A Flexible Sensor-mat to Automate the Process of People Counting

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***Abstract*—Real data on the peoples mobility are an essential input for decision-makers of city and regional planning. They allow for various optimizations like traffic routes, public places or safety measures at public events. Obtaining such data in an automated and reliable way is a burdensome task since usually the requirements on the respective solutions depend on the actual situation (e.g., indoors, outdoors, different counting cross-sections). This paper reports on the work-in-progress of the development for a flexible, low-power sensor-mat that automates people counting.**

***Keywords*-sensor-mat; people counter; mobility; wireless networks.**

I. Introduction

Accurate and representative mobility data, especially for motorized traffic is a vital information for our daily life. It allows for up-to-date traffic control and provides input for spatial planning and resource optimizations of the public infrastructure, see, e.g., [8]). In fact, many automated counting techniques (e.g., [12], [11]) are in use today and have superseded almost all manual counting's. In fact permanent, fully automated counting solutions are installed at many street sections of high interest, delivering reliable traffic data that is used for dynamic speed control information systems, navigation systems, etc.

Respective mobility data for non-motorized traffic, so far, is primarily used by operators of infrastructures like railway stations, airports or shopping malls for various optimizations. For example, using this data one can optimize train schedules and respective transfer times to enhance the attractiveness of public transportation. Likewise, a shopping mall operator can influence the habitual buying behavior and thus better the overall property value. The same data can be used for safety measures in public buildings or at large events by, e.g., restricting access to certain regions when the number of people exceeds the respective capacity. There exist a multitude of automated people counting technologies, see, e.g., [2], [5], or [16]. At present, however, none satisfies all the diverse requirements commonly encountered in practice.

Section II highlights our motivation and lists requirements contributed in a project workshop by various infrastructure operators and urban planners. Next, section III elaborates on related work, before we highlight the challenges and our first concepts in section IV. Finally, we present our status quo before we conclude the paper with an outlook of our next steps.

II. Motivation and Requirements

Manual people counting's using some sort of tally counter are still frequently performed in practice to gather information on the non-motorized traffic patterns. This manual approach suits short counting's and low to medium traffic densities; especially since almost no installation/setup overhead is required. For longer durations or dense traffic, however, the data gathered using a manual approach is often either not representative or inaccurate. To overcome this issue, many automated people counting approaches exist, see Section III for an overview. However, many of these solutions only fit part of the requirements on an automated people counting system as listed below:

Costs: Some solutions for automated people counting necessitate rather high equipment investments (e.g., many solutions based on laser technologies), require elaborate software for data analysis and are costly in terms of extra on-site installations (power and/or network access).
Flexibility: Restriction due to local geometries (e.g., at entrance situations) or due to size restrictions of the measurement technology frequently limit the flexibility of existing methods in practice. Furthermore, most automated people counters require dedicated on-site installations.
Quality: Especially in dense traffic or extreme environmental situations the automatically gathered data is often inaccurate. Furthermore, for almost all commercial-off-the-shelf people counters no explicit measuring error probability is available, limiting the use of collected data in such situations.
Environmental Influences: Several sensors have problems with fluctuations in temperature or lighting – e.g., at entrances – and eventually wind-up delivering incorrect data. Furthermore, only a sub-set of the available solutions can be used out-doors.
Mobility: For temporal people counting's spanning several days/weeks (e.g., to optimize pedestrian traffic lights) an autonomous, almost energy self-sufficient system is required. Existing, solutions that fit this requirement are only available

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for counting individuals (e.g., using active infra-red sensors).

Data collected via sensor fusion addresses most of the aforementioned requirements, increases, however, the system complexity and costs, cf. [14]. In the project Flexicount we are developing an outdoor capable sensor-mat that enables plug&play counting of people crossing a defined intersection.

III. Related Work

In recent years different technologies for counting people have been developed and used. The following list gives a short overview and provides an informal assessment of the respective strengths and weaknesses:

