A Proposed Computer-Based System Architecture for Crowd Management of Pilgrims using Thermography

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Abstract: Over the years, overcrowding and difficulties in crowd control have resulted in a number of fatal accidents during the Hajj. Despite many efforts and improvements for roads and footbridges, ensuring the safety of pilgrims continues to challenge especially with the annual increase of the number of pilgrims. The challenge has attracted many researchers who provided several methodologies for crowd monitoring and estimation of its density. This paper proposes to extend an earlier monitoring effort done by the same authors to develop a decision support system allows for close monitoring and control of crowd movements. It incorporates data acquisition and processing via several thermal cameras deployed as sensors at strategic points on Nafra (Arafat to Muzdalifah) access roads. The sensors are linked to an analysis module, which in turn measures crowd flow and density in real time. When crowds become too dense, an alarm is triggered according to different density levels. At this point, the integrated decision support system generates different alternatives to the controllers in order for them to take the appropriate actions. The paper illustrates the proposed system component. It also describes the architecture of each component as well as the architecture of the entire system. The system can contribute to provide complete safety for crowds during the Hajj event that attracts millions each year.

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1. Introduction

Once a year, around 3.0 million Muslims of every ethnic group, color, social level, and culture gather from all over the world in Makkah to perform the Fifth Pillar of Islam, Hajj. The pilgrimage involves a number of sacred rituals, and represents a profound personal and spiritual journey for Muslims. **Ben-Mahmoud *et al.* (2010)** have shown that the number of pilgrims will dramatically increase in the next few years to reach almost 3.75 million Muslims. Moving this giant number of people with uncontrolled manner resulted in many accidents in the past 20 years (**Still, 2011**). One area in particular has seen a number of fatalities: the city of Mina, located south-east of Mecca, during the ritual at Al-Jamarat. Despite continuous development of the pilgrim's additional access points, footbridges, and emergency exits, ensuring the safety of pilgrims continues to challenge the authorities.

Many researchers discussed the situation of Al-Jamarat rituals at Mina, and many efforts by the authorities have been made to provide safety to pilgrims during this ritual. However, after the sunset of the ninth day of Dhul-Hijjah pilgrims go to Muzdalifaduring "Nafra". The "Nafra" process includes the movement of 3.0 Million pilgrims from Arafat to Muzdalifa before sunrise using certain limited routes. Figure 1 shows the "Nafra" routes on a map and a view of pilgrims during the "Nafra". This is the focus of this paper.

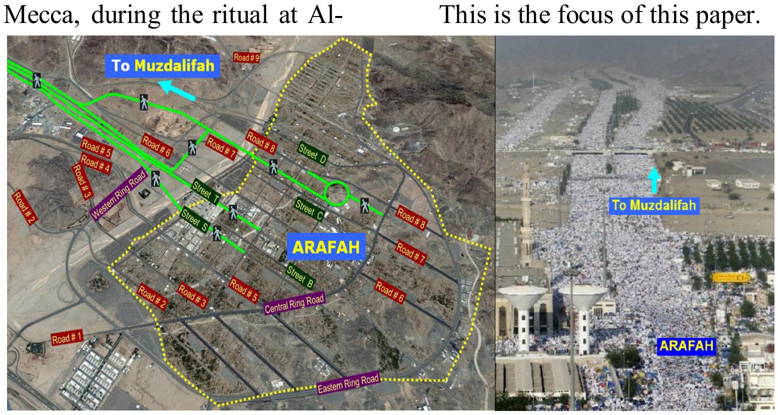

Figure 1: "Nafra" Routes

The main objective of this paper is to provide an integrated decision support system allows for close monitoring and control of crowd movements providing an early warning of any buildup for not only guidance of pilgrims and protection against accidents caused by overcrowding but also preserving a level of comfort during the movement to keep the sanctity of emotions at its best.

