ON THE USE OF OPTICAL FLOW TO TEST CROWD SIMULATIONS

David J. Kaup[(a)], Thomas L. Clarke[(b)], Linda Malone[(c)], Rex Oleson[(d)], Mario Rosa[(e)]

[(a,b)] Institute for Simulation and Training, 3100 Technology Parkway, Orlando, FL 32826
[(a,b)] Mathematics Department, University of Central Florida, Orlando, FL 32816-1364
[(c)] Department of Industrial Engineering and Management, University of Central Florida, Orlando, FL 32816-2450
[(d,e)] Institute for Simulation and Training, 3100 Technology Parkway, Orlando, FL 32826

[(a)]kaup@mail.ucf.edu, [(b)]tclarke@ist.ucf.edu, [(c)]lmalone@mail.ucf.edu, [(d)]quazerin@juno.com, [(e)]mer4m@yahoo.com

ABSTRACT

A method for extracting estimates of crowd movement from videos of the crowd was reported at EMSS 2007. The goal of this method is to provide a means to validate the accuracy of crowd models such as the Helbing-Molnar-Farkas-Vicsek (HMFV) model and to provide a means to refine model parameters. The method uses optical flow extracted from the video with an empirical calibration constant to convert the optical flow to boundary crossing rates of crowd movement. A simple proportional relationship between optical flow and crossing rates of people was postulated on the basis of theoretical considerations. This paper reports on further crowd observations designed to confirm the simple form of the proportionality constant. While the research is on-going, preliminary results support the relationship.

Keywords: optical flow, people flux, culture differences, crowds, social force model.

1. BACKGROUND

1.1. Crowd Modeling

In our research (Kaup, Fauth, Walters, Malone, and Clarke 2006) we have been focusing on a continuous space crowd model, which we refer to as the Helbing-Molnar-Farkas-Vicsek (HMFV) model. This model is described in Helbing, Farkas, and Vicsek (2000). In the HMFV model, each pedestrian feels, and exerts on others, two kinds of forces, "social" and physical. The social forces do not have a physical source; rather, they reflect the intentions of a pedestrian not to collide with other people in the room or with walls and also to move in a specific direction (e.g., towards an exit) at a given speed. Symbolically, the force exerted on pedestrian *i* by pedestrian *j* has the form:

$$\vec{f}_{ij} = \vec{f}_{social\ repulsion} + \vec{f}_{pushing} + \vec{f}_{friction} \qquad (1)$$

The first term in Equation (1) describes the social force,

$$\vec{f}_{social\ repulsion} = Constant_{\boldsymbol{B}} \times exponential(interpersonal\ distance)_{radial\ direction} \qquad (2)$$

while the second and third terms describe the physical forces of pushing and sliding friction between the two pedestrian bodies.

$$\vec{f}_{pushing} = Constant_{\boldsymbol{k}} \times threshold(interpersonal\ distance)_{radial\ direction} \qquad (3)$$

$$\vec{f}_{friction} = Constant_{\boldsymbol{\kappa}} \times threshold(interpersonal\ distance)_{tangential\ direction} \qquad (4)$$

The form of the latter two terms ensures that they vanish when the pedestrian bodies are not in physical contact. An expression similar to equations (3) and (4) holds for a force between a pedestrian and a wall or another immobile obstacle (e.g., a column) in the room.

1.2. Comparison to Real Crowds

Video imagery of moving crowds was obtained for the purpose of providing experimental verification of predictions of crowd models such as the Helbing-Molnar-Farkas-Vicsek (HMFV) model. With Institutional Review Board (IRB) approval, cameras were set up at university and other public events. The field of view of the cameras was aimed at exit points or other locations that could be easily simulated.

The optical flow field can be extracted from a video using the Lucas-Kanade algorithm (Lucas and Kanade 1981) as implemented in the Intel OpenCV (Intel 2001) image processing library. A frame from such a video taken at a local church is shown in Figure 1. A 400-frame sequence (13.3 seconds) from this video was used to create the optical flow field shown in Figure 2.

