Dead Reckoning for Consumer Electronics

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BIOGRAPHY

Mark D. Amundson P.E. is the applications engineer for Honeywell Magneto-Resistive sensor products at the Honeywell Solid State Electronics Center in Plymouth Minnesota. He has worked on many new magnetic sensor and MEMS rate sensor products and applications for personal and vehicle navigation systems. In working with compatible navigation chipset vendors and consumer electronics manufacturers, Mark has unique insights on the status of dead reckoning technology and its fusion to GPS navigation systems.

ABSTRACT

Most portable personal electronics today are quickly adding a GPS receiver to the standard complement of features. These wireless phones, dashboard navigators, pagers, and personal digital assistants (PDAs) all have the challenge to be useful navigators, even when their GPS receivers are prevented from attaining a fix on enough satellites.

When the loss of GPS navigation occurs, dead reckoning via direction and distance is the next most accurate way of maintaining position location. And with multiple obstructions like indoor navigation, heavy tree canopies, and canyons; dead reckoning technology is sure to be implemented in consumer electronics devices that value position for both commerce and personal security applications. This paper describes the value of dead reckoning technology and how close we are to placing it into consumer electronic products

DEAD RECKONING

A compass and a map is what most educated persons think when they hear the term dead reckoning. But today's personal navigation products put the mapping information in their memory chips, use Global Positioning System (GPS) receivers to determine their latitude and longitude on the map, and use a digital compass to indicate direction.

But now we as consumers are demanding "personal navigation" in products other than stand alone GPS handheld receivers. Most John and Jane Doe consumers have automobiles and wireless phones, and see plenty of value in map presentations on dashboard displays and phone color screens. And the automotive and consumer electronics industry sees the same profit opportunity, and has begun to respond with onboard navigation systems and phone chipsets with additional GPS downlink capability. Then throw in Telematics and Location-Based Services subscription fees for a recurring revenue stream.

But there are a couple points of customer dissatisfaction that the nascent personal navigation industry has to over come. The first is cost, and the second is quality of service in less than ideal situations. We as consumers have been spoiled by cheap wireless handsets and service plans that give away or substantially subsidize the handset purchase for a one or two-year contract. Now add in tens of dollars to implement the GPS receiver, antenna, and navigation engine electronics; and many consumers will balk at the extra feature costs, or at least re-evaluate the value of maps, LBS pointing, and data mining.

But through the miracle of broadcast advertising and immense pressure on GPS chipset makers to reduce costs, the public is warming up to personal navigation as a requirement in new auto and phone purchases, and manufacturers are offering navigation systems at attractive prices.

But as veteran personal navigation consumers can attest, some locations are just not providing accurate map locations in circumstances of tall buildings nearby, covered bridges, tunnels; and worse yet, no navigation inside commercial buildings with your handset. And a lost person inside an unfamiliar building is just the kind of application you want your personal navigation handset to perform at its best. Yes, us engineering geeks can explain the problem as a loss of GPS fixes, but it is not comforting to consumers.

Of course dead reckoning navigation sensors are the answer to the missing GPS location updates. In vehicles, we can add wheel speed sensors for distance from last GPS waypoints, and add digital compasses or rate gyros for direction tracking. But these add-ons do not come free, and some sensors (like rate gyros) begin to drift out within seconds of time from last GPS readings.

For wireless handsets, we do not have "wheels" to measure location displacement. So another form of sensing motion must be found, and then integrating motion into change of location.

ENTER PEDOMETERS

Pedometers have been around for quite awhile. Joggers and exercise enthusiasts have been using mechanical or electric-based pedometers to count footsteps. And even McDonald's has given pedometers away if you come in for their special offer McSalads.

But pedometers for dead reckoning are a whole different application. Counting footsteps or "strides" is just the beginning as the total kinematical motion has to be cataloged for accurate location change. To do this, the consumer's handset needs to count strides while GPS reception is available to gather the average strides between GPS waypoints to derive a "stride length".

And stride-length prediction is just the beginning. Better pedometry algorithms should adjust stride-length based on stride rate (slow walk, fast walk, running). And stride direction is just as important. Such strides like forward steps, backward steps, side-steps, and even stair steps are important to be cataloged while GPS is available.

To do the sophisticated pedometry algorithms, high quality tri-axis accelerometers are employed to measure the foot-falls and human-body accelerations for stride event detection and stride category. Both accelerometer manufacturers and pedometry algorithm designers need to collaborate on the right amount of firmware versus hardware required to get accurate pedometry. If the accelerometers do not offer some stride signal processing, then the poor handset processors are tied up doing mundane kinematic problem solving instead of giving consumers the information they require in a timely fashion.

Of course a dead reckoning module could be remotely left on the belt and communicate via short range bluetooth protocol to a handset, much like the wireless headsets do. However it may be a challenge to integrate the GPS receiver remotely as humans are excellent L2 RF absorbers, and the handset may be a better location with integrated RF ICs.

