ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

Assessing the Human Perceptions of Physical Environmental Stressors Through Behavior Response Examination

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Abstract: Environmental stressors considerably influence the health and safety of humans and must thus be continuously monitored to enhance the urban environments and associated safety. Environmental stressors typically act as stimuli and lead to behavioral changes that can be easily identified. These behavioral responses can thus be used as indicators to clarify people's perceptions of environmental stressors. Therefore, in this study, a framework for assessing environmental stressors based on human behavioral responses was developed. A preliminary experiment was conducted to investigate the feasibility of the framework. Human behavioral and physiological data were collected using wearable sensors, and a survey was performed to determine the psychological responses. Humans were noted to consistently exhibit changes in the movement and speed in the presence of physical environmental stressors, as physiological and psychological responses. The results demonstrated the potential of using behavioral responses as indicators of the human perceptions toward environmental stressors. The proposed framework can be used for urban environment monitoring to enhance the quality and safety.

Keywords: environmental stressors, behavioral responses, perception, collective sensing

1. INTRODUCTION

Cities consist of various environmental aspects that can positively or negatively influence people. For example, well-maintained landscapes, trees, benches, and lighting can encourage people to be outdoors, whereas graffiti, litter, vandalism, and abandoned or run-down buildings may function as physical stressors for people, leading to chronic stress, discomfort, and fear [1]–[4]. Such stressors must be constantly monitored to enhance the environmental quality. Researchers have attempted to identify the environmental factors influencing people and recommended appropriate urban environment standards [4]–[9]. Notably, most of the existing studies evaluated the effects of environmental factors on people by administering questionnaires. However, the survey method cannot continuously and quantitatively assess the factors that are intricately intertwined.

Furthermore, because the urban environment changes with use, it is essential to rapidly and continuously understand the environmental factors to promptly enhance the urban environment.

Recent technological advancements have provided a basis for assessing the people's perceptions of environmental factors in a real-time manner. Several researchers have demonstrated the possibility of inferring people's behaviors and emotions by collecting and analyzing sensor data such as global positioning system (GPS) data, acceleration values, electrodermal activity (EDA), electroencephalograms (EEGs), and heart rate variability (HRV) values [10]–[13]. Furthermore, video data can be analyzed using supervised or unsupervised machine learning algorithms (e.g., action classification and anomaly detection) to detect people's actions and identify abnormal behaviors [14], [15]. Therefore, the discomfort felt by people due to environmental factors, particularly environmental stressors, can likely be quantitatively assessed by analyzing people's behavioral and physiological responses.

This study is aimed at developing a framework for objectively analyzing people's behavioral and physiological responses to identify environmental stressors. The proposed framework is expected to facilitate decision-making regarding environmental improvement in complex and rapidly changing cities. The findings are expected to help establish measures to decrease people's discomfort and stress, enhance the urban environment, and promote safety.

2. LITERATURE REVIEW

The premise of this study is that a noticeable human behavioral response is generated when a person is exposed to stimuli. According to Helbing & Molnár [16], various environmental factors function as stimuli and cause behavioral changes in people such as deceleration and avoidance due to repulsion against entities that may cause discomfort. Helbing & Molnár [16] proposed the social force model to explain human behavior, with three considerations: (1) People typically take the shortest possible path (a path with no detours). (2) People may feel uncomfortable with certain people or objects and thus maintain a distance from these entities owing to repulsion. (3) People may be attracted to other people or objects. This attraction effect can be modeled similar to the repulsion, although the former effect decreases with time. The social force model considers people and environmental factors (e.g., other people, walls, and obstacles) as independent factors and predicts human behavior based on mutual social forces. Researchers have adopted the social force model to perform human movement simulations in various environments and validated the model [17]–[19]. Therefore, human behavioral responses can likely be used as indicators to infer people's perceptions of environmental factors.

Several researchers have attempted to analyze human-behavior-related data to monitor conditions and situations in cities by using information and communications technologies for data acquisition. For example, GPS data can be used to observe and measure human movements by visualizing their trajectories and have been used to analyze the influence of environmental factors on people's route choices [9], [20]. Moreover, accelerometer data have been used to analyze people's behavior, such as gait patterns [21], [22] and abnormal movements [23], [24]. In addition, behavioral analysis based on video data has attracted considerable research interest. Many researchers have attempted to classify and detect abnormal human behaviors using various machine learning algorithms and obtained accurate results [14], [15], [25], [26].

