Automated Bicycle Counting System's Prototype to Evaluate the Necessity of New Bicycle Lanes in Jelgava City

Armands Kviesis, Aleksejs Zacepins, Vitalijs Komasilovs, Normunds Vetra and Nikolajs Bumanis
*Department of Computer Systems, Faculty of Information Technologies,
Latvia University of Life Sciences and Technologies, Jelgava, Latvia*

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Abstract: Every year the number of vehicles on the road is increasing. But there are people that start to choose public transport or greener transportation options like bicycles or electric cars over typical fuel cars. Regarding bicycle usage, the problems that arise are related to insufficient bicycle lanes and determination of future lane locations, so that the resources used for bicycle lane construction would be properly invested. To resolve mentioned problems municipality first need to learn where the suitable bicycle lane location for cyclists should be. Such a task can be done by applying a cyclist counting system. This paper describes a portable automatic cyclist counting system's prototype for bicycle lane location planning and also identifies the limitations for such a system. Proposed prototype is based on rubber tubes and pressure sensors, Wi-Fi module and open source electronic platform Arduino. This study is carried out within the ERANet-LAC project RETRACT (Enabling resilient urban transportation systems in smart cities).

1 INTRODUCTION

Urban air pollution is one of the environmental risks in modern cities (Elsom, 2014). There are several factors affecting urban air, like population growth, industrial expansion, urbanisation and increase in motor vehicle usage (Bickerstaff and Walker, 2001). Reduction of vehicle emissions is a major component of sustainable transportation development (Kitthamkesorn and Chen, 2017).

Many governments promote usage of green transport, like bicycles for citizen daily transportation (Goodwill, 2015; Kitthamkesorn and Chen, 2017). Municipalities are investing funds (for instance Danish capital Copenhagen invested 150 million USD in cycling infrastructure) to develop new separate bike lanes or even bridges or trying to improve existing infrastructure and adapt it also for bicycle needs (Bao et al., 2017). Bike along with walking is the greenest mode of transportation (https://greenseat.nl/en/how-to-travel-green/). Many municipalities are changing their development strategies and define new mobility principles in cities, where mobility priority focuses on pedestrians, cyclists and public transport not on private car drivers. Traditional ways of planning bike lanes in a city rely mainly on empirical experience or citizen surveys (Sustrans, 2014; Hyodo et al., 2000; Rybarczyk and Wu, 2010). With the growth of smartphone and smart GPS applications, more data-driven approaches on planning bike lanes emerged (Evans et al., 2012; Evans et al., 2013; Jiang et al., 2016; Bao et al., 2017).

New bike lane planning requires the municipality to have some data about the number of bicycles on a specific road/walkway. It is highly important to invest in right directions, because building of 1 km bike road costs approximately 145000 EUR, but each developed bike road increase the bikers count for 20% and decrease car number for 10%, according to the data by the Latvian Cycling Association (www.rdsd.lv/uploads/media/551901879d5eb.ppt). As stated by (Weigand et al., 2013) it is not trivial to precisely determine the cost of integrating a bike lane into existing infrastructure. This is also proved by several sources as the costs are closely related to project design and other specifics, for example, as it was estimated by City of Portland, the cost for a bike lane per foot (approx. 0.30 m) is approximately 3 USD; the cost can be in a range from 5000 USD to 535000 USD (with average of 130000 USD) per mile (approx. 1.6 km) for about 1.5 m wide bike lane (Bushell et al., 2013) or even much higher, like the 12 USD million-a-mile bike lanes (Alexander, 2018).