HOW IT WORKS

Dead reckoning from a last GPS waypoint or fix entails a detection of a stride event, an instantaneous compass heading associated with the stride, and accrual by the navigation engine to update the location by the stride length and direction. A measure of quality of the location after GPS is unavailable is an error value described as

"percent of distance traveled". For example, an error of 5 meters for a walk of 0.1 kilometers, is 5% of distance traveled.

Note that this dead reckoning quality does not include time, as it would with an inertial navigation system using rate gyros. Gyros drift with time, as opposed to pedometry-based dead reckoning that accrues no additional error if no additional footsteps are taken. Figure 1 shows this concept.
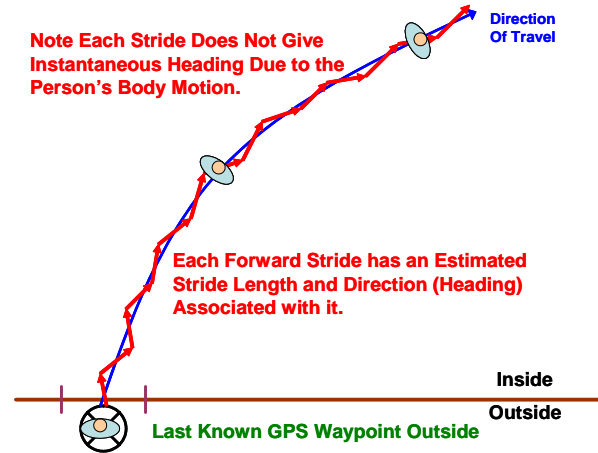

Figure 1
Pedometry-Based Dead Reckoning

The 5% of distance traveled error budget is considered a reasonable limit of location prediction for a consumer indoor navigation unit without GPS assistance. Military (soldier) and First Responder (police, fire) dead reckoning with pedometry typically have a 2% to 4% distance traveled error budget, but have more stringent navigation accuracies and a larger navigation electronics budget for the reduced errors.

When examining the sources of pedometry-based dead reckoning errors, about 75% of the error comes from inaccuracy in the compass heading. As you can see from Figure 1, every step has a heading associated with it and our bodies tend to twist with each step beyond the actual direction we intend to travel. Each of these twisting actions can sum to minor errors. Also the motion of the body contributes a modest amount of acceleration that is difficult to discern from pitch and roll angles that the accelerometers provide the compass algorithm for tilt compensation. And each 0.1° of tilt error can contribute to 0.2° of compass heading error at North American latitudes.

Stride prediction errors attribute the other 25% of dead reckoning error sources. This usually means that basic algorithms for stride length and length adjustment (strides per second) are good enough without extra kinematic characterization. The good news is that no extra recurring

cost is added if the stride length algorithm is refined for more precision.

THE VALUE PROPOSITION

When adding pedestrian navigation to a wireless handset, you gain additional hardware blocks to the system. The digital compass function typically adds three magnetic sensor elements plus an Application Specific Integrated Circuit (ASIC) to signal process the sensors into digital magnetic vector quantities. As part of both the pedometer and digital compass function, a tri-axis accelerometer and its integral ASIC is required for tilt and kinematic data. For reasonable vertical position dead reckoning, a pressure sensor and ASIC is integrated to be used as barometric altimeter to sense the change in altitude as the consumer uses the stairs, escalator, or elevator within a building. And of course a multi-channel GPS receiver is required as the primary source of location information. Figure 2 show a typical handset navigation block diagram.
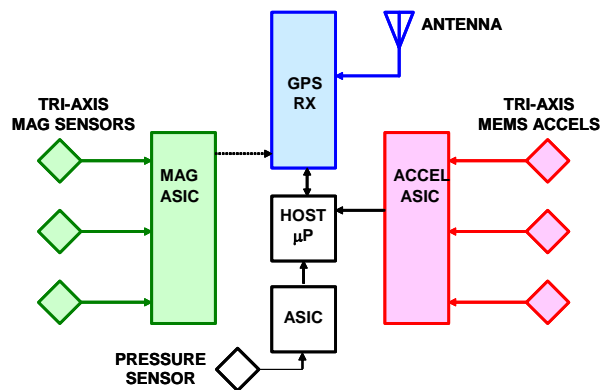
Figure 2
Handset Navigation Block Diagram

When an electronic version of a magnetic compass is added to LBS and Telematic systems, the pointing task now becomes the responsibility of the compass circuits, and the GPS receiver is the backup system. While electronic compassing is prone to heading inaccuracy inside steel and concrete buildings, the errors will be smaller outside where most LBS will be used.

When GPS is unable to maintain the location, dead reckoning backup becomes feasible with a tilt-compensated electronic compass. The compass provides the direction from the last GPS waypoint, and the compasses MEMS accelerometers do double-duty by becoming a pedometer to count footsteps by the user. The error build-up in location CEP is dependant on quantity of footsteps, not with time, such as in inertial-based systems. Honeywell's dead reckoning algorithms are proven to have good location accuracies, from the initial phases of the Army's Land Warrior program.