These studies demonstrated that external stimuli such as environmental factors generate immediate behavioral responses that can be easily identified visually and/or through sensor data. These behavioral responses can be successfully analyzed and detected through recent technologies and can thus be used as objective evaluation indicators. Despite this potential, only a few studies have focused on the physiological and behavioral responses in analyzing and assessing the effects of environmental factors on people. Therefore, this study is aimed at developing a method to assess people's perceptions of environmental stressors based on their behavioral responses.

3. FRAMEWORK FOR ASSESSING HUMAN PERCEPTIONS BASED ON RESPONSES

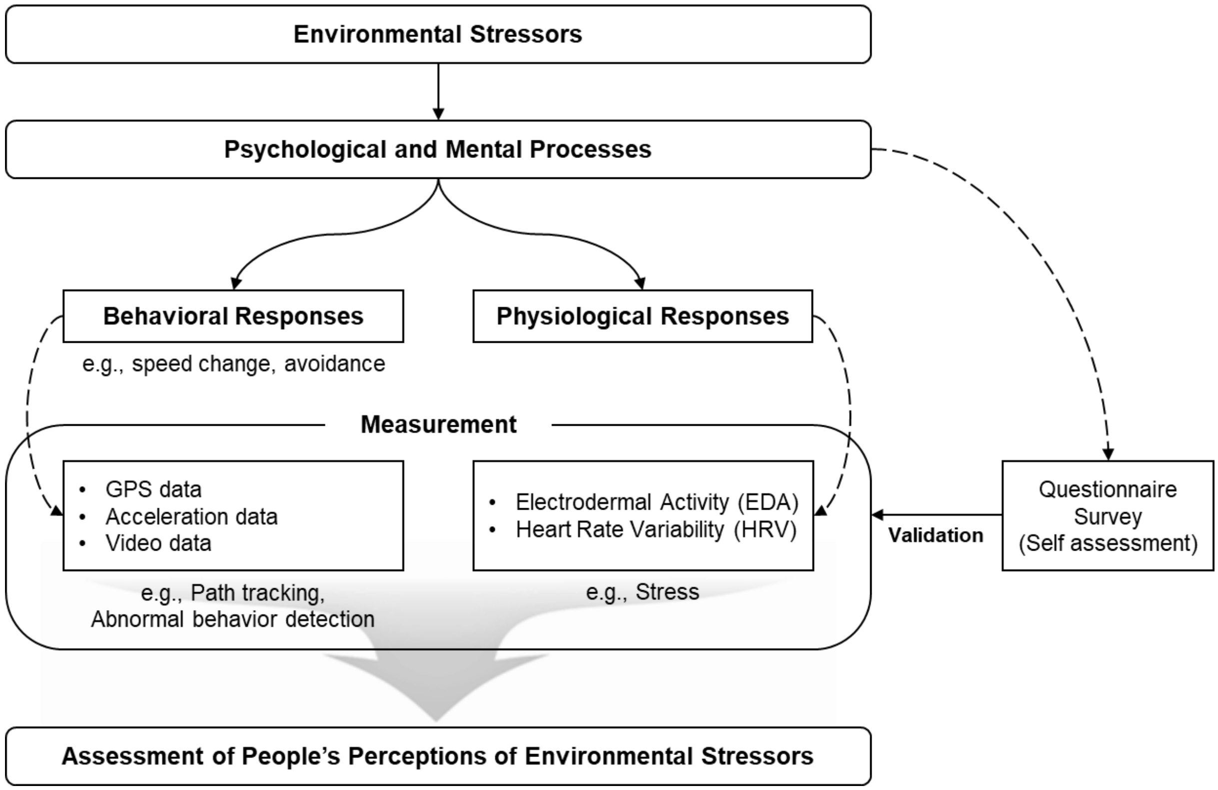

Figure 1. Framework for assessing people's perceptions

A framework is established for objectively assessing people's perceptions (especially, discomfort or displeasure) of environmental stressors based on their behavioral responses. Environmental stressors act as stimuli and influence the psychological and mental processes of people, thereby generating reactions [16]. These reactions can be divided into behavioral and physiological responses. The behavioral responses (e.g., speed changes and avoidance) can be identified visually or by using a surveillance video system. According to the existing studies, the behavioral changes can be determined considering various types of data such as GPS data, accelerometer data, and video data [10]–[15].

