Data Article

Southern inner ring road in Ljubljana: 2021 data set from traffic sensors installed as part of the citizen science project WeCount

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A R T I C L E   I N F O

Article history:
Received 13 December 2021
Revised 18 January 2022
Accepted 25 January 2022
Available online 28 January 2022

Keywords:
Traffic data
Cars
Pedestrians
Large vehicles
Bicycles
Citizens science

A B S T R A C T

The southern inner ring road in Ljubljana, Slovenia was equipped with low-cost sensors supported by the Telraam integrated platform. The sensors were built with open-source components (Raspberry Pi). The software is running, and the counting data is collected and analysed via an internet portal (www.telraam.com). The Telraam sensor counts pedestrians, cyclists, cars and freight/heavy vehicles using the images provided by the device sensor and the analysis performed by the “Raspberry Pi” (a small computer on which the device is based). The sensor software uses the size and speed of the passing object to determine and classify the different vehicles. The classification is based on the average observed full value and the axis ratio of each observed object (which meets a set of criteria that helps filter out any movement in the field of view that should be associated with road users). The five traffic sensors camera is mounted directly on the inside of the window glass facing the street at varying distances from the road (from 3 to 15 meters), where they count traffic only during daylight hours, update their count every hour and separate car traffic by direction.

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https://doi.org/10.1016/j.dib.2022.107878
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## Specifications Table

| Subject                  | Computer Science (1), Engineering (2) |
|--------------------------|----------------------------------------|
| Specific subject area    | Computer Vision and Pattern Recognition (1.1), Municipal Engineering and Urban Design (2.1) |
| Type of data             | Figure Table Xlsx data files |
| How the data were acquired | Raspberry Pi v3A+: with camera module and Telraam software version 9 or version 10 (updated) |
| Hardware:                | Raspberry Pi v3A+: |
| Version 9 was launched in 2019 and was the first version of the software. Version 10 was launched in August 2020. The most important innovation was the possibility to check a photo of the street every day to verify the position of the camera. See this article for more details: “The Telraam background image”. Version 11 has been released in August 2021. |
| Data format              | Raw filtered and classified |
| Description of data collection | The data collected was part of the Citizen Science Initiative carried out as part of the WeCount H2020 project. The data was collected with low-cost sensors supported by the Telraam integrated platform and based on the “Raspberry Pi”. The Telraam sensor detects and counts pedestrians, cyclists, cars and trucks based on the images provided by the device. The five cameras of the traffic sensor were placed directly on the inside of the window glass facing the street at different distances (from 3 to 15 metres), where they count traffic only during daylight, update their count every hour and separate car traffic by direction. Some data may be missing due to the lack of Wi-Fi signal or human intervention. |
| Data source location     | Institution: University of Ljubljana, Faculty of architecture City/Town/Region: Ljubljana Country: Slovenia |
|                           | • Road segment 1 / 9000000596 A /Šolski Center Ljubljana, Aškerčeva cesta 1, 1000 Ljubljana, Slovenia. (46.04638575298333, 14.500125929382342) |
|                           | • Road segment 2 / 9000000002 B / Faculty of architecture, Zoisova cesta 12, 1000 Ljubljana, Slovenia. (46.045839498656285, 14.503865836796408) |
|                           | • Road segment 2 (control segment) / 9000000728 B / Faculty of architecture, Zoisova cesta 12, 1000 Ljubljana, Slovenia (Control camera) (46.045839498656285, 14.503865836796408) |
|                           | • Road segment 3 / 9000000649 B / Karlovška cesta 24, 1000 Ljubljana, Slovenia, (46.04320463685884, 14.51269801100263) |
|                           | • Road segment 4 / 90000001499 A / Roška cesta 11, 1000 Ljubljana, Slovenia, (46.045702300389685, 14.518832562305665) |
| Data accessibility       | Repository name: Zenodo Data identification number: 10.5281/zenodo.5583921 [8] [Data set] https://doi.org/10.5281/zenodo.5583921 |
Fig. 1. The locations of the sensors on the southern inner ring road in Ljubljana. The data points are described in detail in the table section of the Data source location.