LOCATION BASED SERVICES BASICS

To make a quality LBS experience, pointing accuracy must be moderate to precision-grade. Defining moderate accuracy heading errors as $\pm 2°$ to $\pm 5°$, and precision heading errors as less than $\pm 2°$; these errors are important in being able to point to moderately distant businesses for product or service discrimination. Figure 3 shows the typical scenario in LBS pointing.
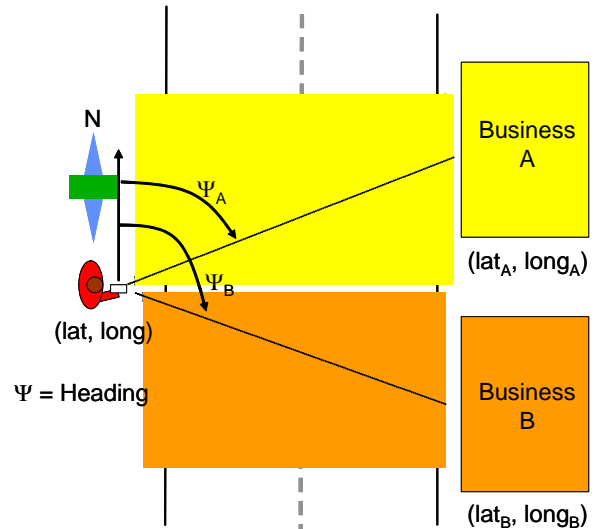
Figure 3
LBS Pointing Accuracy

In Figure 3, the ability to pick out business A from other surrounding businesses, the LBS servers need accurate latitude and longitude, plus an accurate heading. Then the nearest subscribed LBS business will appear on the customer's LBS enabled phone. When the distance between the customer and the LBS businesses is large, or when the businesses are densely packed together, then pointing (heading accuracy) is most important.

LBS APPLICATIONS

From the fledgling LBS and Telematics industry, several baseline applications have come forth as reasons for customers to acquire the services. The number one application, or "killer" application, is map display navigation and turn-by-turn navigation. Other applications of significance are person finders, business finders, and topographic map displays.

HARDWARE COSTS

With GPS chipset and antenna costs plummeting from tens of dollars to below ten dollars, the same pressures for the other dead reckoning sensors and support circuits are also occurring. Wireless phone chipset makers have been also working to lower navigation feature costs by integrating more support electronics into existing

chipsets. A good example is Qualcomm's MSM radio chips multiplexing phone and GPS radio frequency blocks in one chip and the phone demod and GPS correlator in another chip. In another tactic, both SiRF and Texas Instruments GPS chipsets include extra logic and ADC input pins for dead reckoning sensor interfaces.

MEMS accelerometers are getting deserved attention to both lower the price for 2 and 3-axis products, plus more digital interfacing with either Pulse Width Modulation (PWM) or with I^2C serial data streams. It is very likely that these accelerometers will drop into the couple dollar range in pricing while providing more capability. MEMS Rate Gyros are still struggling with the challenge of cost and bias drift rates, and are still the province of tens to hundreds of dollars for near navigation grade usage.

The digital compass market has heated up competitively, and magnetic sensors with support ASICs are dropping into the few dollar range for various grades of accuracy. It is very important to understand the technologies available (Magneto-Resistive, Magneto-Inductive, and Hall-Effect) and the tradeoffs with each. It is important to reinforce that dead reckoning (indoor navigation) requires a precision accuracy compass; and that both the sensor type, and the method of digitizing the sensor outputs will set the basic accuracy. In general, you will need at least 13 effective bits of ADC accuracy, and sensors with less than 1% of cross-axis effect and sub-milli-gauss resolution.

From a wireless phone standpoint, the addition of a precision digital compass, 3-axis MEMS accelerometer, and a good pressure sensor currently adds beyond 10 dollars of before profit cost; on top of the GPS features. While it is expected that the sensors will continue to incrementally drop in price, a major challenge will be not to choose lesser accuracy sensors in the attempt to save cost.

While MEMs rate sensors are still too costly for handsets, their near-navigation grade bias drift performance would be an ideal enhancement to a digital compass for indoor environments. In most commercial building, metal beams and studding can bend up a compasses predicted heading if the person is near enough. By adding a yaw rate gyro and software to revert to the gyro's heading under gyro/compass divergence conditions, further performance improvement is possible.

Also there is plenty room for better integration of the dead reckoning algorithms in the effort to create an acceptable indoor navigation solution with all the computation power required. Gathering the last GPS heading plus processing all the sensors into accurate and meaningful distance and direction data updates is computationally intensive. In addition, Kalman filter smoothing of the sensors and GPS data types will require more processor resources.

In conclusion, we are just a few dollars of hardware cost and a moderate amount of processor firmware away from committing the indoor navigation feature to consumer electronics. At present both military and first responders can afford the dead reckoning technology, and the experience of designer here will lead to benefits in the future for wireless phones and vehicles.

MDA

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