There are many methods and systems (piezoelec-

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tric strips, radio beams, active infrared, pneumatic tubes etc. (Ryus et al., 2014)) available for bike counting. Over the last decade, there has been increasing interest in counting bicycles and establishing non-motorized counting programs (Nordback et al., 2016). Three types of commercially available pneumatic tube counters (dual and single tube configuration - bicycle-specific, classification and volume counters) were studied by (Nordback et al., 2016), where counting accuracy decreased with high traffic volume and longer tubes. The undercounting problem is also highlighted by (Ryus et al., 2014) where two products were compared. Counting can be done manually or in automated way. Automated counting make it possible to collect data for long time period and to monitor temporal data variety in volumes more effectively than manual counts (Proulx et al., 2016). Automated counting can be done using different technologies, like infrared, radio beam, pneumatic tubes, inductive loops and also image processing (Zangenehpour et al., 2015; Komasilovs et al., 2018). As well publicly showing the number of bikes going on the specific roads or comparing speed of bike and car on the specific part of the road can increase individual motivation to use the bike next time.

By the data of Latvian Central Statistical Bureau, 17% of Latvian citizens almost twice per week are using bikes (https://www.csb.gov.lv/lv/statistika/statistikas-temas/socialie-procesi/veseliba/meklet-tema/2141-17-latvijas-iedzivotaju-vismaz-divreiz-nedela), in capital Riga number of cyclist's increases approx. by 10% each year. In Latvia bike counting is mainly done manually by persons standing at the bike lanes and counting the bicycles, but this approach has many disadvantages (https://www.diena.lv/raksts/latvija/zinas/ritenbrauceju-skaita-izmainas-fikse-ar-_masinredzi_-un-maksligo-intelektu-14110736). It is not possible to collect data on the long time period, to compare data on different weather conditions and day periods, as well it require more staff time per hour of data collected. Therefore, local municipality is searching for better ways on how to collect data on the number of bikes using specific roads with the purpose to build bike lanes on the most popular roads/sidewalks.

Pneumatic or rubber tubes are commonly used for gathering short-duration motor-vehicle number (http://www.windmill.co.uk/vehicle-sensing.html), but it is possible to adapt this technology also for bicycle counting. Equipment for this task consists of two main elements: rubber tubes to place on the road surface and a data recording and processing unit. As object (vehicle or bicycle) pass over the tubes, pulses of air travel through the tubes to the data recorder, which detects them due to change in the pressure. Authors of this research propose a prototype based on a popular open-source electronic platform *Arduino* (https://www.arduino.cc/) for bicycle counting. Main advantage of such approach could be the price of the whole system, which gives benefit for local municipality.

2 MATERIALS AND METHODS

Proposed automatic bicycle counting system's architecture (see Fig. 1) consists of two pressure sensors MPX5010DP with rubber tubes, electronics development platform *Arduino Uno*, ESP8266 Wi-Fi module, remote server with Laravel Framework and MariaDB in the back end, and HTML, CSS, Javascript, Bootstrap forming the front end.

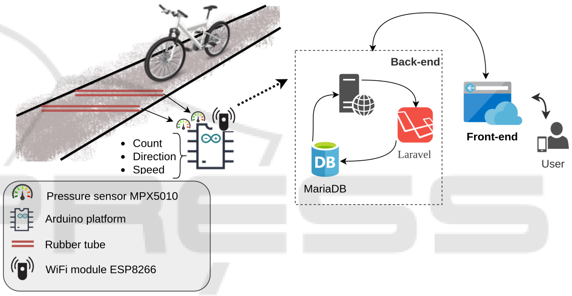

Figure 1: Architecture of bicycle counting system's prototype.

Arduino platform acts as a data collector and at the same time is capable of calculating bicycle speed, direction and count at the given time. Mentioned pressure sensor is a piezo resistive transducer that outputs analogue signal proportional to the pressure applied (https://www.nxp.com/docs/en/data-sheet/MPX5010.pdf). The data collection part is similar as posted in https://hackaday.io/project/4567-traffic-counter-road-tube. For testing purposes, a Wi-Fi technology for wireless data transfer was used. In remote locations, the Wi-Fi can still be used, when, for example, a mobile phone is turned into a portable hotspot and sharing cellular data plan. Other solution would be to choose a GPRS module. Since *Arduino Uno* board itself lacks Wi-Fi functionality, data were transferred to the remote server by using a Wi-Fi module (in this case Adafruit HUZZAH ESP8266), which is connected to the *Arduino* via Universal Asynchronous Receiver-Transmitter (UART). After a certain period of time (defined in the software), *Arduino* communicates with ESP8266 module and sends the necessary data (direction, count, speed).