Counters based on *active infrared sensors* are typically low-cost, have low power consumption, allow for a simple installation and are portable. These devices, however, are not able to discern between pedestrians and other moving objects (e.g., raindrops) and cannot separate multiple pedestrians crossing a given line-of-sight at the same time.
Passive infrared counters, see e.g., [7] and [9], using thermal images are available at moderate costs, feature low energy consumption and are operable in humid or foggy weather conditions. Furthermore, these systems are legally defensible with regard to data privacy. Drawbacks of these devices are their rather limited usability in dense traffic situations, the requirement for over-head installation, the limited co, see [3]verage of widths where counting is feasible and their dependence on temperature differences.
Better counting accuracy is obtained by relying on *laser-scanners*, see [15], [6]. These counters work reasonably well even in crowded areas, allow separation of individuals, usually are simple to setup and can operate on wider cross-sections. Their drawback is mainly due to the high initial costs, their limited usage under different weather conditions and their rather bulky and heavy construction.
Vision based counting solutions, see [10], [13], can operate on larger cross-sections, and give somewhat accurate results – some even under varying lighting conditions (stereo vision based systems) and when recorded allow for further post-analysis. These systems are usually simple to setup and require only moderate installations. Drawbacks are influences of the operation on different environmental conditions, legal issues with respect to data privacy, and are often only available for indoor scenarios.
The company eco-counter (http://www.eco-compteur.com) distributes an *acoustic counting solutions* where plates are buried about $5cm$ below the surface. Individuals crossing the respective section get counted by acoustic means. This outdoor capable solution operates in an almost energy self-sufficient way for several years, allows, however, to count only one crossing person per plate. Thus this method is only usable for low traffic density scenarios. Multiple plates are required for bi-directional counting and significant installation overhead is required. Hence, the solution is best suited for fixed installations.
A solution measuring the change in the *magnetic field* is distributed by the company Future Shape (http://www.future-shape.com) under the product name *SensFloor*. This technology, however, has only limited use for actual people counting's since it was specifically developed for the domain of *ambient assistive living*.

A detailed overview and evaluation of existing people counting solutions was presented in [1] and [4]. Despite all the advances, manual counting's using *tally counters* are still used most of the times, see [3], [4]. For small samples this method is cost-effective and allows high accuracy for low traffic densities. However, bidirectional counting's, higher people traffic densities, and the short time-spans that can be covered in this way limit this method.

IV. Flexicount - Development of a flexible sensor-mat for people counting

A flexible solution that enables an automated counting of passenger traffic delivering reliable data is needed with growing urbanization and ever increasing traffic. In particular, such a solution should be mobile, allowing to count for several days or weeks, cost effective and require only a minimum of installation and maintenance overhead. In addition it must be adaptable for various different cross-sections (counting widths) and robust against environmental influences for outdoor use.

A. Aims

In the project Flexicount we are developing a sensor-mat with integrated sensors that register people traversing the mat. The gathered measurement values are relayed via a wireless sensor network to a host computer that performs the actual analysis and counting. The mats are self-sufficient and can be simply placed beneath each other, hence one can flexibly cover different cross-sections. Figure 1 illustrates the prospective approach.

The following functional requirements will be addressed in Flexicount:

- (r1) sensors to identify people crossing in any direction (ability to discern between people and most other objects)
- (r2) temporal referenced, multi-directional counting's
- (r3) real-time wireless data transmission (plug&play operation)
- (r4) high accuracy with known error probability
- (r5) ability to calibrate the electronics
- (r6) energy self-sufficient operation for multiple weeks
- (r7) polymer-matrix that provides a reasonable load and pressure distribution (e.g., to handle stilettos)

Furthermore, we will address the following non-functional aspects:

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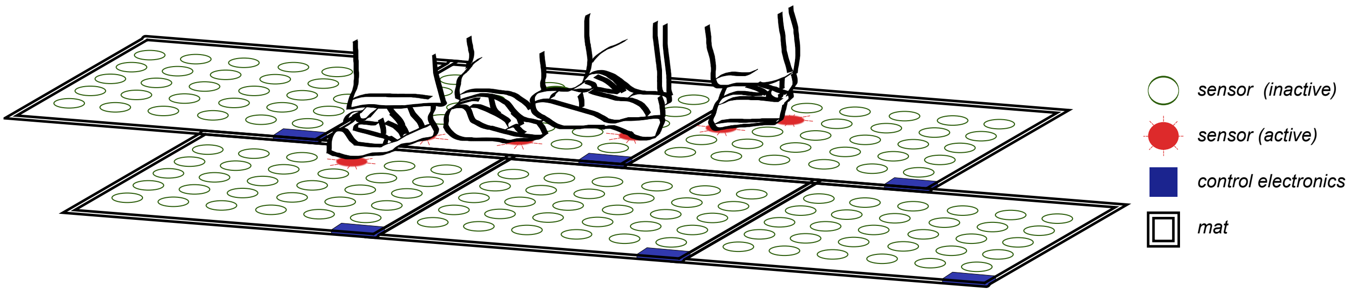

Figure 1. Multiple Flexicount mats in operation

(r8) small weight
(r9) simple adaption to different cross-section
(r10) minimum installation and maintenance overhead
(r11) usable for in- and out-door applications (waterproof, wide temperature range, robustness)
(r12) safety related features (skid-proof, small mat heights, markings, etc.)
(r13) hardened against vandalism and denial-of-service
(r14) low cost

B. Status Quo

So far, we have developed the sensors with respective control electronics, evaluated some commercial-off-the-shelf wireless radios for our application, and performed a polymer integration with a first prototype.

