M-009

A Pedestrian Navigation System for Thermal Comfort

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1. Introduction

Environmental factors surrounding pedestrians are important because they significantly influence the trip qualities. In the extreme circumstances environmental factors might be even hazardous. For example hot and humid environments can result in heat strokes and sometimes cause deaths.

Although in many cases the heat strokes happened in local environments such as homes and work areas it is also crucial to consider such factors in global environments which influence the sensation of pedestrians.

Sensing and navigation technologies can help people avoid the adverse situations. In our earlier research we proposed a general framework [1] to systematically construct pedestrian comfort navigation systems.

The framework contains four key components which are the environmental data warehouse, the environmental predictor, the multi-modal sensor data fuser, and the dynamic path planner.

In this paper we illustrate the application and evaluation of the framework for thermal comfort navigation.

2. System Architecture

The system architecture can be described as a multi-layer structure shown in Figure 1. It is convenient to explain it from bottom to up.

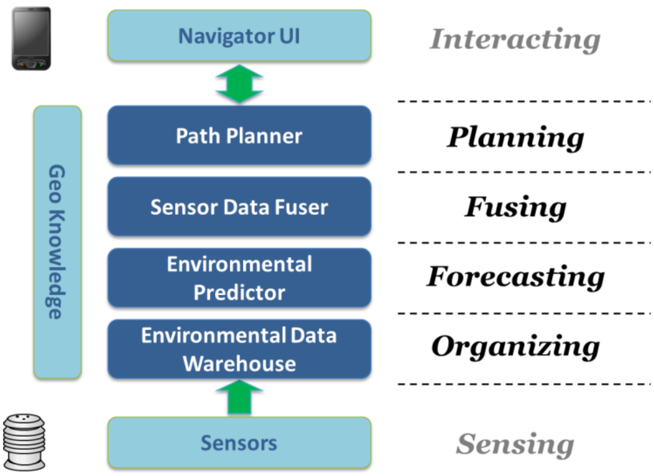

Figure 1. System architecture diagram.

At the bottom layer the sensors detect the environments. The sensors are dedicated climate devices which detect air temperature and relative humidity conditions [2].

Sensor data are sent to the environmental data warehouse in which they are organized. Raw sensor data are stored in fact tables and the aggregated values are stored in dimension tables. Data merging and interpolation techniques are applied to improve the data quality and coverage. Map matching is also performed to attribute refined geographic information to the sensor data.

The fundamental geographic knowledge is the representation of the walkable space of the pedestrians, which is modeled as a street network. The intersections are treated as nodes and the street segments are treated as edges. Such geographic information is common knowledge accessed by other components.

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The environmental predictor works closely with the environmental data warehouse since the later provides necessary information stored in dimension tables. Time series techniques have been applied to build the environmental predictor which forecasts future environmental information.

With the data fuser the multi-modal sensor data are aggregated by applying the multi-factor cost model. Then the aggregate cost value of each edge can be calculated by multiplying the aggregate cost rate by the travel time for that street edge.

The street network with attributes of environmental information is a time-dependent network. The path planner receives path queries and makes optimal path plans which have lowest aggregate cost values. Dynamic path planning techniques have been applied in constructing the path planner.

A user interface which runs on a mobile phone interacts with the pedestrian. The pedestrian uses this interface to submit path queries and receive path plans from the path planner. The received path plan is displayed on a map view on the mobile phone to perform the navigation service.

3. Application and Evaluation

Thermal comfort can be defined as: “that condition of mind which expresses satisfaction with the thermal environment” [3]. Outdoor thermal comfort in an urban climate may be affected by a wide range of environmental factors. However in many cases only sensor data of air temperature and relative humidity are available and consequently they are used to approximately estimate the thermal environmental conditions.

In the presented system time series model has been applied to build the environmental predictor which forecasts the future conditions of air temperature and relative humidity. In the selection of the appropriate model we have sampled some data sets and plotted the autocorrelation functions (ACF) and partial autocorrelation functions (PACF) of the data sequences.