We make the following assumptions concerning the relation between apparent optical flow and actual crowd motion or flux:

1. Any motion is due only to that of people in the crowd
2. The mapping between physical space in which people move and the image space is assumed to be a simple scaling
3. The reflectivity and illumination of people and other elements in the scene are taken to be uniform

Figure 1: Hispanic Crowd Exiting Church at Frame 200.

It can be shown under these assumptions that the rate at which people cross a boundary is proportional to the optical flow in a region surrounding that boundary. Figure 3 illustrates this; the number of people F_y crossing a horizontal boundary in a vertical direction is simply proportional to the average vertical optical flow V_y in the shaded region surrounding the boundary. A similar relation holds for F_x and V_x in the horizontal direction.

The proportionality constant between $F_{x|y}$ and $V_{x|y}$ is not dependent on the number of people in the crowd and is primarily a function of the camera distance.

To determine the proportionality constant between optical flow and actual crowd motion, hand counts of people crossing the boundaries of a 3 by 4 grid were pre- formed on selected segments of the videos taken at an American football game. These counts were compared with optical flow calculated on a 6 by 8 grid. Use of a doubly fine grid for the optical flow facilitated the analysis of the relation shown in Figure 3. Limited comparisons confirmed the relation between flux of people and optical flow (Clarke, Kaup, Malone, Oleson, and Rosa 2007).

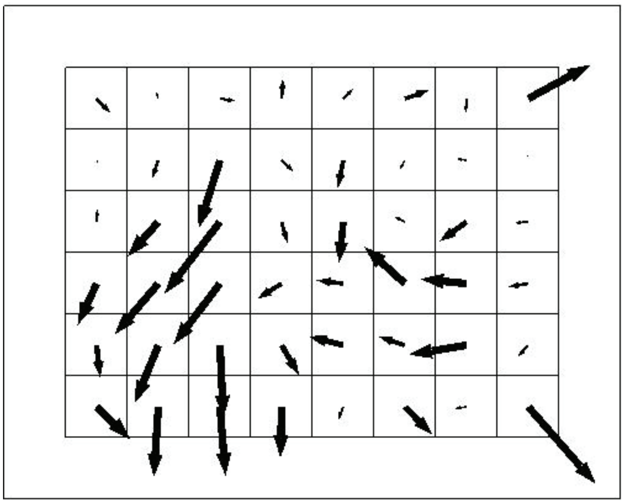

Figure 2: Optical Flow Field for Hispanic Case from Frames 1-400.

2. CURRENT RESULTS

To further confirm the relation between flux of people in a crowd and optical flow, further videos have been acquired and analyzed for optical flow and subjected to hand counting of people flux.

These videos came from the following venues:

1. A primarily Hispanic congregation exiting a church
2. A primarily Anglo congregation existing a church

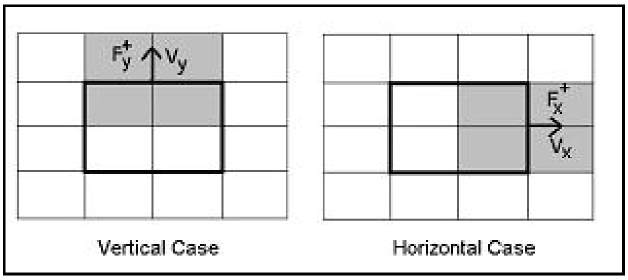

Figure 3: The Geometrical Relation between Optical Flow and Boundary Crossing Rate.

2.1. Hispanic Case

The video taken of the Hispanic crowd exiting the church was 1100 frames long. The first 400 frames (13.3 seconds) and the last 400 frames were separated out for analysis. Figure 1 shows the 200th frame in the center of the first analysis interval. The optical flow field calculated from frames 1-400 for the Hispanic case is shown in Figure 2.

The 3x4 grid boundary crossing rate was hand-counted from frames 1-400 and plotted versus the optical flow. The relation was essentially random for this case. This is not too surprising, however. Examination of frames 1-400 shows the crowd is milling about during this time interval of 13.3 seconds as suggested by Figure 1 and the optical flow field in Figure 2. Whence the time interval used was too long to effectively pick out any motion other than the average; in this case the average is essentially zero.

Figure 4 shows the single frame 900 of the Hispanic-exit case, and Figure 5 shows the optical flow calculated from frame 701-1100.

