A Low-Cost Bidirectional People Counter Device for Assisting Social Distancing Monitoring for COVID-19

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Abstract
Accurately estimating the number of people is a useful information to monitor the occupancy level of spaces due to the COVID-19 pandemic in order to keep social distancing. Automated counters are responsible for accurately counting people movement. This paper proposes a cost-effective automatic counting system based on a microcontroller through an infrared sensor integration to monitor occupancy of indoor spaces. In order to evaluate the proposed system in real-world scenarios, experiments were carried out at the main campus of the University of Campinas—Brazil. For the first case, two prototypes were installed at both the front and rear door of a bus in order to count the number of passengers boarding and alighting on the vehicle during its operation. In the second case, three prototypes were installed in the university restaurant ticket gates in order to count the number of people entering during lunchtime. Experimental results showed an accuracy of 91.45% and 98.65% for Cases 1 and 2, respectively. The results are promising, showing that the device has potential to be used for different proposes, such as controlling access to public and indoor spaces, public transportation planning, occupancy monitoring, and security system.

Keywords COVID-19 · Social distancing · Automated counters · Controlling access · Transportation planning · Security system

1 Introduction
Since the ongoing COVID-19 coronavirus outbreak was declared a pandemic in March 2020, authorities around the world have taken actions aiming to keep the social distancing once the risks of virus spread can be minimized by avoiding physical contact among people Ahmed et al. (2021). Thus, researchers have been working and putting a lot of efforts on studying physical distancing measures Ugail et al. (2021). For example, Pataro et al. (2021) investigated algorithms based on model predictive control to plan social distancing policies that minimize the pandemic effects in Brazil. The study presented by Punn et al. (2020b) showed the positive social distancing impacts on the spread of the COVID-19 outbreak once it can reduce the physical contact between possibly infected individuals and healthy persons. The approach aimed to monitor social distancing among people through surveillance video.

During the COVID-19 outbreak, it is necessary to approach accurate social distancing measurements in order to avoid the healthcare system collapse and the economic crisis
Sensors (Souza et al., 2011) and Strathman et al. (2005), by activity can be detected either by infrared or ultrasonic sensors are used for people counting. For example, passenger accurate data on people movement. Many different technologies indoor spaces, to assist today’s public transportation, and promotes security. Therefore, even very simple and cheap APC devices can significantly contribute to monitor and control the social distancing, preventing the spread of the COVID-19. The main objective of automated counters is to collect accurate data on people movement. Many different technologies are used for people counting. For example, passenger activity can be detected either by infrared or ultrasonic sensors (Souza et al., 2011) and Strathman et al. (2005), by cameras Chen et al. (2012) and Lefloch et al. (2008), and mobile devices by collecting Wi-Fi signals (Bernini et al., 2014). Studies such as (Kimpel et al., 2003; Ma, Liu, et al., 2015; Strathman et al., 2005) have shown the effectiveness of an automatic counting system compared to manual data collection. Beyond being more expansive, manual counting of people is not adequate in the COVID-19 context. Different studies have been done with the help of technology-based solutions to contain the outbreak (Punn & Agarwal, 2021; Punn et al., 2020a; Sonbhadra et al., 2020).

According to Segen (1996), bus passenger flow is an important information for the transportation system. It can help to understand the distribution of passengers travel and help to manage, schedule, and optimize bus routes. In addition, automatic counters can be useful for counting cars and people on roads, at gates, or entrances of buildings. Therefore, it can be noticed that automatic counters can be a very important tool for assisting city transportation planning as well.

The University of Campinas counts with a sustainable campus project that consists in an integrated Living Lab for renewable generation, electric mobility, energy efficiency, monitoring, and energy demand management da Silva et al. (2018). According to Ugarte et al. (2019), this project aims to produce technological solutions in order to make the university a suitable laboratory to support practical studies. The study stated in this paper is presented as a solution for monitoring spaces where the access of people needs to be controlled, specially, in the context of the coronavirus disease. Thus, different environments at the university are proponed to be monitored, such as buses from the university internal transportation service, restaurants, laboratories, classrooms, and libraries. This study is also in partnership with the Smart Campus Unicamp project that provides an IoT communication network within the campus and promotes studies focused on IoT concept (SMART Campus Unicamp, 2018).

