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Lap Detection of Ice Skaters
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Abstract

This paper proposes an approach for counting laps during a lap-based so-called Skate-A-Thon fund-
raising event in ice-hockey. Although this paper specifically focuses on this usage scenario, the met-
method is equally suited for a variety of similar events. The described system uses active tags working
in the 2.4 GHz ISM band and a single receiving antenna. Evaluations are based on a maximum of 30
concurrently active tags and theoretical considerations show a good performance reliability-wise for
this number of concurrent users.

Keywords

sports, lap counting, lap detection, rssi, signal strength, Kalman filtering

1 Introduction

In various sports such as ice-hockey, hockey with inline skates, and others, it is common to or-
ganize so-called Skate-A-Thons for the purpose of fundraising within junior levels. Usually each
athlete tries to find as many sponsors from the circle of friends and acquaintances as possible. The
 event is organized as a lap-based performance activity and each sponsor commits himself to sup-
port the athlete with an agreed-upon amount of money for every lap the athlete is able to complete
within the given time. This implies that a means for lap counting is needed. This work describes
a Received-Signal-Strength-Indicator (RSSI)-based lap counting system which can be employed at
such events. A local sports club annually organizes such a Skate-A-Thon for fundraising, celebrating

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ice-hockey, and increasing public enthusiasm. Around 900 athletes usually participate in total, with groups of 30 athletes being concurrently on the ice. The current solution uses an UHF RFID system, where athletes wear a passive tag. The installation effort is rather high, especially the installation of the receiver antennas is tedious to ensure proper function. Therefore a new system, reducing the necessary installation effort, is desired. The receiver shall be compact, e.g., the size of a thumb drive but the tags may be actively powered.

Most existing, similar systems are designed for timekeeping rather than lap counting and their installation effort is even higher compared to the current system. Since an alternative to the system currently used is desired, only non-UHF-RFID systems are taken into account. Three examples of commercially available systems are bibchip (bibchip 2017), Chronotrack (Chronotrack 2017), and Lynx (Lynx 2017). Bibchip offers two systems which are both based on RFID. Both systems require the installation of an antenna in the path of the athletes, i.e., under a floor mat or similar. The Chronotrack system also requires receiving antennas to be installed beneath a floor mat in the athletes’ path, similar to the system from bibchip. Due to the infeasibility of such an installation on an ice rink, these and similar systems are not considered further. While the systems from Lynx are in general based on photo-finish cameras for accurate timekeeping on the finish line there is an RFID-based system in their range of systems for ice-skating. It is used for lap counting and split generation but requires the installation of an antenna loop into the ice which is contrary to the desired low installation effort.

2 Hardware

Along the line of expertise from similar projects, different radio-based approaches are considered. A previously conducted evaluation yielded ANT/ANT+ (Ant+ Alliance 2017), Bluetooth, and ZigBee as potential technologies. Any of these technologies might be similarly suited for the desired purpose.

Since the suitability of a Bluetooth-enabled solution is already being examined in a parallel project, this technology is not considered herein. Due to existing experience with the CC2530 from Texas Instruments, designed for the ZigBee protocol in the 2.4 GHz ISM band, this chip’s suitability for the given task is known. The mentioned chip is already used in the HSRvote system, enabling interactive teaching, developed by the Institute for Communication Systems (ICOM) at the University for Applied Sciences in Rapperswil (HSR) (Knutti, Tobler, & Mathis 2014). For the lap counter the HSRvote hardware was equipped with an adapted firmware and equipped with an additional power section, based on supercapacitors. They provide a total capacitance of 50 F. A full charge takes 50 seconds and powers the tag for 10 hours.

3 Usage Scenario

At the Skate-A-Thon the system is used inside an ice rink. The surrounding stadium usually is, to a considerable percentage, constructed from metal. For the given frequencies, both, ice and metal, do reflect RF signals well. This creates a challenging environment with pronounced multipath propagation, as shown later. The dimension of the ice rink itself, if built to international standards, is 61 x 30 m.
4 Detection Methods

The first method, referred to as partial visibility, is based on the assumption that an athlete’s tag is only detectable on the path segment which is closest to the receiver. For a lap to be counted, the athlete’s tag must become undetectable for a certain time before being detected again. Detectability is not clearly defined in terms of distance and depends on multiple factors such as reflection, multipath fading, shadowing and others. Therefore, this method is difficult to implement in a robust way.

The second method, referred to as Continuous RSSI Tracking, continuously monitors the RSSI of all tags on the rink. The RSSI variation as the athlete moves along the set path is then analyzed for lap detection. This approach has the advantage that there is no fixed threshold in terms of received signal strength, as with the partial-visibility method, but rather a minimal RSSI-dynamics criterion.

5 System Design

The system is designed to count skated laps with half-lap resolution. The RSSI-based measurement in the given surroundings inherently introduces some counting uncertainty, predominantly for only partially completed laps. This is not an issue for the described case of application since it is not of legally binding character.