Value of the Data

• There is little data on traffic flow and street use demand in Ljubljana except on major crossroads. At other locations it is practically impossible to collect traffic flow data in good quality and at reasonable cost with current counting technologies.
• Present dataset provides traffic flows facts and figures on the selected roads and is the only dataset providing this information at the selected location [8].
• This dataset is of immediate use to practitioners in ITS system design (traffic capacity assessment, the development of congestion prediction, the development of mitigation algorithms and strategies), urban planners (to develop strategic traffic plan of the city of Ljubljana, municipality spatial plan and detailed municipality spatial plans) and researchers studying the impact of COVID19 restrictions.
• The data is also of immediate use by residents and interested parties to support a viewpoint or decision about transportation measures.
• Traffic scientists can use the dataset to create road profiles for cars and trucks, pedestrians and cyclists and thus optimise street design.

1. Data Description

The data publication consists of five individual datasets:

(1) A road segment 1 on Aškerčeva street 1 in Ljubljana (Fig. 1); the dataset is available as the file raw-data-900000596-a6ceef.xlsx, which represents: City/Town/Region: Ljubljana;
### Table 1
Description of the structure of the dataset’s attributes.

| Segment Id | Separate road segment in OSM |
|------------|-------------------------------|
| Street     | Street or road name           |
| City       | City                          |
| Date       | Date and time when the data was recorded |
| Uptime     | When the camera counted traffic (lighting conditions) |
| Pedestrian (A > B / lft) | Number of counted pedestrians from left to right according to the camera position |
| Pedestrian (B > A / rgt) | Number of counted pedestrians from right to left according to the camera position |
| Pedestrian Total | All counted pedestrians together |
| Bike (A > B / lft) | Number of counted bicycles from left to right according to the camera position |
| Bike (B > A / rgt) | Number of counted bicycles from right to left according to the camera position |
| Bike Total | All counted bicycles together |
| Car (A > B / lft) | Number of counted cars from left to right according to the camera position |
| Car (B > A / rgt) | Number of counted cars from right to left according to the camera position |
| Car Total | All counted cars together |
| Large vehicle (A > B / lft) | Number of counted lorries and busses from left to right according to the camera position |
| Large vehicle (B > A / rgt) | Number of counted lorries and busses from right to left according to the camera position |
| Large vehicle Total | All counted lorries and busses together |
| Speed Car 0-10 km/h | Just the speed of cars driving in the range 0-10 km/h |
| Speed Car 10-20 km/h | Just the speed of cars driving in the range 10-20 km/h |
| Speed Car 20-30 km/h | Just the speed of cars driving in the range 20-30 km/h |
| Speed Car 30-40 km/h | Just the speed of cars driving in the range 30-40 km/h |
| Speed Car 40-50 km/h | Just the speed of cars driving in the range 40-50 km/h |
| Speed Car 50-60 km/h | Just the speed of cars driving in the range 50-60 km/h |
| Speed Car 60-70 km/h | Just the speed of cars driving in the range 60-70 km/h |
| Speed Car 70+ km/h | Just the speed of cars driving in the range 70-80 km/h |

Country: Slovenia; Road segment 1 / 9000000596 A / Šolski Center Ljubljana, Aškerčeva cesta 1, 1000 Ljubljana, Slovenia, (46.04638575298333, 14.500125929382342)

(2) A road segment 2 on Zoisova street 2 in Ljubljana (Fig. 1); the dataset is available as the file raw-data-9000000002-db978c0.xlsx, which represents: City/Town/Region: Ljubljana; Country: Slovenia; Road segment 2 / 9000000002 B / Faculty of architecture, Zoisova cesta 12, 1000 Ljubljana, Slovenia, (46.045839498656285, 14.503865836796408).

(3) A road segment 2 (control segment) on Zoisova street 2 in Ljubljana (Fig. 1); the dataset is available as the raw-data-9000000728-def21e0.xlsx (CONTROL SEGMENT), which represents: City/Town/Region: Ljubljana; Country: Slovenia; Road segment 2 / 9000000728 B / Faculty of architecture, Zoisova cesta 12, 1000 Ljubljana, Slovenia (Control sensor) (46.045839498656285, 14.503865836796408).