In this paper, an APC system based on a low-cost microcontroller was developed and tested to aid the Sustainable Campus Project in monitoring social distancing in daily activities at the University of Campinas (Unicamp)—Brazil.

Two case studies were held in the main campus of the university. In Case 1, the devices were installed in the back and front doors of one bus used for public transportation at the campus to count the number of passengers boarding and alighting at each bus stop during its operation—which allows monitoring the occupancy of the bus and contribute to the social distancing control. In Case 2, the devices were installed in each ticket gate of the main entrance of the university restaurant during lunchtime.

## 2 Related Work and Applications of APC Data

Most of the counting systems developed are based on different types of technologies such as mobile devices, cameras, and infrared sensors, which produce results with advantages and drawbacks. Generally, many experiments include electronic components that record the number of people that access a certain space. Significant progress has been made and there are several approaches for people counting developed worldwide.

Nasir et al. (2018) proposed an APC system using image processing based on a skin color detection approach. The results for the images captured under normal or minimal lighting conditions have shown great performance with counting accuracy of 90.64%. However, the system demonstrated that it is unsuitable to be applied if the images are captured under high lighting condition, as most of outdoors scenarios.

Li et al. (2018) proposed a method of counting passengers in public buses by sensing carbon dioxide concentration. The work provides a case study for counting people through sensors that record carbon dioxide concentration and calculate the indoor occupancy. A satisfactory accuracy was achieved. However, some technical challenges should be considered. For instance, ventilation systems and the dynamic air flows caused by open windows would significantly affect the accuracy of the device.

Myrvoll et al. (2017) developed a method for counting public transport passengers using Wi-Fi signatures of mobile devices carried inside a transport vehicle. Through a detector, it was possible to identify an ID for each mobile device, and
based on a number of parameters, an algorithm can classify the detected device as being on board the bus or outside the bus. Validation was made based on manual counting. The results were promising. However, there are some challenges that are difficult to predict, such as the correlation between the number of mobile devices that can be detected and the number of passengers on board.

Kalikova and Krcal (2018) proposed a method to count the number of mobile devices present (number of people) in smart buildings using mechanisms that capture network packets sent by mobile devices. The packets are captured using a Wi-Fi scanner. The measurement results were different for each mobile device captured, which has impact on the accuracy of the results. For example, mobile age and operational system version have influenced the detection success using this method.

Barbosa et al. (2005) developed a method of counting the number of boarding and alighting of passengers in a city transportation system by identifying the capacitance variation of metal plates installed in entrance doors of the bus. The movement direction was determined by the variation of the signal of the metal plates. Results have proven the viability of the method in the urban transportation system. However, the device does not present any location data registered in each event of entering or leaving people, and it has not an easy installation.

Chen et al. (2012) proposed a cost-effective people counting system based on two-stage segmentation using a zenithal video camera. The methodology is based on people-image features, such as the area, height, and width of each people-pattern. It is necessary to segment each person from each individual people-pattern. Results showed that the accuracy can be achieved above 90% if the crowd moves normally.

Lefloch et al. (2008) proposed a real-time system for people counting based on a non-calibrated video camera. Results were obtained by using image processing. The counting process is based on two areas (IN and OUT) delineated by a virtual line (arbitrary defined). Each time an object crosses the line, the counter linked to the crossing direction is incremented. Experiments showed good results, but the system is not able to recognize humans in the scene, only objects. Therefore, it can lead to some erroneous count.

Cetinkaya and Akcay (2015) proposed a method for people counting system based on human face detection. The proposed people counting system was built by using the OpenCV library. Every time a person passes through the camera a rectangle is drawn for each detected face. Thus, an ID is given for each rectangle created. A good accuracy has been obtained with an average of 83.74%. However, the results have shown that the system is sensible to video quality and scenario.

Wang et al. (2018) proposed a method for estimating the crowdedness of a bus using a single-camera-based convolutional neural networks (SCNN) and multi-cameras-based convolutional neural networks (MCNN). The system combines the data from multi-cameras installed in the front and back of a bus. Results show an accuracy of 96.3% using SCNN and 99.1% using the MCNN. However, there are some limitations, for example, passengers boarding and alighting at the same time may bring some errors to the counting process.