Figure 4: Hispanic Crowd Exiting Church at Frame 900.

The results of plotting 3 by 4 grid crossing rates versus optical flow were much better for this case as illustrated in Figure 6. The slope of the best fit line is 0.0092 and the correlation is 0.329. The reason for this relatively good correlation seems to be the purposeful movement of the crowd as shown in Figure 4. While the crowd appears sparse in frame 900 (Figure 4), in the video prior to frame 900 the crowd is much denser.

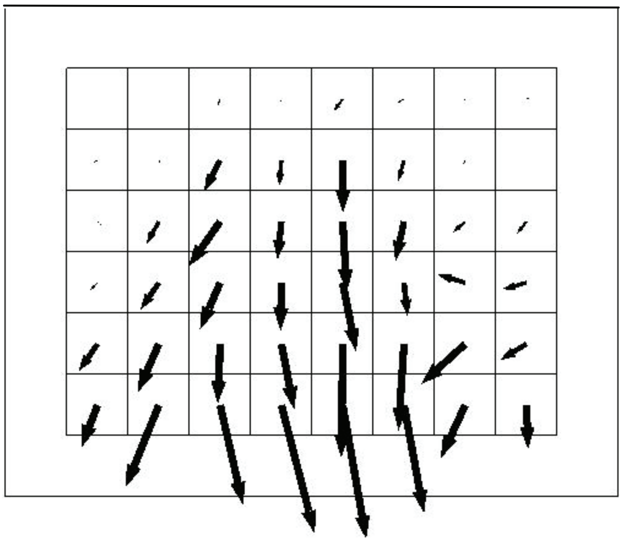

Figure 5: Optical Flow Field for Hispanic Case From Frames 701-1100.

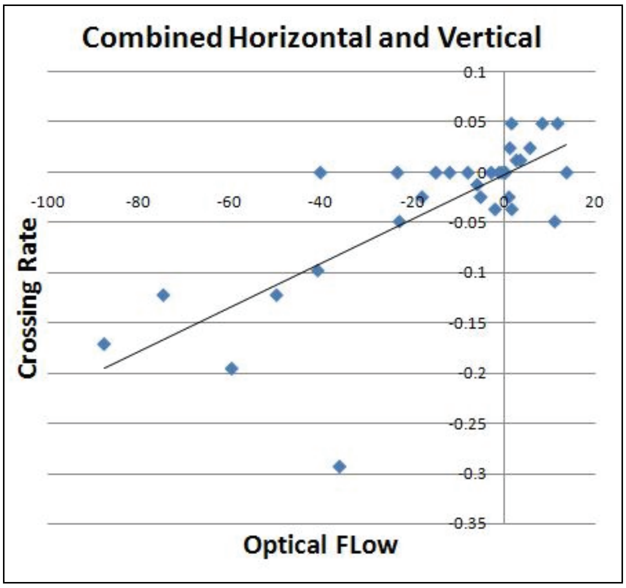

Figure 6: Correlation Plot of 3 By 4 Grid Crossing Rate Versus Optical Flow for Hispanic Frames 701-1100.

2.2. Anglo Case

Figure 7 shows frame 200 of the Anglo (English speaking) congregation leaving the church. The Anglo-case video was 5400 frames long (180 seconds). The camera angle and distance were also different from the Hispanic case.

Figure 7: Anglo Crowd Exiting Church at Frame 200.

Figure 8 shows the optical flow field for the Anglo case for frames 1-400. Note the minimum in the velocity at the position corresponding to a stationary priest who can be seen in Figure 7.

Despite the presence of the priestly obstacle in the Anglo case, the correlation between crossing rate and optical flow was good as can be seen in Figure 9.

