

A Personal Dead Reckoning Module

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BIOGRAPHY

Dr. Tom Judd is Chief Scientist at Point Research Corporation. For the past four years he has been responsible for developing and implementing algorithms for dead reckoning. Dr. Judd received his Bachelor of Science degree in Physics from St. Mary's College of California, and his Ph.D. in Biophysics from the University of California, Davis.

ABSTRACT

Point Research Corporation of Santa Ana, CA has developed a new lightweight miniature Dead Reckoning Module (DRM) for drift-free navigation by personnel on foot. The traditional compass and pace-count dead reckoning navigation has been replaced by a continuous hands-free module. An internal solid-state 3 dimensional compass provides a robust tilt-corrected heading. We automate step counting with an electronic pedometer. The pager-sized module also includes a barometric altimeter. The module reports data, and is controlled via bi-directional RS-232 serial interface. A second serial port on the module may be connected to a GPS receiver. When GPS is available, the module will blend the data with DR using a Kalman filter. It provides a seamless navigation solution through many buildings, in canyons, or other areas where the GPS signal is compromised. The DRM is protected under U.S. patent number 5,583,776.

INTRODUCTION

GPS is not always available. The signal may be blocked by buildings, canyons, or jungle canopy. In a military situation, it may also be jammed. It is not always easy or desirable for a user on foot to position himself to receive good GPS. In particular, a soldier will seek out sheltered areas that are not generally good antenna locations. Dead reckoning can be coupled with GPS to provide continuous high-quality position estimates when traveling through these challenging environments. We extend to foot travel,

what has been done in vehicular and aircraft applications where inertial navigators are used to bridge the dead spots.

Dead reckoning has been used for ages to obtain a position estimate based on velocity, time, and direction from a starting point. For a person on foot, measuring distance directly using a pedometer is a practical means for measuring distance traveled. Take the pace count and multiply by the distance for each pace, and you get the total distance traveled. Pace count has in the past been an important measure of distance over land. The word mile originates from the Latin word for one thousand, *milie*, the number of paces in a mile.

There are several advantages in weight, size, power consumption, and accuracy to using electronic dead reckoning over a conventional inertial navigator. Inertial navigators double integrate accelerations to obtain positions. Even small errors in accelerations build in time. Error velocities of 1 meter/second after an hour of integration, while acceptable for aeronautical applications, are absurdly high for personal navigation on foot. [1] And very often, the power requirements are so high as to make any extended trip on foot to be impractical with an inertial navigator.

A pace count works great for travel along a road because the problem is one dimensional. A compass might be needed at a crossroad or as an occasional check; but does not need to be observed continuously. Off the road it gets a bit harder. One may take a bearing on a distant landmark and then count paces towards it. The actual track becomes series of measured segments. The process gets yet harder when the forest limits visibility, or when the trip is taken at night. In hilly terrain, a trail may wind along a contour, so there might not be any straight path segments.

Add to these difficulties the fatigue factor. It is easy to lose count when you are tired or stressed or distracted. And who is going to do all the trigonometry in their heads anyway? It would be so very convenient to automate this process with an electronic compass and step counter. This way, we could shrink the track segments and perform a continuous calculation automatically without having to take special note of one's direction of travel. Point Research's Dead Reckoning Module (DRM) does just that.

DEAD RECKONING MODULE

The DRM is a two-board sandwich about the size of a PC (PCMCIA) card. An analog board carries both the tri-axial accelerometers and the tri-axial magnetometers. A temperature sensor and a barometric altimeter are the two other analog sensors. The digital board has a microprocessor, memory, power conditioners, serial interface chips, and other logic for addressing and control.

The two boards together are about 2 x 3 x 0.6 inches. The weight is less than 3 ounces. Power consumption is about 0.5 Watts; it operates on 2 to 5 volts dc. The current configuration of the DRM circuit boards is shown in Figure 1.

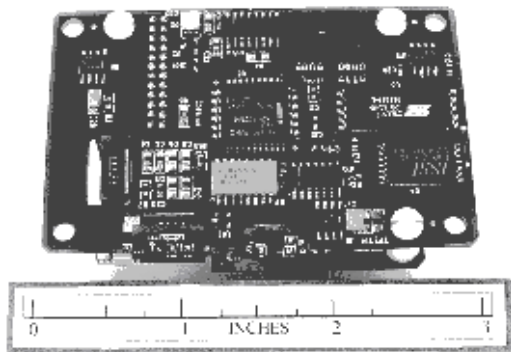


Figure 1 DRM Circuit boards.

FUNCTION

The magnetometers provide a three dimensional vector of the earth's magnetic field relative to the platform. The accelerometers determine a horizontal plane. It is critical to only look at the horizontal component of the magnetic field since the vertical component can be quite large. The dip angle of the earth's field near our office in Santa Ana, California, is approximately 60 degrees, so the vertical component is actually larger than the horizontal

component. A one degree error in tilt can cause nearly two degrees of heading error.