Hsieh et al. (2012) proposed a bidirectional people counting system through a Kinect platform. A system was developed to detect people using the depth image information from the Kinect that was developed to detect people using the depth image information from the Kinect that was set above the doorway to capture the direction pedestrian flow. Results were compared with a manual count. The system provides almost 100% accuracy for bidirectional counting under normal circumstances. Coşkun et al., (2015) presented a people counting system by using a low-cost Kinect sensor. The proposed system detects the heads of the people through a water filling algorithm (Zhang et al., 2012).

Choi et al. (2017) developed a people counting algorithm using an impulse radio ultra-wideband (IR-UWB) radar sensor. The algorithm is based on the pattern of received signals according to the number of people. A probability density function of the amplitudes of the main pulses was generated, and a maximum likelihood (ML) equation was derived. From the derived ML, it was possible to count the number of people in real time. Experiments were held in indoor rooms and metal-filled elevators. Results showed a mean absolute error of less than 1 person.

Souza et al. (2011) proposed a tracking system for urban buses based on a microcontroller that collects data to count the number of people on a bus through infrared sensors—the PIC18F452 microcontroller was used in this system. Also, the prototype receives data from a GPS module. This work aims to improve the public transportation service quality by creating efficient routes from the APC data. The system was tested in the laboratory through indoor simulations. However, no real-world experiments were presented.

Strathman et al. (2005) proposed an evaluation of the accuracy of an APC device from the Tri-County Metropolitan Transportation (TriMet) in the district of Oregon/EUA. The APC is based on infrared beams, which include a passive and an active infrared component, responsible for registering the thermal radiation of passengers and the reflection of the emitted infrared radiation from persons. Signals from each event are sent to on-board computer, which calculates the numbers of boarding and alighting at each stop. The data collected from the APC system was compared with manually recorded count. Results showed that there were systematically undercount passenger boardings and overcount alightings.
As it was shown, the people counting devices available are mainly based on infrared sensors, stereo cameras and face detection, videos and images, sensors that capture carbon dioxide concentration, Kinect sensor, mobile devices, and Wi-Fi signals. Each method has advantages and drawbacks. The main issues observed on these devices are due to complex people counting algorithms, difficulties in working with different light conditions and environmental vibrations, limitations in identifying boarding and alighting direction, high-cost, and difficulty to reproduce and produce in large scale.

In this paper, an accurate and low-cost automatic people counting device based on a microcontroller through infrared sensors integration was developed and presented. The proposed system can be used for different proposes, such as controlling access to public and indoor spaces, estimate and control the demand in public transportation, and even to support security systems.

The use of infrared sensors showed to be an adequate method for detecting and counting people. Due to its simple installation, low cost, and building simplicity, the device can be quickly and easily used in different environments. Moreover, the infrared sensors allow a bidirectional counting. Thus, through this method, the device can be used to monitor people entering and leaving a specific area in real time.

Unlike other technologies, through infrared sensors it is possible to directly count people, instead of monitor indirect quantities and, then, estimate the amount of people. Beyond that, unlike many devices based on image processing proposed in the literature, the usage of infrared sensors can provide complete anonymity due to the fact that the privacy of people is completely protected once the people counters do not recognize faces.

Given its accuracy, simplicity, capacity to differentiate boarding and alighting direction, reproducibility, scalability, low cost and, storage and communications features, the proposed device can be very useful to support the real-time social distancing monitoring and controlling in the context of Coronavirus disease.

APC devices provide a great number of applications, such as those related to control of access to confined spaces in the context of the ongoing pandemic COVID-19, as well as, some applications on transportation planning and security systems.

2.1 Social Distancing Measures In response to COVID-19

Several studies can be found in literature exploring the effectiveness of keeping the social distancing in indoor places to control the coronavirus spreading. Social distancing is associated with measures that can be taken to overcome the virus’ spread. It can be done by minimizing the physical contacts of humans at public spaces (e.g., schools, restaurants, airports, cinemas, workplaces, etc.), avoiding crowd gathering, and maintaining a safe distance between people (Adlhoch et al., 2020). According to Sun and Zhai (2020), social distancing avoids the direct contacts among people and it can reduce the potential cross-transmission of virus-carrying droplets from human respiration.

