A Novel Wireless Sensor Network Architecture for Crowd Disaster Mitigation

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***Abstract*— Disasters aroused due to dynamic movement of large, uncontrollable crowds are ever increasing. The inherent real-time dynamics of crowd need to be tightly monitored and alerted to avoid such disasters. Most of the existing crowd monitoring systems is difficult to deploy, maintain, and dependent on single component failure. This research work proposes novel network architecture based on the key technologies of wireless sensor network and mobile computing for the effective prediction of causes of crowd disaster particularly stampedes in the crowd and thereby alerting the crowd controlling station to take appropriate actions in time. In the current implemented version of the proposed architecture, the smart phones act as wireless sensor nodes to estimate the probability of occurrence of stampede using data fusion and analysis of embedded sensors such as tri-axial accelerometers, gyroscopes, GPS, light sensors etc. The implementation of the proposed architecture in smart phones provides light weight, easy to deploy, context aware wireless services for effective crowd disaster mitigation.**

Keywords-context; crowd; mobile computing; wireless sensor networks

I. INTRODUCTION

The demand for security and safety within the public spaces is gaining attention nowadays due to the increase in crowd disasters. The reports [2] indicate that crowd disasters in public gatherings for pilgrimage, sports events etc are increasing tremendously. India experiences more than 100 deaths per year due to crowd disasters. The major motivation for the research work is the stampede of pilgrims occurred at the hilltop Sabarimala shrine in the state of Kerala in southern India, which took the life of 102 devotees [2]. The stampede was set off when a jeep drove into the crowd of pilgrims. The pilgrimage area was flooded with people and the situation went uncontrollable. The other causes of crowd disasters are majorly due to terrorist activities which are focused on public gatherings resulting in the loss of life of many innocent people.

The current research in the field of crowd safety in public spaces highlights the need for light weight, user friendly and cost effective systems. Smart Phones are becoming increasingly popular and more common people are getting attracted to its variety of functionalities. The mobile phone penetration rate is increasing tremendously all over the world and in India it is expected to reach upto 97% of the total population in the year 2014 [9].

Figure 1. Crowd formed as part of Sabarimala Pilgrimage [2]

Integration of context aware computing with the mobile phones make it capable to sense the physical world, process the current scenario, and adapt and react to dynamic changes of the environment. The proposed system uses the above mentioned capability to develop an application suitable for crowd management, real-time monitoring of crowd behavior, and disseminate alerts and instructions for crowd control. The major relevant crowd context includes communication context such as network connectivity, communication cost etc., physical context includes lighting, noise levels, traffic conditions, temperature, etc., and user context specifies user profile, location, time, etc. The well deployed wireless sensor networks (WSN) are capable of providing real time information such as environmental data.

The proposed wireless sensor network architecture for crowd disaster mitigation consist of three major modules: the wireless multimedia sensor network with external audio, visual and temperature sensors, the smart phone sensing modules which make use of embedded smart phone sensors such as tri-axial accelerometers, GPS, light sensor etc. and the crowd controlling station dealing with appropriate assignment of security officials in stampede prone areas, evacuating people in case of higher criticality and alerting the Government administrators, police, paramedical forces, citizens and individuals in the crowd.

The paper is organized as follows: Section II discusses related works including the study of causes of crowd disasters and crowd models. Section III gives the proposed architecture for crowd disaster mitigation. Section IV provides description of implementation of smart phone sensing module using Android HTC Google Nexus One for predicting stampede.

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II. RELATED WORKS

The conventional manual crowd monitoring is a tedious effort which requires the dedicated participation of many security officers. The manual monitoring was replaced later on by closed circuit television systems (CCTV). The crowd monitoring using image processing discussed in [3], gives an automated CCTV based technique. The cost of deployment and maintenance of these systems is very high.

