Technical & Data Protection Aspects of a Smart Digital Control Center for Smart Cities

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Abstract: The advances of smart city infrastructure spark an increasing interest in digital twins for cities using the plethora of new sensors that will be deployed across the city to monitor the urban environment. In normal operation, the digital twin provides an overview of the current state of the city. During disaster scenarios, the digital twin of the city will be able to provide the emergency services with an overview of the situation, increasing their effectiveness and supporting them in planning their course of action. This calls for a discussion about the data protection laws as well as data protection by design approaches and secure processing techniques in accordance with current European law. Our paper will discuss the related data protection laws and describe the technical overview of a system with both, permanent stationary sensors and mobile on-demand agents.

Keywords: Situation Control Center; Smart Cities; Data Protection Laws; Smart Street Lamps; Rescue Robotics; Emergency Response

1 Introduction & Motivation

Future smart cities are dependant on sensors that are distributed across the city to maintain their digital twin. Smart street lamps have been proposed as the ideal platform [Mü20] to introduce sensors into a smart city since street lamps are an essential facility of a city's environment and are already densely deployed in the urban landscape.

In normal operation, i.e., during normal days the smart street lamps continuously capture data and relay the required data where needed. The smart street lamps have a wide array of sensors such as laser scanners (LiDARs), cameras, temperature sensors, and other environmental sensors, to capture data from the surrounding environment [Mü20]. This poses multiple questions regarding the data protection laws, such as: What sensors can be used? What data can be captured and processed during normal operation?

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During a state of emergency, be it natural or man-made disasters, getting an overview of the current situation is of paramount importance for the emergency services, helping them plan their course of action [NKP15]. A Smart Control Center (SCC) acts as a hub for the information during an emergency, combining, processing, and visualizing the sensor information provided by all the agents. The SCC should encompass the following characteristics: human-centered, comprehensive, proactive, coordinated, and self-healing as defined by the vision presented in [ZLB10].

Let us assume that due to a natural or man-made disaster (be it an earthquake, gas explosion, fire, etc.) a shopping mall has collapsed. Some people will be trapped and others will be fleeing the area. The smart street lamps will be able to gather information from the surrounding area which will provide an overview of the current situation from their perspective area, which in turn can help save many lives. However, the smart street lamps are stationary and, therefore, will have blind spots that require exploration to get a near-complete overview.

Mobile search and rescue robots are able to reach and explore these blind spots and provide a more detailed and maneuverable overview of the situation [CM03; Su19]. Unmanned ground vehicles (UGVs) and unmanned aerial vehicles (UAVs) can assist the human operators with performing complex tasks from a safe distance. Additionally, UAVs can provide a bird's eye view of the scene, e.g., as a rough situation overview or locally, to aid the UGVs in their manipulation tasks. This leads to further questions regarding the data protection laws. The type of data (anonymous data, personal data, and/or special categories of personal data) has a significant impact on the legal requirements and thus on the concrete design of the systems used. In addition to the basic applicability of the General Data Protection Regulation (GDPR), it is also a matter of fulfilling the other obligations under data protection law. Data protection should already be comprehensively considered during the technical development of the systems.

In addition to the question of what can be permissible under data protection law, data protection-friendly technology design should also be used in order to comply with the right to informational self-determination on which data protection is based on (BVerfGE 65, 1, 41 et seq. (census ruling)) to the greatest possible extent in order to achieve broad acceptance among the population [KN19] and preventing malicious use [Wh21] of such sensor data. Concretely, the following questions arise: What changes from the normal operation and what can now be processed?

2 Technical Aspects

In this section, we shortly introduce the technical aspects of the smart control center.

2.1 Smart street lamps

The vision of smart cities revolves around the idea of having the city providing its citizens a wide range of services that improve their quality of life, in terms of mobility, health, resource management, and overall experience [Al18; Ri18]. These sensors can also assist first responders in detecting and handling disasters. To achieve this vision, street lamps as a platform (termed SLaaP) has been proposed, allowing to provide novel services to citizens through an innovative true city infrastructure [Mü20].

2.1.1 Street lamps in perspective

Street lamps are an essential and pervasive facility of city environments. Three of their natural characteristics have been recognized as key aspects for the development of smart digital city capabilities [Mü20]. First, street lamps are in general connected to existing electric power lines, which can become the basis for a next-generation digital infrastructure that incorporates various computing, networking, and Internet-of-Things (IoT) components [AIM10]. The second natural characteristic of street lamps refers to how densely deployed they are in the urban landscape. This makes them already ubiquitous in the life of the cities' inhabitants and thus the perfect starting point towards establishing an urban digital infrastructure that is easily accessible and scalable. The third characteristic is that street lamps are at large publicly owned, which allows to establish broad and comprehensive control mechanisms and regulations at the city level.