People tend to choose the shortest path and maintain a distance from entities that they find discomforting [16]. Therefore, the influence of the environmental stressors can be clarified by tracking peoples' paths using GPS data and calculating the degree of deviation from the shortest path. Moreover, the discomfort experienced by people can be clarified by analyzing gait patterns using accelerometer data. In addition, video analysis can be introduced to automate path tracking and detection of abnormal behavior such as stopping and speed changes.

Physiological data can be incorporated in such analyses to increase the accuracy of the human-behavioral-response-based assessment. Physiological data such as EDA and HRV are typically used to measure human stress. These data can be easily collected through off-the-shelf wearable devices (e.g., Empatica E4 wristbands). In addition, questionnaire surveys regarding the degree of influence of environmental stressors can reflect the people's psychological state, and the assessment method can be enhanced by considering the corresponding results. Therefore, behavioral, physiological, and psychological data can be integrated to strengthen the human-behavior-based environmental stressors assessment framework. Figure 1 shows the proposed framework.

4. PRELIMINARY EXAMINATION OF THE FRAMEWORK

A pilot study was conducted to evaluate the feasibility of the proposed framework. The test site was a one-way, mixed-use road in a residential area with few vehicles and several types of environmental stressors. The environmental stressors (in a walking context) were objects labeled "caution_zone" in an existing dataset (AI Hub, https://aihub.or.kr/aidata/136).

The preliminary experiment was conducted between 3 and 4 PM on a clear day for two days, from January 26 to 27, 2022. The participants were three healthy women in their 20s. The participants wore an E4 wristband and a GPS receiver and walked along a set path of approximately 400 m. The experimental path included various environmental stressors such as gratings, maintenance holes, litter, discarded materials, stairs, cracked roads, railings, curbs, and shrubs. The authors followed the participants during the experiment and recorded videos. After the experiment, the participants were requested to respond to a questionnaire while watching the recorded videos. The questionnaire involved the following questions: 1) Did you see the stressor during the experiment? 2) If you saw the stressor, did it affect your walking? 3) If t

he stressor influenced your walking state, please evaluate the degree of influence on a five-point scale. Figure 2 shows the set path and various environmental stressors in the path.

