Decision Support for Route Planning to Reduce Heat Stress Considering the Time of the Day

January 20, 2017

Heat stress is a serious risk, in particular for certain groups like elderly or patients with multiple sclerosis or heart disease. Developments like the ageing of society, the increasing urbanisation (urban heat island effect) and the climate change are increasing the risk that people are affected by heat stress. One way to reduce those risks is to adapt the everyday behaviour, e.g. by performing purchases in the supermarket or pharmacy in the morning or evening when temperatures are lower.

Therefore we are presenting two different approaches for decision support tools that can help people to adapt their everyday behaviour. At first we're presenting a route planer for pedestrians that can find a route with minimal heat exposure. The second approach we're proposing is a tool that supports the user to select the point in time with a minimal risk of heat stress, considering e.g. the opening hours of a shop. In both cases we are utilizing, among other, remote sensing data of a thermal flight scanner.

Our results are showing that both approaches are able to reduce the heat exposure and therefore can help people to decrease the risk of heat stress in their everyday life.

1 Introduction

Heat is one of several natural hazards our society is faced with today. High temperatures cannot only lead to a discomfort, e.g. because of increased sweating, it can also have serious negative effects on the health.

In numerous studies an increase in both mortality and morbidity has been associated with a high ambient temperature (Basu 2009). For example an excess of mortality during the

2003 heat wave in Europe have been reported for several European countries (Kovats, Wolf, and Menne 2004).

Certain groups are especially vulnerable to heat stress such as older people or people with health problems like high blood pressure, heart, kidney, liver or metabolic diseases (Ebi et al. 2004; Hübler, Klepper, and Peterson 2007). For patients with multiple sclerosis an increased body temperature can lead to a worsening of their symptoms (Davis et al. 2010).

Developments like the ageing of society, the increasing urbanisation and the climate change is making the adaptation to heat stress danger more and more important. For instance due to the tendency that a rising number of people is moving into the cities, the urban heat island effect (UHI) is gaining more importance in the future. Because of the UHI effect an urban area can be 8 °C to 12 °C warmer than the rural areas (Prashad 2014). This is caused by the fact, that urban materials such as asphalt, concrete, and bricks are storing the energy from the sun and releasing it later to their surrounding (Prashad 2014).

There are several steps that can been taken to reduce the risk of heat stress. For instance urban planning measures like more green areas or construction measures like air conditioning or building insulation. Another important step can be the implementation of a heat warning system that enables authorise, hospitals, or retirement homes to take the appropriate actions in time (Ebi et al. 2004).

Additionally, by adapting their everyday behaviour everybody can reduce their risk by themselves. For instance, activities should be performed in the morning or evening when the temperatures are lower.

1.1 Goals

The goal of our work is to help people adapting their everyday behaviour to reduce their heat stress risk. As a use case were looking at everyday actions like go shopping in a supermarket or pharmacy. Those actions usually cannot simply be omitted because there are necessary to challenge the everyday life. Since more and more people are living in cities and do not necessarily own a car, we are focusing on pedestrians.

One possibility to reduce the heat stress is to select the appropriate time to go shopping, because usually in the morning and evening the heat exposure is lower than middays. So, it can make sense to select a shop that is further from the starting point but has longer opening hours.

Another possibility to reduce the heat stress risk is the selection of an appropriate route between the start and the destination. For instance, a longer route with more shadows and green areas can have a lower heat exposure than a shorter route and so that selecting the longer route can reduce the heat stress risk.

1.2 Related Work

Several research projects have considered environmental factors for pedestrian routing in the paste. The AffectRoute routing algorithm proposed by Huang et al. (2014) for instance takes the affective responses to the environment into account, e.g. to find a route that a person considers safer. Sharker, Karimi, and Zgibor (2012) are proposing a method to find a health optimal route, considering several environmental factors like complexity of the walking trail (slope etc.) and weather (only "Good", "Fair" or "Bad"). A method to find a route with a minimal pollution exposure has been proposed by Hasenfratz (2015) in his PhD thesis.