The accelerometers are also used to detect foot falls. Each step is counted by carefully filtering the vertical acceleration. We raise a step signal threshold to eliminate false detections from normal body movements while standing still.

The DRM communicates to a host computer via the RS-232 serial interface. Message packets are defined which enable the host to control the DRM. The default configuration is such that on power up, the DRM starts sending position messages without any input from the host. The DRM will poll its second port for GPS position data. If available, the module will include an estimate of the current latitude and longitude in the position message; otherwise it simply reports the changes of position from when it was turned on. If precision GPS is available, then it will also be used to calibrate the module to user and environment in which it is operating.

STAND ALONE MODULE

The DRM works right out of the box. No GPS is needed for stand alone dead reckoning. However, the module does need to be initialized with two system constants. The first is an estimation of the size of each step. The second is a compass bias that is a function of the orientation of the unit with respect to the user's body. The bias can be canceled with a quick alignment procedure.

We have found that on even, level ground, a person's step size is remarkably constant. Typical step counts over a measured course might vary by less than one percent for ideal conditions. This suggests that we can have the user enter a known step size, and get good results from the DRM. Provisions have been made in the software to initialize the step size to values that the user may enter. Once entered, the step size is stored in a configuration file. This has worked out very well in practice. Much of our testing is performed without entering any value at all, since the previously entered step size remains valid. The track produced in Figure 2 was made without user intervention using stored parameters.



Figure 2 Stand alone DRM track.

The step direction is determined assuming the module is attached to the user in an orientation that is fixed relative to his body. A fixed bias, called the body offset, is added to the observed heading in order to align it with the true direction of travel.

A separate offset originates from the natural variation of the earth's magnetic field. Magnetic north and true north are not the same. In Santa Ana, the difference is about 14 degrees east. Facing north, an uncorrected compass would read about 346 degrees. The DRM can be programmed to cancel out this offset.

KALMAN FILTER

Estimates of step size and body offset may be entered manually or derived from map data. However, it is most convenient to allow the module to estimate them automatically using the built-in Kalman filter. The user does not have to manually enter the parameters when the Kalman filter is enabled. He simply straps on the module and starts walking. The module blends dead reckoning and precision GPS to obtain optimal estimates of position, body offset, and step size. When GPS is lost, the most recently estimated parameters are used by the DRM for dead reckoning.

Figure 3 shows Kalman filter estimates for the body offset and step size vary while walking. Normally, the body offset would only be a few degrees, since its initial orientation is fairly well known. We can more clearly demonstrate the operation of the Kalman filter by intentionally introducing an error. To make the test more challenging, we do *not* program the module with the local magnetic variation. This forces the Kalman filter to estimate the sum of the body offset *and* the much larger magnetic variation. Most of the offset that is being

canceled has been artificially introduced. Not surprisingly, the body offset settles to a value near the local magnetic variation.

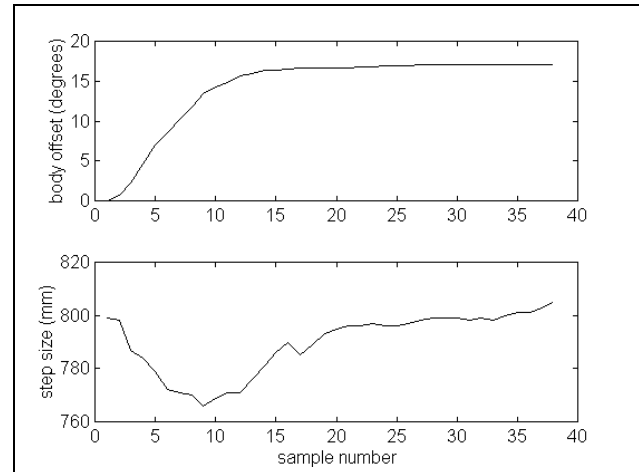


Figure 3 Kalman filter estimates of body offset and step size versus sample number.

There is a curious dip in the step size estimate right at the beginning. It is an initial transient. As the body offset gets corrected, the step size returns to its nominal value (800 millimeters). Total distance traveled for this exercise was about 500 meters; samples were about 11 seconds apart.

SOFTWARE

We have developed two software packages to support the DRM. The first is targeted for a low-power palmtop computer, the HP-200 LX. The second runs on a ruggedized portable PC made by Texas Micro.