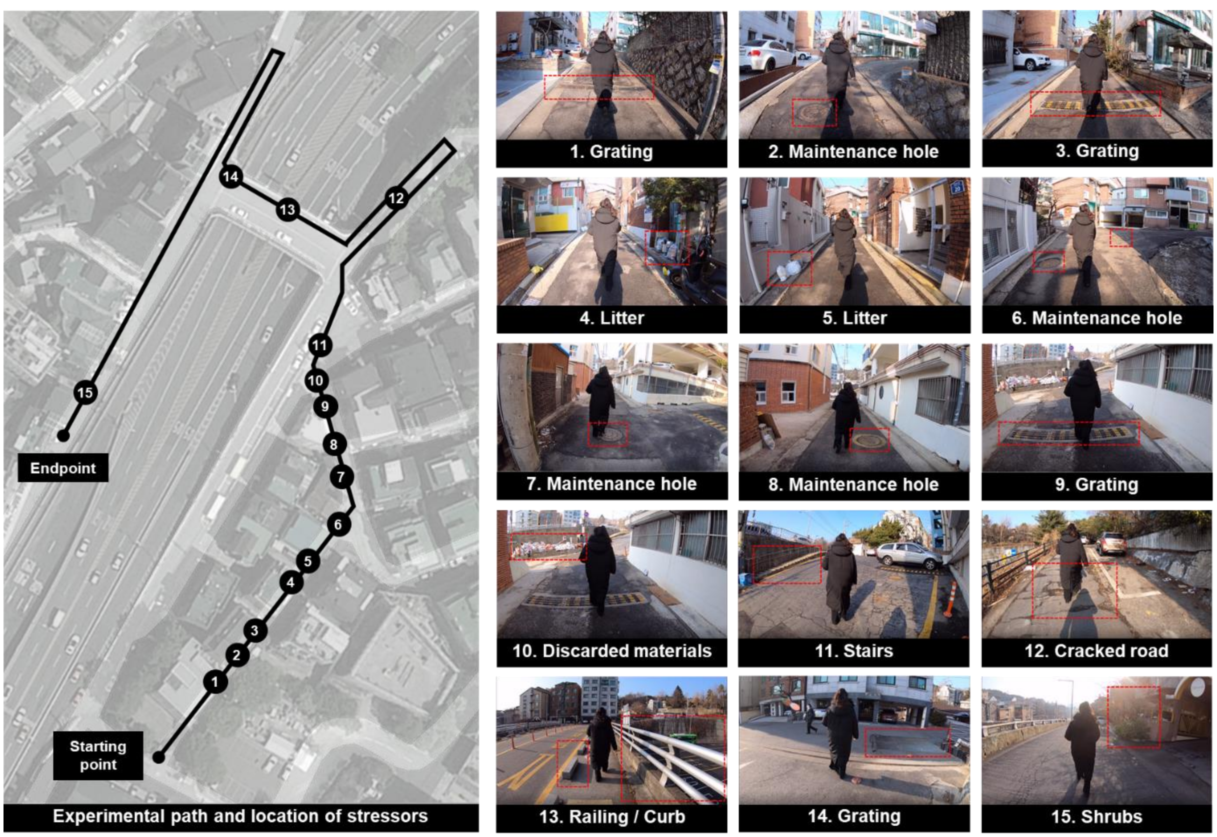

Figure 2. Experimental path and environmental stressors in the path

Figure 3 shows the behavioral and physiological data of the participants over time, collected using a GPS receiver, E4 wristband, and survey results. Figure 3(a) shows an example of the path data, showing the participants' actual paths and photographs when they walked the area including stressor 14 (i.e., grating). The path was attempted to be identified using the latitude and longitude data collected through the GPS receiver. However, the coordinate conversion accuracy was insufficient, and thus, the authors manually drew paths while watching the recorded videos. Participants 1 and 2 selected paths that bypassed stressor 14, with Participant 2 choosing a more deviated path. In contrast, Participant 3, who indicated a lower subjective influence score for stressor 14, simply passed by stressor 14. The path data indicated that the movement path pattern and degree of change differed across participants, even for the same stressors. The yellow boxes in Figures 3(b) and 3(c), show the section in which the environmental stressors (e.g., gratings, maintenance holes, litter, discarded materials, stairs, cracked roads, railings, curbs, and shrubs) existed. Figure 3(b) shows the participants' speed over time, collected through the GPS receiver. The speed was lower in the areas containing the environmental stressors. Figure 3(c) shows the integrated SCR (ISCR) values over time, obtained by analyzing EDA data. EDA indicates the change in the electronic properties of the skin in response to sweat that is autonomously secreted in an aroused state. Among various EDA characteristics, the ISCR values can indicate people's stress [27]. In this study, the ISCR values were higher in the areas containing environmental stressors. Figure 3(d) shows the responses (on a 5-point scale) for the degree of influence of environmental stressors perceived by the participant on walking behavior. The environmental stressors perceived by each participant were different, and the influence scores of each stressor were different.

