[i]THE MUNICH LARGE-SCALE DRONE DATA SET CONTAINING PEDESTRIAN, CYCLIST, MANUALLY DRIVEN AND AUTOMATED VEHICLE TRAJECTORIES

M. MARGREITER, A. KUTSCH, K. BOGENBERGER
Chair of Traffic Engineering and Control, Technical University Munich, Germany
martin.margreiter@tum.de, alexander.kutsch@tum.de, klaus.bogenberger@tum.de

ABSTRACT

To evaluate the impact of new intelligent mobility solutions like automated vehicles or C-ITS, the access to proper data observations in real-world environments is an absolute necessity. The challenges new automated mobility faces in urban areas are manifold and require spatially and temporally extensive data from real world traffic situations and interaction scenarios with other road users.

This paper focuses on supporting the shift of our current urban mobility systems – made possible by the emergence and confluence of new transportation technologies like vehicle automation – by providing such real-world mobility data.

The data was recorded in the city of Munich, Germany, continuously for several hours a day and several days with all together twelve camera-equipped aerial drones. The aim was to generate a large-scale continuous data set including various interactions between classical human-driven cars and automated vehicles as well as active mobility users with human-driven and automated vehicles. For this purpose, the urban area drone footage covers trajectories for both human-driven and automated vehicles as well as active road users like pedestrians, cyclists, and persons with disabilities. The trajectories were extracted from the video images and merged continuously in time and space across several drone observation areas and subsequent time slots.

During the simultaneously running field test, the participating connected and automated vehicles were also made clearly visible to other road users as being automated. This was ensured by large explanatory stickers at the car body and a sensor mounting structure on the roof.

The whole data set will be published open source to ensure a perfect global accessibility for scientists and practitioners for further research.

1. MOTIVATION

Traffic data nowadays becomes more and more important to understand the behavior and the strategic, tactical, and operative maneuvers of traffic participants and to increase with this knowledge traffic safety and traffic efficiency. The need for data is therefore interesting in the field of general traffic behavior but also of individual traffic maneuvers like turning, overtaking etc. It gets especially important when looking at the traffic behavior of vulnerable road users (VRU) like cyclists and pedestrians, as proper data sets about those traffic participants are quite rare and therefore also knowledge about their behavior in the traffic system is quite limited. For motorized traffic most large-scale datasets also stem from observations on freeways, where the sensor density and the need for traffic detection is also higher and therefore data generation is easier. For urban traffic systems with a much higher variety of different traffic participants and also a more complex road network structure it is rather difficult to use (existing) infrastructure-based sensors like on freeways to have a full data coverage of all traffic participants and their interactions. Most sensor types rely on

particular components of motorized vehicles to be able to detect their presence, like metal parts for inductive loops and magnetic field detectors or license plates for automatic license plate recognition (ALPR). Technologies like LiDAR, or infrastructure-based video cameras as well as infrared cameras need sophisticated point cloud or image recognition algorithms to identify and categorize individual traffic participants. This present work goes one step further and elaborates the use of large-scale drone video footage in combination with such recognition algorithms to provide a temporal and spatial fukk overview of the complete set of all traffic participants. This enables further research to study in particular the interactions between different traffic participants especially motorized road users and VRUs with a focus on traffic safety and to understand better the multimodal traffic patterns. Such data contributes significantly to improve traffic safety and optimize the road network operations [1]. Another benefit is the availability of such a data set to train further video recognition algorithms and neural networks.
The data set was gathered within the Munich TEMPUS project [2], a project to prepare the Munich urban and suburban road network for connected and automated driving. Lots of data sets and research for the implications of connected and automated vehicles on the safety and operation are already available for freeways [3] Therefore this work also contributes to further knowledge about the traffic behavior of such vehicles particular in urban traffic networks.