The palmtop is very convenient. It fits in a shirt pocket, is light, and battery use is so low that it is not a concern. The CGA resolution graphics is used to display a track path. The scale may be expanded so that each step may be seen. Figure 4 below is a sample of dead reckoning data taken with the palmtop. No GPS was used. The data was taken while pacing off the name 'Tom' in the parking lot. Rotate the plot 90 degrees counterclockwise to view the letters in the normal orientation. The plotting software used for this paper smooths the discontinuities in the data; even so, single steps can be seen where the direction changes at the top of the 'o'.

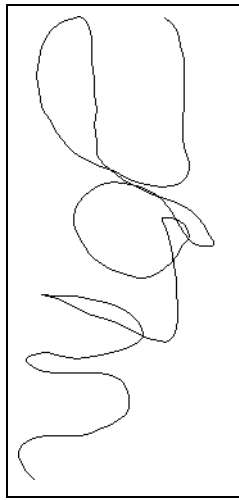


Figure 4 Sample of fine track resolution: the name 'Tom' created by walking the letters. Name is about 23 meters by 7 meters.

While good for demonstrations, the palmtop is too slow for general purpose data collection. The second software package is a Windows based program. It displays waypoints and user position on a digital map. We display diagnostic test data along with text versions of the current position in latitude/longitude and MGRS. Most useful is a body-relative azimuth indicator that points to the next waypoint. No keyboard is required, the menus all operate with a touch-pen.

With digital maps, there is always a tradeoff between the desired resolution, and the capacity of the computer in both storage and speed. Our compromise is a pixel size of about 5 meters. A sample of the resolution is shown in the field test below. Note that three or four pixels would completely cover the data taken in Figure 4.

FIELD TEST

We tested the module in hilly forested terrain. Users saw the module and software for the first time on the day before the test. Some training was required to get them used to carrying a computer and running the software. The important point for this test is that they were not engineers. A sample track from one of the users is shown in Figure 5.

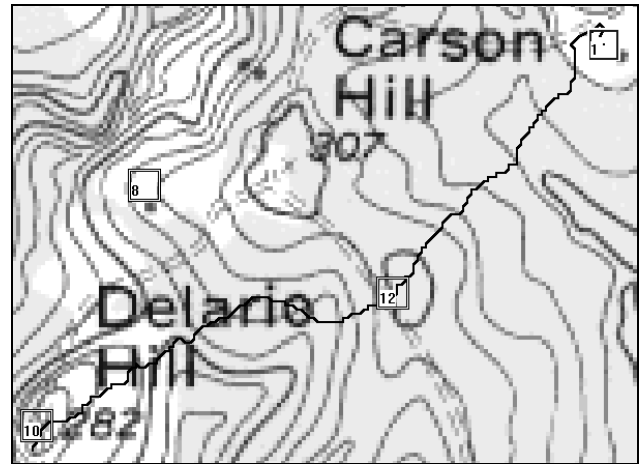


Figure 5 Cross country track. DRM plus GPS for first leg (waypoints 1 to 12), DRM alone for second leg (waypoints 12 to 10).

The trip started at the top right waypoint, the box numbered 1, and ended at the bottom left waypoint, box number 10. Waypoint 12 was placed on dirt road that cut across the track near the half way point. The GPS was enabled for the first leg of the trip. The user stopped at waypoint 12 and turned the GPS receiver off. This forced the module to use dead reckoning for navigation. It also halted any changes to the calibration constants obtained from the Kalman filter. The second leg was made using the DRM dead reckoning as the only navigation aid.

The direct path distance is about 900 meters, but the overland track took about 1100 meters. There was no trail, the path taken was mostly through pine forest. Towards the end, the forest opened up but was replaced by thick shrubs and tall grasses. Visibility was limited; the user could not see the final destination until he emerged from the brush onto a paved road. Because of the limited visibility and lack of landmarks, the user mostly relied on the software display to indicate the direction to the next waypoint.

The plot of the track taken demonstrates the accuracy of the DRM. It slices right through the destination waypoint. The test also showed that a valid calibration could be achieved with no prior knowledge of the user's gait. Just turn it on and go. The system successfully adapts to the user's stride for the terrain over which it is used.

APPLICATIONS

The two major categories of dead reckoning applications are tracking and navigation. With tracking, position reports are sent to a remote site via a radio link. Included here are such applications as keeping track of prisoners, watching elderly, and monitoring ambulatory patients. For safety or logistics one may want to know where one's fellows are. We have built such a system using off the

shelf radio modems. We can easily track several users around an urban environment.

Navigation at night or under difficult conditions can be accomplished without much thought to pace counting. The module works under jungle canopy, indoors, and in urban canyons, where GPS receivers tend to have problems.

Data can be post-processed to obtain information secondary to tracking: the layout of a tunnel, position and orientation of doors or portals in an enclosed structure, or a map of pedestrian accessible regions of a complex.

For more information on the Dead Reckoning Module please contact

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REFERENCES

[1] The Global Positioning System, RAND Corp., 1995, pg. 70.