2.1.2 Key aspects of smart street lamps

In order to use street lamps as the basis of a citywide infrastructure that can enable a smart control center as proposed, they should be augmented both in hardware and software in a selective and strategical manner across the city to ensure effective and efficient coverage. In terms of hardware, there are four aspects that have been identified as essential for this purpose [Mü20].

- *Sensors* and *actuators* should be installed to allow for data acquisition and interaction. Specifically, for a smart control center, it is necessary to obtain accurate spatio-temporal data, for which range active sensors such as LiDAR and radar are ideal, as they allow to create 3D representations of the scanned environments with high precision. Concerning interaction, next-generation laser based projectors installed on the street lamps can provide situation-aware and personalized information to citizens.
- Concerning *computing* and *storage* resources, 4D visualizations such as the one proposed by our smart control center require nearby computational resources such as fog/edge computing, edgeClouds, or cloudlets [Sa17]. These resources can be

provided by street lamps with their unique characteristics detailed above. Single-board computers suitable for executing complex neural network based machine learning and computer vision approaches directly on the street lamps are required to enable privacy-preserving processing of the 4D data, preserving privacy-critical information in the lamps, while transferring the rest of the data to the cloud.

- In terms of *communications* and *networking*, as the focus of our smart control center relates to critical situations, it is essential to augment the lamps as to guarantee connectivity to the Internet, to nearby users and devices, as well as to other street lamps. This can be achieved by taking advantage of the natural proximity and density of street lamps, which opens up the possibility of establishing a true decentralized mesh network. To this end, a minimum viable set of street lamps would be connected to a fiber network, acting as the gateway nodes for the street lamp network. Then, the gateway nodes would relay the traffic to nearby lamps via WiFi or millimetre wave (mmWave) communication, taking advantage of the spatial distribution of street lamps.
- Smart street lamps can be of help for *energy management* by providing charging points for mobile agents.

2.2 Mobile Agents

Mobile rescue robots in the air, called UAVs, and on the ground, called UGVs, can temporarily provide a more detailed and movable overview of the situation in local areas of interest than provided by the stationary smart street lamps. The mobile agents can be tele-operated by human operators to perform tasks from a safe distance in hostile environments.Using complex software, they can also perform tasks autonomously with minimal or – in the case of connection loss – no supervision, and assist the human operators in performing complex tasks with smart assistance functions. Furthermore, teams of agents could collaborate to perform tasks that are impossible or too difficult for a single agent. Table 1 shows an overview of the sensor types that are presented in the following section and for what purposes they may be aggregated. The listed sensor types cover the types usually employed in a rescue robot such as the robot built by and used in the SIM research group [Sc21b]. UAVs supporting the ground robots from air can provide detailed camera images in a bird's eye view to facilitate navigation or manipulation tasks.

- *LiDARs* are visual distance sensors that provide a cloud of surface points in the environment by emitting laser impulses and measuring the time for the reflected light to return to the sensor. These surface points are aggregated to collect information about the surface of the robot's environment. Using Simultaneous Localization and Mapping (SLAM) techniques, the robot can localize itself in the aggregated pointcloud data and match new pointclouds to build a consistent map. Based on this localization of the incoming pointclouds multiple environment representations are

Sensor	*Usage*	*Aggregation*
LiDAR (Pointcloud)	On Robot, Streamed	Low-resolution static 3D model
Radar, Sonar	On Robot, Streamed	Low-resolution static 2D model, Vital signs
Cameras (Color, Thermal)	On Robot, Streamed	Optional
Point Measurements	On Robot, Streamed	Single hypothesis (e.g. GNSS position, Radiation source localization)

Tab. 1: Overview of the sensor data types present used by the mobile agents. On Robot means that the data is processed on robot and aggregated into a model, streamed means that the the data is streamed to operator station for visualization.

built including but not limited to an elevation map and an occupancy grid. Elevation maps are a 2D grid representation of the ground surface that is often employed for UGV path planning where each cell represents the maximum elevation at this cell above a previously set zero-plane. Occupancy grids are used for collision avoidance and divide the world into 3D voxels (cubes with fixed size) that are either occupied, free or unknown. The pointclouds can also be colored using camera information and aggregated into meshes.

