DDS as a Crowd Management Systems Integration Platform

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Abstract - *The significance of crowd management systems resides in their potential to safeguard lives, enhance the quality of experiences, and facilitate the successful execution of events. Technology stands out as a pivotal facilitator in the domain of crowd management; its absence renders the process nearly insurmountable. Amidst the myriad technologies and methodologies deployed in crowd management systems, the efficacy of the overall system is contingent upon the integration platform employed. This study conducts a comprehensive review of pertinent literature to delineate the diverse technologies and methodologies applied in crowd management systems. Through this survey, discernment of essential attributes for an integration platform transpires. These identified features culminate in the advocacy for the adoption of Data Distribution Service (DDS) Middleware as the preferred integration platform for crowd management systems.*

***Key Words*:** Crowd management systems, integration platform, middleware, distributed system, DDS.

1.INTRODUCTION

Crowd management is commonly used as an umbrella term used to refer to a collection of tasks performed to manage a crowd. Crowd management is a must in events such as religious rituals, sporting events, concerts, and in many other scenarios with crowd intensive must be monitored to guarantee the safety of the crowd members and the success of the intended event. The process starts by detecting the crowd and collecting data about the crowd, where different solutions for sensing the crowd are proposed in the literature and implemented in crowd management systems. Followed by analyzing the collected data using a wide variety of techniques and method used to extract information about the crowd from the different crowd sensing data sources. Lastly, the analyzed data is used to assess the situation and to guide the decision-making process regarding how to control and monitor the crowd. The importance of crowd management comes from the fact that if crowd management is neglected or improperly carried out, catastrophic outcomes can lead to the death of hundreds or sometimes thousands of crowd members, along with fatal injuries and other devastating outcomes [1][2][3]. Crowd management is can also be detrimental in maintaining infrastructure integrity by control the flow and the capacity of the crowd at any certain time and place.

Crowd management is an inter-discipline topic, where inputs from different fields of study can aid in improving the area of crowd management and the outputs obtained from it are used in context beyond crowd management. The topic of crowd management is addressed from different aspects such as planning in the case of disasters [4], safety science [5], statistical mechanics [6], risk reduction [7].

Without the use of technology, performing the tasks required for crowd management would be next to impossible, especially when the number of crowds grows higher. All crowd-intensive events show great success when crowd management is properly implemented. The religious event of Hajj season in Saudi Arabia, which takes place in the city of Makkah, is considered as a clear example, where the focus on crowd management from different perspectives shows great reduction in the number of fatalities and injuries among the pilgrims during the season[8].

Regardless of the different technologies used for sensing the crowds, the different techniques used in analyzing the crowd data, or the different tools used for managing the crowd, the components in a crowd management system must be properly integrated using a well-suited integration platform in order the ensure optimal utilization of the different components of the system. This work aims to survey the literature to identify the different technologies used in crowd management systems, how they are integrated, and to identify the requirements of an integration platform that would enable crowd management systems to reach their best performance.

The work is divided into the following section, the first section is the introduction, followed by the literature survey of related works and a representative set of proposed architectures and frameworks for crowd management systems. The third section is a discussion about the findings from the survey work and proposes suitable integration platform, lastly the fourth section is conclusion and future direction.

1.1 MOTIVATION

The motivation behind this work is to conduct a survey on the different crowd management technologies used and to survey the different integration platforms proposed to be used for crowd management systems. The goal of this paper to compile the requirements of the different components in crowd management systems from the different proposed solutions in the literature, in order to come up with a set of specifications required to be supported by any integration platform proposed for such systems. This work also proposes an integration platform that best suits crowd management systems based on generic requirements and assumptions that would fit the widest possible variety of conditions at which a crowd management system is to be used.

2. Literature Review

The topic of crowed management has seen many contributions in the research field, concerning how to perform the different tasks of crowd management. The first part of this section focuses on presenting works dedicated towards surveying the different technologies and approaches applied in the field of crowd management. The second section surveys the different proposed crowd management systems found in the literature.

This will highlight the contribution of this paper in comparison with similar works about crowd management.