The Wi-Fi module then prepares HTTP message and executes POST request to the remote server (example is shown below).

```
POST /api/data HTTP/1.1
Host: example.host.com:port
Content-Type: application/json
{
  "count":5,
  "direction":1,
  "speed":12
}
```

Remote server processes the incoming requests and inserts data into the database. The front end can provide user with information about cyclist directions during selected day and cyclist count by hours as well (see Fig. 2).

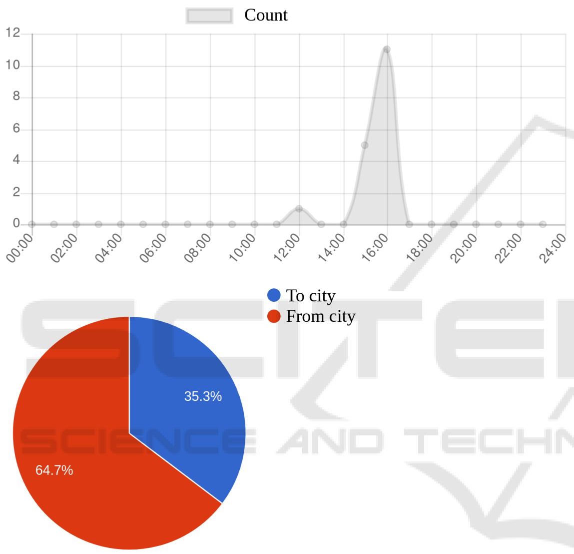

Figure 2: Bicycle count chart representation.

The MPX5010DP pressure sensor can measure up to 10 kPa pressure with a response time of 1 ms and in combination with rubber tubes is suitable for the task. Tests were performed to determine the pressure applied to the sensor tubes by bicycle. As it was found, pressure did not exceed 2 kPa (as measured and calculated by *Arduino* using the given transfer function (1) (https://www.nxp.com/docs/en/datasheet/MPX5010.pdf):

$$V_{out} = V_s * (0.09P + 0.04) \pm (P_{error} * T_f * 0.09V_s) \quad (1)$$

where:

V_{out} – output voltage from sensor, V;
V_s – supply voltage (5.0 V $\pm$ 0.25 Vdc), V;
P – pressure, kPa;
P_{error} – pressure error, kPa;
T_f – temperature factor, °C;

As it was concluded, such values fall within the sensor minimum and maximum range and the pressure applied by bicycle is enough to detect changes. However, precise pressure values (in kPa) are not very important, since this sensor application mostly requires the detection of pressure being applied (in other words: True or False). The analogue value of the sensor is required in terms of calibration - it helps to adjust the threshold when the tube is pressed.

Two sets of tubes (different material and diameter) were used for testing, those were of material polyurethane/rubber (further in text ”Tube 1”) and rubber (”Tube 2”). The length of the tubes were 3 m (Tube 1) and 2 m (Tube 2); outer diameter 6 mm (Tube 1) and 10 mm (Tube 2); thickness 1.2 mm (Tube 1) and 2mm (Tube 2).

In order to set up the counting system for proper operation, it was critical to place the tubes so that the distance between them is constant. This distance is hard-coded in the system for precise speed (if needed) calculations. During testing, tubes were placed on a concrete surface, since in Jelgava city we mostly have walkways of such material. Setup of the system is shown in Fig. 3. As it can be seen in the figure, the *Arduino* is not in an enclosed box, since the testing phase was aimed to test the working principle and identify the limitations. The cost of the tested prototype was approximately 100 EUR.