(4) A road segment 3 on Karlovška street 4 in Ljubljana (Fig. 1); the dataset is available as the raw-data-9000000649-ff3e3fa.xlsx, which represents: City/Town/Region: Ljubljana; Country: Slovenia; Road segment 3 / 9000000649 B / Karlovška cesta 24, 1000 Ljubljana, Slovenia, (46.043204663685884, 14.51269801100263).

(5) A road segment 4 on Roška street 11 in Ljubljana (Fig. 1); the dataset is available as raw-data-9000001499-a5ed88c.xlsx, which represents: City/Town/Region: Ljubljana; Country: Slovenia; Road segment 4 / 9000001499 A / Roška cesta 11, 1000 Ljubljana, Slovenia, (46.045702300389685, 14.518832562305665).

The attribute of each individual dataset is briefly described and listed in Table 1. Description of the attributes generated by the Telraam device and listed in Table 1, is:

**Segment Id**: is the identifier generated by the Telraam platform system that refers to a street segment in OSM (Open Street Maps). OpenStreetMap is a free editable map of the whole world, mostly created by volunteers and published with an open content license.
The segment ID is selected by citizen scientists during the registration process. The number field is expressed in natural numbers.

**Street:** is the name of the street or road to which the segment ID refers. The name of the "Street" attribute is automatically generated and defined by the OSM platform. It is a text field expressed in text characters.

**City:** is the name of the city to which the segment ID refers. The name of the "City" attribute is automatically generated and defined by the OSM platform. It is a text field expressed in text characters.

**Date:** The attribute specifies the date and time interval when the data was recorded, calculated and counted. The Telraam sensor calculates and counts the recorded data "on the sensor", without the involvement of external servers, and stores it in one-hour increments. After the calculations for the one-hour interval are complete, the sensor sends the data to a remote server over the available Wi-Fi network. The remote server stores the calculated data. The field is formatted in the date/time format YYYY-MM-DD HH:HH.

**Uptime:** This attribute was added to the platform later to ensure reliability of the devices. The first iteration of Telraam sensors used to calculate and count traffic has some drawbacks. The drawbacks include Wi-Fi availability, sporadic Wi-Fi reception, external factors affecting sensor position, and power supply issues. However, the user is warned in low light conditions and at night because the sensor does not work in low light conditions. The value is measured as a percentage of the time of the one-hour time window that the sensor counts and is expressed in real numbers [5].

**Pedestrians (A > B / lft):** The sensor can detect pedestrians and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the pedestrian attribute Pedestrian (A > B / lft) means that the counted pedestrians walk from the left to the right side of the sensor frame. Expressed in natural numbers [5].

**Pedestrians (B > A / rgt):** The sensor can detect pedestrians and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the pedestrian attribute Pedestrian (B > A / rgt) means that the counted pedestrians walk from the right to the left side of the sensor frame. Expressed in natural numbers.

**Pedestrian Total:** The attribute denotes the sum of the two attributes Pedestrian (A > B / lft) and Pedestrian (B > A / rgt). Expressed in natural numbers.

**Bike (A > B / lft):** Bike (A > B / lft): The sensor can detect bicycles and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the bicycle attribute Bike (A > B / lft) means that the counted bicycles travel from the left to the right side of the sensor image. Expressed in natural numbers [5].

**Bike (B > A / rgt):** The sensor can detect bicycles and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the bicycle attribute Bike (B > A / rgt) means that the
counted bicycles travel from the right to the left side of the sensor image. Expressed in natural numbers.

**Bike Total**: The attribute denotes the sum of the two attributes Bike (A > B / lft) and Bike (B > A / rgt). Expressed in natural numbers.

**Car (A > B / lft)**: The sensor can detect cars and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the attribute Car (A > B / lft) means that the counted cars travel from the left to the right side of the sensor image. Expressed in natural numbers [5].

**Car (B > A / rgt)**: The sensor can detect cars and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the car attribute Car (B > A / rgt) means that the counted cars travel from the right to the left side of the sensor image. Expressed in natural numbers.