The contributions of this paper are to summarize the components used in different crowd management systems, and to take an overview of the different approaches utilized towards integrating those components to extract the required features to be supported by an integration platform. Lastly, based on the available enabling integration platforms, the paper will propose an integration platform to be used in crowd management systems that meets the required functionalities of the platform.

2.1 Related Works

This work [9] surveys what the literature proposes in the three phases involved in crowd management, starting from cowed detection to crowd monitoring and lastly how to manage the crowds. This works looks into the subject of crowd management from the interest point of view of different disciplines, concerning technical and non-technical aspects related to crowds.

Felemban et al. in[10], conducted a survey on the technologies used during Hajj seasons as a concrete case study where crowd management systems are being deployed. The survey studies a plethora of technologies that are used during the seasons for a variety of purposes, such as crowd detection, monitoring, analysis, and management using different techniques and approaches.

The survey conducted by Vishwanath and Vishal in [11] demonstrated how crowd counting and density estimation and their related tasks are of interest to a wide variety of research fields and how they are used in many applications. The survey focuses on the different published techniques that apply Convolutional Neural Network (CNN) on the tasks used in Computer Vision for crowd counting and density estimation.

Zitouni et al. in [12] have conducted a systematic survey on crowd modeling and analysis based on visual data. The work focuses on explaining the different crowd modeling trends and techniques of the surveyed works and providing statistical data about the literature direction in crowd modeling. This work is an attempt to uniformly represent the surveyed works in crowd analysis to evaluate the proposed techniques and methods.

In [13], the survey conducted is focused on examining the different researched methods and techniques employed in people counting and crowd density estimations using surveillance as the source of information with the aid of computer vision techniques to process the input visual data. The survey dives into the different methods used for crowd counting which are categorized into direct approach, where such systems are concerned with detecting individual people within the crowd, and indirect approach, where the crowd is counted as a whole based on certain features used to analyze the crowd.

In[14], Zhang et al. have surveyed the literature focusing on how physics-based methods and concepts such as energy, entropy, fluid dynamic and others can be used in crowd analysis to effectively employ such concepts in various fields of crowd management such as density estimation, people counting , behavior analysis and others. Such surveys can clearly show how the topic of crowd management is rooted in different fields and disciplines.

Grant & Flynn in[15], have conducted a survey on computer vision techniques and methods applied on video to analyze crowds. The conducted survey divides the area of interest in literature towards crowd statistics, which is another term for crowd modeling, and crowd behavior analysis. The survey goes on describing six different methods used on analyzing video for crowd counting. The paper then details the techniques used in behavior analysis showing that different analysis techniques are used depending on the setting of the monitored area and the density of the crowd to detect abnormal crowd behavior.

[16] represents a systematic survey on CNN crowd counting approaches within the literature. The survey starts by presenting three network architectures used in density estimation and crowd counting obtained from the surveyed works. The survey then categorized the surveyed works based on the learning paradigm used for each method, Inference manner, and supervision method among other features. The survey continues by evaluating the performance the different CNN-based crowd counting methods. The survey also describes the major challenges to be overcome in any visual based approach in crowd counting.

The survey conducted by Kaiser et al. in [17], explores the different data sources used by crowd analytics system which is used to extract various crowd related information. The survey then explains in detail how each data source has been used by the different works in literature and the crowd related task that can use the provided data. The survey then goes into the different techniques and methods employed in the surveyed works to perform crowd analysis.

Sreenu & Durai in [18], surveyed deep learning techniques employed in the literature concerning crowd analysis based on data obtained from video surveillance footage. The work categorized crowd analysis methods/models obtained from the literature into deep model methods and non-deep leaning methods giving a brief overview of the latter. the survey then discussed the different approaches in detecting crowd behavior then illustrated some of the results obtained from researched works to derive and address some of the shortcomings within the field.