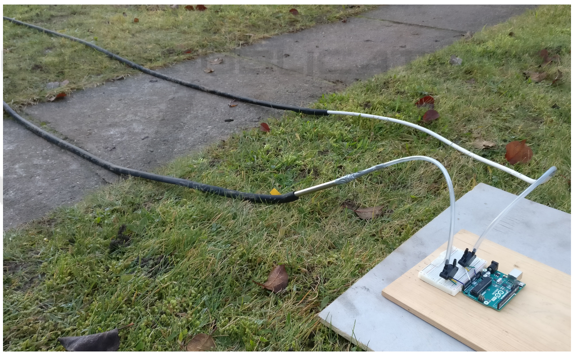

Figure 3: Counting system’s setup for testing.

3 RESULTS AND DISCUSSION

As mentioned previously, two different rubber tubes were selected to attach to pressure sensors. Tube selection is very important, since they are made of different materials. Material choice adds extra factors that can have impact on system’s correct operation and thus needs to be taken into account. Factors, such as size and flexibility of the tubes, can be mentioned. The smaller and harder are the tubes, the less pressure can the bicycle tire apply to them. Another factor is temperature, that has impact on pressure, as this is defined by Gay-Lussac's law (Pressure Law). In colder environment, pressure decreases (if the volume and mass is constant). Results section is divided in two subsections - tests with both material tubes.

3.1 Tests with Tube 1

At the beginning the system was tested by simply rolling over a bicycle, to see how the air pressure changes. In this field test with Tube 1 (made of polyurethane) it was concluded that pressure values changed minimally or not even at all. Temperature also affected the tubes – the material became much harder and the pressure decreased. As this was observed by bringing the tubes from warmer room (23°C) to the outside environment (5°C). It was concluded that in this test case bicycle tire did not have any effect on the tube, thus no changes in sensor readings were noticed. Therefore it was impossible to use such tubes for reliable system operation.

3.2 Tests with Tube 2

Single Rubber Tube (bicycle count only)
If information about bicycle speed and direction is not important, then a single sensor with one tube is enough. During field tests all single bicycle riding cases were counted correctly, but some specific situations, conditions where recognized, that causes interruptions of the systems operation. Thus following limitations were identified:

- only count can be determined. Single tube limits the operation of the system regarding the details that can be obtained from data. It is not possible to detect direction the cyclist is driving from and speed as well. Although it is possible to know the time that takes both tires to cross the tube, it is not enough to calculate the speed, as the distances between tires vary almost with each bicycle;
- simultaneous crossing of multiple cyclists. System counts cyclists with error when several bicycles are crossing the tube simultaneously. Sensor reading in such situation will reach the threshold, but in order to distinguish the difference between one or two cyclists it would mean to hard-code sensor values. And as tests showed, there are no distinguishable differences when two cyclists are crossing the tube simultaneously, because when the tube is pressed by one cyclist, the other cyclists pressure does not show any impact on the sensors value.

Two Rubber Tubes (direction, count, speed)
In order to detect also speed, two rubber tubes were placed on a concrete surface with distance of 50 cm between them. Since bicycles are in various lengths (also the reason why speed can not be detected when using only one sensor), such a distance should ensure, that both tires are not on the sensor tubes simultaneously (in this scenario the system will fail to count such case). Total of 50 bicycle riding tests were carried out. Tests included driving with various speeds – from 6 to 20 km/h. Speed was calculated within the *Arduino* by formula (2):

$$v = \frac{s}{t} \tag{2}$$

where:
v – speed, m/s;
s – distance between rubber tubes, m;
t – time it took for the first tire to cross both tubes, s.