2. LITERATURE REVIEW

Several attempts for collecting traffic data using videos from a top view or an almost top view perspective have been made. An almost complete dataset for evaluating microscopic traffic models, and mainly the first attempt for extracting trajectories from video data on a large scale is the NGSIM dataset from 2006 [4]. This is covering some hundred meters of traffic mainly on major freeways, collected by several stationary cameras on high buildings, but does not include dense, urban networks, only single intersections and major streets. Further development and technical progress then led to aerial observation for traffic monitoring, where drones became an option that was used several times. Reasons for that are lower costs compared to stationary sensors for a whole network, more flexibility and less restrictions than manned aerial vehicles and they cover large scale information [5]. Until now, most of the experiments were conducted on a limited space with only a single drone [6,7]. Further such examples for urban traffic data, can be found in Germany, such as the inD dataset, containing data at several urban intersections [8], the rounD data [9], covering a roundabout or the uniD data, where besides the location of the participants, also their dimensions are described. Also, for freeways and highways, some datasets exist containing vehicle trajectories, such as the highD dataset for free stretches [10], exiD with data from ramps [11] or the Automatum [12]. Further experiments on that can be found in [5].
The first attempt to take this aerial observation to a large scale in an urban city network was made by Barmpounakis and Geroliminis in 2020 [13]. They used a swarm of ten drones to monitor an area of more than a square kilometer, covering around 200 links on a road network in the city center of Athens. This open-sourced data called pNEUMA was and is widely used, since it delivers a rich ground truth data set. Examples of the applications with this data set are traffic state estimation approaches [14], emission modelling [15] or network modelling and control attempts [16]. Even though the richness of this data is undisputed, there are at least two shortcomings that have not yet been solved in any other experiment.
Using drones with a limited battery capacity, the flight intervals, during which data can be collected, do only have a length of around 15 to 20 minutes. Afterwards, batteries need to be swapped and therefore the recordings are stopped in between. To the best of our knowledge, no time continuous data set exists, covering several hours of uninterrupted trajectory data. Secondly, experiments covering a wider area of not only one intersection,

such as the pNEUMA experiment, do not include vulnerable road users. Only the trajectories of the motorized road users were collected, whereas pedestrians, bicyclists and further non-motorized participants could not be detected. These two problems were addressed with the Munich dataset, which is described below.

3. THE DATASET

3.1. Location

Figure 1 – The six observation locations in the North of Munich (based on Google Earth).

The drone surveys were conducted along Rheinstrasse in Munich, Germany, between Bonner Platz and Leopoldstrasse. Six locations were covered by two drones each, as shown in Figure 1. The drones had a flying altitude of 110 meter when taking the videos, resulting in a recording area of 143 meter on 75 meter for each drone location. With the need for an overlap in between the individual locations for reconstructing the whole trajectories throughout the whole stretch, a total length of 700 meter was recorded. The street is highly frequented and can be classified as a main street. The perimeter includes two signalized intersections, one right-of-way-controlled intersection, two non-signalized T-junctions and two signalized pedestrian crossings. Motorized traffic has one lane in each direction, which is split up into turning lanes in the approaches of towards the signalized intersections.
To the west, the observed area begins with Bonner Platz, shown in Figure 2. The intersection is controlled by a traffic signal system. In both the western and eastern approaches to the intersection, there is a dedicated left-turning lane and a combined lane for straight and right-turning traffic. The approaches from the north and south each have a combined lane for all turning directions. Bicycle traffic is guided on a protective lane on the roadway in the intersection area from all approaches. In the southern and northern approaches to the intersection, there is also a bicycle queuing area in front of the stop line for motorized traffic. For pedestrians, there is a separate pathway with signals for each pedestrian crossing. In addition, except for the northwestern approach, there is a bypass at all quadrants. These are only of small width and are primarily intended for parking, not to relieve traffic. At the northwestern as well as the southeastern corner of the intersection, there are also entrances and exits to the Bonner Platz subway station, where access is provided by a staircase and an escalator, respectively.