The NaviComf framework for pedestrian routing proposed by Dang, Iwai, Umeda, et al. (2012, 2013), enables to improve the comfort considering environmental factors varying over time. The proposed framework uses a multi-factor cost model for the evaluation of the route and enables them to consider heterogeneous environmental information from multi-modal sensors like air temperature and humidity. To find a optimal route Dang, Iwai, Tobe, et al. (2013) are proposing three different algorithms, a bounded depth-first search algorithm, an adjustable dynamic planning algorithm and a heuristic particle planning algorithm. As a sample application, the authors implemented a routing app for thermal comfort navigation. The meteorological used for this sample application have been collected using a network of 40 micro-climate sensor nodes which detected air temperature and relative humidity.

1.3 Thermal Comfort

To achieve our goals, we need a measure to describe the influence of heat on the human body. In this context, the term thermal comfort plays a key role, which describes climatic conditions consider comfortable, i.e. neither to warm nor to cold.

To describe the influence of the atmospheric environment on the human body it is not sufficient to only take the air temperature into account. Other factors like the humidity, wind speed, sun radiation clothing and physical activity playing an important role as well (Henning Staiger, Laschewski, and Grätz 2011; Hübler, Klepper, and Peterson 2007). Those it's essential to consider a complete heat budget model of the human body to be able to make any reliable statements on the thermal perception and the physiological load on the cardiovascular system (H. Staiger, Bucher, and G. Jendritzky 1997). A complete heat budget model of the human body must reach a balance between the internal heat production and environment by exchanging heat, e.g. via sweating (Henning Staiger, Laschewski, and Grätz 2011).

Over time different indices that considers a complete human heat budget model haven been developed like Steadman's heat index (Steadman 1979a, 1979b), the predicted mean vote (PMV) (Fanger 1973), the perceived temperature (H. Staiger, Bucher, and G. Jendritzky 1997; G. Jendritzky et al. 2000) or the universal thermal climate Index UTCI (Gerd Jendritzky et al. 2010).

For the examination of the thermal comfort the following meteorological parameters are important: air temperature, vapour pressure, wind velocity and mean radiant temperature of the surroundings (Matzarakis, Mayer, and Iziomon 1999).

Because we only had air temperature and the relative humidity at hand we used Steadman's heat index (Steadman 1979a) and, as a simple comparison measure, the air temperature. To compute an approximation of the heat index we used the formula published by Stull (2011, p. 77).

1.4 Contribution

In this paper we are making contributions to finding a route with minimal heat stress as well as to find a point in time with a minimal heat exposure.

To find a route with minimal heat exposure we are using a different approach then Dang, Iwai, Umeda, et al. (2012, 2013). First of all we didn't have data of a mobile sensor network at hand, instead we're used the remote sensing data of thermal scanner flight as well as the data of weather station. Another contribution is the comparison of different thermal comfort measures like air temperature and heat index. A further difference is the application of static routing algorithm instead of dynamic one as used by Dang, Iwai, Umeda, et al.

Another impotent contribution of this paper is the finding of a point in time with a minimal heat exposure. The approach which we are proposing allows to find a place and a point in time within a given search radius with a minimal heat exposure, considering constrains like the opening hours of the feasible places. Thereby we're taking the heat exposure as well as the distance to the respective places in to account.

2 Minimize Heat Exposure

We are presenting to possible ways how people can be supported to reduce their heat stress risk in their everyday life. First we're presenting an approach to find a route for pedestrian with a minimal heat exposure. On this basis, we show an approach to find a point in time with a minimal heat exposure, for instance to go shopping in a supermarket.

2.1 Finding a Route with Minimal Heat Exposure

Finding a route with minimal heat exposure can either be modelled as time-dependent or as a time-expanded routing problem. In case of a time-dependent routing problem the edge weighting function is not static and may vary over time. That means that many speed up techniques developed for static routing problems like bi-directional search cannot simply be applied (Delling et al. 2009). In the case of time-expanded routing problem every node is replaced by multiple nodes representing the node at a different time. The advantage is, that finding the shortest path in the expended graph is a static routing problem, but there can be a huge blow up of the number of nodes in the network. Those the time-expanded modelling is usually applied on e.g. timetable information (Delling et al. 2009) and we are focusing on the time-depended approach.

