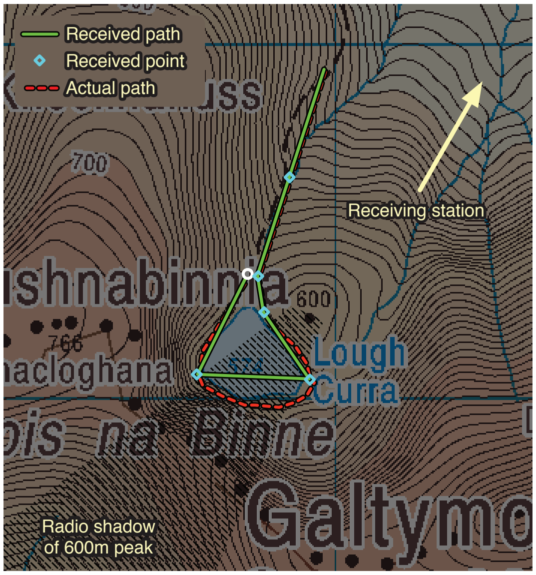


Fig. 5. Radio shadows and misleading interpolation between received points. The searcher's movements behind the peak are not seen by receiving station, leading to a misleading track plot.

SRP9130 radios report positions: received position reports do not have to be acknowledged, so the radios do not store positions for later re-transmission. This problem could be addressed in future by employing an ad-hoc network between searchers' radios, or alternatively by using Delay Tolerant Networking [6] techniques to relay positions back to the receiving station.

It should be noted that these problems apply only to the live (or near-live) tracking of team members: the current operational procedure requires each team member to have a second GPS unit to records their movements. It is these recorded GPS traces that are used for debriefing and search planning purposes, and not the positions received over-the-air.

3) Visual overload: On a long operation, users reported that the accumulation of previous tracks could obscure the map to the extent that it becomes unusable.

To address this, a post-trial revision of the GAISS software: the "full path" tracks of the field trial were replaced with "short tail" indicators showing the last 4 positions, which give the direction and speed of travel without overly cluttering the display.

4) Operational Status: Another concern raised was that there was no obvious and unambiguous visual-indication whether:

- A radio has beaconed with valid GPS data
- A radio has beaconed with invalid GPS data
- A radio has not beaconed within an operator specified interval

A later version of the software addressed these concerns by highlighting on the display those stations which had not beaconed recently.

VI. Conclusions

In the opinion of SEMRA, the search managment features, even in their current state, represented a significant advance in computer-aided search management.

The GAISS software is able to create a Probability of Area (POA) map based on the missing person profile. This shows the areas where the software thinks the person is most likely to be found.

The intelligence in the GAISS software is that the POA predictions it makes are not static. As the search progresses, and teams are de-briefed, the software re-calculates the model to reflect the search results. For instance, if a team searched an area with a high level of confidence, the software will use this information (gleaned from the de-brief), and the actual track the team has taken (as recorded by their GPS equipment) to update the probabilty map for the scene: an area that has just been searched has a lower probability of containing the missing person than an un-searched area.

This allows the search manager to quickly see not just that an area was searched, but also how confident the team leader was of their results, and also how long ago the search was. Because the missing person is often a "moving target", it is quite possible for the missing person to enter an area that has previously been searched. To model this, the weight applied by the software to a searched area's results diminishes over time.

At this point, it is necessary to talk about the deficiencies of the software model. First, and most important: this model is only useful if the missing person is correctly categorised and the Point Last Seen is correct. As with any statistical system, good outputs depend on good input. No software is ever going to replace a thorough search of the Point Last Seen. The software provides only information — decision making still rests solely in human hands.

The second point is that the GAISS software is only one interpretation of how search area modelling could work, and a rudimentary one at that. The software has been developed with considerable valuable input from members of SEMRA, SARDA and also Dave Perkins of the CSR, but it still remains in a very early stage of development.

The early and frequent consultation with SEMRA and SARDA personnel was invaluable to the project: their strong rejection of the automatic allocation feature illustrates clearly how a development team's perception of user needs can markedly differ to the user's actual needs.

VII. Future Work

This project was funded by Enterprise Ireland under its Proof of Concept programme, which aims to support academic researchers to explore concepts with commercial potential. The concept to be explored was the algorithmic allocation of scarce resources over a large area to maximum effect. Mountain Rescue was chosen as a test-case because it illustrated a "worst-case" environment, with poor communications and little other infrastructure in place.

The GAISS project finished in January 2008, and while the researchers continue to seek an avenue for further research or work in the area, this has not yet been found.

Further research in dealing with loss of radio visibility would be beneficial, as would further improvement of the statistical modelling (the ability to recognise different terrain types, and adapt the lost person projections accordingly, for example).

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