The survey work conducted by Afiq et al. in [19] discusses the different abnormal crowd behavior detection techniques and methods recently published in conference and journal papers focusing on computer vision related techniques. The survey discussed five main techniques that analyze visual data for detecting abnormal crowd behavior. The first technique is Gaussian Mixture Model (GMM), followed by Hidden Markov Model (HMM), then they explored Optical Flow (OF) functions, followed by Spatio-Temporal Techniques (STT), and lastly CNN models.

Draghici & Steen in [20]conducted an extensive survey on crowd behavior detection works that uses application-based and infrastructure-based systems for data collection based on Wi-Fi tracking and Bluetooth beacons rather than depending on visual video data. The survey details some of the major aspects of the surveyed crowd sensing systems such as architectural aspects, crowd sensing models and technologies, maturity, and other evaluation features. application-based and infrastructure-based systems are then discussed in detail showing how they work, and the challenges faced by each approach. The paper then gave evaluation criteria used to rate various surveyed systems based on major factors that can affect the system adoption and the quality of outputs.

2.2 Approaches in Crowd Management Systems

This section showcases the trends of crowd management system architectures and technologies found in various works within the fields of crowd management giving an overview of what technologies are used and how the different components within a crowd management system interface with each other.

Santana et al. [21] propose a crowd management system architecture that maintains soft real time requirements based on capturing Wi-Fi frames for crowd assessment using Wi-Fi sensors, while ensuring the privacy of the people. The proposed architecture is divided into 3 layers, Data gathering layer, data aggregation layer, which anonymizes the collected data extracting key information from the captured frames. Lastly, the data processing layer, which performs the required analysis and processing of the gather anonymized data. The integration between the aggregation layer and the processing layer is done using raw streaming of data over TCP, where ZeroMQ was used for transport communication.

Jiang et al. [22] propose a solution based on data generated from CCTV, LiDAR, infrared, gas and ultrasonic sensors which are then transmitted to the edge-cloud to gather data from the different sources and to control the virtual software defined network (SDN) and perform initial data processing which is then transmitted to the private cloud which would further process the data making use of AI crowd assessment and modeling.

Al-Nabhan et al. in [23], are proposing a solution based on RFID ,which is represented by a card, or a wearable tag provided to the pilgrim, Wireless Sensor Network (WSN), CCTV cameras, and IoT devices for collecting data about the crowd in Hajj season. The collected data is processed in order to assess and simulate the congestion level, predicting expected congestion and determining alternative evacuation paths.

Shalash et al. in [24] have proposed a solution that uses two main components. server-side component, where the server is connected to IP cameras responsible for crowd data collection. The collected data is then processed to detect crowd level within a certain location using texture based on image texture analysis. The second component a mobile application used by crowd members to receive alarms in case the server detects a high crowd level informing the users about crowd severity level in specific locations using google maps.

A framework for crowd management based on Internet of Things (IoT) was proposed by Mohamed et al. in [25]. The proposed framework is composed of three layers, the first layer "Sensor Layer" is responsible for collecting data about the crowd. The second layer " Management Layer" is responsible for processing the collected data and representing the processed data to the third Layer "Interface Layer", which acts as the decision-making layer in the framework. The proposed integration between the different components in the system is to use redundant web-services acting as brokers between the different components.

Almadani et al. in [26], have proposed a framework that includes crowd management as a component where the crowd is sensed using RFID and thermal cameras. the integration platform proposed in this work is using Data Distribution Service (DDS) middleware to integrate the various crowd sensing devices, along with other devices, with the backend system.

In [27]a crowd management system is enabled using Unmanned Arial Vehicles (UAVs) equipped with visual data capturing sensors. The UAVs will collect the crowd sensing data from a specific location and relay the collected data to a Ground Station (GS) which in turn will also relay the data to a control center where the data will be processed using human-based decision-making feedback.

Mishaal et al. in [28]s proposed a framework for crowd management based on a wide variety of crowd sensing technologies and data sources, such as smart phones, RFID, applications dedicated towards crowd sensing and feeds from social media applications. The collected data is then sent to what is called the "Fog Layer" for initial processing. The output from the previous layer is sent to the cloud layer to further processing and enabling interoperability between the different components in the framework and lastly the application layer offering different functionalities and tools related to crowd management. The work states that integration is a key consideration in a crowd management system, but it did not specify what integration platform to be used.

