Proxsystec vs other Indoor Positioning Systems

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Abstract

We propose that as a convergence of technologies such as GPS, Internet-enabled devices, smart signage and so forth, Indoor Positioning is going to become much more widespread in the coming decade. In this Technology White Paper, we study available Indoor Positioning technologies using criteria from existing research in this field. We then describe in detail our application of Ultra Wideband (UWB) ranging to Indoor Positioning and Proximity Sensing, listing a number of deep challenges inherent in this application and how we have addressed them.

1 Introduction

We live in a time of incredible technological change – ideas which seemed like science fiction only a few decades ago are completely normalized and integrated into our day-to-day lives, as well as the commercial operations of companies large and small. Some ideas that we will touch upon in this paper will be:

- GPS was launched around 1990 and rapidly became ubiquitous, it has all kinds of commercial and military uses, for consumers it became popular firstly as an in-car or in-boat navigation system and eventually for smartphone navigation.
- Internet was launched around 1970 and eventually gathered a critical mass to be in everybody's home in Western countries from 2000 onwards and to become the ordinary means of performing many daily transactions in the following decade.

- Mobile phones were launched around 1985 and eventually went to GSM and then Internet-enabled phones, and more recently everybody has a powerful portable computer and communications terminal in their pocket which we call a ”smart-phone”.
- Internet of Things (IoT) has become popular since about 2010 and now it is normal to see sensor networks such as atmospheric sensors or electronic meters widely deployed, along with smart fridges, smart lightbulbs, smart TVs and so on.
- The environment around us is rapidly becoming filled with smart signage such as QR-codes, and there are further leanings towards a smart environment which we can interact with through technology. For instance, with driverless cars becoming the new normal, it is highly likely we’ll have smart roads in the near future, which could for example replace computer vision or traffic lights in mediating between drivers using the roads. Some propose embedding RFID tags everywhere.

We propose that as a convergence of these kinds of technologies, Indoor Positioning is going to become much more widespread in the coming decade. Some investment is already taking place into the necessary infrastructure, for instance, indoor GPS transmitters have been installed in shopping centres and road tunnels.

2 Indoor Positioning Context

To understand Indoor Positioning and its applications, we need to consider the context. A GPS-like system would be useful for finding a particular store in a shopping complex or for tracking a slow-moving vehicle such as a disabled scooter. In such contexts the distance scale might be up to a kilometre or at least hundreds of metres and the time scale might be minutes or at least tens of seconds.

On the other hand, for safety applications we need to work in metres or tens of metres, and seconds to tens of seconds. Even where safety is not a concern, the tracking of fast-moving items such as luggage on a carousel or stock moving around a factory (e.g. partially finished goods on a production line), requires smaller distance and time scales than GPS. We believe that the indoor environment of the future will contain various such systems interworking at different scales.

Furthermore, there are instances where a positioning system needs to work on smaller scales than GPS and needs to interwork between indoor and outdoor – for example, a large industrial plant with a number of separate buildings and persons and stock moving between these. There might be a need for access control and there might be a safety issue at entrances, exits or intersections generally. A smart environment might be significantly sparser in the outdoor parts than indoor.

3 Alarms and Proximity Warnings

Coming at it from another direction, if we avoid thinking about position and instead only think about range, it has for some time been possible to detect or measure with technologies such as sonar, infra-red or laser interferometry (builders use this for laying out the framing of a building). These systems have been built into various kinds of alarms or proximity warning systems from 1980 or so. Other applications are things like people-counters, automatic door openers, etc.

These systems, while useful, have been somewhat limited in scope, i.e. they do one thing and do it quite well but are not ”smart devices” and do not interact in any significant way with their environment. So they are not always intuitive to use. We expect to see this improve though convergence with smart environments. At the very least, digital control will allow to create smarter alarms and warnings by integrating various kinds of measurements to create an overall picture.