- Visual sensors such as LiDAR and cameras provide only inadequate and unreliable measurement values under the influence of aerosols such as smoke, fire, swirling dust or fog. To ensure robust localization and navigation under these conditions, *radar* and *sonar* sensors are deployed as these are not significantly affected by these aerosols. Furthermore, radars can be used to perform vital sign detection, e.g., to estimate the vital parameters of human beings.
- *Camera data* (e.g., color, omnidirectional or thermal images) can improve the situation awareness when combined with the 3D information, e.g., using the omnidirectional images, the 3D mesh can be colorized. By using thermal data, heat spots can be detected or color images can be processed to add semantic information to the world model.
- The robot is also equipped with various sensors that measure environmental factors at the location of the robot, which are called *point measurements*. This can be, for example, the radio signal strength at the robot's antennas, the concentration of gases such as CO2, Global Navigation Satellite System (GNSS) location information, and radiation measurements.

Due to the nature of the sensors used on mobile agents, they should only be used in the event of a disaster to limit the processing of personal data to what is necessary for the purpose of crisis handling.

2.3 Visualization

An operation center with access to the information gathered by street lamps and mobile agents enables its users to get a quick and detailed overview of the disaster at hand. This knowledge in turn can not only be used to plan rescue operations but also identify areas in need of exploration by either the mobile agents or the rescue personnel.

With the immense volume of data generated by the plethora of sensors deployed in such a potential emergency scenario, pre-processing – using fog or edge computing – becomes a necessity in order to keep the data manageable. A possible solution for this problem is an abstract, model-based approach breaking down sensor data to a sensible minimum before transmitting it away from the sensor node, in order to enforce privacy. Model-based here meaning transmitting, e.g., *human*, *adult* instead of a pointcloud and using this data to drive a rendered 3D representation.

This data can then be used to drive a model-based immersive and interactive virtual representation offering high-fidelity to the user while autonomously managing the level of detail presented as demonstrated by Prandi et al. [Pr14]. Such an extensive virtual scene offers the operator an overview of the whole disaster while more detailed or even raw data can then be requested as required.

With the spatial nature of city data, modern technologies such as Augmented Reality (AR) and Virtual Reality (VR) with their inherent 3D representation offer the ideal visualization environment [Mo18]. The 6-Degrees of Freedom (DoF) controllers usually employed alongside current VR Head Mounted Displays (HMDs) also offer an intuitive interaction method for the spatial data at hand [Ja17]. The same holds true for mid-air interaction methods featured by current AR headsets [Zh18].

Additionally, information could be shared through secure communication channels with authorized rescue personnel equipped with AR devices enabling them to better react to the situation at hand [SMS21] while maintaining security of processing in accordance to Art. 32 GDPR. Such support can range from providing expert knowledge [Gu12] to supporting their decision-making in, e.g., triage [Mi12] and enhance their situational awareness [Al14].

Finally, local storage in the operation center enables the operator to examine the timeline of the catastrophe. This would also allow conducting less urgent tasks after the scenario is concluded, such as prosecuting onlookers. Additionally, this central storage approach also allows for easier deletion of the data within legal deadlines once the incident has concluded in compliance with the principle of storage limitation Art. 6 (1) (e) GDPR. Here, suitable visualization techniques such as the space-time cube presented by Filho et al. [FSN20] can aid the operator in understanding events in their temporal context or even highlight correlations not readily apparent with current visualization techniques.

3 Data Protection Aspects

The use of the various sensors described above generates a large amount of data, which always includes personal data. In order to be able to operate such systems in a legally secure manner, the first step is to comply with the data protection requirements, in particular, those of the GDPR. This includes the implementation of data protection requirements through technical design (Art. 25 (1) GDPR) [Ho11]. In the second step, consideration should also be given to further measures for the data protection-friendly and data-secure design of such systems which under certain circumstances may go beyond mere permissibility to strengthen acceptance among the public. Furthermore, the different operation conditions (non-crisis/crisis) also lead to questions of differentiation in terms of data protection law with regard to the existing legal bases for processing personal data [HS21a; HS21b].

For the assessment of the applicability of the GDPR, with the accompanying follow-up questions, the “processing” of “personal data” within the meaning of Art. 4 No. 1 GDPR must first be determined in accordance with Art. 2 (1) GDPR. Processing in the sense of Art. 4 No. 2 GDPR is given both in the collection of data by means of the sensors installed in the smart street lamps, as well as by the UAVs and UGVs, since various data is automatically collected, processed and transmitted to the Control Center in these systems (see Section 2).

Then there is the question of the personal reference of the data within the meaning of. Art. 4 No. 1 GDPR. According to the definition pursuant to Art. 4 No. 1 GDPR, “personal data means any information relating to an identified or identifiable natural person [...]”. In addition, the GDPR considers an identifiable natural person as “one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person”. Recital 26 pp. 1 to 4 to the GDPR provides further guidance on how the European legislator believes the provision should be made. However, these again include terms that are subject to interpretation, such as “according to general discretion”, “probable”, “objective factors” or the technological standard to be used as a basis.