Qiao et al. in [29] proposed a crowd management architecture that uses CCTV Cameras to obtain videos data about the crowd. The obtained data is then sent to propagate through the layers of the architecture to be processed by an AI engine used to analyze the input data and gain situational awareness of crowd behavior. Lastly the terminal devices are used to present the analyzed data obtained by the different stages in the proposed architecture.

In [30] the proposed system uses CCTV Cameras to obtain video data of the crowds. The video data is sampled into images for pre-processing where samples with low quality or subjected to environmental elements are removed and candidate samples are selected for further processing.

The work of Al-Sheary et at. In [31]proposed the use of UAVs for crowd detection and density estimation. The proposed work relays on images obtained by the UAVs to determine the crowd level where the captured area of interest at which the data is collected from is geographically referenced for monitoring and decision-making purposes.

ElAdly in [32] proposed a crowd management model that uses RFID tags provided to the crowd members, where Hajj season is the targeted use case of the proposed solution, and the managed area is divided into zones with RFID Readers distributed at the entrance of each zone. The data read by the readers are sent to "centralized crowd management and communications center" for monitoring and decision-making.

The proposed work in [33] relays on GPS data obtained from the smartphones of individuals consenting to share their GPS coordinates every five minutes. after a full day of coordinates being logged of a large number of users, the GPS data is then mapped into a grid to which would allow the system to predict the videos of the crowd flow and density.

It is clear that the majority if not all proposed solutions for crowd management generate and analyze huge amounts of data, leading to concerns when it comes to privacy and security and on how such data are to be how those data can be utilized [34].

3. Integration Platform

The information acquired from surveying the different technologies used for crowd management systems, which is compiled in Table 1, we can notice that the majority of the works in this field are not concerned with how the different components of the system are to be integrated with each other. Integration of the different components is a major factor in deciding the overall performance of a system and it cannot be neglected when in a proposed crowd management architecture.

Based on the information obtained from Table1 and the surveyed works, In order to put forward a suitable integration platform for crowd management systems, we can assume the following about the environment at which the system is deployed:

- Lack of networking infrastructure,
- Highly dynamic environment,
- Large area required to be covered
- The presence of heterogeneous systems

Working with the mentioned assumptions will ensure that the integration platform that can perform well in such an environment will be suitable for a wide range of deployment configurations where crowd management systems are required.

Table -1 technologies used in crowd management systems

Reference	Crowd Sensing Technologies	System Integration Technology
[21]	- Wi-Fi Detection	ZeroMQ (Message Oriented Middleware)
[22]	- CCTV Cameras - LiDAR - Infrared Sensors - Ultrasonic Sensors	Not Specified
[23]	- RFID - CCTV Cameras	Not Specified
[24]	- CCTV Cameras	Not Specified
[25]	- Monochrome Cameras	Web-Based Broker

	- Infrared Cameras - RFID - GPS	
[26]	- Thermal Cameras - RFID	DDS (Data Centric Middleware)
[27]	- UAVs - Surveillance Cameras	Not Specified
[28]	- RFID - Smart Phones - Crowd Sensing Mobile App - Social Media Apps	Not Specified
[29]	- CCTV Cameras - LiDAR - Infrared Sensors	Not Specified
[30]	- CCTV Cameras	Not Specified
[31]	- UAVs - Surveillance Cameras - GPS	Not Specified
[32]	- RFID	Not Specified
[33]	- GPS - CCTV Cameras	Not Specified

3.1 Platform Key Features Considerations

The following features must be supported by the integration platform in order to meet the requirements and assumptions made about the generic environment at which any crowd management system is to be deployed:

A) Support of Real Time Systems:

Since some of the components in the system operate in real time, the integration platform must be able to support real time operations. An example of real time operations would be controlling and operating the UAVs.

B) Interoperability:

Any integration platform must allow the different components to exchange information between themselves according to the proposed architecture of the solution.