2.1.1 Modelling as a Time-Dependent Routing Problem

To find a optimal route we have to model the road network in an appropriate manner. In the following, we are representing the road network as undirected graph $G = (V, E, w_d, w_h)$, where V is the set of vertices or nodes (e.g. junctions) and $E \subseteq V \times V$ is the set of edges (e.g. road segments) each connecting a pair of nodes. Furthermore $w_d : E \to \mathbb{R}_{\geq 0}$ and $w_h : E \times T \to \mathbb{R}_{\geq 0}$ are to edge weighting function, at which:

- $w_d(e)$ is the length of the edge e, and
- $w_h(e, t)$ is the heat exposure of edge e at time t.

Below, a path p from node v_0 to node v_k starting a time t_0 is denoted as sequence of edge time pairs $((e_{v_0 v_1}, t_0), (e_{v_1 v_2}, t_1), \ldots, (e_{v_{k-1} v_k}, t_{k-1}))$, where t_i is the time at which node v_i is leaved. The weight of an edge is fixed at the time the traversing of the edge is started (the so-called frozen link model, Orda and Rom 1990). The point in time t_i can be computed as follows: $t_i := t_{i-1} + t_{walk}(e_{v_{i-1}, v_i})$ where $t_{walk}(e_{v_{i-1}, v_i})$ is the time needed by a pedestrian to traverse the edge e_{v_{i-1}, v_i}. The starting time t_0 is ether given or set to 0.

To compute the weight of a path $w_h(p)$ the following formula can be applied:

$$w_h(p) := \sum_{(t,e) \in p} w_h(e,t). \tag{1}$$

Those means we are looking for the path p^* from a node u to a node v that has the minimal weight of all possible path from v to u. Below, we are using $w_h(p,t)$ to denote the weight of the path p starting at time t.

The time-dependent routing problem is $\mathcal{NP}$-hard, if it is not allowed to wait on a node and the FIFO (first in, first out) or non-passing property is not fulfilled (Orda and Rom 1990). A edge weighting function $w : E \times T \to \mathbb{R}_{\geq 0}$ stratifies the FIFO property if for all edges $e = (u,v) \in E$ and all points in time $t, t' \in T$ with $t \leq t'$ the following holds (Ahn and Shin 1991):

$$t + w(e,t) \leq w(e,t'). \tag{2}$$

In other words, a weighting function w fulfils the FIFO property when the numerator (change of the edge weight) decreases not faster than the denominator (change in actual time) increases, i.e. the slope of the weighting function is greater or equals to -1 (Kaufman and Smith 1993).

Usually, we cannot assume that w_h fulfils the FIFO property, because the function most of the time depends on the air temperature and the decrease of the air temperature can be more than -1. Since, most people are not willing to wait at a node as well, finding a route with a minimal heat exposure is $\mathcal{NP}$-hard. Therefore, hereafter the edge weighting is frozen at the starting time t_0 so that we have static route planning problem a classic algorithms like Dijkstra's algorithm (Dijkstra 1959) can be applied.

2.1.2 The Edge Weighting Function

- general modelling (distance times heat exposure), $T^{comfort}$ as lower bound
- mapping raster cells to road network
- explain data available (or should that be part of)

2.2 Finding the Optimal Point in Time

- general idea
- the three steps to find the optimal point in time

1. Nearby search
2. Find the optimal point in time
3. ranking by the optimal value found in step 2

2.2.1 Modelling as a Optimization Problem

- modelling of the constrains
- objective function (only the modelling where the heat exposure of the path is used as objective function, equation 4.5 in the master thesis)

2.2.2 Optimization

- transformation of the constrains to a lower and a upper bound
- introduction of a penalty term if the constrains are violated
- simple optimization algorithms without derivatives like Brent's method can be applied

3 Evaluation

3.1 Data Set

3.2 Evaluation of the Routing

- How wo the evaluation performed / what was the setting used
- results (only an overview and some of the most impotent numbers)
- an example

3.3 Evaluation of the Optimal Time

- How wo the evaluation performed / what was the setting used
- results
- results (only an overview and some of the most impotent numbers)
- an example

4 Conclusion

- main insights:
  - both routing and finding the optimal time can reduce heat exposure significantly
  - the proposed approaches can help people ot adapt their everyday behaviour to reduce their heat stress risk
- non restrictions of our approach / possible improvements
  - the data basis can be improved (e.g. via a locale sensor network)
  - using a dynamic instead of static routing approach
  - find a optimal tour for multiple shops

5 Story

- Motivation
  - heat is critical for humans
  - particular problems for risk groups (illness, old, etc)
  - walking to areas often done action in particular to typical locations (shopping, health care, etc)

