62 Assessment and accuracy improvement of monitoring of tourism traffic in a mid-mountain national park (MSTT: Monitoring System of tourist traffic) in Stołowe Mountains National Park, SW Poland

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The sustainable management of vulnerable natural areas requires accurate measurement of visitor flows, especially in protected natural areas (Andersen et al. 2013). According to Andersen et al. (2013), the most often used counting system is a pyroelectric sensor that features a lens sensitive to heat radiation emitted by the human body (Eco-Counter model: PYRO sensor). An important challenge with automatic counting systems is their accuracy, since all types of counters are subject to counting errors (Pettebone et al. 2010).

This study focuses on visitor counting accuracy in national parks situated in mountain areas that are also one of the most popular tourist areas. It illustrates the attention to detail required to carry out accurate visitor counting. The purpose of the study was to evaluate the accuracy of pyroelectric sensor measurement errors in relation to different visitor flow levels and different time intervals between visitors. This verification was based on field experiments and on-site observations of the pyroelectric sensors working as part of the Monitoring System of tourist traffic (MSTT) in Stołowe Mountain National Park (SMNP) in Sudety Mountains, southwestern Poland. SMNP is visited by about 900,000 tourists per year. (Rogowski 2020). In mountain areas, it is difficult to collect data over a longer period of time. In addition, field and weather conditions may yield a higher error rate. This evaluation of accuracy was performed to yield calibration formulas.

Methods

The data presented in this paper were collected in the summer seasons 2018 and 2019. PYRO Sensors by Eco Counter devices (called later pyroelectric sensor), with its passive-infrared, pyroelectric technology and a high-precision lens, counts people passing within the range of its sensor by detecting their body temperature. The pyroelectric sensor takes into account the direction of movement. In the configuration used for testing, data were recorded every hour. In a situation where the observer is equipped with a mobile device within Bluetooth range, it is possible to view the counts in real time.

Pyroelectric sensor accuracy was investigated in three steps:

1. A field experiment aimed to determine how the number of volunteers passing continuously and with various time gaps in front of the sensor affects the count result,
2. On-site observation in Szczeliniec Wielki of how the sensor works in visitors flow,
3. Calibration formulas based on field hourly measurements were then generated.

Pyroelectric sensor data analysis concentrated on the following variables: each visitor's passing configuration, time intervals between passing visitors, number of visitors in groups.

Results

The field experiment provided the following results:

1. The studied pyroelectric sensor can both overcount (visitors walking continuously) and undercount (1-second time gap),
2. For the passage of more than 6 persons walking continuously, generated errors occur in the range from 10.0% to 21.4%;
3. For passages with shorter than 3-second time gaps between persons walking by, a generated average errors occurs from 2.8% (2-second time gap) to 16.1% (walking continuously).

On-site observation provided results as follows:

1. Ratio of incorrect measurements and average error size increase with increasing number of persons walking by continuously,
2. In groups smaller than 6 persons per passage, an error occurred in the process of

real-world conditions observation, although not in the field experiment,

3. In a group as small as 2 or 3 persons per passage the average error ratio is 18.3%. While in a group with 4 to 10 persons, the error ratio was 11.9%, and in a group with over 10 people per passage – it was 15.5%,
4. The highest number of, and biggest error size for, incorrect measurements happened around midday (from 11 a.m. to 2 p.m.) and reached from 50% to 68% of total hourly measurements. In this period of time, the density of visitors was the highest, and reached > 200 visitors per hour,
5. At a high visitor traffic site (> 200 visitors per hour) during one day of observation the studied sensor overcounted by 14%.

The analysis of the causes of errors of the pyroelectric sensor provided the basis for a typology of error circumstances gave the ground to generate the typology of error circumstances: the main factor of error occurrence was density of visitor flow, but also visitors passing simultaneously in both directions, the difference between the temperature of the human body.

In the course of the field experiment and on-site observation, unique situations were noted, which were related to errors made by the studied sensor: opposite-direction counting, fatigue effect and impact of higher air temperature on counting errors.

The calibration formula produced in the present study is as follows: $y = 0.9416\,x – 5.401$. The formula may be used for groups of at least 20 persons per hour. This calculation is based on hourly observation data from manual counting and pyroelectric sensor counting. For data obtained in real-world conditions, the original overall error rate was 12.6%. By using the proposed calibration formula, the estimated overall error rate becomes 6.3% (tab. 1).

Follow up

The calibration formula discussed in this study was used to process pyroelectric sensor data generated by MSTT, a system used to monitor visitor flow in Stołowe Mts. National Park. The said formula represents one potential way of using data from MSTT for sustainable tourism management in a middle mountain national park (Rogowski 2020). Finally, the said calibration formula is simple and universal

Tab. 1 Calibration of measurements based on calibration formula

	Average error size	*Error standard deviation*	*Average error rate*
Pyroelectric sensor counting	16.1	13.3	12.6%
Calibration result	8.3	6.6	6.3%

References

Andersen O., Gundersen V., Line C., Wold Line C., & Stange E. 2013, **https://doi.org/10.1080/09669582.2013.839693**. Pettebone D., Newman P., & Lawson SR., 2010, **https://doi.org/10.1016/j.landurbplan.2010.06.006**. Rogowski M., 2020, **https://doi.org/10.1007/s11629-019-5965-y**.