With the advancement of wireless sensor networks, the frameworks based on sensors were deployed such as a prototype for stadium surveillance integrated with increased situational awareness was proposed by [4] for better knowledge of real-time incidents within the stadium. This system [4] is less reliable since it uses temperature and acoustic sensors only for developing the situational awareness, leading to higher false alarm rates. Based on the analysis of exiting frameworks, we try to bring in a new idea of integrating smart phone sensing with wireless multimedia sensor networks (WMSN).The proposed system for crowd abnormality detection utilizing the capabilities of WMSN and embedded smart phone sensors should provide reliable alert generation with real time values and ease of deployment & maintenance.

For the design of the proposed wireless sensor network architecture, the study was conducted on paper works dealing with causes of crowd disasters and crowd models to effectively monitor the crowd [10]. The study was also conducted to extract activity recognition using Mobile Phones [5], [6] to incorporate context aware wireless services in the proposed system.

III. WIRELESS SENSOR NETWORK ARCHITECTURE FOR CROWD DISASTER MITIGATION

The occurrence of stampede is one of the major reasons [11] behind the recent crowd disasters which took the life of hundreds of people. Our proposed crowd disaster mitigation system shown in figure 2 focuses on estimating the probability of occurrence of stampede in a crowded area based on the distributed sensor data fusion and analysis of sensor values from tri-axial accelerometer, GPS, acoustic sensors and video sensors, thereby aiming to avoid or decrease the impact of imminent stampede. In the stampede suspicious area, this system will provide the service to make the crowd controlling station more vigilant and provide alerts on facilitating evacuation schemes in case of emergency.

A. Crowd Modeling for Stampede Prediction

The basic model for our system is the FIST model [10]. The FIST specifies Crowd Force, Information upon which crowd acts, Physical Space and Time (duration of Incident). The key parameters for crowd modeling are the following

(i) Type of crowd
  - Homogeneous, heterogeneous, aggressive crowds

(ii) Crowd density estimation

(iii) Crowd flow pattern:
  - Ordered, stop and go, random pattern.

(iv) Crowd flow velocity.

(v) Crowd behavior estimation.

B. Estimation of Probability of occurrence of Stampede

In our proposed system, we assume that we are aware of the motivation of the crowd, geographical space and its topography, the time of the event, and the allowed capacity of the chosen space. Integrating these assumptions, the objective of the proposed work is to estimate the probability of occurrence of stampede in a specific area based on correlation of distributed heterogeneous and homogeneous sensor values with known space and time values.

This application explores the use of participatory sensing approach, where our assumption is that the people in the crowd act as participant sensor nodes for crowd monitoring using their personal mobile devices and web services to systematically explore the key aspects of their current context.

For the estimation of probability of occurrence of stampede perform data mining on heterogeneous and homogeneous sensor values when the crowd density is high and crowd flow pattern becomes stop and go.

Sensor data are analyzed and mapped to activities based on distributed consensus of 'n' neighboring participant nodes. Sensor data will be analyzed to determine the following activities:

i) Forward force in the crowd towards the common destination.
ii) Backward force in the crowd against the common destination.
iii) Crowd force on the side walls, or building structures.
iv) Fall detection in a crowd.
v) Heat and thermal rise due to increased crowd density.
vi) High noise level due to screaming.

Correlation of Multiple Datasets from Multiple Sources is required to appropriate estimation of probability of occurrence of stampede.

i) Wireless Multimedia Sensing Module consists of:

a. Temperature sensors indicate heat and thermal rise due to increased crowd density.

b. Acoustic sensors indicate high noise level due to screaming.

c. Visual sensors indicate crowd density and flow pattern estimation.

ii) Smart Phone Sensing Module:

a. Accelerometer and Gyroscope are used for activity recognition and flow pattern inference.

b. Location Sensors provide location context.

