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Crowd macro state detection using entropy model

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ABSTRACT

In the crowd security research area a primary concern is to identify the macro state of crowd behaviors to prevent disasters and to supervise the crowd behaviors. The entropy is used to describe the macro state of a self-organization system in physics. The entropy change indicates the system macro state change. This paper provides a method to construct crowd behavior microstates and the corresponded probability distribution using the individuals' velocity information (magnitude and direction). Then an entropy model was built up to describe the crowd behavior macro state. Simulation experiments and video detection experiments were conducted. It was verified that in the disordered state, the crowd behavior entropy is close to the theoretical maximum entropy; while in ordered state, the entropy is much lower than half of the theoretical maximum entropy. The crowd behavior macro state sudden change leads to the entropy change. The proposed entropy model is more applicable than the order parameter model in crowd behavior detection. By recognizing the entropy mutation, it is possible to detect the crowd behavior macro state automatically by utilizing cameras. Results will provide data support on crowd emergency prevention and on emergency manual intervention.

1. Introduction

Crowd motions that represent the crowd behaviors macro state have typical features [1] in different system. Vicsek [2] proposed five fundamental types: (i) disordered (particles moving in random directions); (ii) fully ordered (particles moving in the same direction); (iii) rotational (within a rectangular or circular area); (vi) critical (flocks of all sizes moving coherently indifferent directions, and the whole system is very sensitive to perturbations); (v) quasi-long range velocity correlations (for elongated particles). In this study, the disordered and fully ordered motions were considered since they represent the two most typical states.

There are two categories of crowd analysis models. One considers the crowd as a close system, and the other takes the crowd as an open system, which can exchange information and energy with outside environment.

• Crowd system as a close system.

Physical models and statistical methods have been reported to study the crowd behavior as a close system. Dirk Helbing [3] proposed the social force model to analyze pedestrian dynamics. Psychology factors were also added in simulating crowd dynamic features [4], which propel the social force model to be more practical. Vicsek developed the self-driven particles model [1,5], which is another physical model used for crowd motions. The order parameter of the particles was also calculated. Xue Zhi-bin [6] concluded several Attractive/Repulsive force model in his thesis.

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Statistical methods are used for the detection of abnormal motions or crowd disasters. Dirk Helbing [7] studied several physical parameters, like speed, density, flow, pressure, etc., to predict the crowd disaster, describe the transition from laminar to stop-and-go state and investigate the turbulent flow. X.L. Zhang [8,9] analyzed the velocity profile during a real mass event. J. Ma [10] studied that different clusters of pedestrians displayed different velocity features in crowd-quakes. Cao [11] also adopt the kinetic energy to detect anomaly motions. Vijay Mahadevan [12] proposed that temporal anomalies are equated to events of low-probability, while spatial anomalies are handled using discriminate saliency. Borislav Antic [13] presented a probabilistic model that localized abnormalities using statistical inference. Louis Kratz [14] presented a novel statistical framework for modeling the local spatio-temporal motion pattern behavior of extremely crowded scenes. Ramin Mehran [15] calculated the social force based on velocity and adopt LDA model to detect the abnormal behaviors. Haines [16] presented Delta-dual hierarchical dirichlet processes which was similar to LDA. Andrade [17] and Marco Bertini [18] also adopt statics methods to detect anomaly. In summary, the statistical methods were mainly focused on using physical parameters to predict the public moving trend and to describe the public motion, however the external artificial force was not considered in these cases, which were often and essential in mass incidents analysis.

• Crowd system as an open system.

Crowd motion was assumed as an open system in two fundamental research aspects: the dissipative structure theory developed by Prigogine [19] and the synergetics developed by Haken [20], which focused on entropy and the order-parameter research respectively. In 1865, German physicist Rudolf Clausius provided the first mathematical version of the concept of entropy. In 1877 Boltzmann visualized a way to depict the entropy, in which a relationship between the microstates of a system and the macro entropy was described. In thermodynamics, entropy is a measure of the number of specific ways in which a thermodynamic system may be arranged, commonly understood as a measure of disorder. According to the second law of thermodynamics, the entropy of an isolated system never decreases; such systems spontaneously evolve towards thermodynamic equilibrium, configured with the maximum entropy. Systems that are not isolated may decrease in entropy. The order parameter is a measure of the degree of order across the boundaries in a phase transition system; it normally ranges between zero in one phase (usually above the critical point) and nonzero in the other. In 1948, Shannon entropy model was first introduced in the landmark paper [21]. Shannon is the first people to induct the entropy into the information field.

Using the concepts related to those from non-equilibrium thermodynamic, Dirk Helbing [22] presented computational and analytical results indicating that self-organizing systems tend to reach an optimal state. Robert [23] concluded that the entropy theory established the information theory foundation and inspired modern age of ergodic theory. Entropy theory provides key information to describe the long-term behavior of the random process. Feng [24] discussed the features of Boltzmann's entropy theory $s = k \log w$ as well as the Shannon's information entropy and analyzed the stationary state of motion. Wang [25] analyzed the entropy and the order format in detail to show that the entropy is the indicator of chaos. Vijay P. Singh [26] broadened the entropy application in prediction and decision support. Entropy was used to detect the abnormal crowd behaviors these years. Xuxin Gua [27] provided a method to obtain the particle entropy by considering the velocity direction. Saira [28] calculated the social entropy which depicts the uncertain motion instead of the order state of crowd, and used the Support Vector Machines to detect crowd behaviors. Luo [29] studied the evolution of mass emergency based on the entropy concept.

However, it is difficult to carry on research on inducting external force to control and supervise crowd behaviors which is important to emergency response, if studying the crowd system as a close system, despite its capability of detecting the anomaly. Meanwhile, it is more realistic if the crowd system is studied as an open system. But the crowd behavior entropy was not built, which was essential in describing the crowd behaviors and predicting the crowd behaviors.

This work establishes an effort on building the crowd behavior entropy model using the individual velocity to represent the crowd microstate; and, by calculating the probability of each microstate, this paper provides a method to express the crowd macro state using Shannon entropy. Entropy mutation is analyzed when there is a sudden transition of the crowd behavior. The criterion of crowd macro state is also discussed based on the investigations.

2. Methodology

Based on the Shannon's Information Entropy Theory [21], a crowd behavior entropy model was created to depict crowd behavior. Then the order parameter model was modified to verify the created entropy model and to evaluate the crowd order level.

2.1. Crowd behavior entropy model

The crowd system is considered as a macroscopic synergetic system. A dynamic system was built using variables of microstate space and probability (Ω, P, T), where $\Omega = \{Q_i; i = 1, 2, \ldots, \|A\|\}$ is the whole microstate space matrix, P is the probability function of crowd, and T represents the time. Let Q_i denote the state i and $\|A\|$ denotes the total number of states, then $P(Q_i)$ denotes the probability function of crowd in the state i.

Assume that the probability distribution is normalized as

$$\sum_{i=1}^{\|A\|} p(Q_i) = 1. \tag{1}$$