C) Portability:

Since crowd management is a critical task, the proposed system may require the seamless transfer from one hardware or software component to another.

D) Scalability:

Crowd management systems might have to deal with crowds consisting of millions of people covering a vast area of interest, the integration platform must allow the system to scale up in capacity without losing functionality.

E) Reliability:

since crowd management systems must act in a proactive manner, the data flow from one component to another must be guaranteed and time bounded.

F) Ease of Use:

Some events at which crowd management is required can be spontaneous, such as concerts, entertainment events and festivals. The crowd management system must be deployed in a prompt manner, this can be facilitated greatly by the Integration platform.

G) Security:

The crowd management system must not be susceptible to attacks introduced by the integration platform. The platform must be equipped with security measures following well-established security standards.

3.2 Proposed Integration Platform

The proposed integration platform that meets the requirements is Data Distribution Service (DDS) Middleware by Object Management Group (OMG). OMG develops enterprise integration standards for a wide range of technologies, they are considered as a leading standardization body in the field of technology integration[35].

DDS Architecture

There are several implementations of DDS developed by several entities, however, DDS standard ensures that the different implementations have a common interface for the different implementations to be able to communicate with each other. This means any DDS enabled number of entities will be able to communicate regardless of the specific DDS implementation they are using.

DDS is a Data Centric middleware, meaning the data being sent between peers are sent within a specific context. The entities receiving the data can understand the meaning the of received message based on the datatype of the message [36].

DDS uses a publish subscribe model for communication. Publisher publish (send) data and subscribers subscribe (receive) data from what is called “Global Data Space” based on “topics” accessible through the data space. Publishers and subscribers perceive the “Global Data Space” in a manner analogous to how a computer perceives its own memory.

Publishers write to that "memory" and subscribers read from "memory". This model, which separates the publisher from the subscribers allows for added scalability and flexibility in any DDS enabled architecture [37].

DDS defines a core standard called "Data Centric Publish Subscribe (DCPS)", which specifies the communication and integration models of distributed applications. This standard ensures that the different applications within the DDS domain are able to integrate with one another. The behavior of this communication between the publishers and subscribers is controlled through what is called "Quality of Service (QoS) Polices" [38].

DDS defines over twenty QoS Polices, where polices can have multiple attributes that can be tweaked by the system developed to achieve the required behavior between the different entities in the domain. DDS is designed in a manner that accounts for a wide variety of system specifications and configurations. Through manipulation of the different polices, the system developer can tailor the behavior of the system according to what their system can handle [39]. Defining the reliability level required, how the system can handle the data from the different data sources, allocation of resources to the different components in the system, how the system should behave in case of unexpected event, along with real-time operation requirements[40]. All of these functionalities are facilitated by DDS, and they can be utilized using any implementation of DDS.

DDs is equipped with security measures to ensure integrity, authentication, access control, availability, and confidentiality. Depending on the implementation of DDS, plugins can also be used to build more security constraints on top of the one provided by DDS standards [41].

Due to the versatility of DDS, is has been used in a wide variety of systems and applications, such as robotics systems[42], agro-industries[43], wireless sensor networks[44], UAV formation control[45]. Such works show that DDS can be used in a variety of applications, and it can handle different data sources with different specifications and requirements. DDS has been used in crowd management system as seen in [26], although the context of crowd management is limited to managing the crowds on buses leading to the destination. However, this work shows promising results showing DDS capabilities and ability to meet the real-time and other requirements hinting at the premise of using DDS as an integration platform for crowd management systems.

4. Conclusion

After surveying the literature, it was noticed that the majority of the proposed crowd management systems in the literature focus on the individual components of the system, and they don't consider how these components are to be integrated with each other. After compiling the different technologies used in crowd management systems and developing a generic environment at which those systems are to be deployed, we were able to extract the features required in an integration platform to be used in crowd management systems. Based on the required integration platform features, we propose the use of DDS middleware which meets the requirements of the generic environment for crowd management systems. Partial results of using DDS as an integration platform from different works show a promising indicator that a crowd management system enabled by DDS would ensure optimum performance and results.

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