  - those actions have to be done

- Problem definition
  - how to minimize the impact of heat stress on walking paths?
  - subdivided into:
    * for a given route?
    * When and how to walk typical routes, e.g. pharmacy, doctor

- method:
  - Goal of this paper: We want to provide a routing method to minimize the heat stress of typical walking actions
  - We do so by providing a value function for heat stress which can be used in route planning

- Evaluation:
  - Our data set
  - Evaluation 1 on routes given date in time. (pure routing approach) and its metrics
  - Evaluation 2: producing queries for typical walking tasks (our selection) and their evaluation
  - implementation as a demonstrator is produced and available at *homepage*

- Conclusion and contribution

References

Ahn, Byong-Hun and Jae-Yeong Shin (1991). "Vehicle-Routeing with Time Windows and Time-Varying Congestion". In: *The Journal of the Operational Research Society* 42.5, pp. 393–400. DOI: 10.2307/2583752.

Basu, Rupa (2009). “High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008”. In: *Environmental Health* 8, p. 40. DOI: 10.1186/1476-069X-8-40.

Dang, Congwei, Masayuki Iwai, Yoshito Tobe, et al. (2013). “A framework for pedestrian comfort navigation using multi-modal environmental sensors”. In: *Pervasive and Mobile Computing*. Special Issue: Selected Papers from the 2012 IEEE International Conference on Pervasive Computing and Communications (PerCom 2012) 9.3, pp. 421–436. DOI: 10.1016/j.pmcj.2013.01.002.

Dang, Congwei, Masayuki Iwai, Kazunori Umeda, et al. (2012). “NaviComf: Navigate pedestrians for comfort using multi-modal environmental sensors”. In: *2012 IEEE International Conference on Pervasive Computing and Communications (PerCom)*. 2012 IEEE International Conference on Pervasive Computing and Communications (PerCom), pp. 76–84. DOI: 10.1109/PerCom.2012.6199852.

Davis, Scott L. et al. (2010). “Thermoregulation in multiple sclerosis”. In: *Journal of Applied Physiology* 109.5, pp. 1531–1537. DOI: 10.1152/japplphysiol.00460.2010.

Delling, Daniel et al. (2009). “Engineering Route Planning Algorithms”. In: *Algorithmics of Large and Complex Networks*. Ed. by Jürgen Lerner, Dorothea Wagner, and Katharina A. Zweig. Lecture Notes in Computer Science 5515. Springer Berlin Heidelberg, pp. 117–139. DOI: 10.1007/978-3-642-02094-0_7.

Dijkstra, E. W. (1959). “A note on two problems in connexion with graphs”. In: *Numerische Mathematik* 1.1, pp. 269–271. DOI: 10.1007/BF01386390.

Ebi, Kristie L. et al. (2004). “Heat Watch/Warning Systems Save Lives: Estimated Costs and Benefits for Philadelphia 1995–98”. In: *Bulletin of the American Meteorological Society* 85.8, pp. 1067–1073. DOI: 10.1175/BAMS-85-8-1067.

Fanger, P. O. (1973). “Assessment of man’s thermal comfort in practice”. In: *British Journal of Industrial Medicine* 30.4, pp. 313–324. DOI: 10.1136/oem.30.4.313.

Hasenfratz, David (2015). “Enabling Large-Scale Urban Air Quality Monitoring with Mobile Sensor Nodes”. PhD thesis. Zürich: ETH-Zürich. DOI: 10.3929/ethz-a-010361120.

Huang, Haosheng et al. (2014). “AffectRoute – considering people’s affective responses to environments for enhancing route-planning services”. In: *International Journal of Geographical Information Science* 28.12, pp. 2456–2473. DOI: 10.1080/13658816.2014.931585.

Hübler, Michael, Gernot Klepper, and Sonja Peterson (2007). *Costs of Climate Change: The Effects of Rising Temperatures on Health and Productivity in Germany*. Kiel Working Paper 1321. Kiel: Kiel Institute for the World Economy. URL: https://www.ifw-members.ifw-kiel.de/publications/costs-of-climate-change-the-effects-of-rising-temperatures-on-health-and-productivity-1/Costs%20of%20Climate%20Change%2009-2007.pdf (visited on 01/14/2017).