**Car Total**: The attribute denotes the sum of the two attributes Car (A > B / lft) and Car (B > A / rgt). Expressed in natural numbers.

**Large vehicle (A > B / lft)**: The sensor can detect large vehicles such as trucks and buses and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the attribute Large vehicle (A > B / lft) means that the counted large vehicles travel from the left to the right side of the sensor image. Expressed in natural numbers [5].

**Large vehicle (B > A / rgt)**: The sensor can detect large vehicles such as trucks and buses and their direction. The direction is calculated according to the user’s choice of the street section during the registration process when the user is asked to select the street section and the side of the street section where the sensor is located. In this case, the attribute Large vehicle (B > A / rgt) means that the counted large vehicles travel from the right to the left side of the sensor image. Expressed in natural numbers.

**Large vehicle Total**: The attribute denotes the sum of the two attributes Large vehicle (A > B / lft) and Large vehicle (B > A / rgt). Expressed in natural numbers.

**Speed Car 0-10 km/h**: Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 0 and 10 km/h. Expressed in real numbers.

**Speed Car 10-20 km/h**: Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 10 and 20 km/h. Expressed in real numbers.

**Speed Car 20-30 km/h**: Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 20 and 30 km/h Expressed in real numbers.

**Speed Car 30-40 km/h**: Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 30 and 40 km/h Expressed in real numbers.

**Speed Car 40-50 km/h**: Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 40 and 50 km/h Expressed in real numbers.
Fig. 2. Both figures represent the axis ratio and the full frame value. The black rectangular polygon is the circumscribed rectangle, while the width and height are represented by the arrows. The surface of the car or cyclist is represented by the irregular red shaded area. The full screen value indicates how much this red shaded area fills the space inside the black rectangle. The axis ratio is the ratio of width and height represented by the two arrows. The area of the car is much larger than that of the cyclist and it becomes even larger when looking at the objects from the typical height of a Telraam sensor (from above), while the axis ratio of the cyclist (is about one, since width and height are more or less equal) is larger than the axis ratio of the car (where width is twice the height, so axis ratio = width/height = 0.5) [6].

**Speed Car 50-60 km/h:** Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 50 and 60 km/h Expressed in real numbers.

**Speed Car 60-70 km/h:** Percentage of all counted vehicles (passenger cars only) traveling in a speed range between 60 and 70 km/h. Expressed in real numbers.

**Speed Car 70+ km/h:** Percentage of all counted vehicles (passenger cars only) traveling in a certain speed range that is greater than 70 km/h. Expressed in real numbers.

2. Experimental Design, Materials and Methods

The classification of the data collected by the device still raises some questions and is under constant development. The results will depend on the device components, the iteration of the software and the placement of the device in the real world. For a good understanding it is necessary to explain what exactly is shown in the data, how we get the numbers and what the possible inaccuracies are.

2.1. Classification

The objects are ranked on the average value of the observed full frame value and the axis ratio of each observed object (which meets several criteria that help to filter out any movement in the field of view that is unlikely related with road users). These two parameters are independent of both distance (between sensor and object) and speed. This means that a car that is 3 or 15 metres from the sensor travelling at 10 or 80 km/h will have the same axis ratio and full frame value.

These parameters help in the classification with the global classifier, which is essentially a two-dimensional table in which we have (by an automated process) determined the areas where cars, cyclists and pedestrians are typically located (in the parameter space of the axis ratio richness) (Fig. 2). Below is such a matrix (Fig. 3) together with the set of classified objects. Using a global classifier means that the same classifier is initially applied to each sensor. In this way, the axis ratio and richness are independent of distance and velocity, but there are potential uncertainties in the classification. Point cloud clusters sometimes overlap, indicating that misclassification may occur. The axis ratio also depends on the angle of the camera sensor on the window, which is an environmental factor. This also means that a global classifier for all locations is less
accurate than a classifier for a single location. The accuracy of the local classifier is higher than that of the global classifier, which means that in the future a move to sensor-specific classifiers will take place.