4 Indoor Positioning Tradeoffs

Referring to Wu et al (2007), there are five main quality metrics of Indoor Positioning systems:

1. System accuracy and precision;
2. Coverage and its resolution;
3. Latency in making location updates;
4. Building’s infrastructure impact; and
5. Effect of random errors on the system such as errors caused by signal interference and reflection.

Referring to Alarifi et al (2016), there are two main questions that need to be addressed by the developers of Indoor Positioning Systems (IPSs):

1. What are the suitable technologies for implementing the desired IPS? and
2. How can we achieve the most appealing trade-off between the different quality metrics in order to obtain an effective IPS?

Alarifi et al (2016) propose a new classification of Indoor Positioning technologies, and provide examples, as follows:

1. Building dependent:
   (a) Building dependent and not requiring dedicated infrastructure:
      (i) radio frequency that is either RFID or UWB;
      (ii) infrared;
      (iii) ultrasonic;
      (iv) Zigbee (we won’t consider this as it is mainly for communication); and
      (v) laser.
   (b) Building dependent and utilizing the building’s infrastructure:
      (i) WIFI;
      (ii) cellular based; and
      (iii) Bluetooth.
2. Building independent:
   (a) dead reckoning based; and
   (b) camera and image processing based.

In the remainder of this paper we will consider Ultra Wideband (UWB) technology in particular. The others will be mentioned mainly in comparison with UWB. We will consider the tradeoffs particularly in a safety context (i.e. proximity warnings and location alarms), and secondarily from the viewpoint of pure location.

5 Suitability of UWB for Safety Application

We shall evaluate the criteria of Wu et al (2007):

System accuracy and precision:

UWB has resolution about $\pm$10cm, which is competitive with infrared and ultrasonic but not laser.

Coverage and its resolution:

(i) UWB has range about 30m, or more in ideal conditions or at high transmitter power, which is competitive with infrared and ultrasonic but not laser; (ii) UWB can see through some objects, potentially many objects at high transmitter power, which the others cannot; (iii) UWB is much less directional than the other technologies, particularly laser which has a very focused beam and must be pointed at something in particular to be of any use.

Latency in making updates:

This is both a strength and an Achilles' heel for UWB. It is fast (milliseconds to take a range measurement), BUT, because it is higher in range, can see through some objects and is less directional, it must share the airwaves with all nearby transmitters. We will discuss this further below.

Building's infrastructure impact:

UWB stations are independent and communicate in peer-to-peer fashion which reduces the need for infrastructure as compared with the other methods. On the other hand, the limited range of 30m means that tracking faraway objects will be difficult or impossible without infrastructure (infrastructure makes much it easier to handle objects moving in and out of range). Existing building infrastructure doesn't use UWB bands much, so there should be little interference with a new UWB deployment (but this may change in future).

Effect of random errors on the system such as errors caused by signal interference and reflection:

This is another significant challenge with UWB. On the one hand, the very precise pulsed nature of the UWB signal allows sophisticated signal processing to resolve information about reflections and time of arrival. On the other hand, reflections are still a very real problem, since sometimes the direct line-of-sight signal is momentarily weaker than a reflected signal. Whilst a reflected signal still gives a useable range, it adds a significant noise component (equal to the path difference between the direct and the reflected signal).

Overall:

The evaluation shows that UWB is a very promising technology, indeed the most promising technology evaluated here, but that there remain significant challenges. In the remainder of this paper we will discuss how we approach these.

6 Latency in Making Updates

We handle the latency problem in several different ways:

1. We make very efficient use of the airwaves through channels and timeslotting, so that there is always a measurement or several measurements taking place (except under light load when we are able to take all the measurements we need to).
2. We dynamically increase the channels or timeslots dedicated to measurements between stations that are closer, or moving closer, together. Far-apart stations simply do an occasional range to see if they are moving closer together and therefore should begin to be monitored more closely. Closer stations are monitored more closely and thus the distance is known with less latency and more accuracy.