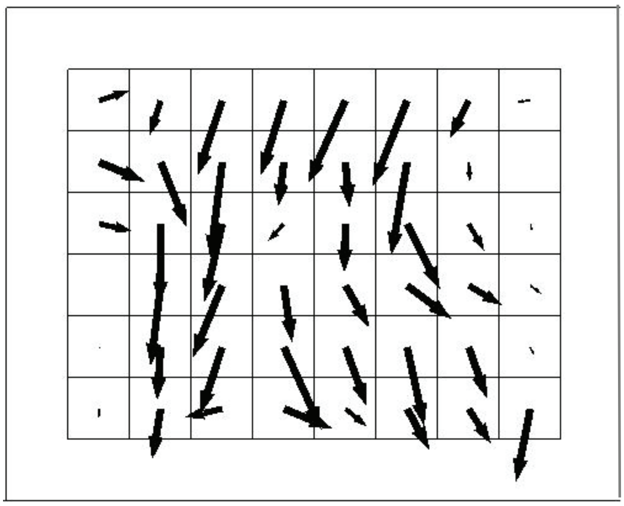

Figure 8: Optical Flow Field for Anglo Case from Frames 1-400.

The slope of the linear fit in Figure 9 is 0.0036 and the correlation coefficient is 0.467. The relative magnitudes of the slopes in Figures 6 and 9 are consistent with the difference in camera distance and angle for the two cases.

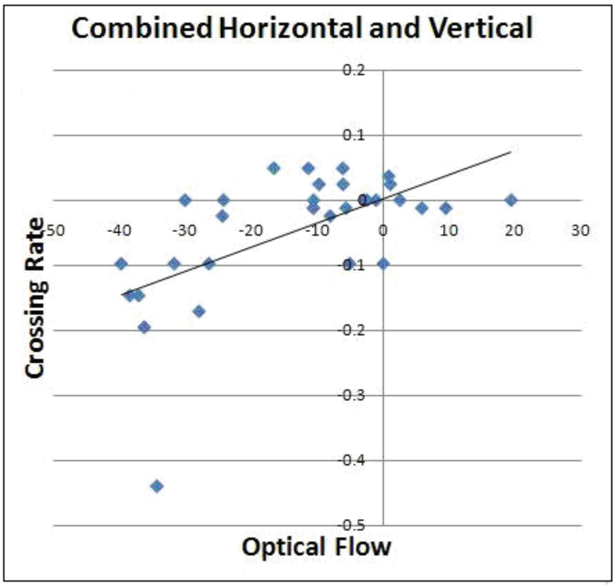

Figure 9: Correlation Plot of 3 By 4 Grid Crossing Rate Versus Optical Flow for English Frames 1-400.

Figures 10 and 11 show frame 5200 (173.3 seconds into the video) and the optical flow field for frames 5001-5400. The crowd had become fairly sparse and was milling about more or less randomly by this time, so the crossing rate/optical flow relation was random much like the first Hispanic case presented.

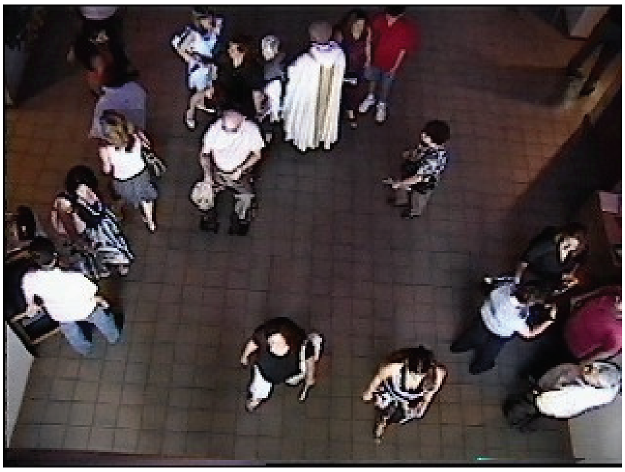

Figure 10: Anglo Crowd Exiting Church at Frame 5200.

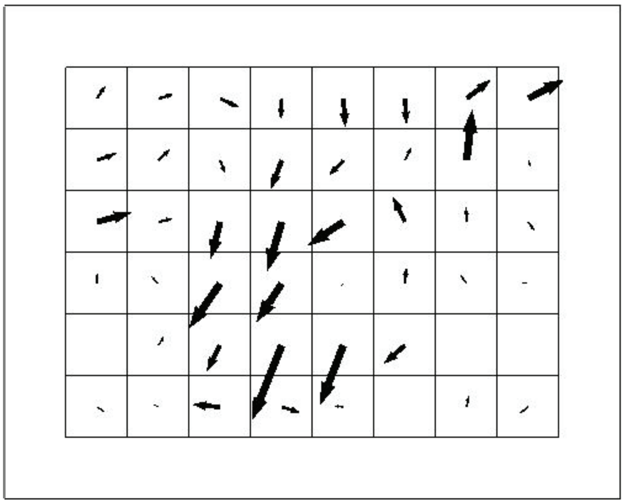

Figure 11: Optical Flow Field for Anglo Case from Frames 5001-5400.

