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# Visualization of Spatial Uncertainty Improves Map Matching

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**Abstract:**

Landmark representations play an important role in map-based orientation and navigation. By matching these representations, usually in the form of pictograms, to the represented real-world landmarks, people are able to self-localize themselves within real-world space (Kiefer et al., 2014). However, successful map matching has been found to be affected by the spatial accuracy of landmark representations in a map (Keil et al., 2022). Spatially inaccurate landmark representations evoke uncertainty in the map reader whether map representations match the represented 3D space. These findings imply that, despite the spatially accurate representation of other map elements, a single spatially inaccurate map representation might compromise self-localization. Especially in the context of maps based on volunteered geographic information (VGI), it is important to address issues of potential spatial inaccuracies and the resulting uncertainty. VGI data quality can be very heterogenous, as it depends on the equipment, motivation and skills of the volunteers involved in the data acquisition process (van Exel et al., 2010; Girres & Touya, 2010).

According to Pang et al. (1997), visualizing uncertainty of data leads to more informed decision making. In the context of map matching, we argue that visualizing uncertainty concerning the correct spatial representation of landmarks helps to sustain successful self-localization. If map users are informed about potential spatial inaccuracies, they could adapt to discrepancies between the real-world landmark locations and landmark representations in the map or focus on other (less uncertain) map representations. Thus, visualizing spatial uncertainty should decrease the likelihood of a perceived mismatch between maps and represented 3D spaces due to single spatially inaccurate landmark representations. We investigated this assumption by expanding the experimental approach applied by Keil et al. (2022). Participants were asked whether displayed maps matched simultaneously displayed virtual 3D environments containing a visually salient landmark. The use of a virtual 3D environment allowed us to fully control the displayed stimuli and the location of landmarks. Responses were given by selecting a value on a continuous scale ranging from a certain mismatch to a certain match. Random spatial inaccuracies were applied to a landmark representation in the maps. Additionally, we used different visualizations to communicate spatial uncertainty concerning the locations of the landmark representations. In addition to a control condition, size and transparency of landmark pictograms as well as circular transparent uncertainty areas were used to represent spatial uncertainty. Size and transparency were chosen based on suggestions of Padilla et al. (2014) and Kinkeldey et al. (2014). Uncertainty areas were investigated due to their use in Google Maps as a visualization for spatial uncertainty of GPS information.

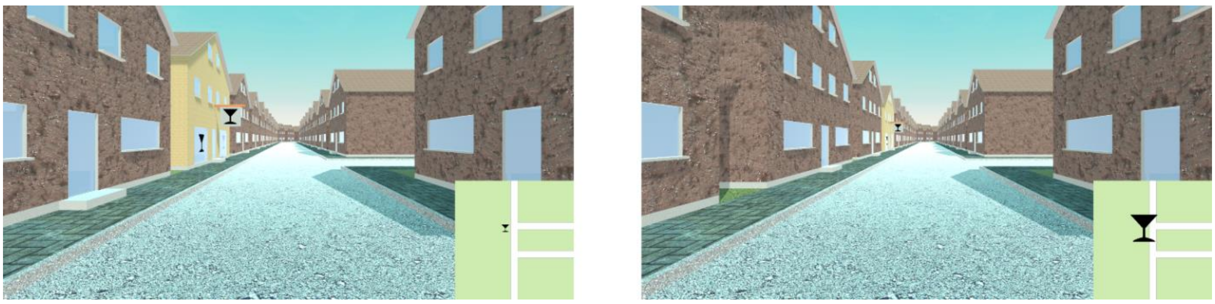

Figure 1. Experiment design and examples of pictogram size modifications. In the left example, spatial inaccuracy of the landmark pictogram is low. In the right example, spatial inaccuracy of the landmark pictogram is high and the size of the landmark pictogram is increased to visualize uncertainty concerning its correct spatial representation.

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The results demonstrate that participants were significantly more likely to perceive a match between the maps and the corresponding 3D environments when uncertainty areas or pictogram size modifications were used to visualize potential spatial inaccuracies. However, applying transparency to the landmark pictograms did not lead to significant differences compared to the control condition. According to MacEachren et al. (2012), transparency can only be perceived if background elements are visible through the transparent element. Thus, as the map background behind transparent pictograms was a monochrome green, participants might only have perceived transparency based on different transparency values from previous trials.

Taken together, the findings support our assumption that the visualization of uncertainty can help to sustain successful self-localization in the context of spatially inaccurate map information. Uncertainty areas and pictogram size modifications were identified as effective means to communicate spatial inaccuracy of map representations and to improve map matching. Concerning the use of transparency, more research is required, as its effectiveness might depend on an interaction with the underlying map elements.

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