7 Building's Infrastructure Impact

The critical difficulty comes with the lack of infrastructure, or potential lack of infrastructure, meaning that the network of stations (referred to as anchors and tags in the literature) must be self-organizing, and must reorganize as the mobile stations move in and out of range of each other. But, this is significantly complicated by our already-mentioned approach of tight channelling and timeslotting.

We mitigate these issues in several different ways:

1. The stations will always ”elect” a leader, among those that are in range, and there is a seamless transition to a next-best leader if one goes out of range.
2. The leader provides timing of the network, and timeslots are based on this.

Overall, our algorithm allows a continuum between infrastructure-based and peer-to-peer operations. Suppose there are particular places where the approximately 30m range is problematic, or there are particular obstacles such as concrete walls or sliding doors or similar. Then a ”fixed” peer placed with a line of sight to several approaches can help to lead the network and share timeslotting information.

Placing some ”fixed” peers also has the further benefit that alarms can be attached to these peers, e.g. Proxsystec's advanced door-warning system which can warn if a vehicle is approaching and about to transit through a warehouse entry or exit. This means we do not need to rely on the driver to sound a warning in such cases.

8 Effect of Random Errors on the System

As mentioned, UWB is generally quite accurate, but there are cases where it simply returns an incorrect or less accurate range. Reasons for this can include:

1. Radio frequency noise;
2. Interruption to line of sight;
3. Near the limit of the range; or
4. Multipath (reflections from nearby objects).

We have mitigated these problems with some quite advanced techniques:

1. The signal processing in the radio receiver can calculate a confidence level as well as calculating a range. It arises from calculating the amplitude level of the signal detected as the earliest arrival (the direct line of sight), as compared with other copies of the signal that the receiver assumes are multipath.
2. Every range datum transmitted or stored within our system includes the confidence, and this forms an integral part of location processing, since we take into account any conflicting information, numerically weighted by its confidence.
3. Our system stores the range information for the last 8 seconds, and for close-together objects this can include up to 8 ranges per second or 64 ranges in total. An advanced regression scheme allows to estimate not only the range to the object, but its velocity and acceleration when there is sufficient confidence.
4. Outliers are naturally ignored by the regression when there is sufficient weight of other data to overrule them. On the other hand, to avoid sluggishness in response due to too much averaging, older data are numerically less weighted.

9 Battery Life Optimization

One aspect given less attention in Wu et al (2007) and Alarifi et al (2016) is battery life. We shall simply point out that our wearable tag has a battery life of several days in standby (i.e. when not in close proximity to hazards and therefore only monitoring the network rather than performing frequent ranges) and at least 16 hours in operation. The way that we achieve this is as follows:

1. The tag spends most of its time sleeping (the radio draws no power and the processor very little). It is still tracking timeslots and wakes up as required.
2. Once per second the tag wakes up for an announcement from a nearby leader or other tag, to remain locked to network time, and to receive shared information.
3. Once per second the tag announces itself and also re-shares any information.
4. Occasionally the tag must lead the network. This ensures that somebody is always listening, and hence two networks cannot merge without being aware of it. The

leader consumes more battery, but still operates the radio in a significantly lowered power mode, by quickly pulsing the radio on/off during idle listening.

10 Location vs Range Processing

We have provided a sophisticated mobile base station which is capable of tracking large numbers of tags (theoretically up to 64 peers of which realistically about 40 of them may be tags), and which contains multiple antennas, audible alarms, and a VDU showing the large easy-to-understand alerts showing directionality.

The multiple antennas significantly improve the directional coverage of the system, avoiding any dead spots due to the UWB antenna configuration (we are not aware of good omnidirectional antennas for UWB and this is a useful workaround), and they also form the basis of the directional alerts based on trilateration.

The approach we've taken is to give each antenna a completely separate radio, and to make each antenna operate as a separate peer on the network from the viewpoint of timeslotting. They also form a wired network that includes the VDU unit.

Having multiple antennas also allows monitoring multiple channels simultaneously, allowing nearby tags to be much more aware and collision-resistant due to the policy of peers sharing all known information about the channels and timeslots.

