Energy-efficient Localization for Virtual Fencing

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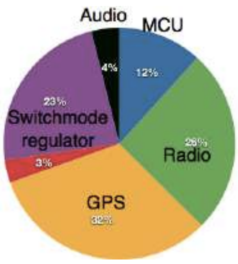
Overview

We focus on the tradeoff between energy consumption and localization performance in a mobile sensor network application. Our approach is to combine GPS location with more energy-efficient location sensors to bound position estimate uncertainty in order to prolong node lifetime. The target application is outdoor location monitoring for tracking cattle using smart collars that contain wireless sensor nodes and GPS modules, as shown in the Figure below [1]. We use empirically-derived models to explore duty cycling strategies for maintaining position uncertainty within specified bounds. Specifically we explore the benefits of using short-range radio contact logging alongside GPS as an energy-inexpensive means of lowering uncertainty while the GPS is off. Results show that GPS combined with radio-contact logging is effective in extending node lifetime while meeting application-specific positioning criteria.

A cow fitted with our smart collar

Node Energy Profile

Always on GPS



5% duty cycled GPS

The collars include a Fleck node, a GPS module, and an audio board for generating audio cues to indicate to animals that they are crossing a virtual fence line. The active mode power consumption of the GPS board is by far the largest of all components at 165mW, compared to 50mW for the radio and 18mW for the MCU. The Figure above compares the collar node energy consumption for an always on GPS module (Figure 2(a)) against a 5% duty cycled GPS module. Both configurations use a 10% radio duty (using low-power listening). The always-on GPS module accounts for 88% of the power consumption of 209 mW and limits the nodes' lifetime to 19 days, while 5% duty cycle GPS accounts for about a third of the overall node power consumption of 25mW, which extends the nodes' lifetime by a factor of 7.5.

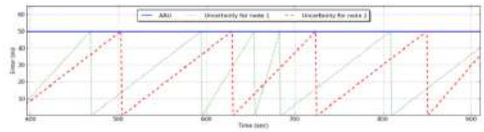
GPS Duty Cycling

The total time during which the GPS can be powered off while guaranteeing an error threshold is:

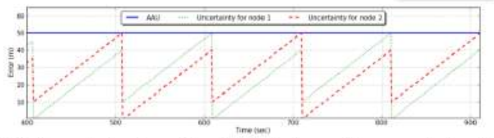
$$T_{\max} = \frac{AAU - U_{gps}}{S} - T_{lock}$$

AAU: absolute acceptable uncertainty
S : speed
T_{lock}: GPS lock time
U_{gps}: GPS module error

GPS Duty Cycling with Contact Logging

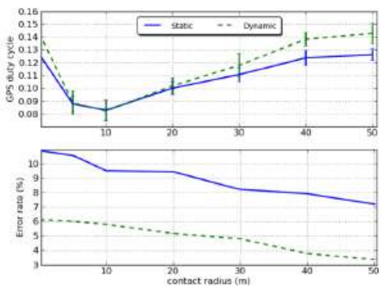


(a) Error behaviour for GPS duty cycling



(b) Error behaviour for GPS duty cycling coupled with contact logging

To evaluate the impact of our algorithms, we have implemented the duty cycling strategy in a Python-based simulator using the large dataset of actual cow positions. The Figure above illustrates the impact of contact logging on GPS duty cycling for two nodes with dynamically set speeds. Without contact logging (a), each node independently tracks its uncertainty estimate and acquires a GPS position fix whenever its uncertainty approaches AAU of 50m, resulting in 5 fixes for node 1 and 4 fixes for node 2. Using contact logging, the nodes can reduce their GPS fixes to 3 and 2 respectively in the same time window.



The final figure summarizes the impact of contact radius on GPS duty cycle and error rate over the entire dataset. The optimal contact radius is at 10m, with a 25-33\% reduction in duty cycle over GPS duty cycling (R=0).

Conclusion

Coupling GPS duty cycling with short-range radio contact logging can both extend the lifetime and reduce positioning errors in a multi-agent tracking application.

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References

[1] Zack Butler, Peter Corke, Ron Peterson, and Daniela Rus, "From robots to animals: Virtual fences for controlling cattle", The International Journal of Robotics Research, vol. 25, no. 5-6, May 2006.

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