Moreover, managing millions of people gathered from diverse countries around the globe is not only a matter of placement them in the correct route. The gathered troops are different in nationalities and so in customs. Pilgrims coming from Gulf area prefer to move by cars or buses; pilgrims coming from India, Pakistan and Bangladesh prefer to move by walking together, and pilgrims that belong to Shi'a[1] also prefer to stay together. This makes the challenge more difficult in order to manage the moving of different troops together.

To control pilgrims, the Kingdom of Saudi Arabia, Ministry of Hajj has established six establishments to provide services for pilgrims plus GCC and interior establishment. Each establishment is responsible for managing pilgrims from different locations such as South Asian, Non-Arab Africans, South East Asians, Arabians, Iranians (Shi'a) and Turkish and Muslims of Europe, Americas and Australia. Each establishment has around 100 offices; each office is responsible for around 5000 pilgrims. These establishments will be the objective stack holders of the proposed crowd management system.

The proposed system incorporates data acquisition through real-time thermal video sequence analysis and processing, and management information distribution, via several thermal cameras deployed as sensors at strategic points on "Nafra" routes. The sensors are linked to an analysis module, which in turn measures crowd flow and density in real time. When crowds become too dense, an alarm is triggered according to different density levels. At this point the decision support system fires and provides operating authority by different alternate actions to regulate site access accordingly.

The proposed system architecture consists of two main components: the information management component, and the decision support system module. The information management module incorporates acquiring the required information about the crowd density and behavior, whether it's accelerating or decelerating in different roads on "Nafra" route. It uses infrared thermal video sequences (**Abuarafah *et al.*, 2012**) in monitoring process. Then it uses fuzzy logic to manipulate the outcome of the thermal video analyzer in integration with road parameters to deduce the status of each individual road in the route. The second component is the decision support module which integrates operations research with an expert system. The operations research works to determine pilgrims mass per minutes for each available road due to road parameters and possible time remains. The expert system divides hajj in homogeneous groups according to establishment and religious party. Then the decision support system works to generate alternate decisions based on closed roads, road priorities, and which group should move through which road. These alternatives will be available to the decision makers in each establishment to manage their crowds.

This paper is divided into four sections. The first section is this introduction. The second section discusses the crowd management issues and related work. The third section illustrates different component architecture. And the last section concludes the work and discusses the future of the research.

2. Related work

Generically, crowd can be defined as a large number of people gathered together with or without orderly arrangement. Crowd management is defined as the systematic planning for, and supervision of, the orderly movement and assembly of people. Crowd management involves the assessment of the people handling capabilities of a space prior to use (**Fruin, 1993**).

A moving crowd, even a large one, has the capacity to 'self organize' safely if the density is low enough. Under normal conditions, crowds have a spontaneous intelligence of their own, developing 'laminar flows', or streams, that keep everyone moving. As density increases, these smooth patterns start to disintegrate. **Helbing *et al.* (2007)** came up with some unexpected findings. As crowd density rose, they identified the onset of stop-and-go waves similar to those found in road traffic jams. This was followed by transition to a much more chaotic state, with outbreaks of panic as individuals lost control. This phenomenon – known as crowd turbulence – can trigger disasters.

Figure 2shows different level of crowds that can be noticed by human eye. In (a) the entire body is visible so there is no crowd; in (b), only body and head visible so overcrowding may occur. In (c) and (d) the crowd level need to be managed.

[1] Shia Islam (Arabic: شيعة, Shīʿah) is the second largest denomination of Islam. The followers of Shia Islam are called Shi'ites or Shias. "Shia" is the short form of the historic phrase Shīʻatu ʻAlī (شيعةعلي), meaning "followers of Ali", "faction of Ali", or "party of Ali".