Due to on-ice restrictions an athlete’s path can be approximated by two half-circles joined by two straight-line segments, as illustrated in Fig. 1. The placement of the receiving antenna is critical. The receiving antenna must be placed close enough to the track to not let dynamic range compression occur, but also far enough to prevent small distance variations, close to the receiver, from generating large RSSI dynamics. This can be explained with the fact that the path loss difference, and hence the RSSI dynamics during a lap, depend both on the ratio of the largest and smallest distance of the tag to the receiving antenna (Eq. 1). Since the athletes are free to skate anywhere between the boards and the inner edge of the track area, the minimal distance from tag to receiver can vary considerably. Hence, the RSSI dynamics of an athlete’s tag during a lap varies considerably depending on the ska-
ted path, as shown in Fig. 2. One can see that the RSSI increases with the inverse power of two to the distance as the athlete approaches the receiver. Placing the receiver close to the skating area, i.e., on the boards, causes the RSSI dynamics to differ largely between a skater passing close to the receiver and one skating close to the innermost path. Circling close to the boards where the receiver is placed generates an RSSI dynamics similar to when skating an entire lap along the innermost path. This is illustrated by the lines for receiver location one in Fig. 2.

Placing the receiver antenna at a location further from the skating area, shown as receiver location two in Fig. 2, alleviates the previously described problem while maintaining a sufficient RSSI dynamics during an entire lap. This is shown by the lines for receiver location two in Fig. 2.

\[
\Delta_{\text{RSSI}} = 20 \times \log_{10} \left( \frac{d_{\text{max}}}{d_{\text{min}}} \right) \tag{1}
\]

Fig. 2 RSSI vs. distance for different paths on the ice and different receiver locations.

6 Filtering and Processing

Fig. 3 shows the RSSI of an athlete’s tag, measured during a real-world test with 8 participants concurrently on the ice. The test was conducted in a local ice rink with the athletes skating a simulated Skate-A-Thon path. The receiver was placed outside the boards at a location similar to receiver location two in Fig. 1.

The unfiltered RSSI data in Fig. 3 impressively shows how pronounced multipath effects are. The RSSI error frequently is in the range of 10-15 dB, which is similar to the total RSSI dynamics during one lap. Therefore the RSSI values are filtered with a Kalman filter modeling RSSI and its first two derivatives.

Lap (half-lap) detection is performed by detecting RSSI minima/maxima and requiring them to differ by more than a predefined threshold. For some laps the peak-to-peak RSSI dynamics barely
exceed 10 dB, see Fig. 3, therefore a threshold of 8 dB is currently used. Using this setting for lap
detection on the experimental dataset results in an accumulated counting error of one lap for a total
of 66 laps skated. This performance is on par with the currently used RFID system where occasional
lap misses also occur.

Having 30 tags transmitting asynchronously results in a substantial possibility of two or more mes-
sges colliding. The tags transmit periodically, i.e. every 100 ms, with a random backoff delay yielding
a channel occupation similar to the ALOHA system (Abramson 1970). Since the system continu-
ously tracks the RSSI, missing a few messages does only have a limited impact even if the messages
are consecutive. To estimate the impact on the system, the collision probability was estimated analy-
tically and using a Monte Carlo simulation. The analytical figure is based on Abramson (1970) with
some adjustments to account for the nonexistent extra retransmissions. The probability of a message
being lost due to a collision is

\[ 1 - \exp(-2r\tau), \]  

(2)

with \( r = k\lambda \), where \( k \) designates the number of active users, \( \lambda \) the average transmission rate from a
single user, and \( \tau \) the duration of one radio message, respectively. From this the probability of \( N \) or
more consecutive transmissions being blocked follows as

\[
p_b = \sum_{k=N+1}^{\infty} (1 - \exp(-2r\tau))^{k-1} \cdot \exp(-2r\tau)
\]

(3)

\[
= 1 - \sum_{k=1}^{N} (1 - \exp(-2r\tau))^{k-1} \cdot \exp(-2r\tau).
\]

Figure 4 shows the resulting probability of a certain number of consecutive messages being blocked
by a collision when using 30 tags simultaneously. The results from the Monte Carlo simulation are
nearly identical to the analytical evaluation which confirms the similarity to the ALOHA system. As
can be seen, the chance of nine or more consecutive messages being blocked is around \( 1 \times 10^{-6} \).
This implies that the situation of a tag not having measurements for at least one second occurs about
once per hour. Even this situation does not necessarily lead to a missed lap.

![Fig. 3 RSSI measured during experimental data collection, unfiltered and after Kalman filter.](http://doi.org/10.3929/ethz-b-000225585)
7 Conclusion

A system for lap counting on an ice rink has been presented. The results obtained so far are promising and suggest that the system might be used at live events. Pending work includes gathering data with 30 athletes concurrently on the rink and further development of the GUI application, used to monitor the results.

References


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