When a new object is uploaded to the server, the server searches the lookup table for the class corresponding to the axis ratio and the full frame value of the object and classifies it as a car, cyclist, or pedestrian. For cyclists and pedestrians, the story ends here, but cars at this stage include both passenger cars and larger motorized vehicles such as vans, trucks, and buses [6].

2.2. Distinguishing cars from vans, trucks, and buses

Size distinguishes cars from larger motorised vehicles [5]. It is difficult to define the absolute sizes of vehicles (since the exact distance between the sensor and each observed object cannot be precisely determined), but we can assume that most cars passing in front of the sensor are approximately the typical size of a passenger car (about 4.1 metres). This assumption means that a clearly defined peak in the size distribution (histogram) corresponds to this physical size. As the statistic defines the typical size of a car and a van, it also defines the boundary for the size between car and van. Each of the two directions is calculated separately (to determine the distance between moving objects and the sensor) (Fig. 4).

After a few months of operation, we have found that while this system works quite well in most situations, there are some cases where it is compromised [6].

2.3. Roads that are a one-way street for cars (or that are car-free) can still generate (a great deal of) cars and trucks in our measurements

This is a limitation of the system. First, in classification - the system is not aware that it should not classify an object as a car if its properties (axis ratio and full frame value) mean that it falls within the range of the global classification matrix where cars are located. This finding means that cyclists or a close group of two or more cyclists are classified as cars even if no cars are passing. Even two cyclists standing close together (overlapping from the sensor’s point of view) can result in a single object that is larger than a typical cyclist should be. This fact causes the combined shape of the two cyclists to be classified as a car. If it is a one-way street or a car-free street, the automatic calculation of the exclusion of cars/landscapes will take into account all these misclassified cyclists and apply the algorithm described above. In this case, however, there are no cars in the distribution, so pseudo-objects dominate the histogram with a much smaller size than would be the case with actual cars. Both the typical size and the cut-off
value are calculated from these false values, resulting in a cut-off value that lies somewhere in the observed distribution. However, since the observed distribution is misclassified bicycles, the vehicles above the cut-off value are classified as trucks, even though their absolute size is much smaller than one would expect. There are some possible workarounds, but a better solution is still being sought [6].

It happens that at certain times of the day there is a significantly higher percentage of trucks on the roads than at other times of the day. Normally, a single car can classify as a lorry if the light conditions are right. This problem does occur on car-free streets (at least in one direction), but it can occur anywhere. When the sun is low and shining on a particular road, moving objects cast long shadows (when the sun is high, the shadows are small and do not extend far from the objects casting shadows, and when the sun is low but not shining along the road axis, the road surface is usually not in the sunlight, so the objects do not get any extra shadow). The image recognition algorithm cannot distinguish between shadows and cast shadows, so shadows are considered part of an object. In most cases, this is not a problem as the shadow does not change the important parameters of the object to such an extent that this would lead to misclassification, but in extreme cases this can become a problem for the following two reasons:

1. Cars with long shadows parallel to the road: This significantly lengthens the observed shape of the cars and increases the observed size, probably leading to a misclassification of these cars as trucks. It depends on the time of year and the time of day, but the key message is that if the sun is low parallel to the road surface at a certain time of day, this anomaly will occur leading to a temporary increase in the share of vans/trucks/buses in the group of motorised vehicles (which also means a temporary decrease in the share of cars).
2. One or more cyclists riding together: The shadow cast by one (or more) cyclists can merge cyclists even if they do not overlap from the sensor’s point of view. This artificially increases the size of the observed binning (and the axis ratio and full frame values) [6].
Ethics Statements

General

The Telraam sensor is pointed at the road to count pedestrians, cyclists, cars and heavy traffic and processes the sensor images immediately. The sensor does not store images and films in low resolution, so it cannot recognise faces or number plates.

The device is designed in such a way that the sensor image itself is not visible (neither to the owner of the Telraam device nor to third parties). The sensor images are only visible to the user during the Telraam installation for a period of up to 10 minutes (to align the sensor correctly). The data collected by Telraam is transmitted wirelessly to a central database where it is further processed. The results of Telraam devices are freely available to everyone at www.telraam.net.