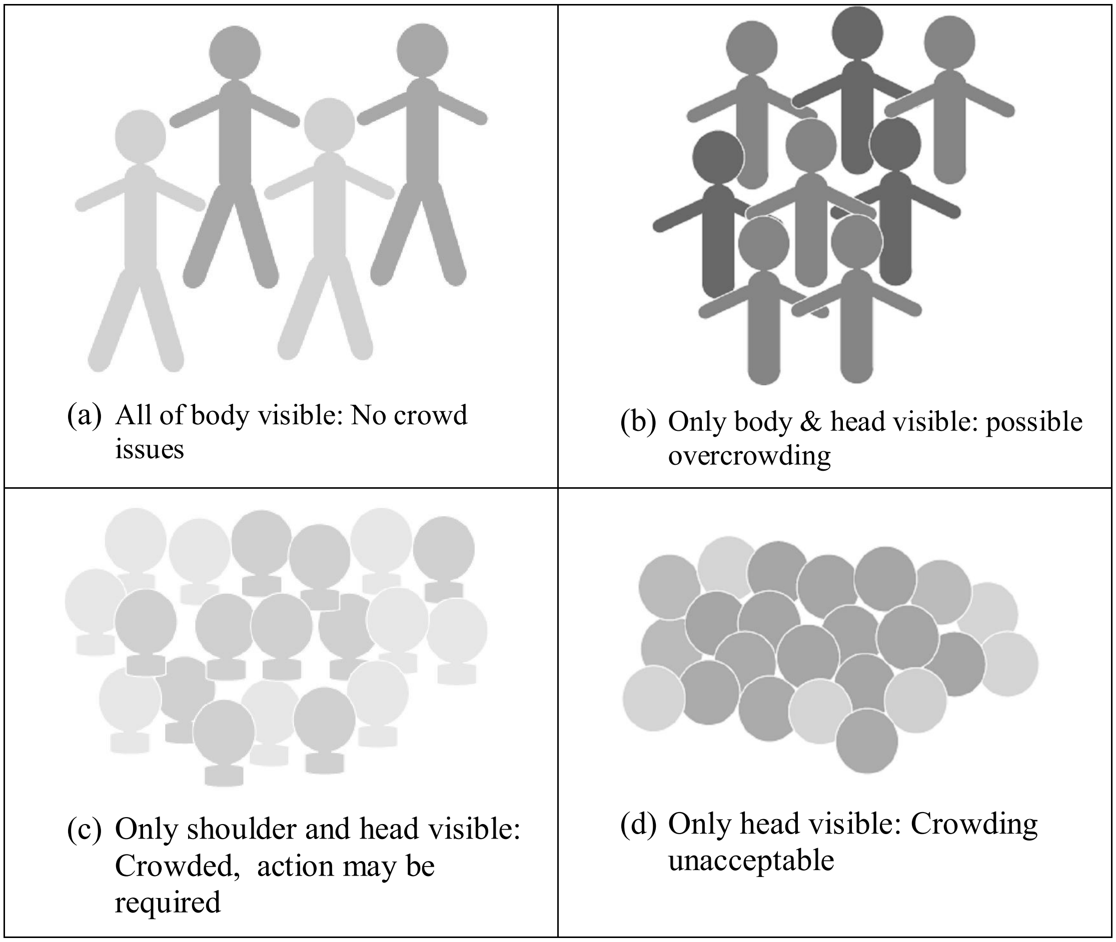

Figure 2: Different Levels of Crowd

Most major crowd disasters can be prevented by simple crowd management strategies. The primary crowd management objectives are the avoidance of critical crowd densities and the triggering of rapid group movement (**Fruin, 1993**). In the next two paragraphs, two crowd management systems have been studied.

Schubert *et al.* (2008) presented a decision support system for crowd control. Decision support is provided by suggesting a control strategy needed to control a specific disturbance situation. Control strategies consist of deployment of several police barriers with specific positions and strengths needed to control the disturbance. The control strategies are derived for a set of pre-stored example situations by using genetic algorithms where successive trial strategies are evaluated using stochastic agent-based simulation. The optimal control strategy for the current situation is constructed by the best linear combination of pre-stored example situations. The optimal strategy is given as the same linear combination of associated strategies. So, their system is using a decision making algorithm where a current situation is compared to all simulated situations.