Punn et al. (2020a) proposed a real-time deep learning-based framework for automating the process of monitoring social distancing through surveillance video. The authors used the YOLO v3 object detection model to segregate humans from the scene. This method can predict the type and location of an object by looking only once at the image. Moreover, a Deepsort approach was used to track individuals present in the surveillance footage with the help of bounding boxes and assigned IDs. The generated bounding boxes are responsible to identify the clusters or groups of people according to the closeness property computed using a pairwise vectorized approach.

Khoumeri et al. (2020) developed a bidirectional automated method to count the number of people entering and leaving in a certain area. The authors implemented an algorithm based on image processing using a Raspberry Pi in real time. Moreover, a single camera for image acquisition and a tablet for displaying the number of counted people were used in the scene. The access into the area can be controlled by the maximum occupancy that is displayed on the tablet screen installed at the entrance. Thus, people can see if they can enter or if they have to wait for more people to leave. The screen updates according to the occupation situation. Experiments showed an average counting rate between 95% and 98%.

Fernández-Caramés et al., (2020) presented an IoT occupancy system that allows estimating in real time the people occupancy level of public spaces such as buildings, classrooms, workplaces, or vehicles from transportation services. The system was provided in order to reduce the interactions among people regarding the coronavirus’ spread. The proposed system is based on autonomous wireless devices that are responsible for monitoring and identifying devices that are placed in a monitored space. Several tests were carried out to evaluate the accuracy of the proposed system. Results performed with the system showed a good accuracy estimating occupancy.

These counting technologies, or people counters, present an important role in today’s COVID-19 scenario. As shown, occupancy monitoring can be achieved by measuring, and limiting, the number of people who can visit certain spaces. Since the coronavirus COVID-19 became a pandemic, controlling indoor areas occupancy has been a challenge. Thus, the counting of people in a certain region of interest is an important tool to control the area occupancy in order to minimize human virus transmission (Khoumeri et al., 2020).
2.2 Transportation Planning

Mandelzys and Hellinga (2010) focused on using data from an APC device to evaluate the performance of bus schedule by presenting a methodology responsible for identifying bus stops that do not meet performance standards for schedule adherence, as well as, the causes of this event at a given bus stop. Recorded data computed from the APC device was used including, passenger on–off counts, information on arrival–departure times, odometer readings, and more. The use of APC data can also be seen in (El-Geneidy et al., 2006). The authors proposed an analysis focused on the effects of bus stop consolidation on passenger activity and bus operating performance based on boarding and alighting information collected from an APC device from the Tri-County Metropolitan Transportation (TriMet) in the district of Oregon/EUA.

Meanwhile, Ma, Hsiao, et al. (2015) described how a bus stop measuring system on a GIS analytical platform is developed using major transit performance-related variants, such as ridership, transfer stops, distance between bus stops, and trip destination. For the ridership analyses, it is crucial to understand the usage level of a bus stop based on the number of boarding and alighting at each bus stops. For this study, the data were collected through on board and field surveys, which can bring considerable costs for the operational service. Thus, the use of an automatic counting device could have optimized the collection data process.

In this sense, data accuracy generated from APC devices is crucial when it comes to increase performance and effectiveness of public transportation system. According to Nasir et al. (2018), automatic counting systems have been an applicable issue for today’s public transport once it can track all the information about their passengers. Thus, understanding the flow of passengers is an important task for public transport companies, which aim to use their resources, improve service quality and lower the transportation’s cost. Lengvenis et al. (2013).

According to Zheng et al. (2020), the public transportation plays an important role in the spread of COVID-19. Gkiotsalitis and Cats (2021) presented some challenges associated with the coronavirus COVID-19 pandemic crisis and related public health regulations that are relevant for public transportation planning. For Jones et al. (2020) the combination of environmental factors, such as bus occupancy level, bus frequency, contact time, ventilation level, the use of face masks, among others, may affect the virus transmission rates on a vehicle. Measures can be taken to reduce the spread of the virus, and it includes the reduction of service frequencies, the change of timetables and vehicle schedules, and the reduction of the total duration of the daily operations (Gkiotsalitis & Cats, 2021).

Therefore, understanding passenger demand patterns is fundamental in order to support distance among people and reduce the chances of virus transmissions. Based on the passenger demand, some operators have either completely suspended or altered certain line services by selecting which stations to close in an attempt to prevent crowding at stations’ entrances (Batsas, 2020).