Due to the terms requiring interpretation, it is disputed how exactly the allocation is to be determined in terms of identifiability [BE15; Ec21]. This discussion has been controversial for years and has been repeatedly decided by the highest court for various constellations [see, for example, ECJ v. 19.10.2016 - C-582/14, CR 2016, 791 m. Nink - Breyer (dynamic IP addresses), BGH v. 16.5.2017 - VI ZR 135/13, CR 2017, 662 m. Note Keppeler = NJW 2017, 2416]. The ECJ’s decision in Case C-582/14 was decisive in this regard: In this decision, the ECJ pointed out that recital 26 requires controllers to take into account the means that they themselves or another person are generally likely to use. On the other hand, it is not required that the necessary information or means are directly available to the responsible body or are used in a specific individual case. Rather, it is sufficient if the responsible entity can legally and reasonably access this data. The access does not have to have actually taken place. Personal data, on the other hand, must always be denied if identification is not practically feasible. Such cases can arise, for example, from a disproportionate effort in terms of time, costs and manpower. In such cases, the risk of identification is so low that it is negligible [ECJ, NVwZ 2017, 213 para. 39 et seq.; in summary: Karg, in: Simitis/Hornung/Spiecker gen. Döhmann, Datenschutzrecht, 2019, Art. 4 no. 1 marginal no. 61 with further references]. After the very abstract clarification of the question of the personal reference of data, the core of the future dispute will move to a lower level of abstraction by asking the question of the use of the means by the responsible party.

Based on this, the following applies to sensor data at hand: LiDARs do not in themselves allow for the identifiability of individuals, so that the scope of the GDPR is not opened for this type of data due to the lack of personal reference. The same applies to radar, sonar and point measurements. In the case of cameras (as per the specific design selected here), identifiability is possible on the basis of the real image, so that a reference to persons is given [Sc21a, ECJ, 11.12.2019 – C-708/18, recital 34]. When using thermal imaging cameras, on the other hand, it depends on the concrete image reproduction, i.e., the question of how detailed the imaging is. Therefore, as an interim conclusion, the GDPR initially only applies to the data generated by the cameras.

When a large amount of data is combined, it is precisely the combination of these different data that creates a reference to a person. Therefore, in particular for LiDAR, radar, and sonar data, it must be answered to what extent a combination with other data can lead to identifiability. In this constellation, special consideration must be given to the fact that the data is merged into a database that is operated by a public entity. Therefore, in addition to the restrictions under data protection law, questions about the informational separation of powers (separation of the processed data according to the task assignment/purpose fulfilment of different or also the same authorities) [La10, p. 337 et seq.] must also be taken into account, but this is not the focus of this paper. Along with this, the purpose limitation principle acquires greater weight since it has implications for the separation of informational powers.

Based on the criteria established by the ECJ to be taken into account when assessing the purpose of a person, the fundamental question arises as to what measures are reasonably taken by a public body. In principle, public authorities act on the basis of powers granted to them by law or otherwise. Within this allocation of tasks, the need for data processing is also recognized in principle by the GDPR, as can be seen from Art. 6(1)(e) of the GDPR. Here, the corresponding national task allocation norm or the corresponding norm in the Federal Data Protection Act (BDSG) or the state data protection laws must also be consulted. Therefore, it depends on which specific authority collects this sensor data and what other data is already available to this authority. This leads to the conclusion that this question must be determined in each case for the specific application scenario. With reference to the sensor data described here, for example, identifiability can be achieved by combining the recorded LiDAR data with real images of the UAVs or UGVs, thus enabling identification of the corresponding person by means of motion tracking. Furthermore, it must be taken into account that such a reference to a person can also only occur " creepingly" in the course of time. This should also be taken into account in the technical design in such a way that technical measures to minimise this danger should be considered [HW19].

These possibilities show that in the vast majority of cases personal data is processed. This means that the requirements of the GDPR must be met in their entirety. This applies in particular to the principles of processing in Art. 5 of the GDPR and, in particular, the lawfulness of processing. Thus, as far as data is used for disaster preparedness and response, a legal basis from Art. 6 of the GDPR is required. Since area-wide consent is unrealistic in the smart city, legal bases in national law will be required for state operators of the systems (Art. 6(1)(1)(e), (2), (3) GDPR). With regard to the question of the relevant legal basis, a distinction must be made between "normal operation", i.e., such operation that does not involve any special incidents and "disaster operation". Data processing primarily by UAVs and UGVs in the event of a disaster will prima facie be possible within the framework of the applicable security law. For this, the corresponding legal requirements must be determined for the respective concrete operational scenarios. The specific reason for the processing results in restrictions regarding the collection (such as the link to a relevant risk) but also the further processing for other purposes (principle of purpose limitation). Therefore, new legal bases are required for the permanent use of smart street lamps (as part of informational disaster preparedness), insofar as, as explained above, a merging of data is intended, since in these cases personal data will regularly be available. This also applies in particular against the background that the data obtained is also to be used further for damage analysis and prevention [HS21b].

