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الملتقى العلمي الخامس لأبحاث الحج

(دراسات منطقة الجمرات)

A Model to Simulate the Movement and Behavior of Hajjis

Jamarat While Throwing

إعداد

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A Monte Carlo model to describe the movement and behavior of hajjis while throwing jamarat was developed. The model was implemented in a computer code with some graphics capabilities. The model is very flexible and expected to be of significant usefulness for studies carried out on the jamarat area.

Introduction:

A mathematical model that describes the behavior of hajjis (pilgrims) while throwing jamarat has been developed. A two-dimensional probabilistic approach of the Monte Carlo method was used to sample from discrete probability distributions or probability density functions (pdfs) that describe the real behavior of hajjis in their approach towards the area, while throwing, and on the way out. Movements of hajjis (random walks) were traced out in a two dimensional (٢-D) plane step by step using standard Monte Carlo procedures. The model takes into account personal traits such as gender and abilities as well as architectural features of the area. Although the geometric configuration focuses on a single pillar (target to be stoned) i.e. one-pillar module; the model is general and could be applied contiguously to model all three pillars by changing event probabilities and pdfs. To further illustrate this point, concatenation of the model for three pillars could be accomplished by setting appropriate values for the probabilities of same-direction returns (p_{return}) and the probabilities of forward-movement orientations ($p_{frwd/right}$, $p_{frwd/left}$, and $p_{frwd/straight}$). Therefore, for the first pillar module, the probability of same-direction return is set to zero (p_{return} = ٠) and the forward movement probabilities are set to $p_{frwd/right}$ = ٠ , $p_{frwd/left}$ = ٠, and $p_{frwd/straight}$ = ١; followed by a module (could be of different geometrical dimensions) for the second pillar with p_{return} = ٠ and $p_{frwd/right}$ = ٠ , $p_{frwd/left}$ = ٠, $p_{frwd/straight}$ = ١; concluding by a module for the third pillar with p_{return} = optional and $p_{frwd/right}$ = optional , $p_{frwd/left}$ = optional, $p_{frwd/straight}$ = optional. These optional probabilities are explained elsewhere in the manuscript. The time distribution of arrival of hajjis at the beginning of the first pillar's area could be estimated or obtained from field observations. The time distribution of arrival at the beginning of the next pillar's area is taken to be the time distribution of crossing a finish line after the preceding pillar and so forth. The finish time distribution is an output within the computer code.

The probabilistic approach in the model:

For practicality, an illustrative example might be useful. A Monte Carlo history of a random walk is followed from "beginning" to "end". A hajji begins to perform the ritual of stoning by proceeding towards a global direction leading to a pillar's area. A hajji for instance, could be a male, a female, alone, within a group of two or more, of particular physical traits and abilities (body size, walking speed, range of throwing), or throwing on behalf of other hajjis . Furthermore, the time of arrival has to be determined. All such parameters are to be Monte Carlo sampled from relevant pdfs that had been obtained from field observations or had been estimated properly. At a point of approach when the pillar is within sight, a choice is to be made whether to globally approach the pillar directly with $p_{approach-DIR}$ probability, from right-side with $p_{approach-RS}$ probability, or from left-side with $p_{approach-LS}$ probability. The probabilities of global approach are estimated from field observations, and are influenced by religious believes, intentional crowd management regulations, or even conveniences such as shaded areas. Traversing the distance to destination (immediate vicinity around the pillar's enclosure) the hajji might change local directions of movement due to pedestrian congestions, i.e. traversing in a zigzag path while maintaining the global direction of approach. Each change of local direction and steps between such changes are sampled and tracked in ٢-D following standard Monte Carlo techniques. The zigzag pattern is a function of crowd density (hajji per unit area) at the given locality. The closer to the vicinity immediately surrounding the pillar the higher the crowd density will be. Henceforth, the hajji is subject to being randomly pushed around (will forcefully resist pushes that result in deviations from destination orientation but follows along for favorable pushes). The act persists until a predetermined personal circle corresponding to a personal throwing range is arrived at. The hajji commences throwing one stone at a time (needs to hold still for τ seconds to do so otherwise a push-around result in a change of the hajji's position and orientation) and continues to throw as long as the hajji is within the personal circle. The dwell time within the personal circle depends on how many push-arounds the hajji is subjected to and on the number of stones to be thrown; which in turn depends on whether the hajji is throwing on behalf of somebody else (wakala) besides self. Going out is treated similarly to in-going with the exception that the hajji's preferred out-going direction is radial until out of the heavily crowded area. The history is carried on such that the hajji either foregoes doaa with a (١-p_{doaa}) probability or proceeds to perform doaa with a p_{doaa} probability. The possibility of going back in the same direction has to be sampled with a p_{bkwd} probability followed by sampling from a discrete pdf of $p_{bkwd/RS}$ or $p_{bkwd/LS}$. In the event that the hajji happens to be moving in the forward direction wanting to perform doaa; the global direction will be the direction of the designated area for doaa and the movement is characterized by a zigzag path until arriving at the doaa area at which an arbitrary (estimated from field observations) dwell time is tallied. On the other hand if doaa is to be foregone but forward direction is sought or forward direction is intended after doaa; the direction is sampled from a discrete pdf comprised of $p_{frwd/right}$, $p_{frwd/left}$, $p_{frwd/straight}$ and the movement is followed until crossing a pre-determined line at the end of the area and the history is considered to be ended. The foregoing briefing illustrates that a high degree of physical realism had been retained in the mathematical formulation of the problem.

When statistically significant number of histories is followed; information about expected behaviors or averaged functionals could be deduced and used in further analysis. For instance, analyses of crowd densities and dwell times as well as tallied parameters of interest could be used to draw conclusions about local pedestrian congestions for regions of interest.

Implementation into a computer code:

The mathematics and cumbersome logics of the preceeding model were implemented into a computer code. Quick Basic™ language was adopted for its graphics capabilities and ease of debugging. The input to the code contains deterministic and probabilistic information. The generality of the code is exemplified in the input data. The geometry of the surrounding area and enclosures of pillars are defined by global coordinate points and dimensions. The event probabilities and the pdfs are either estimated from field observations or factually known. Thus, for a given set of input conditions, the output of the code provides quantitative measures that could be analyzed to draw conclusions about the behavior of the real situation. Moreover, by specifying different sets of input decision conditions and running the model repeatedly, one can predict fairly accurately the expected response of the real situation to changes in various model parameters. A demo-version of the code is demonstrated during the presentation of this manuscript.

Conclusions:

When a model that accurately describes a system is evaluated numerically by a digital device (a computer); it constitutes a powerful versatile tool to facilitate meaningful studies. Thereby, the code could be utilized to predict localities of over-crowdedness, to estimate capacities conforming to predetermined conditions that deemed to be acceptable congestions, and most of all the code could be used as a simulator to try out suggested modifications and alterations within the area or on the event probabilities and distribution functions (e.g. time distribution of arrival). The results and consequences of such alterations could be predicted without having to go through the physical in-situ alterations. Henceforth, ineffective alterations could be avoided without high prices to pay. Finally, the stochastic modeling scheme could be utilized to model areas of crowdedness such as ALMATAF and ALSAFA WA ALMARWA to render improved services to visitors of the Holly City of Makkah.

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