2.3 Security System

There are several applications for people counting system in indoor environments, such as in smart buildings helping occupancy monitoring, in hospitals helping to analyze patients traffic patterns and behavior, in shopping malls and supermarkets helping stores to identify customer trends, at airports and railway stations obtaining valuable data about passenger footfall, in hotels helping to improve customer service, etc. (Sruthi, 2019). Moreover, all these indoor environments can use the data generated from automatic people counters for security matters.

(Ahmed et al., 2015) proposed a low-cost evacuation system for enterprise buildings that can count the number of people accessing the study area and can also localize those people in the scene. The system named “SmartEvacTrak,” can be used for static evacuation planning. Experiments were performed in a building, and the results showed a counting accuracy of over 98% with a location people value at a coarse level with around 97% accuracy.

(Pore & Momin, 2016) presented a bidirectional people counting system in video surveillance which can be used for security application, pedestrian traffic management, tourists flow estimation, etc. The approach is based on three main steps: (I) Frame acquisition and background estimation; (II) People detection; and (III) Tracking is performed and counting algorithm is applied to count people directionally. Indoor video sequences were taken from surveillance camera and results showed an accuracy ranging from 91 to 100%.

3 Proposed System

In this section, an accurate and low-cost automatic people counting device based on a microcontroller through two infrared sensors (IR) is proposed. The adopted IR contains a detection distance feature, which is configurable. The IR can detect the presence of any object within the specified range it has been set for. The IR are disposed 15 cm from each other. They are operated over a common time base provided by a real-time clock (RTC). Therefore, depending on which IR detects the object first, it is possible to determine the direction the object is moving. The main features of the proposed devices are the high accuracy, simplicity, capacity to differentiate boarding and alighting direction, reproducibility, scalability, low cost, low-energy consumption, and storage
and communications features. It shows to properly works despite the environmental vibrations and lighting condition.

Figure 1 illustrates the basic operation of the proposed system. If someone interrupts the infrared sensor 1 followed by the infrared sensor 2, it counts a boarding/entering. Otherwise, an alighting/leaving is computed. These events can be stored into a MicroSD card for future processing or sent in real time for a database, given the adopted microcontroller contain several communication features. The counting cannot be processed if only one of the sensors is interrupted, or if both are interrupted for a long period of time because it considers that there is someone standing in front of the device and not moving.

The current version of the counting device can be seen in Fig. 2. In order to make the system portable and easy to install it is powered by a rechargeable power supply, which is a fair solution, once the device presents low-energy consumption.

3.1 Hardware Architecture

The hardware architecture of the proposed device contains the following main components:

ESP32 Wroom-32 Devkit V1-Doit, Infrared Sensor E18-D80NK, DS3231 RTC (real-time clock), MicroSD Card Adapter, and LEDs. Moreover, it presents a power bank to supply the device, which significantly simplifies the field installations. The hardware architecture of the proposed prototype is shown in Fig. 3.

For the proposed system, the microcontroller ESP32 Wroom-32 Devkit V1-Doit was adopted as the main board. This is a highly integrated, low-cost, and low power microcontroller suitable for IoT applications. It presents three alternative methods for connectivity, namely, Wi-Fi, conventional Bluetooth, and BLE (Bluetooth Low Energy). These connectivity features allow the communication among the proposed Automatic People Counting (APC) device with others APCs devices, and with a data concentrator located at the university campus. In our case, the main campus of the University of Campinas has a large Wi-Fi infrastructure covering the entire campus which is currently been used for the on-line communication of the developed IoT devices. Additionally, it could be established a Master/Slave communication among devices installed in the same area through Bluetooth technology. In this case, the communication is unidirectional and the device modules set in Slave mode would only send data to the Master module, which is responsible for sending the data to the data concentrator. It is important to notice that this
approach depends on the distance between the devices due to the limited range of the Bluetooth technology. Beyond that, a general packet radio service (GPRS) communication module can be easily integrated to the proposed device in order to send the data throughout the available mobile network. All these communication solutions have been successfully tested in our Sustainable Campus Projects (da Silva et al., 2018; Ugarte et al., 2019).