All 50 testing cases with single cyclist riding over the tubes were successfully identified and counted. During testing phase the following limitations were identified:

- threshold adjustments. As it was observed, in colder weather the pressure decreased after longer periods of time. It was detected by the analogue values received by the pressure sensors. This has an impact on defined threshold – if the pressure decreases dramatically the threshold could never be reached, thus cyclists can not be detected;
- pedestrian factor. Since described system is intended to be placed on pedestrian walkway that also is used by cyclists, pedestrians can intervene by stepping on tube(-s). There are possible solutions to filter these cases out. If pedestrian only steps on one tube leaving the other untouched, the system should check time till the other tube is activated. If the time exceeds some defined limit, this case should be ignored;
- cyclist behavior. There may be cases when cyclists behave differently when they see tubes on the road/walkway. They could try to avoid crossing them or drive them over with one tire. But these also could only be some rare, specific cases (enthusiasts of ”extreme” bike riding).

The system was also tested when multiple cyclists entered the scene. It was observed that system does not operate reliably in such situations: only about 40% of 50 testing cases (riding from the same and opposite direction) were correctly recognized as two cyclists. Such poor performance was due to the fact, that analog sensor is being used and detection is highly dependent on a threshold. As a result, if the sensor's value is being read frequently, e. g., each 10 ms, then one cyclist's applied pressure that is greater than the threshold, could be counted as multiple cyclists, because the value does not stabilize so fast. Sensor values, after a single bicycle has driven over the tubes, is illustrated in Fig. 4. In a single cyclist case, this can be resolved by ignoring the specific sensor values after the threshold is reached, and continue to read the sensor value after the second sensor threshold has been reached.

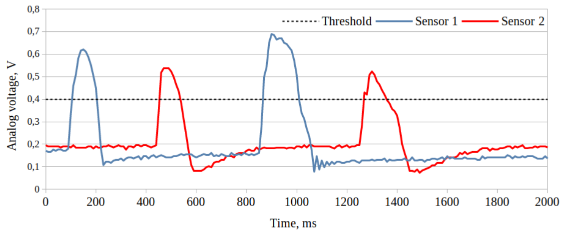

Figure 4: Sensor responses after bicycle impact.

As the figure (Fig. 4) shows, the sensor is in active state (threshold is reached) approximately 100 ms or even more, meaning that to ensure correct systems operation, next value should be read after 100 ms. But this is not a reliable solution, as in some cases the value is more than 100 ms above threshold. Also adjusting the threshold (increasing its value) is not the best solution either, as each sensor registers different values (see Fig. 4).

4 CONCLUSIONS

During this study a bicycle counting system's prototype based on pressure sensors and rubber tubes was developed and tested, showing promising results (all bicycle riding cases were counted correctly in a single cyclist's case). Although there are several limitations and cases that causes the system to work poorly. More than one cyclist counting simultaneously could be highlighted as the main limitation.

Using digital signal sensors (for example, piezoelectric swithces) instead of analogue (pressure sensor in our case) should perform better, as there are no thresholds involved which needs to be adjusted.

Additional tests should be performed on different type (structure, hardness) of walkway surfaces (for example, gravel), because there is a possibility, that on softer surfaces the rubber tubes could be pressed inside the surface.

Described prototype during testing phase included Wi-Fi module for data transmission, but usually the walkways are not close to any internet access points. Thus, the module can be replaced by a suitable GPRS module to access mobile internet, for example, SIM900. Other cases may include SD card module and closed range data transfer technologies, to store collected data locally. Also the use of an low-power wide-area network (LPWAN) can be considered for data transfer, for example, implementation of LoRaWAN. Although it could be somewhat complex task if the LoRa network should be built from scratch. Different scenario - if the city already has a developed LoRaWAN network. Then it is possible to collaborate with the according telecommunication company. Jelgava city is one of the cities in Latvia that has a LoRaWAN network (built by telecommunication company Lattelecom Group) and a collaboration with Lattelecom has already been successful as described in (Zacepins et al., 2018).

In order to improve (resolve some of the limitations) some additional sensors could be considered to add to the system, for example, ultrasonic sensors in order to distinguish patterns between pedestrians and cyclists or to identify cyclist riding direction in a single tube case.

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