In addition, the requirements of Art. 25, 32 GDPR must be complied with [see: ENISA, Privacy and Data Protection by Design - from Policy to Engineering]. At this point, it is possible to comprehensively take into account the protection of the data subjects' informational self-determination from the outset when designing the systems. Article 25 of the GDPR, through its reference to Article 5 of the GDPR, but also the entire GDPR, intends a comprehensive implementation of the requirements through an appropriate "design" whereby organisational processes are also addressed in addition to the technical design [Hansen, in: Simitis/Hornung/Spiecker gen. Döhmann, Datenschutzrecht, 1st ed. 2019, Art. 25 recital 15 et seq.]. To this end, data protection requirements are to be included in the development at an early stage by considering appropriate measures. However, these measures must explicitly still be fulfilled during the processing itself [BG17, Martini, in: Paal/Pauly, 3rd ed. 2021, DS-GVO Art. 32 recital 1b et seq., Hansen, in: Simitis/Hornung/Spiecker gen. Döhmann, Datenschutzrecht, 1st ed. 2019, Art. 25 recital 19].

In contrast to Art. 25 GDPR, Art. 32 GDPR addresses aspects of security of processing and thus concretizes the data protection principle of "integrity and confidentiality" from Art. 5(1)(f) GDPR (although this could also be considered to be encompassed by Art. 25 GDPR). This includes measures that serve in particular to protect personal data and processing systems both from attacks and from a failure or impairment of the reliability of the systems [Hansen, in: Simitis/Hornung/Spiecker gen. Döhmann, Datenschutzrecht, 1st ed. 2019, Art. 32 recital 1 et seq.].

First of all, it should be noted that the most data protection-friendly systems are those that only collect data, that do not originally contain any reference to individuals, since in this respect there are also no risks to the informational self-determination of individuals. Therefore, an area analysis with LiDAR sensors is to be welcomed from a data protection point of view. The same applies to the survey using radar and sonar sensors.

However, since as shown, many systems cannot work without personal data, data protection within the meaning of Art. 25, 32 DSGVO must be considered comprehensively. Measures can be implemented at various points within the processing procedures (collection, storage, transmission, etc.) of the data. In the following, individual measures corresponding to the processing steps will be presented and explained by way of example:

- *Data collection*: In the context of data collection by the smart street lamps, UAVs, and UGVs, the data should be stored in a ring buffer[7] containing a limited time window to ensure data-protection in normal operation but also enabling the reconstruction of events in case of a incident.
- *Data transmission*: Since a transmission of data to the control center is necessary for the presentation and further coordination of operations, the following measures can be taken to secure the transmission in terms of data security according to Art. 32 GDPR:
  - Minimizing the amount of data transmitted to the control center by applying edge computing where-ever possible. Sending abstract model-based data instead of raw data also reduces the requirements regarding the mobile connection quality.
  - Anonymize the data before transmission, e.g., by pixelating video streams using onboard computing for teleoperation using detected objects. By this operation, biometric data can be waived according to Art. 9 DSGVO as well.
- Apply *access restrictions* with appropriate technical protection (e.g., role concepts) in the control center to reduce the information displayed to each role to a minimum.

4 Conclusion & Outlook

In this paper we presented the legal and technical frame for a potential Smart Control Center in future smart cities as well as its potential benefits for crisis management. We elaborated possible, privacy compliant approaches for data collection, both in crisis scenarios as well as normal smart city operation. To comply with law, a smart city SCCs needs to be designed from the ground up with data protection by design and security of processing. Considering the data protection by design approach in the conceptualisation of the SCCs could lead to broad public acceptance in the use of the proposed infrastructure. Finally, an automated, GDPR compliant, data deletion mechanism should be employed.

[7] A ring buffer is a storage structure that overwrites old data as new data is received.

In future work, the subject of data storage will be considered in more detail. Simulations will likely be the main method of emergency response training, however, real world data from previous emergency responses is still beneficial for the comprehensive training of rescue personnel. Especially, if and when the purpose merits, unanonymized storage should be discussed separately.

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