The digital Infrared Sensor E18-D80NK presents a detection distance function, ranging from 3 to 80 cm, which can be set through a potentiometer. In each sensor, an IR transmitter emits IR light and an IR receiver detects the IR light that is reflected in the objects to determine if it is within a specific range or not. The Schematic of the adopted IR E18-D80NK can be seen in Fig. 4.

The DS3231 real-time clock is responsible for providing a common time basis for all system components. This module is powered by an extra small battery and, therefore, it can keep tracking the time even if the microcontroller is out of power. In, the statuses of the infrared sensors are continuously verified. Depending on the order the infrared sensors are activated, boarding and alights are distinguished, i.e., when the infrared sensor 1 is activated followed by the sensor 2, a boarding/entering event is counted; otherwise, the device counts an alighting/leaving.

According to the basic programming, the statuses of the infrared sensors are continuously verified. Depending on the order the infrared sensors are activated, boarding and alights are distinguished, i.e., when the infrared sensor 1 is activated followed by the sensor 2, a boarding/entering event is counted; otherwise, the device counts an alighting/leaving. Additional conditions can be included to improve the accuracy of the device and reduce counting error. For example, to count one event, both sensors need to be activated with a time difference of up to 300 ms. If only one sensor is activated in a 300 ms time window, counting does not occur and the activation of this sensor is discarded. If two or more counts are observed in the same second, just one is considered. Two consecutive counts must be shifted by at least 300 ms. If an object is stopped in front of both sensors, just one event is counted. The 300 ms time window was empirically set and found to be adequate in the field tests. A much more elaborated programming can be done; however, even this basic programming leads to sufficiently accurate results, adequate to the envisioned applications.

### 3.2 Software Architecture

According to Maier et al. (2017), the microcontroller ESP32 Wroom-32 Devkit V1-Doit can be programmed in different environments, such as Arduino IDE, Micropython, and JavaScript. For this project, it was adopted the Arduino IDE. This programming language is similar to C language. Once the infrared sensor is digital, a very simple sketch can be written in the Arduino IDE and uploaded on the ESP32 microcontroller board for execution. The basic programming used in the proposed counting device can be seen below.

#### Set variables

\[
\begin{align*}
in &= 0; 
\text{out} &= 0; 
in1 &= 0; 
\text{out1} &= 0; 
count &= 0;
\end{align*}
\]

#### Start Loop

- **Read** status of IR1
- **Read** status of IR2
- **IF** (IR2 is active)
  - **IF** (in1 == 0) \{ out = 1; \}
  - **IF** (out == 1 and in == 1)
    - **Boarding Event**: out = 0; in = 0; in1 = 1; count = 0; \}
- **IF** (IR1 is active)
  - **IF** (out1 == 0) \{ in = 1; \}
  - **IF** (in == 1 and out == 1)
    - **Alighting Event**: in = 0; out = 0; out1 = 1; count = 0; \}
- **IF** (IR1 and IR2 are inactive)
  - in1 = 0; out1 = 0; count = count + 1; 
  - **IF** (count >= 30) \{ in = 0; out = 0; count = 0; \}
- **Delay** 10ms;

#### End Loop

The total cost of the proposed automatic people counting system relies on a number of parameters, such as cost production, installation, future expansions, technical support, and so on. The cost production for one prototype of the APC proposed in this paper is summarized in Table 1. Recall that this cost can be significantly different of the large-scale production.
Table 1 Cost breakdown for the proposed counting device

| Components          | Quantity | Total cost, USD ($) |
|---------------------|----------|---------------------|
| ESP-WROOM-32        | 1        | 12.28               |
| RTC DS3231          | 1        | 2.70                |
| IR E18-D80NK        | 1        | 7.18                |
| SD Card Adapter     | 1        | 1.66                |
| LEDs                | 2        | 0.45                |
| Jumpers             | 20       | 2.22                |
| Mini Protoboard     | 2        | 1.10                |
| **Total Cost**      |          | **27.69**           |

Table 2 References to cost of existing APC devices

| Developed device                                      | Counting technology                                                                 | Total cost, USD ($) |
|-------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------|
| Bus passenger counter (BBC) (Time Energy, 2019)        | 2pcs image processor, 3pcs camera                                                  | 1010.00             |
| Low-cost bus seating information technology system     | Infrared sensors, force-sensitive resistors, GPS sensor, Raspberry Pi, and an USB  | 475.00              |
| Privacy threats in low-cost people counting (Maltoni et al, 2020) | ESP8266 board, Wi-sensors, Protoboards, micro-USB port, Raspberry Pi Zero W board | 56.41               |

As it can be seen in Tables 1 and 2, despite the simplicity of the analysis, the proposed APC presents a very affordable cost compared to the available systems. It’s important to notice that only the price of the device itself was taken into consideration. Aspects such as installation and maintenance need to be considered for a fairer comparison.