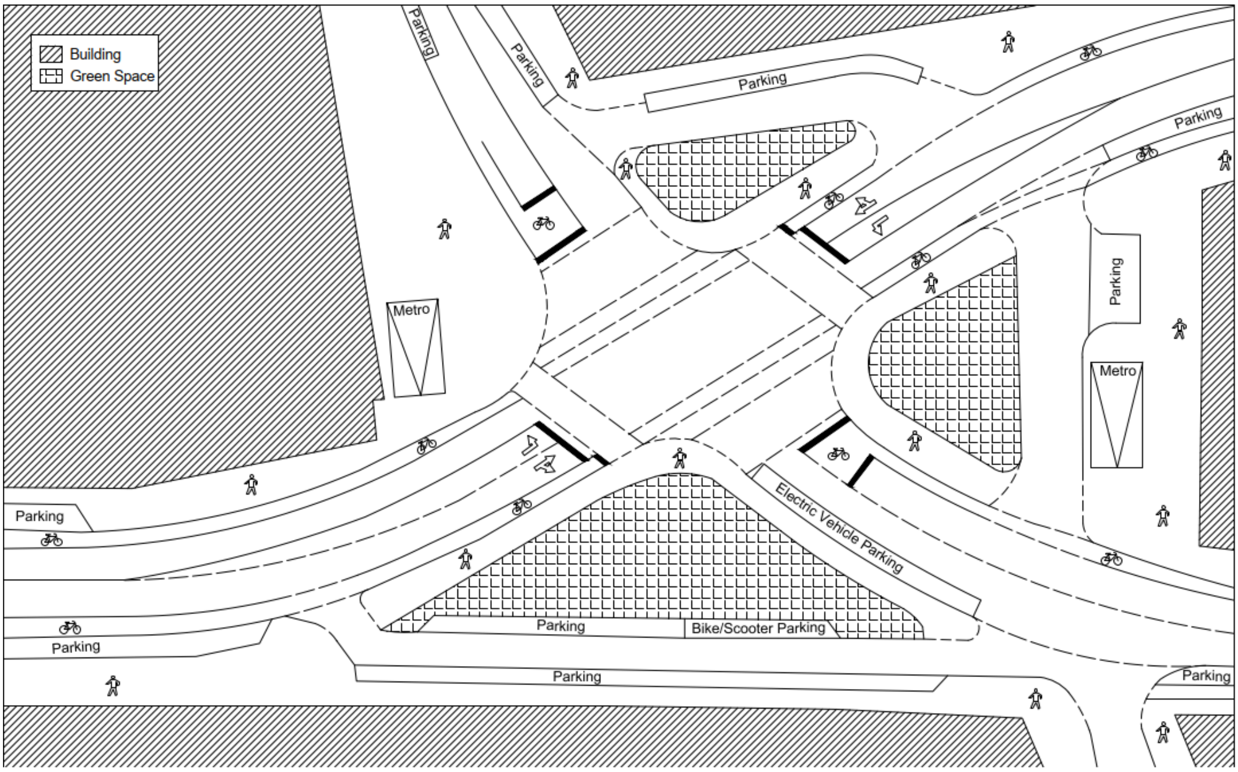

Figure 2 – Schematic intersection plan of the Bonner Platz.

Directly adjacent to Bonner Platz, the protective lanes for cyclists transition eastward into a separated bicycle lane, which is now routed between the sidewalk and on-street parking spaces. At the intersection with Mainzer Strasse, there is a traffic signal for pedestrians on the western approach. There is also a signalized pedestrian crossing including a demand responsive push button at the Simmerstrasse intersection, which is located at the eastbound approach of the intersection. The western approach extends here in the area of the T-junction, so that left-turning vehicles can be passed.

At the eastern end of the study area is the intersection with Leopoldstrasse, visualized in Figure 3. Again, the west- and eastbound approaches each have a dedicated lane for left-turning traffic, as well as a combined lane for the other flows. For vehicles approaching the intersection from the north, there is a left-turning lane, a centered straight lane, and a mixed lane for straight and right-turning. On the opposite, southern approach, there is a separate right-turning lane, as well as two straight ahead lanes. Turning left is prohibited here. In the middle of the street there are tram tracks, to which stops are located north of the intersection for the south-north direction and south for the opposite direction. These are also built in a central position. In addition, a bus line southbound from Leopoldstrasse turns right into the Potsdamer Strasse, with the bus stop located immediately behind the image section. The bicycle lane is also separated from motorized traffic by a curb in the entire intersection area. The lane is also texture-wise and visually separated from the sidewalk.

