Design and energy optimization of a multifunctional IoT solution for connected bikes

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Motivation

Electro mobility market trend

New Passenger Car And Bicycle Sales (2012)

<table>
<thead>
<tr>
<th>Country</th>
<th>Bicycles ('000)</th>
<th>Passenger cars ('000)</th>
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</thead>
<tbody>
<tr>
<td>Germany</td>
<td>3966</td>
<td>3083</td>
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<tr>
<td>Britain</td>
<td>3600</td>
<td>2045</td>
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<tr>
<td>France</td>
<td>2835</td>
<td>1899</td>
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<tr>
<td>Italy</td>
<td>1606</td>
<td>1402</td>
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<td>Spain</td>
<td>780</td>
<td>700</td>
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</tbody>
</table>

Market forecasts for pedelecs (<25 km/h) 2014–2023

Source: Allianz.com
Motivation

Many bike tracking and cycling analysis tools hit the market in the last years.

Cloud-based fitness tracking
https://www.velohero.com/

“Wearable” GPS trackers
source google shopping
Motivation

Bike security systems

http://bitlock.co/

Anti-theft GPS tracking devices for Bicycles

Arm your bicycle with the latest tracking technology. Covert and secure, our innovative devices provide you with the peace of mind that your bicycle can be traced should it be stolen.

https://noke.com/pages/ulock

http://www.spybike.com/
Motivation

However, millions of bicycles are stolen every year:

- Stress
- Personal monetary losses
- Market losses (≈150M only in Italy)

We seek a compromise between security, reliability, portability, efficiency, ease of installation/customization...
Challenge

Electronic device for enhanced security and monitoring

Invisible
Charge-less
Effective

Cloud infrastructure
Data Management
Efficient
Affordable

Mobile application
User assistance
Parking recommendations
Legal retrieval assistance
System Infrastructure

Embedded IoT system -> Core of Infrastructure
Retrieves and communicates data to cloud with heterogeneous interfaces
*Hidden in bikes’ frame*
Embedded IoT System

HW Optimized for energy efficiency
Low-power BLE SoC as main MCU controlling sensors and communication peripherals
Dedicated DC converters for energy hungry sub-systems
**Power Management Unit**

**Multi-source Power Supply and Management**
Automatic switching between USB and Harvesting + Supercapacitors by means of HW XOR
Fuel Gauge -> precise battery charge/discharge/state control
Energy Harvesting Configuration and Tests

**Kinetic Energy Harvesters**
(i) Bottle Dynamo
(ii – iii) Contactless single-/double-coil transformers

**Energy Transformers**
(i) TI BQ-25570
(ii) Linear LTC-3588-1
Energy Harvesting Performance

Results
Solar PV panel as reference
(i) Dynamo + LTC can sustain very large electronic loads
   DRAWBACK – can’t be hidden
(ii) Double inductive coil can provide more than 125 mW at 5 m/s travelling speed
(iii) LTC3588-1 with internal rectifier outperforms in efficiency BQ + external diode bridge solution

Experimental Data

![Graph showing experimental data for power vs. speed with different power sources and coil configurations.](image-url)
Security and Fitness Tracking Tasks have different performance requirements

- Reliability and long lasting autonomy
- High resolution spatial data, one day of autonomy

Power Consumption characterization of any sub-system is crucial to optimize performance focusing efforts on power hungry components.
SW Optimization – Adaptive Tracking

Algorithm 1: Time based tracking algorithm

<table>
<thead>
<tr>
<th>Input: currentTime, lastSamplingInstant, targetTime</th>
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<tbody>
<tr>
<td>while Forever do</td>
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Algorithm 2: Distance based tracking algorithm

<table>
<thead>
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Time-Based Tracking
Periodic sampling of GPS location
Embedded in modern GPS modems
Simple yet effective

These realize the **Adaptive Tracking** - user selects its preferred tracking mode

Distance-Based Tracking
External sensors to measure speed
Minimal GPS utilization

-> Cloud post-processing to optimize tracking depending on activity and user habits/preferences
Simulated Power Profiles
Power consumption of Time-based tracking as function of GPS sampling rate and buffering (delayed transmission of data to cloud)

Independently from the rate, buffering severely increases performance, reducing current consumption down to 10 mA introducing a delay of 180 seconds, considering 20s rate and a buffer of size 9 packets
**Simulated Battery Discharge**

One GNSS sampling per minute
Direct data streaming (cellular)
Constant 10 km/h speed

Theoretically, with harvesting, we expect up to 2400 hours of Autonomy

Reasonably, more than 1000 hours of autonomy are expected in a real scenario

Even more implementing data buffering and adaptive tracking
Conclusion

We presented an Embedded System and IoT based Infrastructure for bicycle tracking and enhanced security

We analysed the HW design of the power management subsystem and presented different energy harvesting solution for extending system autonomy and battery self recharge

We investigated SW improvements for minimization of power consumption of the tracking task and data synchronization with cloud
thank you very much for the kind attention

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Service

✓ Bicycle identification
✓ Parking recommendations and security maps
✓ Tracking service with global coverage
✓ Legal retrieval assistance
E-bike installation
Plain seatpost