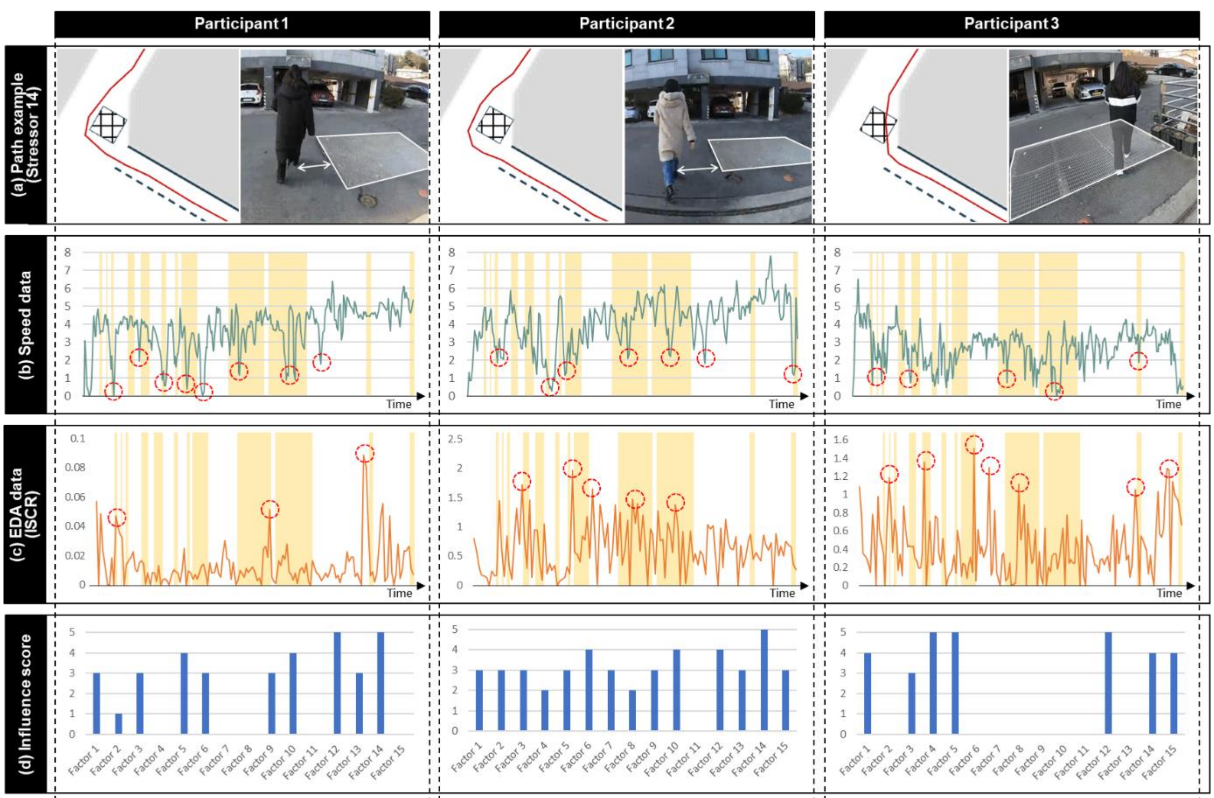

Figure 3. Behavioral and physiological data of participants over time and survey results: (a) Examples of path data (in the area containing stressor 14), (b) speed, (c) integrated SCR (ISCR), and (d) influence score for the stressors

The preliminary experimental results support the premise of this study that environmental stressors induce behavioral responses (e.g., path and speed changes). Additionally, the degree of change in behavior varies across people, and different environmental stressors incur different behavioral responses. Although path data can be used as an indicator to analyze changes in people's behavior, GPS data cannot be used to represent path data owing to inadequate accuracies. With recent advancements in machine learning and computer vision, object detection and path tracking algorithms that can yield accurate results have been established. These algorithms can be used to develop systems to automatically generate path data. For example, the authors have been developing a system for automatic object (people and physical environmental stressors) detection and path tracking, as shown in Figure 4. In future work, this system can be used to assess the human perception of environmental stressors by analyzing the collected path data.

Although the preliminary experiment involved only three participants, the results demonstrated the possibility of developing a human-behavior-based assessment framework for environmental stressors. Future research can be focused on developing quantitative models for environmental stressors by integrating the collected data. Furthermore, additional data (e.g., accelerometer, HRV, and video data) can be used to develop more reliable assessment models.

Figure 4. Sample object detection and tracking system

5. CONCLUSIONS

This paper proposes a framework for assessing environmental stressors based on human behavioral responses. The feasibility of the framework was evaluated by collecting behavioral, physiological, and psychological data of participants in a real urban environment. The proposed framework can be used for continuous urban environment monitoring. By identifying the environmental stressors that lead to considerable discomfort or displeasure, the comfort and safety associated with urban environments can be enhanced in a cost effective manner. In addition, the behavioral-response-based urban environmental stressor assessment method can be integrated into existing intelligent CCTV systems to automatically monitor the discomfort of people based on video data. The human-behavior-based city monitoring system can help understand the inconveniencing aspects of a city and implement measures to enhance the city safety and environmental quality.