3. CONCLUSION

On the basis of preliminary results, the correlation between hand counted boundary crossing rates and optical flow is high and statistically significant when the crowd is moving in a definite direction. When the crowd is milling about the correlation is generally poor. Thus, the easily measured optical flow could stand in place of time consuming manual counts of the flux of people moving in crowds to provide experimental validation of crowd models. The dependence of the proportionality constant on viewing distance has the form expected. It is also clear that one should investigate comparisons at smaller time intervals (perhaps even as small as 10 frames) wherein one possibly could detect fluxes associated with random milling motion.

ACKNOWLEDGMENTS

We thank P. Kincaid, B. Goldiez and R. Shumaker of the Institute for Simulation and Training for their interest and discussions throughout different stages of this work. This research has been supported in part by the National Science Foundation under Grant No. BCS-0527545 and by the U.S. Army Research Development and Engineering Command, Simulation Technology Center, Contract N61339-02-C-0107.

REFERENCES

Clarke, T.L., Kaup, D.J., Malone, L., Oleson, R. & Rosa, M., 2007. Crowd model verification using video data. *Proceedings of EMSS 2007*, paper no. 31. October 4-6, Bergeggi (Italy).

Helbing, D., Farkas, I. & Vicsek, T., 2001. Simulating dynamical features of escape panic. *Nature*, 407, 487-490.

Intel, 2001. *Open Source Computer Vision Library: Reference Manual.* Intel. Available from: www.itee.uq.edu.au/~iris/CVsource/OpenCVreferencemanual.pdf [accessed 15 February 2006].

Kaup, D.J., Fauth, J.E., Walters, L.J., Malone, L. & Clarke, T., 2006. Simulations as a mathematical tool. *SIAM Conference on the Life Sciences,* July 31-August 4, Raleigh (North Carolina, USA).

Lucas, B.D. & Kanade, T., 1981. An interactive image registration technique with an application to stereo vision. *Proceedings of Image Understanding Workshop*, pp. 121-130. April 23, Washington, DC (USA).

AUTHORS BIOGRAPHY

DAVID J. KAUP is Provost Distinguished Research Professor in mathematics at the University of Central Florida with a joint appointment at the Institute for Simulation and Training. He has a PhD in Physics from the University of Maryland. He was a professor at Clarkson University before coming to UCF. His research interests are in the area of non-linear waves, in particular solitons, and he has been recently applying this background to the area of modeling the dynamics of crowds.

THOMAS L. CLARKE is Principal Mathematician at the Institute for Simulation and Training of the University of Central Florida and is also Associate Professor in the Modeling and Simulation program. He has a PhD in Applied Mathematics from the University of Miami and worked at NOAA before coming to UCF. He has a diverse background in applying mathematics to simulation and has investigated areas such as the application of catastrophe theory and nonlinear dynamics.

LINDA C. MALONE is a Professor in the Industrial Engineering Department at University of Central Florida. She got her B.S. and M.S. degrees in mathematics (at Emory and Henry College and University of Tennessee respectively) and her Ph.D. degree in statistics from Virginia Tech in 1975. She is the coauthor of a statistics text, has authored or coauthored 74 refereed papers. She was an associate editor of the Journal of Statistical Computation and Simulation for over 25 years and was a founding co-editor of the STATS Magazine. She has served in various offices in statistical organizations including service on the Board of Directors of the American Statistical Association. She was awarded the honor of Fellow of the American Statistical Association.

REX OLESON graduated from Susquehanna University with a B.S. in physics and mathematics. Following four years of software development, he obtained an M.S. in Mathematics from UCF. He is currently working on a Ph.D. in Modeling and Simulation. He is working through IST.