Even though the cost comparison indicates that the proposed APC is attractive compared to commercial devices, it is important to mention that these commercial devices usually provide more functionalities and facilities, while the proposed device is focused in counting boarding/entering and alighting/leaving in real time.

4 Experimental Results

The counting system was evaluated in two different scenarios providing a realistic and effective accuracy evaluation. Experiments were held in order to analyze the counting accuracy and evaluate its usage on controlling and monitoring occupation of different environments at the university, such as buses, and indoors spaces which includes restaurants, laboratories, classrooms, libraries, etc. Two experiments are described in the following.

4.1 Case Study 1—University Public Transportation Service

Due to the large area of the Unicamp main campus, a free transportation system is offered for all the internal and external community. The system is controlled by an IoT Circulino solution which manages in real time the enclosed routes (Barbosa et al., 2018). The internal circular, as it is known, consists of five routes operating in the campus area. The study area and the bus route and the location of each bus stop can be seen in Fig. 5. Perceiving the number of people boarding and alighting throughout the campus is very important since it can be used to enhance overall transportation service. In addition, the location of each bus stop can be rethought according to the observed demand, as presented for (de Oliveira et al., 2020). Beyond that, control the amount of people inside the buses is fundamental in the context of COVOD-19 to prevent social distancing (Table 3).

The proposed device was installed at both the front and rear door of one circular bus in order to count the number of passengers boarding and alighting at each bus stop. From the five routes of the internal circular operating, the FEC II route was chosen because it is the more used by people on the campus. Simultaneously to the automatic counting, a careful manual counting of the passengers was performed.

A density map in Fig. 6 was generated to illustrate the passenger flow behavior throughout the campus. It can be confirmed through the hotspot region that the highest crowd
Date: June 6th, 2020. 
Escale: 1:10,000 
Coordinate System: SIRGAS2000 
UTM Fuso 23S

Legend:
- Blue: FEC II - Route 
- Black: Road Network 
- Green: Bus Stop

Fig. 5 Study Area—University of Campinas

Legend:
- Main Restaurants 
- Bus Stop 
- Road Network

Value
- High Density: 2588.01 
- Low Density: 0

Date: June 6th, 2020. 
Escale: 1:10,000 
Coordinate System: SIRGAS2000 
UTM Fuso 23S

Fig. 6 Density map from boarding and alighting events

Table 3 Counting accuracy

| Experiments | Boarding (%) | Alighting (%) |
|-------------|--------------|---------------|
| 1st         | 93.33        | 91.54         |
| 2nd         | 92.25        | 90.85         |
| 3rd         | 90.96        | 90.96         |
| 4th         | 91.92        | 91.50         |
| 5th         | 92.10        | 89.15         |
| Total Average Accuracy |            | 91.45         |

concentration is over the restaurant areas—indicated in the map. Moreover, it can be noticed that the bus stop number 3, that is located in the South part of the campus, presents a high concentration due to the fact that it is closed to the University Hospital which is a region accessed by many people during the day.

The device registers the boarding and alighting information every time a passenger enters or leaves the bus. Also, a green LED (meaning a boarding) and a red LED (meaning an alighting) were used to indicate these events during the experiments, aiming to analyze the reason for possible system wrong counting.

The automatic counter accuracy was obtained assuming the manual counting as reference. In Case 1, the proposed device was evaluated through 5 separated experiments. The experiments were held during lunchtime, which is the highest demand period of the day. Comparing the manual counting to the automated counting, it was obtained an average accuracy of 91.45% in the five experiments. From a total of 386 events (meaning boarding and alighting), the device counted 353 events properly. Table 3 shows the accuracy calculated for each experiment separating boarding and alighting. In the worst case, the accuracy was 89.15%.