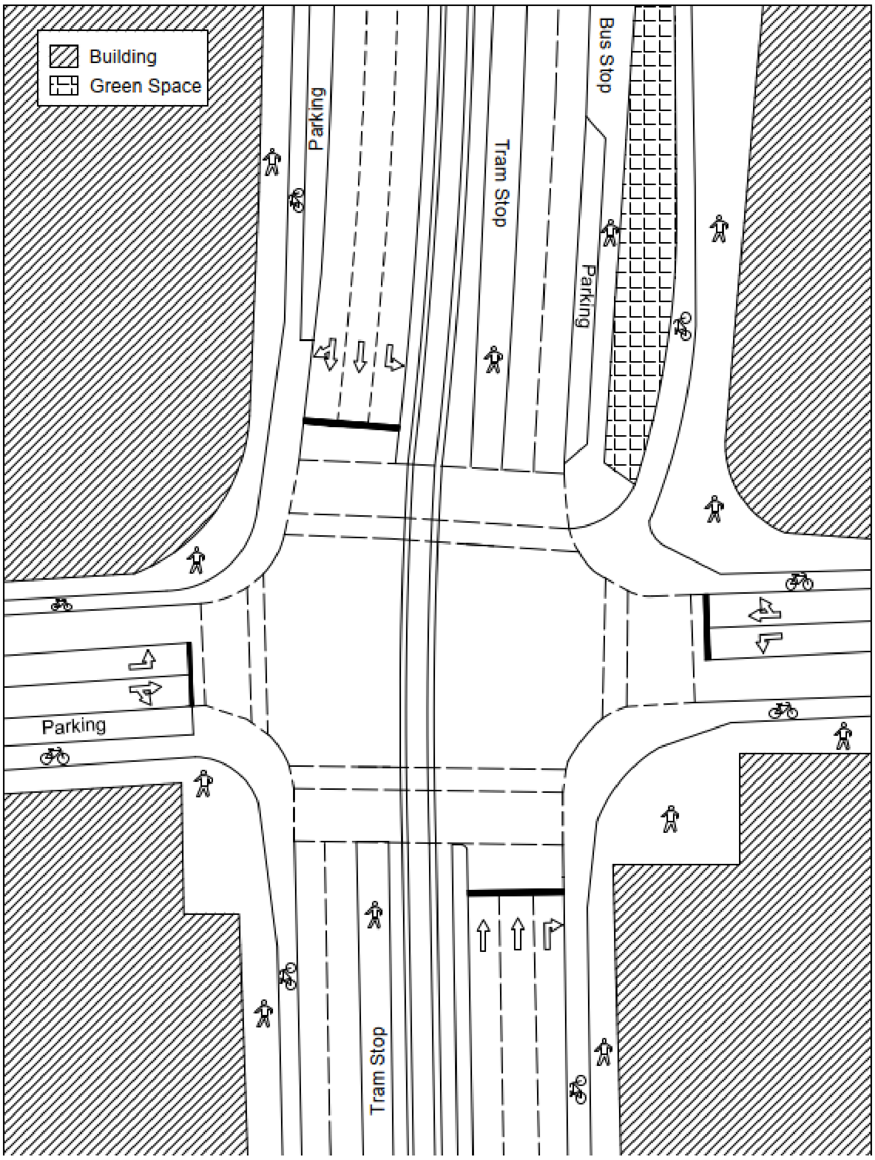

Figure 3 – Schematic intersection plan of the crossing Rheinstrasse - Leopoldstrasse.

There are several points of interest within the recording area and the immediate surroundings. In addition to a school and a kindergarten, several doctors and pharmacies, as well as numerous shopping facilities, both for groceries and drugstores, recreational activities are also available. Several restaurants, a sports club and three hotels are located in the area. There are also several access points to public transport, namely a tram and several bus stops on Leopoldstrasse, as well as a Subway access point on Bonner Platz. The surrounding area is shown in Figure 4.

Figure 4 – Recorded area (marked in red) and the surrounding points of interest.

3.2. Temporal Extension

Until today, drones have a maximum flight time of around 30 minutes due the limited battery capacity. Various systems, such as Balloons and tethered drones with power supply, have been assessed but do not provide the necessary image stability or are not suitable due to the high costs and the approval process, which is difficult to implement in the city center. Therefore, in order to create a continuous data set, two drones were used for each location, and a 'shake-hands' was performed in the air so that the drone to be replaced only descended when the following drone was in the air and had fixed the image section. Accordingly, a total of twelve drones were in use. They recorded a total of analyzed videos amounting to almost 42 hours from their respective single locations.