ACKNOWLEDGEMENTS

This work is supported by the Korea Agency for Infrastructure Technology Advancement(KAIA) grant funded by the Ministry of Land, Infrastructure and Transport(Grant 22ORPS-B158109-03) and the National Research Foundation of Korea (NRF) grant funded by the Korean government (NRF-2020R1F1A1073178).

REFERENCES

[1] Z. Asadi-Shekari, M. Moeinaddini, and M. Zaly Shah, "A pedestrian level of service method for evaluating and promoting walking facilities on campus streets," *Land use policy*, vol. 38, pp. 175–193, 2014, doi: 10.1016/j.landusepol.2013.11.007.

[2] T. J. Pikora, F. C. L. Bull, K. Jamrozik, M. Knuiman, B. Giles-Corti, and R. J. Donovan, "Developing a reliable audit instrument to measure the physical environment for physical activity," *Am. J. Prev. Med.*, vol. 23, no. 3, pp. 187–194, 2002, doi: 10.1016/S0749-3797(02)00498-1.

[3] A. Steptoe and P. J. Feldman, "Neighborhood problems as sources of chronic stress: Development of a measure of neighborhood problems, and associations with socioeconomic status and health," *Ann. Behav. Med.*, vol. 23, no. 3, pp. 177–185, 2001, doi: 10.1207/S15324796ABM2303_5.

[4] M. A. Alfonzo, "To walk or not to walk? The hierarchy of walking needs," *Environ. Behav.*, vol. 37, no. 6, pp. 808–836, 2005, doi: 10.1177/0013916504274016.

[5] B. S. Fisher and J. L. Nasar, "Fear of crime in relation to three exterior site features: Prospect, refuge, and escape," *Environ. Behav.*, vol. 24, no. 1, pp. 35–65, 1992.

[6] T. R. Herzog and J. A. Flynn-Smith, "Preference and perceived danger as a function of the perceived curvature, length, and width of urban alleys," *Environ. Behav.*, vol. 33, no. 5, pp. 653–666, 2001, doi: 10.1177/00139160121973179.

[7] Y. Park and M. Garcia, "Pedestrian safety perception and urban street settings," *International Journal of Sustainable Transportation*, vol. 14, no. 11. pp. 860–871, 2020, doi: 10.1080/15568318.2019.1641577.

[8] P. Olszewski and S. S. Wibowo, "Using Equivalent Walking Distance to Assess Pedestrian Accessibility to Transit Stations in Singapore," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 1927, no. 1, pp. 38–45, 2005, doi: 10.1177/0361198105192700105.

[9] A. Sevtsuk, R. Basu, X. Li, and R. Kalvo, "A big data approach to understanding pedestrian route choice preferences: Evidence from San Francisco," *Travel Behav. Soc.*, vol. 25, no. June, pp. 41–51, 2021, doi: 10.1016/j.tbs.2021.05.010.

[10] B. Choi, H. Jebelli, and S. H. Lee, "Feasibility analysis of electrodermal activity (EDA) acquired from wearable sensors to assess construction workers' perceived risk," *Saf. Sci.*, vol. 115, no. February, pp. 110–120, 2019, doi: 10.1016/j.ssci.2019.01.022.

[11] S. Hwang, H. Jebelli, B. Choi, M. Choi, and S. Lee, "Measuring Workers' Emotional State during Construction Tasks Using Wearable EEG," *J. Constr. Eng. Manag.*, vol. 144, no. 7, p. 04018050, 2018, doi: 10.1061/(asce)co.1943-7862.0001506.

[12] H. Jebelli, B. Choi, H. Kim, and S. Lee, "Feasibility study of a wristband-type wearable sensor to understand construction workers' physical and mental status," *Constr. Res. Congr. 2018 Constr. Inf. Technol. - Sel. Pap. from Constr. Res. Congr. 2018*, vol. 2018-April, no. March, pp. 367–377, 2018, doi: 10.1061/9780784481264.036.