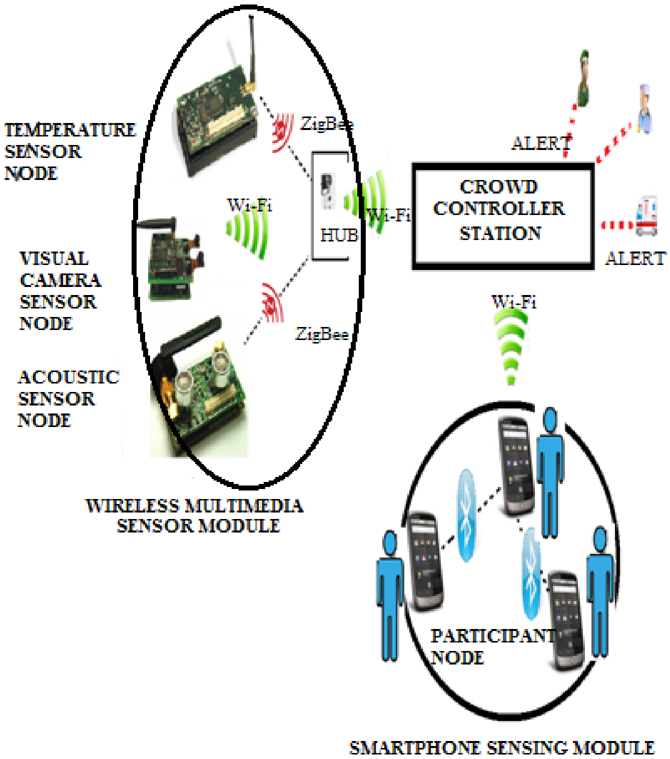

Figure 2. Wireless Sensor Network Architecture for Crowd Disaster Mitigation

IV. IMPLEMENTATION OF SMART PHONE SENSING MODULE FOR CROWD DISASTER MITIGATION

A. Training Phase for Activity Recognition

Training phase was conducted to perform tri-axial accelerometer based activity recognition and thereby predicting the occurrence of stampede. The training was carried out by a master level student of medium height and weight of age 23. The data collection was performed using HTC Google Nexus One by writing accelerometer values on to a file and stored in SD card for further analysis. Training was carried out for standing, walking, peak shake and falling conditions. The values were tabulated and analyzed with respect to each axis.

The accelerometer in smart phones returns 3 current acceleration values in the units of m/s2 along the x, y, and z axes subtracted by gravity vector.

- X-axis (lateral): Sideways acceleration (left to right) for which positive values represent the movements to the right whereas negative ones represent to the left. This is represented as *ax*.
- Y-axis (longitudinal): Forward and backward acceleration for which positive values represent forward whereas negative values represent backward. This is represented as *ay*.
- Z-axis (vertical): Upward or downward acceleration for which positive represents movements such as the device being lifted. This is represented as *az*.

The feature extraction is performed by taking average of a_j values in the 'w' sized sample window using (1) where i can be x, y or z axis. In order to increase the correctness we calculate the deviation of current axis value from previous value. If there is a dominant change, then there is a change in flow pattern of the crowd.

$$a_{average} = (\Sigma^{w}_{j=0}\, a_{ij}) / w \qquad (1)$$

The study of crowd dynamics indicate that stampede in a crowd can be stimulated due to the presence of peak shake and fall experienced within the crowd. For the prediction of stampede our system relies on detection of peak shake or fall simultaneously by 'n' neighboring participant nodes. The threshold values, shakeThreshold and fallThreshold, were analyzed to estimate the peak shake and fall condition in a crowd. The sample values obtained in training phase are shown in Figures 3 and 4.

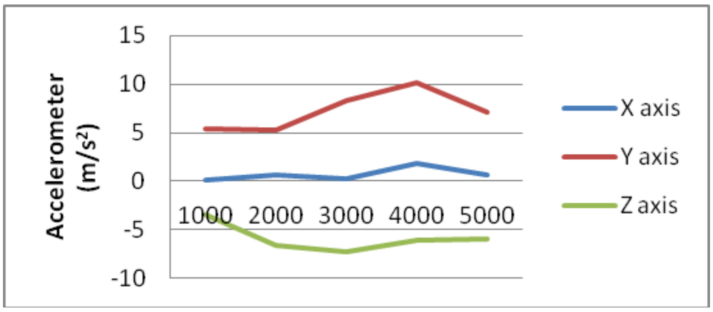

Figure 3. Accelerometer values for fall. X axis indicates time in ms and y-axis indicates accelerometer in m/s^2