In an opinion obtained beforehand, the Data Protection Authority (GBA-APD in Belgium) had no objections to this method of processing sensor images (immediately and on the spot, as opposed to storing images and sending them to a central database for central processing as with traditional sensor systems).

When citizens register with Telraam, they provide some personal information (name, address and email address). Before proceeding, citizens sign a consent form ("Privacy Policy") that, among other things, informs them of what happens to their data. Third parties will not receive citizen's data under no circumstances. Telraam data exchange uses street segment data, not address-specific data.

All intellectual property rights in the traffic statistics collected by Telraam and the databases it contains belong to the Telraam Alliance. To the extent required, the participant's consent constitutes an unconditional, irrevocable and royalty-free waiver of any other rights or claims that the participant may have as a result of his/her participation. In consideration of his/her participation, the participant acquires a non-exclusive personal right to use all data generated by his/her Telraam device and to view and download the data through his/her personal dashboard.

Clarification

The Camera Act does not reply (Art 3 Chapter II of the Act of 21 March 2007 on surveillance cameras):

“This law applies to the installation and use of surveillance cameras in the places referred to in article 2, with the aim of:

1. to prevent, determine or detect crimes against persons or property.
2. to prevent, determine or detect nuisance within the meaning of article 135 of the new municipal law, to check compliance with municipal regulations or to maintain public o order.”

This is not the purpose of Telraam, so the Act does not apply to Telraam.

The response of the Data Protection Authority's (GBA-APD):

“Based on the additional information provided in your email, the use of the cameras as you have explained it does not appear to us to involve any processing of personal data.”

The additional information mentioned is:

1. The sensor is installed on a private property (i.e., in a house) and is pointed at the street.
2. The sensor is permanently pointed at the street.
3. The sensor does not store images and films in low resolution, the image is processed immediately. The images themselves cannot be accessed. Technically, the processing is as follows:
   a. The sensor immediately sends the image (effective image of the street) to the processing unit (a Raspberry Pi, a minicomputer), which is physically connected to the sensor via a 5-10 cm cable.
b. In minicomputers, images are processed immediately for object recognition and only the following information is stored about these objects: the size, velocity and position (top/bottom) of the objects on the image.
c. The image of the sensor itself is not captured, it is transformed instantly and is not visible anywhere.

The object property information is passed to a central database for a second processing where the object properties are translated into vehicles.

Looking at the whole sensor and local processing, the input comes from the sensor (basically frequent images in the colour spectrum per pixel) and the interpretation of the input is done by recognizing general properties of objects (pixel size). In this sense, no images are registered, only the properties of the images that are relevant to us (object recognition and some properties) are filtered out. The sensor counts the number of objects that pass in front of it.

**There are two essential elements here:**

The images themselves are processed locally and immediately. In other words, it is not possible to consult the sensor’s images directly (the device would simply not work in this case because it has too little processing power).

The processed data is generic, not personal: no license plates, no faces, no human features can be detected [7].

**National Ethical Approval**

Each participant in the study was notified and signed the Consent to participate in the survey. All participant data was fully anonymised and the redistribution policy of the platform www.Telraam.net was followed. All personal data will be stored securely and separately from participants’ opinions in accordance with the Data Protection Regulation (GDPR). Personal statements remained anonymous. The data collected in each city was used to discuss transport issues facing those cities. For example, the discussion was about car traffic compared to bicycle traffic, speed of traffic, air pollution, improving road connections for active mobility, etc. Only the results of the group were published and made available. The identity of the participants was not disclosed under any circumstances.

The research and data collection were approved by the Ethics Committee of the University of Ljubljana on 12 June 2020.

**CREdiT Author Statement**

**Péter Pápics:** Software, hardware and technical support, **Carl Van Poyer:** Software, hardware and technical support, **Kris Vanherle:** project manager, **Dave Driesmans:** website and backend development

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Acknowledgments

This work was part of the WeCount: Citizens Observing UrbaN Transport project. The project received financial support from the EU Research and Innovation Framework Programme Horizon 2020 under Agreement number 87274.

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