Jendritzky, Gerd et al. (2010). “The Universal Thermal Climate Index UTCI”. In: *Proceedings of the 7th Conference on Biometeorology, Freiburg, Germany, April 12-14th, 2010*. Ed. by Andreas Matzarakis, Helmut Mayer, and Frank-M. Chmielewski. Vol. 20. Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg. Freibug, pp. 184–188. URL: http://www.mif.uni-freiburg.de/biomet/bm7/report20.pdf (visited on 01/18/2017).

Jendritzky, G. et al. (2000). “The Perceived Temperature: The Method of the Deutscher Wetterdienst for the Assessment of Cold Stress and Heat Load for the Human Body”. In: *Internet Workshop on Windchill, April 3-7, 2000, Meteorological Service of Canada.* URL: http://www.utci.org/isb/documents/perceived_temperature.pdf (visited on 01/18/2017).

Kaufman, David E. and Robert L. Smith (1993). “Fastest Paths in Time-Dependent Networks for Intelligent Vehicle-Highway Systems Application”. In: *I V H S Journal* 1.1, pp. 1–11. DOI: 10.1080/10248079308903779.

Kovats, Sari, Tanja Wolf, and Bettina Menne (2004). “Heatwave of August 2003 in Europe: provisional estimates of the impact on mortality”. In: *Eurosurveillance Weekly* 8.11, p. 11. URL: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=2409 (visited on 01/14/2017).

Matzarakis, Andreas, H. Mayer, and M. G. Iziomon (1999). “Applications of a universal thermal index: physiological equivalent temperature”. In: *International Journal of Biometeorology* 43.2, pp. 76–84. DOI: 10.1007/s004840050119.

Orda, Ariel and Raphael Rom (1990). “Shortest-path and Minimum-delay Algorithms in Networks with Time-dependent Edge-length”. In: *Journal of the ACM* 37.3, pp. 607–625. DOI: 10.1145/79147.214078.

Prashad, Lela (2014). “Urban Heat Island”. In: *Encyclopedia of Remote Sensing.* Ed. by Eni G. Njoku. Encyclopedia of Earth Sciences Series. Springer New York, pp. 878–881. DOI: 10.1007/978-0-387-36699-9_81.

Sharker, Monir H., Hassan A. Karimi, and Janice C. Zgibor (2012). “Health-optimal Routing in Pedestrian Navigation Services”. In: *Proceedings of the First ACM SIGSPATIAL International Workshop on Use of GIS in Public Health.* HealthGIS ’12. New York, NY, USA: ACM, pp. 1–10. DOI: 10.1145/2452516.2452518.

Staiger, H., K. Bucher, and G. Jendritzky (1997). “Gefühlte Temperatur: Die physiologisch gerechte Bewertung von Wärmebelastung und Kältestreß beim Aufenthalt im Freien mit der Maßzahl Grad Celsius”. In: *Annalen der Meteorologie.* Vol. 33. Offenbach am Main: Deutscher Wetterdienst, pp. 100–107. URL: http://www.dwd.de/DE/leistungen/pbfb_verlag_annalen/pdf_einzelbaende/33_pdf.pdf?__blob=publicationFile&v=3 (visited on 06/07/2016).

Staiger, Henning, Gudrun Laschewski, and Angelika Grätz (2011). “The perceived temperature – a versatile index for the assessment of the human thermal environment. Part A: scientific basics”. In: *International Journal of Biometeorology* 56.1, pp. 165–176. DOI: 10.1007/s00484-011-0409-6.

Steadman, R. G. (1979a). “The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science”. In: *Journal of Applied Meteorology* 18.7, pp. 861–873. DOI: 10.1175/1520-0450(1979)018<0861:TAOSPI>2.0.CO;2.

– (1979b). “The Assessment of Sultriness. Part II: Effects of Wind, Extra Radiation and Barometric Pressure on Apparent Temperature”. In: *Journal of Applied Meteorology* 18.7, pp. 874–885. DOI: 10.1175/1520-0450(1979)018<0874:TAOSPI>2.0.CO;2.

Stull, Roland (2011). *Meteorology for Scientists and Engineers*. 3rd ed. Vancouver: University of British Columbia. ISBN: 978-0-88865-178-5. URL: https://www.eoas.ubc.ca/books/Practical_Meteorology/mse3.html (visited on 01/18/2017).