Initially the experiment should have been conducted in the second half of September, because on the one hand, summer vacations in Germany were already over, and on the other hand that the temperatures were pleasant for non-motorized road users. Due to rain and strong winds, the flights had to be postponed. The first two subsequent possible options were used, so that the recordings were then actually performed on Thursday, October 6 and Wednesday, October 12, 2022. The days in the middle of the week were determined according to surrounding detector data in order to capture the most frequented days in the week. On both days, flights were performed in the afternoon in order to be able to depict the leisure traffic as well as the commuter traffic and therefore the peak-hour.

On the first day, the last drone was in the air at 15:35, so that a complete image of the entire stretch could be generated. The recordings were carried out until 18:45. On the second day, the first shots were started even earlier to counteract the earlier sunset. Thus, from 15:00 on all drones were in the air, the end of recording was then accordingly at 18:25. In the course of the recordings, there were a total of four interruptions at individual locations, which occurred due to technical difficulties. However, the total length of the interruptions is only a little more than 23 minutes. The missing gaps are visible in Figure 5. After subtracting the time overlap and the loss times of the individual videos, there are still over six hours of data available, where all locations were recording at the same time.

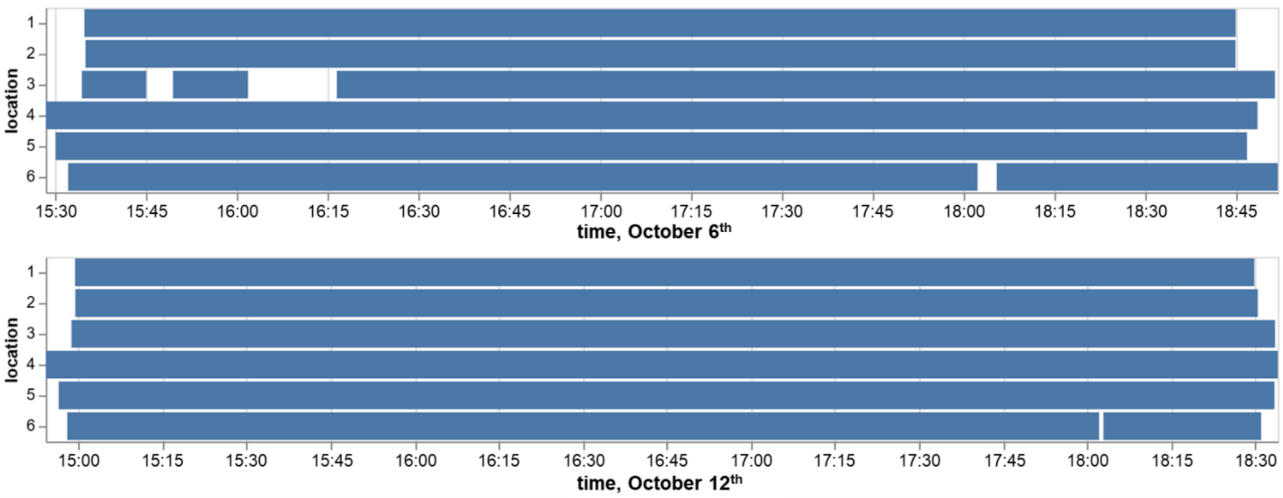

Figure 5 – Available time slots on both recording days.

3.3. Included Traffic Participants

Due to their altitude and mostly unobstructed viewing angle towards the observed road and sidewalk segments, the drones were able to record all traffic participants in the area. This includes passenger cars, busses, trucks, trams, motorcycles, (e-)bicycles, pedestrians and the rising number of (e-)kick-scooters [17]. In addition to that, truck trailers as well as bus trailers (in the city of Munich several high-capacity bus routes operate buses with bus trailers) were also recognized and categorized. The observed road segment also lies in the area of Munich's TEMPUS test bed for connected and automated driving [2], Therefore, also three vehicles with connected and automated driving functions were part of the drone observation data set, mainly focusing on the use cases of automated vehicle platooning (three automated vehicles following a human-driven fourth vehicle) and vehicle interactions with crossing pedestrians at unsignalized locations. In addition to the aforementioned traffic participants the dataset also contains trajectories of an electrified bicycle Rickshaw from the TEMPUS project [18,19], (E-)Cargo-Bikes and persons with a wheelchair.