On the basis of such analysis we applied autoregressive (AR) model in the construction of the predictor. Sensor data of three hours before the current time have been used as inputs to perform the online training to calculate the AR parameters.

Many index technologies which use air temperature and relative humidity information have been developed to evaluate thermal comfort. Among them WBGT (wet bulb global temperature) index plays an important role and is widely applied in many countries [4].

We used WBGT index which is published by Japanese Society of Biometeorology to estimate the cost rates of air temperature and relative humidity. This was done by taking the following steps.

First we determined the environmental states of temperature and humidity which correspond to the minimum and maximum cost rate values. This can be done on the basis of the results of surveys and interviews about thermal comfort [5], [6].

Then we applied curve fitting techniques to estimate the cost rate functions of the air temperature and humidity factors. The derived cost rates of air temperature and relative humidity are modeled as linear functions because of the high linearity exhibited by the WBGT index.

Next the aggregate cost rate can be computed by applying the multi-factor cost model. The final reproduced graph of aggregate cost rate of air temperature and relative humidity is shown in Figure 2.

Relative Humidity Level (%)	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
100	0.35	0.36	0.38	0.39	0.41	0.43	0.45	0.47	0.49	0.51	0.54	0.57	0.59	0.62	0.65	0.69	0.72	0.75	0.79
95	0.32	0.34	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.50	0.52	0.55	0.58	0.61	0.64	0.67	0.71	0.74	0.78
90	0.30	0.31	0.33	0.34	0.36	0.38	0.40	0.43	0.45	0.48	0.50	0.53	0.56	0.59	0.62	0.66	0.69	0.73	0.77
85	0.27	0.28	0.30	0.32	0.34	0.36	0.38	0.41	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.65	0.68	0.72	0.76
80	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.39	0.41	0.44	0.47	0.50	0.53	0.56	0.60	0.63	0.67	0.71	0.75
75	0.22	0.24	0.25	0.27	0.30	0.32	0.34	0.37	0.40	0.42	0.45	0.48	0.52	0.55	0.59	0.62	0.66	0.70	0.74
70	0.19	0.21	0.23	0.25	0.27	0.30	0.32	0.35	0.38	0.41	0.44	0.47	0.50	0.54	0.57	0.61	0.65	0.69	0.73
65	0.17	0.19	0.21	0.23	0.25	0.28	0.31	0.33	0.36	0.39	0.42	0.46	0.49	0.53	0.56	0.60	0.64	0.68	0.72
60	0.15	0.17	0.19	0.21	0.23	0.26	0.29	0.32	0.35	0.38	0.41	0.44	0.48	0.52	0.55	0.59	0.63	0.67	0.72
55	0.12	0.14	0.17	0.19	0.22	0.24	0.27	0.30	0.33	0.36	0.40	0.43	0.47	0.51	0.54	0.58	0.63	0.67	0.71
50	0.10	0.12	0.15	0.17	0.20	0.23	0.25	0.28	0.32	0.35	0.38	0.42	0.46	0.50	0.54	0.58	0.62	0.66	0.70
45	0.08	0.10	0.13	0.15	0.18	0.21	0.24	0.27	0.30	0.34	0.37	0.41	0.45	0.49	0.53	0.57	0.61	0.65	0.70
40	0.06	0.08	0.11	0.13	0.16	0.19	0.22	0.26	0.29	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.65	0.69
35	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.28	0.31	0.35	0.39	0.43	0.47	0.51	0.55	0.60	0.64	0.69
30	0.00	0.03	0.07	0.10	0.13	0.16	0.20	0.23	0.27	0.30	0.34	0.38	0.42	0.46	0.50	0.55	0.59	0.64	0.69

Temperature (°C)

Figure 2. The aggregate cost rate of air temperature and relative humidity.