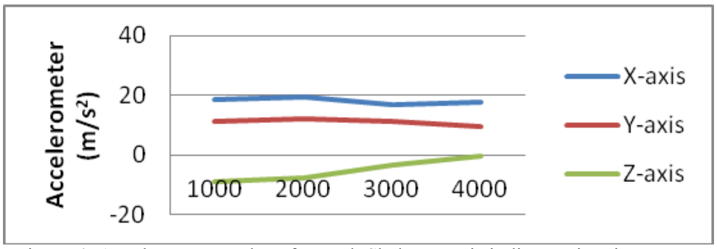

Figure 4. Accelerometer values for Peak Shake. X axis indicates time in ms and y-axis indicates accelerometer in m/s^2

The work in progress for wireless sensor network for crowd disaster mitigation using prediction of stampede was studied and conducted a small shake detection scenario using smart phone sensing module shown in Figure 5 to determine the correctness of shake Threshold value obtained in training phase. The scenario made use of three Android smart phones to act as participant nodes. There were 15 students for the testing to form a small crowd.

Figure 5. Shake Detection Scenario using Smart Phone Sensing Module

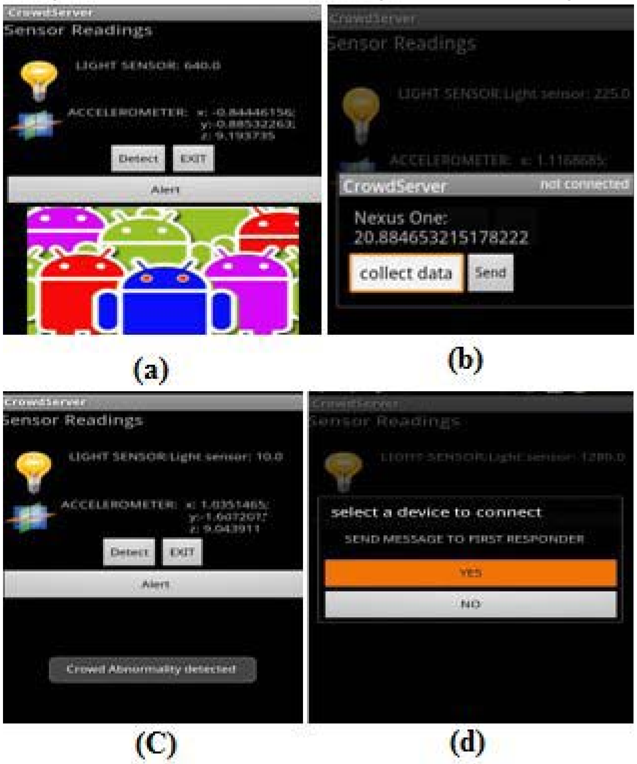

Figure 6. Smart Phone Sensing Module working (a)Participant node in Listening Mode
(b) Alert Collection Mode (c) Alert Indication (d) Crowd Controlling Station Alerting

The smart phone sensing module execution output in a participant node is shown in Figure 6. The shake condition was simulated and the accelerometer value exceeded the shakeThreshold and Bluetooth adhoc network is used to make distributed consensus on the critical shake value of accelerometer and alert message is sent to the crowd controlling station.

V. CONCLUSION

The objective of this research work is to develop techniques for real time continuous monitoring of crowd behavior necessary for good crowd management, for developing alerts and instructions for effective crowd control. This research work has designed a mobile sensor network system integrated with wireless multimedia sensor networks (WMS) for effective prediction of stampede for crowd disaster mitigation. This work has developed and evaluated an Android application for capturing real time dynamics of crowd behavior, space configuration, space capacity, traffic processing capabilities, etc. The crowd abnormalities are captured using the existing mobile phones present in the scenario by capturing light intensity, accelerometer readings, which are capable to predict the shake and fall functionalities, audio sensors and video sensors in mobile phones and external wireless sensor networks. The future work will focus on implementation of WMSN and its integration with smart phone sensing module.

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