3.4. Dataset and Additional Data Sources

The dataset consists of labelled objects per timestep. For a frequency of 12.5 Hz, every object is marked with its class label, coordinates (local coordinates with a global reference point in UTM 32N), 3D-dimensions, orientation and its speed, as well as a track-id.

The trajectories are supplemented by other data sources that were collected or recorded in parallel with the drone flights. For the loop detectors marked in red in Figure 6, traffic counts, aggregated to 15-minute intervals, exist for every individual lane. The detectors are not able to differ between different vehicle types. For both days, so the 6th and 12th of October, the counts will be made available for the whole day. In addition, the signal states of the systems marked in yellow are also available. These are the signals actually shown every second for the respective signal groups.

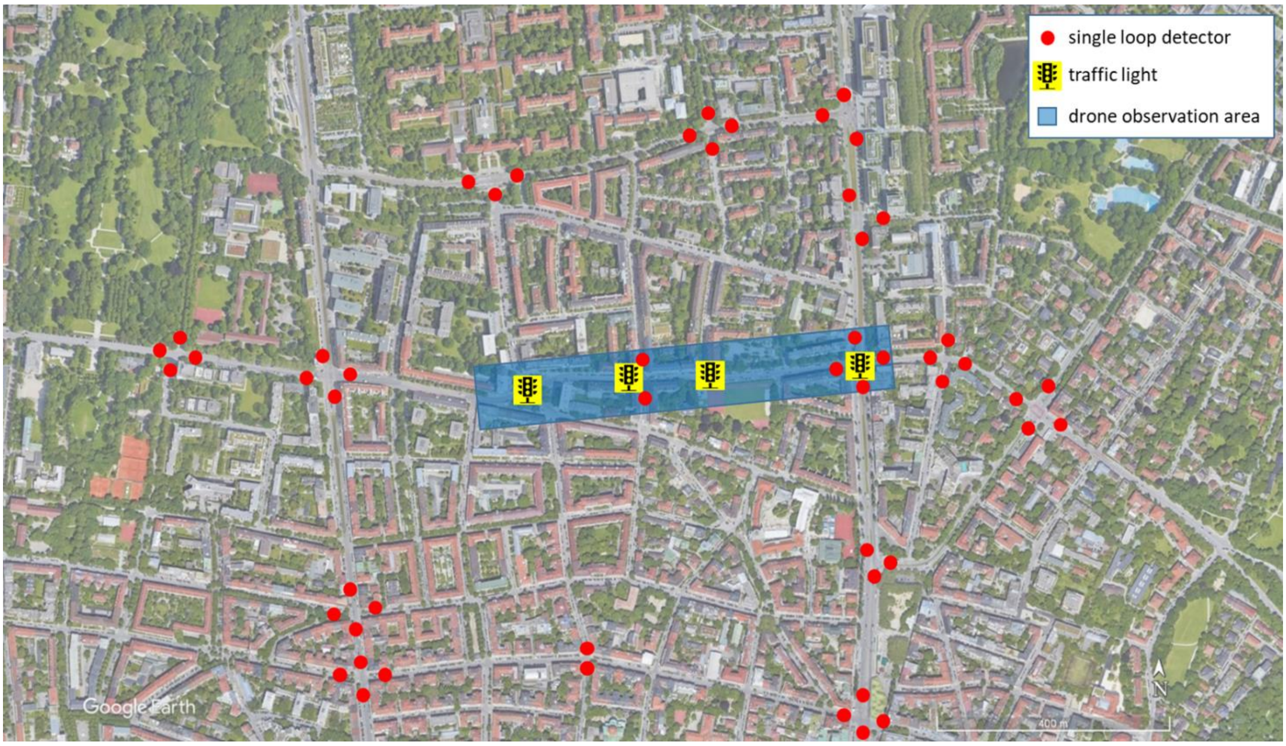

Figure 6 – Available data for the inductive loops and the traffic lights.