We have used sensor data of air temperature and relative humidity gathered in July 2011 in which contain about 1.5 million pieces of sensor records. The data were gathered by 40 micro-climate sensor nodes, which composed a wireless sensor network covering an urban area about 600×600 square meters near a railway station in Tatebayashi City. Snapshots of air temperature and relative humidity distributions in the target area are shown in Figure 3 and Figure 4.

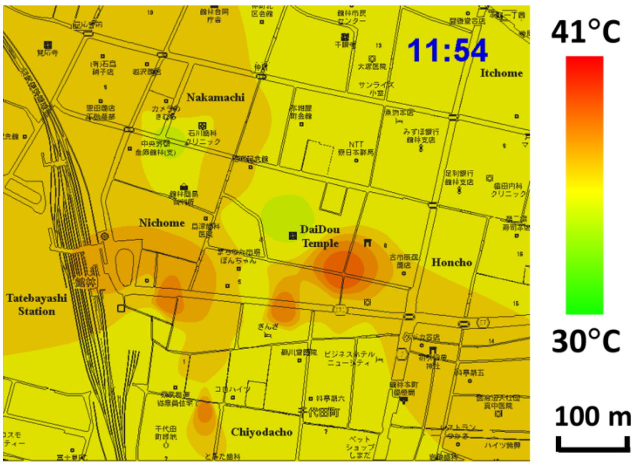

Figure 3. Snapshot of air temperature distribution.

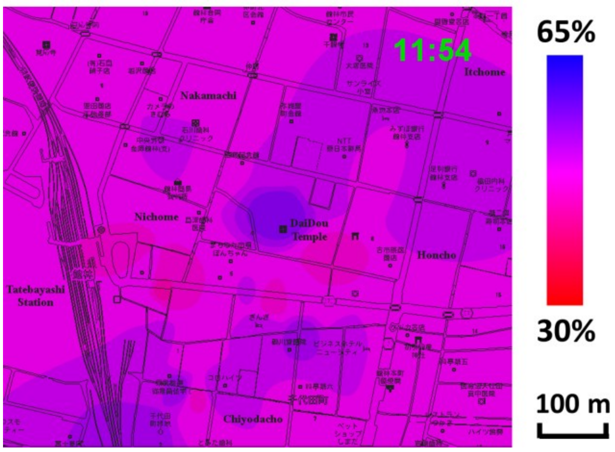

Figure 4. Snapshot of relative humidity distribution.

In the evaluation of the improvement of thermal comfort we used the thermal stress level, which is provided by Japanese Society of Biometeorology, as the metric. The stress level is measured by WBGT index value. Four stress levels are defined which are *caution*, *warning*, *severe warning*, and *danger*. Streets with thermal conditions of higher stress levels are more unfavorable for pedestrians therefore should be avoided by the navigation system in selecting path plans for pedestrians.

We used 18,000 randomly generated path queries as the input. Query distribution was determined according to the results of the person trip investigation conducted by Japanese MLIT (Ministry of Land, Infrastructure, Transport and Tourism). The paths planned by the presented navigation system were compared with the paths planned by a traditional planning algorithm which provided shortest paths.

The stress level of the travel time was checked and the results showed that among the 18,000 paths 24.3% were improved due to the reduction of time under the conditions with higher stress levels.

Compared to travel time of the paths planned by the traditional algorithm, the presented system has reduced 5.7% travel time in danger and 0.7% in severe warning. For those improved paths the average reduction rate of travel time is 14.3% for danger and 3.0% for severe warning.

The results showed that with the presented navigation system the thermal stress of pedestrians can be efficiently reduced consequently the thermal comfort of pedestrians is improved.

4. Conclusion

We have illustrated the application and evaluation of the framework of pedestrian navigation for thermal comfort. Autoregressive model has been applied in the construction of the environmental predictor. WBGT index has been used in the derivation of the cost rate functions of the air temperature and relative humidity factors. Sensor data gathered in real environments have been used in the evaluation of the system. Randomly generated path queries have been used as the input. The evaluation results demonstrated that the planned paths provided by the navigation system can improve the level of thermal comfort efficiently.

References

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