A linear combination of control strategies, whose corresponding weighted superposition of simulated situations most closely resembles the current situation, is given as the required decision.

Deshpande and Gupta (2010) have proposed a computer based system combining fuzzy logic and Graphical Information System (G.I.S) to monitor and avoid the crowding disasters. They have proposed two-step mode. The first step is pre-disaster planning incorporating the determination of sensitive locations and space management, evacuation paths using (G.I.S) and management related arrangements. The second step is real time analysis of crowds to detect a possible emergency. Their system contains two modules. The first is a fuzzy inference system to determine crowding situations and plan of action. The fuzzy interface depends on the number of pixels and shape of objects to determine the crowd density. It also uses object characterization from the image to determine the speed of the crowd. The second is the determination of the shortest evacuation path for the current area under surveillance. The shortest path is determined with the help of G.I.S. and the overall crowding situation. Their proposed system follows certain steps: acquiring basic information, formation of evacuation network, and calculation and decision.

3. Component Architecture

The proposed system consists of two main components. The first component is responsible for the information management. It incorporates data acquisition module through the use of several thermal cameras deployed at critical points on the target route. The thermal videos will be fed into an analyzer to calculate the density of the crowd in each road in the target route. The crowd analysis will be fed into a fuzzy logic module along with pre-stored information about roads geometry to devise the status of each road individually. The second component is the decision support system. It incorporates an operations research module that determines the pilgrims mass per minute for each available road due to road parameters and possible time remains. It also incorporates an expert system module that divides the pilgrims in homogeneous groups according to establishment, country, roads, and religious group. Then decision support component will generate different alternatives showing the closed roads, road priorities, and which group should move through which road. The alternatives will be used by the authorities to take the necessary actions. Figure 3shows a schematic diagram of the proposed system architecture. In the following sections, each module will be discussed.