For the already mentioned vehicles that tested the connected and automated driving functions during the observations, the GPS-signals will be attached. Besides that, the blue marked area in Figure 6 will be available as a map with OpenDrive-standard. From the public transport operator, the time schedules for the buses, tram and subway are available. Finally, after the data processing for the trajectories of the rickshaw, the Cargo-Bikes, as well as the wheelchair tracks will be completed, the categorized object list will be made available as well.

4. POTENTIAL USE CASES AND APPLICATIONS

The data set provides a large range of potential use cases and applications. Especially the extracted trajectories (with id, classification, timestamp and coordinates) offer various insights in the field of driving behavior, the behavior of cyclists and pedestrians as well as the interaction between those modes. To our knowledge this data set concludes the first available multimodal urban interaction data containing all traffic participants. This allows for a better understanding of safety critical interactions, the behavior of vulnerable road users (VRU) and the creating and validation of related behavior models.

Within this project scope a multimodal traffic state estimation at link level for all traffic participants will be created and validated. Additionally, the extracted multimodal trajectories will be used as ground truth for the calibration and validation of the microscopic traffic flow simulation of the City of Munich.

Another potential use case is the verification and validation of the currently existing stationary loop detectors in the observed area to enhance the quality of the traffic models and predictions in the city where those data is the basis for.

The raw video data plays a significant role as a training data set for several applications in the field of Artificial Intelligence and Neural Networks.

5. OUTLOOK AND OPEN DATA INITIATIVE

To enable a wide and global access for scientists and practitioners the drone data set will be published open source. The open data set will include – in addition to the video raw material – all extracted trajectories for all traffic participants continuously in time and space through the whole area covered by all twelve drones at the six locations. Also, the additionally gathered data source mentioned in chapter 3.4 will be connected and reference to the data set and being published as open data. It is planned to publish under the Creative Commons CC BY-NC 4.0 license to guarantee easy access and usability for further research.

In beginning of summer 2023 a similar dataset will be gathered in the city of Ingolstadt, Germany, via the KIVI project [20,21] funded by the German Federal Ministry of Digital and Transport. Likewise, this data set will be made available open source.

6. ACKNOWLEDGEMENT

This research was funded and supported via the TEMPUS project through the German Federal Ministry for Digital and Transport under the research grant 01MM200008K. The drone data was gathered with the help of Fairfleet and DeepScenario. Additional data was provided by partners of the TEMPUS consortium like the City of Munich, BMW, Fortiss, MVG, 3DMS.

REFERENCES

1. Han, C., Hall, M. & Margreiter, M. (2022) Utilizing Data to Optimize Road Network Operations, 2022R09EN - A PIARC Collection of Case Studies, ISBN: 978-2-84060-684-0.
2. Kutsch, A., Margreiter, M., Stüger, P., Fehn, F., Metzger, B., Hamm, L., Engelhardt, R., Ilic, M. & Bogenberger, K. (2022) TEMPUS - Test Field Munich - Pilot Test for Urban Automated Road Traffic, IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), doi:10.1109/ITSC55140.2022.9922303.
3. Motamedidehkordi, N., Margreiter, M., Hoffmann, S. & Busch, F. (2017) Implications of Automated Vehicles on Freeway Safety and Operations, ITS World Congress Montreal, Canada.
4. NGSIM. (2006). Next Generation Simulation - Dataset. Next Generation Simulation - Dataset. From https://ops.fhwa.dot.gov/trafficanalysistools/ngsim.htm
5. Barmpounakis, E. N., Vlahogianni, E. I., & Golias, J. C. (2016). Unmanned Aerial Aircraft Systems for transportation engineering: Current practice and future challenges. International Journal of Transportation Science and Technology, 5, 111-122. doi:https://doi.org/10.1016/j.ijtst.2017.02.001
6. Khan, M. A., Ectors, W., Bellemans, T., Ruichek, Y., Yasar, A.-u.-H., Janssens, D., & Wets, G. (2018). Unmanned Aerial Vehicle-based Traffic Analysis: A Case Study to Analyze Traffic Streams at Urban Roundabouts. Procedia Computer Science, 130, 636-643. doi:https://doi.org/10.1016/j.procs.2018.04.114
7. Barmpounakis, E. N., Vlahogianni, E. I., Golias, J. C., & Babinec, A. (2019). How accurate are small drones for measuring microscopic traffic parameters? Transportation Letters, 11, 332-340. doi:10.1080/19427867.2017.1354433
8. Bock, J., Krajewski, R., Moers, T., Runde, S., Vater, L., & Eckstein, L. (2019). The inD Dataset: A Drone Dataset of Naturalistic Road User Trajectories at German Intersections. From https://arxiv.org/abs/1911.07602
9. Krajewski, R., Moers, T., Bock, J., Vater, L., & Eckstein, L. (2020). The rounD Dataset: A Drone Dataset of Road User Trajectories at Roundabouts in Germany. 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), (S. 1-6). doi:10.1109/ITSC45102.2020.9294728
10. Krajewski, R., Bock, J., Kloeker, L., & Eckstein, L. (2018). The highD Dataset: A Drone Dataset of Naturalistic Vehicle Trajectories on German Highways for Validation of Highly Automated Driving Systems. 2018 21st International Conference on Intelligent Transportation Systems (ITSC), (S. 2118-2125). doi:10.1109/ITSC.2018.8569552