[13] S. Moon, N. Ham, S. Kim, L. Hou, J. H. Kim, and J. J. Kim, "Fourth industrialization-oriented offsite construction: case study of an application to an irregular commercial

building," *Eng. Constr. Archit. Manag.*, vol. 27, no. 9, pp. 2271–2286, 2020, doi: 10.1108/ECAM-07-2018-0312.
[14] A. Ben Mabrouk and E. Zagrouba, "Abnormal behavior recognition for intelligent video surveillance systems: A review," *Expert Systems with Applications*. 2018, doi: 10.1016/j.eswa.2017.09.029.
[15] A. A. Afiq *et al.*, "A review on classifying abnormal behavior in crowd scene," *J. Vis. Commun. Image Represent.*, vol. 58, pp. 285–303, 2019, doi: 10.1016/j.jvcir.2018.11.035.
[16] D. Helbing and P. Molnár, "Social force model for pedestrian dynamics," *Phys. Rev. E*, vol. 51, no. 5, pp. 4282–4286, 1995, doi: 10.1103/PhysRevE.51.4282.
[17] S. Seer, C. Rudloff, T. Matyus, and N. Brändle, "Validating social force based models with comprehensive real world motion data," *Transp. Res. Procedia*, vol. 2, pp. 724–732, 2014, doi: 10.1016/j.trpro.2014.09.080.
[18] Y. Han and H. Liu, "Modified social force model based on information transmission toward crowd evacuation simulation," *Phys. A Stat. Mech. its Appl.*, vol. 469, no. 88, pp. 499–509, 2017, doi: 10.1016/j.physa.2016.11.014.
[19] X. Yang, X. Yang, Y. Li, J. Zhang, and Y. Kang, "Obstacle avoidance in the improved social force model based on ant colony optimization during pedestrian evacuation," *Phys. A Stat. Mech. its Appl.*, vol. 583, p. 126256, 2021, doi: 10.1016/j.physa.2021.126256.
[20] J. Broach, J. Dill, and J. Gliebe, "Where do cyclists ride? A route choice model developed with revealed preference GPS data," *Transp. Res. Part A Policy Pract.*, vol. 46, no. 10, pp. 1730–1740, 2012, doi: 10.1016/j.tra.2012.07.005.
[21] M. F. Shaikh, Z. Salcic, and K. I. K. Wang, "A novel accelerometer-based technique for robust detection of walking direction," *IEEE Trans. Biomed. Eng.*, vol. 65, no. 8, pp. 1740–1747, 2018, doi: 10.1109/TBME.2017.2774924.
[22] H. Kim, "Wearable sensor data-driven walkability assessment for elderly people," *Sustain.*, vol. 12, no. 10, 2020, doi: 10.3390/SU12104041.
[23] C. Pham, L. Nguyen, A. Nguyen, N. Nguyen, and V. T. Nguyen, "Combining skeleton and accelerometer data for human fine-grained activity recognition and abnormal behaviour detection with deep temporal convolutional networks," *Multimed. Tools Appl.*, vol. 80, no. 19, pp. 28919–28940, 2021, doi: 10.1007/s11042-021-11058-w.
[24] R. Jansi and R. Amutha, "Detection of fall for the elderly in an indoor environment using a tri-axial accelerometer and Kinect depth data," *Multidimens. Syst. Signal Process.*, vol. 31, no. 4, pp. 1207–1225, 2020, doi: 10.1007/s11045-020-00705-4.
[25] S. Cosar, G. Donatiello, V. Bogorny, C. Garate, L. O. Alvares, and F. Bremond, "Toward Abnormal Trajectory and Event Detection in Video Surveillance," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 27, no. 3, pp. 683–695, 2017, doi: 10.1109/TCSVT.2016.2589859.
[26] Y. Hu, "Design and Implementation of Abnormal Behavior Detection Based on Deep Intelligent Analysis Algorithms in Massive Video Surveillance," *J. Grid Comput.*, vol. 18, no. 2, pp. 227–237, 2020, doi: 10.1007/s10723-020-09506-2.
[27] D. Caruelle, A. Gustafsson, P. Shams, and L. Lervik-Olsen, "The use of electrodermal activity (EDA) measurement to understand consumer emotions – A literature review and a call for action," *J. Bus. Res.*, vol. 104, no. September 2018, pp. 146–160, 2019, doi: 10.1016/j.jbusres.2019.06.041.