11 Comparison with Nearest Competitor

We consider the LocaSafe Anti-Collision System publically described at https://locatechs.com. It states that it is based on 802.15.4a, which means it is UWB.

The PT10 Personal Safety Tag is described as having a range of 40 metres, 360 degree directionality, a tracking capability of 5 anchors, and a lifetime of 16 hours active, 1 week standby. We shall examine these claims individually:

1. The range of 40 metres may be overstated. We have mentioned a range of 30 metres for our product, but this is 30 RELIABLE metres. We could probably perform to 40 metres in ideal conditions with some droppage (not 100
2. The directionality of 360 degrees may be overstated. If the tag is worn on the chest then the line of sight will be interrupted by the person's body. It requires a high transmitter power to overcome this. But based on their claimed battery life, their transmitter is probably of a similar power level to ours.
3. The tracking capability of 5 anchors is interesting. This seems quite small. Whilst it could be a software limitation, more likely it indicates that they are using ALOHA collision protocol as recommended in the 802.15.4a specification. Unfortunately, ALOHA degrades very quickly as the channel becomes congested. At 10% utilization there are nearly constant collisions (we also hit this problem during development and solved it as described earlier). Did they solve it at all?
4. The battery life is comparable to ours. Their standby time may be overstated. They might also have more standby time due to less advanced algorithms, for instance

their tag would not need to lead the network if it uses only ALOHA. Additionally, we haven't accurately determined our standby time, and will do so soon.

The VA10 Base Station is described as having a range of 40 metres, 360 degree directionality, a tracking capability of 20 tags per second, and requiring wired power. We shall examine these claims individually:

1. The 40 metres may be overstated as discussed earlier. It seems likely that the same radio is used in the base station as in the personal safety tag.
2. The directionality may well be overstated here also. They would probably need to use multiple antennas to really have the claimed 360 degree directionality.
3. The tracking capability of 20 tags per second is again interesting. If they use the same radio as the tag then why does the base station have a greater tracking capability than the tag? It might indicate that they use ALOHA and that the base station rarely transmits and rarely causes a collision since ranging is initiated by tags. It might be a software limitation, or the increased tracking capability might be explained by multiple radios, but the latter seems unlikely.
4. Our base station also requires wired power. We probably use more power than them due to our VDU unit, heavier CPU load for location calculations, and our multiple antennas. We may try a lower power LCD screen and pulsing the radio on/off, we didn't try this yet in case it impacted on range.

In summary, the LocaSafe system has somewhat similar specifications on paper to ours, but the much reduced tracking capability seems to indicate that their use of the airwaves is not very optimal. This would be in line with industry best practice, whereas our system is much more innovative as far as we understand it.

12 Conclusions

We have independently developed a very advanced system that is essentially a superset of 802.15.4a, in that we use standard UWB hardware (but wringing the most out of every feature that our radio supports), and have then layered a sophisticated software system on top of that. At the present time the system is oriented towards ranging and location, but it also forms quite a flexible platform which could ultimately be extended to things like sensor networks or goods tracking.

We have gone through a number of versions of our hardware and software platform during development. Several of these have been evaluated on-site with clients, but ultimately we decided we needed to do further development to produce a system that was sufficiently robust. Along the way we have independently discovered nearly all of the issues flagged by the leading researchers in the IPS field, and come up with highly innovative solutions. These solutions are very patentable.

About the Author

Dr. Nicholas (Nick) Downing has decades of experience in hardware and software development, signal processing, and mathematical optimization. He serves as the CTO at Proxsystec, where he leads a team of engineers in performing sensor research and development, as well as having overall responsibility for commercializing the research. Nick also has strong experience in the IoT field, as he was involved in firmware development for a large manufacturer of smart home devices before joining Proxsystec. Further, he has extensive teaching and research experience in the academic context before he moved to industry, and he now applies this considerable experience to the successful commercialization of academic research.

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