For the sake of comparison, the APC system presented for Pinna et al. (2010), used in transportation service to count the number of passengers boarding and alighting has presented...
### Table 4 Error number ratio

| Type of error                                      | Number of errors |
|---------------------------------------------------|------------------|
| Did not count a boarding                          | 3 (0.78%)        |
| Did not count an alighting                        | 0 (0.00%)        |
| Counted a boarding that did not happen            | 12 (3.11%)       |
| Counted an alighting that did not happen           | 6 (1.55%)        |
| Counted an alighting instead of a boarding        | 11 (2.85%)       |
| Counted a boarding instead of an alighting        | 1 (0.26%)        |

In this case, the validation was done by comparing the results provided by the proposed APC with the counting registered by the gates. In this case, there are only incoming individuals in the scene. The gates registered a total of 1,186 people in this restaurant in a day, while the developed APC counted 1,170 people. This means an accuracy of 98.65%. This very accurate results are due to the unidirectional movement of people and because the ticket gate guarantees that just one person passes in front of the APC at a time. Note that similar conditions can be created in several environments, as in buses, helping increase the accuracy of the proposed APC.

## 5 Conclusion

This paper presents an IoT-based automatic bidirectional people counting device based on a microcontroller through infrared sensors. The microcontroller and the infrared sensors were selected considering aspects as cost, embedded features, and availability. Experimental field results were obtained in two realistic case studies. Results showed that the counting accuracy achieved is over 90% in both case studies. In the second scenario, the accuracy was close to 98%. This very accurate result is due to the unidirectional movement of people and because the environment guarantees that just one person passes in front of the APC at a time. Based on a detailed analysis of the experiments, it can be inferred that erroneous counting come from a number of factors, but the behavior of people passing many times and standing in front of the devices caused most errors.

According to the results of the field tests, the cost, and availability analysis showed in this paper, it can be concluded that the proposed device is sufficiently precise, cheap, and reproducible in large scale. Beyond that, the embedded communication facilities allow to implement automatic real-time control of people in several environments which can be very useful in the context of coronavirus COVID-19 disease. Moreover, it may work with different environmental vibrations, lighting conditions and presents low-energy consumption, which allows feed them with a power bank, significantly simplifying the installation, and which are among the main issues on the literature available methods.

Results from both case studies showed that the proposed counting device is an effective tool that can assist today’s COVID-19 pandemic scenario in different stages, either in indoors spaces or on urban public transportation services. Moreover, due to the increasing concern about security issues, people counters have become important tools for security control matters. It can be used for safety-critical building complexes, as well as, security areas where the number of people is required for maximum occupancy regulations.

Due to the spread of the COVID-19 pandemic globally, the APC device proposed in this work can be considered as...
an occupancy monitoring technology that can be used for limiting the number of people in indoor spaces in order to ensure social distancing and provide healthy and safe environments for the public. It can be used in different indoor spaces at the university campus, such as restaurants, laboratories, classrooms, and libraries, in order to control these spaces occupancy and keep a safe distance between people to reduce the number physical interactions, and consequently, minimize the infection rates arising from the COVID-19 disease.

According to Kotz et al. (2015), APC devices can provide significant data for transit analysis, which include boarding and alighting information associated with time, and location data. Transit authorities have been using this set of data in different applications regarding urban transportation services, including route optimization, bus occupancy rate, service frequency, travel time estimation, bus stop evaluation, etc. It can all has a positive impact of COVID-19 on passenger demand and promote preventive measures in public transport services.

Currently, we are assembling a number of APC devices to operate together as a single people counting system. Indeed, this can be done with the proposed device, since ESP32 Wroom-32 Devkit V1-Doit has embedded Wi-Fi and Bluetooth technologies. For that, a managing module able to communicate several counting devices simultaneously, account the total number of passengers, store data, and report to an operation center in real time is being developed. For application in transportation systems, this multiple APC system is being associated with a global positioning system (GPS) device allowing determining where each passenger gets in and gets off the buses.

All these initiatives are being developed in the context of the Sustainable Campus Project, which is an initiative funded by electrical energy utilities to develop and integrate a set of Living Labs for renewable generation, electric mobility, energy efficiency, monitoring, and energy demand management in our University (da Silva et al., 2018; Ugarte et al., 2019).

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Declarations

Conflict of interest No conflict of interest.

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