11. Moers, T., Vater, L., Krajewski, R., Bock, J., Zlocki, A., & Eckstein, L. (2022). The exiD Dataset: A Real-World Trajectory Dataset of Highly Interactive Highway Scenarios in Germany. 2022 IEEE Intelligent Vehicles Symposium (IV), (S. 958-964). doi:10.1109/IV51971.2022.9827305
12. Spannaus, P., Zechel, P., & Lenz, K. (2021). AUTOMATUM DATA: Drone-based highway dataset for the development and validation of automated driving software for research and commercial applications. 2021 IEEE Intelligent Vehicles Symposium (IV), (S. 1372-1377). doi:10.1109/IV48863.2021.9575442
13. Barmpounakis, E., & Geroliminis, N. (2020). On the new era of urban traffic monitoring with massive drone data: The pNEUMA large-scale field experiment. Transportation Research Part C: Emerging Technologies, 111, 50-71. doi:https://doi.org/10.1016/j.trc.2019.11.023
14. Kutsch, A., Loder, A., Tilg, G., & Bogenberger, K. (2023). Extended Urban Traffic State Estimation Using Different Sensor Strategies. Annual Meeting of the Transportation Research Board (TRB).
15. Barmpounakis, E., Montesinos-Ferrer, M., Gonzales, E. J., & Geroliminis, N. (2021). Empirical investigation of the emission-macroscopic fundamental diagram. Transportation Research Part D: Transport and Environment, 101, 103090. doi:https://doi.org/10.1016/j.trd.2021.103090
16. Paipuri, M., Barmpounakis, E., Geroliminis, N., & Leclercq, L. (2021). Empirical observations of multi-modal network-level models: Insights from the pNEUMA experiment. Transportation Research Part C: Emerging Technologies, 131, 103300. doi: https://doi.org/10.1016/j.trc.2021.103300
17. Brunner, P., Singh, V., Denk, F., Margreiter, M., Bogenberger, K., Huber, W., & Kates, R. (2022) Safety impacts of rising urban micromobility: statistical analysis of e-scooter use and risky rider behavior in Ingolstadt, Germany, 16th International Conference on Travel Behaviour Research, Santiago, Chile.
18. Fehn, F.; Engelhardt, R., Margreiter, M., & Bogenberger, K. (2023) Ride-Parcel-Pooling: Integrating On-Demand Passenger Transportation and City Logistics, PIARC World Road Congress, Prague, Czech Republic.
19. Margreiter, M., Ilic, M., Joshi, A., & Bogenberger, K. (2023) A Self-Driving Cycle-Rickshaw for Autonomous Urban Passenger and Freight Transport, PIARC World Road Congress, Prague, Czech Republic.
20. Ilic, M., Sautter, N., Margreiter, M., Loder, A., & Bogenberger, K. (2022) Changing Strategic Alignments in European Urban Traffic Control - Requirements for Future Developments, 10th Symposium of the European Association for Research in Transportation (hEART), Leuven, Belgium.
21. Ilic, M., Sautter, N., Margreiter, M., Loder, A., & Bogenberger, K. (2022) Revisiting Urban Traffic Control in Austria, Germany and Switzerland - Requirements for Future Developments, Transportation Research Board - 101st Annual Meeting Washington, D.C., USA.