The sensors – addressing requirements (r1-r2) – basically consist of a multiplexed switch array where contacts are placed at regular intervals (30mm apart) on a 0.15mm thick printed circuit board with a dimension of $450x450mm$. On top of this PCB we use a separate contact plane; currently we are evaluating and testing different options with regard to their long-term behaviour (>100.000 load cycles):

(a) a microwave absorbing elastomer with a volume resistivity of 4-5Ω/cm
(b) an array of snap-disks with constant force-displacement characteristics
(c) an elastomer treated with a conductive coating

For the case when we select options (b) or (c) we will complement this sensor array with a number of equidistantly distributed force-sensors. In case option (a) will be selected we are able to omit the latter sensors since the force canöah be directly measured via the contact resistance between the elastomer and the contacts on the printed circuit board. In this case all multiplexed rows must be analog-to-digital converted. First experiments seem promising in this regard, however, a careful long-term evaluation is still under way. Figure 2 shows the mat build-up sequence of an early prototype peeled apart.

For the wireless network we have currently opted for a low-power commercial-off-the-shelf, meshed ZigBee solution; mainly to satisfy the required bandwidth required to handle the worst-case data volume, cf. requirement (r3). For an end-product, we will eventually be able to replace ZigBee with ANT — in case we can reduce the transmitted data volume — in order to optimize for low power consumption. Our prototypes' power is currently supplied via a rechargeable battery that is charged occasionally (after some weeks of operation) via an inductive loop (similar to the principle widely employed in electrical tooth-brushes), cf. (r6).

The polymer integration of our prototype is presently build from a 3mm thick viscous elastic polymer at the bottom to accommodate for various different surfaces (e.g., stone chips). Above we use an elastomer to embed the electronic circuitry; this layer must incorporate the various different heights of the devices. On top of this layer we place our contact plate (options (a)-(c) from above) followed by a

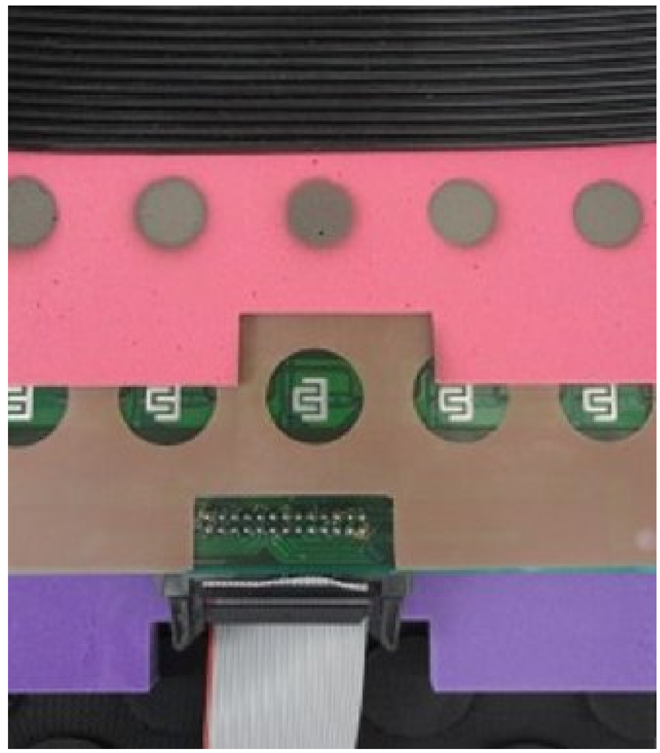

Figure 2. Mat buildup sequence of an early prototype

$3mm$ thick elastomer that provides the desired load and pressure distribution and serves as protective layer. The topmost layer is made of a sunfast abrasive wear that provides the visible surface finish. The entire polymer embedding is waterproof and enables an outdoor use.

V. Conclusion

This paper presents a work-in-progress report of the development of a sensor-mat that will eventually facilitate an automated counting of peoples traversing the mats. The approach has the potential for use even in dense traffic scenarios both in- and outdoors and will eventually provide a solid data basis for regional planners.

Our next steps are to finalize the long-term evaluations and analysis of our contact planes, before we are able to produce the first prototypes. The latter will than be used for field tests in order to optimize the sensor-mats for the given requirements in a follow-up re-design.

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