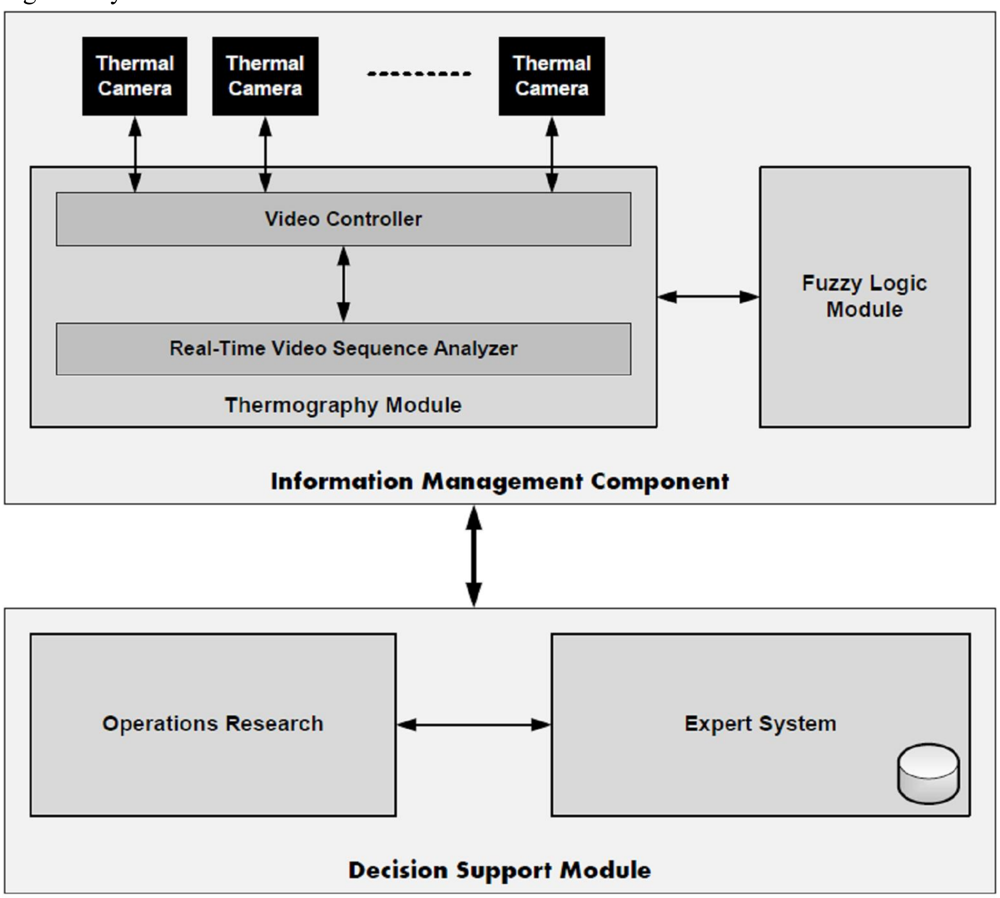

Figure 3: Proposed System Architecture

3.1. Information Management Component

The main objective of this component is to manage information about the crowd and the venue which is the "Nafra" route. The component is divided into two main modules: the thermography module and the fuzzy logic module.

The thermography module (**Abuarafah *et al.*, 2012**) uses a set of FLIR E60bx thermal camera deployed over an elevation about 10m above each pedestrian road in the route. The cameras will be connected to a controller. The controller collects different video sequences about each road in certain period of time and feeds the second module which is the video sequence analyzer with the collected video sequences and the necessary calibration information such as human temperature. The video sequence analyzer module calculates the crowd density in real-time in pre-defined steps; every step includes a specific number of frames pre-defined in system configuration. The less number of frames in the step will result in increasing the accuracy of calculating the average crowd ratio. The module will indicate the crowd density percentage in different colors. In addition the module infers the movement behavior from whether it is accelerating or decelerating. Several reasons make thermography is the most suitable technique for the Hajj event. First thermal imaging is non-contact, i.e. uses remote sensing so it keeps the user out of danger. Meanwhile it does not intrude upon or affect the target at all so it keeps people privacy intact. Also the produced images allow for excellent overview of the target without the need of intelligent recognition of faces or body parts.

The second module in this component is the fuzzy logic component. This module manipulates the output of the analyzer in integration with road parameters such as road length and width to formulate the status of each road individually. The fuzzy logic module prioritizes the roads according to three parameters the crowd density on the road, the road length, and the road width. So, suppose that the crowd density is normalized among several roads; then the priority of them is arranged according to the shortest and widest one. The roads will be assigned a discrete number from 0 (lowest) to 10 (highest) to describe its priority

3.2. Decision Support Component

The decision support component consists of two modules: the operations research module and the expert system module.

The operations research module determines pilgrims mass per minute for each available road due to road parameters and possible time remains.

The expert system module plays a crucial rule in this problem to organize the pilgrims according to country, race, and religious party. Arrangement rules are stored in a knowledge base and the expert system inference engine integrates these rules with the operations research module output in order to do correct placement of different troops of pilgrims according to their preference.

The decision support component hence uses these rules to generate different alternatives to the authorities including the closed roads, other road priorities, and suggestions of which group should move through which road.

3.3.The Proposed End User Interface

Figure shows the proposed graphical user interface (GUI) of the described system. The screen is divided into three sections. The main section includes the map of the “Nafra” routes with different roads through the route. On the right hand side a real-time view of the current situation of each road appear at certain time interval. At the bottom, different alternatives are coming from the system including the closed roads, the road priorities and the suggestion of different actions.

Figure 4: The Proposed System GUI

Conclusion

In this paper, computer-based system architecture for crowd management of pilgrims during Hajj has been proposed. The system integrates real-time thermal video sequence analysis with decision support. The system provides real-time crowd density measurements and communications, making it possible for the security authorities to spot potential problems early and to interfere to reduce the risk to pilgrims.

For future research the implementation of the decision support module will be done and field experiment to the system will be evaluated.

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Biography

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