Trajectory Data Visualization on Mobile Devices with Animated Maps

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Abstract

With the increasing popularity of mobile devices (like smartphones and tablets) and georeferenced applications, more people record and analyse their own movement data. This pattern is noticeable with the increasing usage of mobile applications that, in addition to record the evolution of a person's location over time, also allow the visualization of that information, typically, in the form of 2D static maps, complemented with various representations to extract knowledge from the data. Despite the various studies addressing spatio-temporal data visualization, its application on mobile devices for the representation of personal trajectory data is still somewhat unexplored. Animated maps have been proposed as a potential intuitive and appealing technique for the visualization of information in a dynamic way, particularly for the detection of spatio-temporal data relations. We aim to address these issues by presenting a comparative study between static and animated representations of human movement on a mobile device context. Our results suggest that although it may not significantly improve user understanding of the data, the use of animated maps is a preferred and less interactively demanding option over static maps.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Animations I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques

1. Introduction

The increasing popularity and commercial availability of sensors and location based services, particularly on mobile devices, resulted in an easier and more common collection of large amounts of spatio-temporal data, representing trajectories, actions, and user performance [ARH*15]. Consequently, citizens have been increasingly exposed to large amounts of information, not necessarily related to their professional interests, yet still relevant on a personal context [HTA*15]. An example of this growing pattern consists on the common usage of *mobile exertion* applications, like Runkeeper or Nike Plus (see Figure 1a and 1b) that record the trajectories taken by the users and allow the visualization of that data, complemented with various statistics, like speed or estimated burnt calories. The understanding of this data can, in turn, help non-experienced users (i.e. people without formal spatio-temporal data analysis knowledge) to vary and/or improve their daily activities [HTA*15], making it, therefore, important to use adequate visualization techniques to explore and analyse these data.

Due to the spatial properties associated with spatio-temporal data, particularly trajectories, map-based techniques are regarded as essential tools for their visualization [KO10]. In particular, 2D static maps are among the most used techniques to represent georeferenced information. Typically, points and/or lines are used over
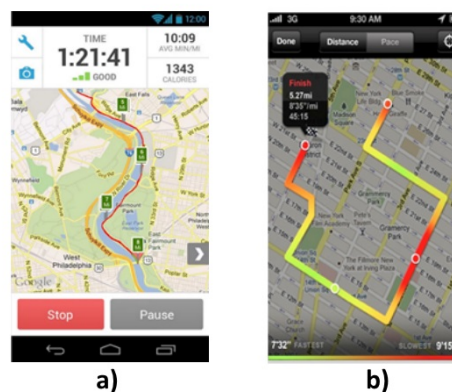
Figure 1: *Mobile applications for personal trajectory data visualization a) RunKeeper b) Nike Plus*

the geographical plane to represent the evolution of the positions of objects over time, while symbols and/or visual variables associated to existing marks, like the colour, or shape of a point, can be used to represent other types of *thematic* information, like speed, direction, or elevation (see Figure 1). Despite excelling in the representation of the spatial component, 2D static maps tend to undermine the

data's temporal component, thus often requiring the combination of additional visualizations (e.g., time series graphs) [AAB*13]. On a mobile device context, this issue is even worse, due to the devices' screen size limitations. Therefore it is important to study alternative approaches to visualize both spatial and temporal data.

Animated maps can be seen as an alternative to common static map representations. By taking advantage of the computer's capability to rapidly update its contents, animated maps automatically display a sequence of maps (*frames*), usually, in a single view. Cartographic animations can be sub-divided into: temporal animations, when information is displayed on a chronological order, implying a direct relation between the animation time and real time; or non-temporal animations, when used to emphasize differences in representation without any relation to real time (e.g. flickering over a symbol to capture the user's attention) [HF08, KO10]. Compared to static maps, animated maps have an additional dimension, animation time, where information can be presented. This allows the use of other visual variables, like colour or size, to represent other types of information. Consequently, previous studies suggest that animated displays can help revealing spatio-temporal features and moving patterns, like variations in speed, that are not evident with common static representations [MCHP98, GMH*06, SSKY04, WvdWvW11]. However, the amount of data presented increases with the duration of the animation. Moreover, each frame will only be displayed temporarily. Consequently, these factors may raise some cognitive and perceptual limitations, since the longer the animation, the less likely the user will memorize all relevant information [HF08]. Consequently, some studies have also concluded that the use of animation displays is ineffective in more complex analysis tasks [KPSL10], even though it may be considered as more engaging to use and that it has the potential for presentation purposes (e.g., in classes) [RFF*08, OK02]. It is plausible to assume that these last results may have an important role in the representation of information in personal contexts, as the visualization of this data tends to be done in contexts that should require a reduced cognitive workload, such as when users want to *fill the gaps* in time when bored or curious [HTA*15].

Despite the increasing number of visualization techniques for spatio-temporal and trajectory data, the study of their usability is often somewhat *neglected*, particularly with inexperienced users, that despite their lack of experience, may still be interested in the analysis of their data [HTA*15, Rot13]. In addition, the study of these issues on a mobile device context, particularly regarding the use of animated map representations is still a *somewhat* unexplored topic. As such, this paper aims to address these issues. For that, we conducted a preliminary user study to compare two types of animated map prototypes for the visualization of personal trajectory data, with a static counterpart, on a mobile device context. The remainder of this paper is organized as follows: the next Section presents the three prototypes studied; Section 3 describes the user study and results obtained; and Section 4 concludes with a discussion on the results, and with ideas for future work.

2. Compared Visualizations

We developed three prototypes focused on the visualization of personal trajectories: two variants of the animated map technique and one 2D static map. All prototypes used a similar representation focused on four types of information, based on related applications: the trajectory followed and the differences in altitude, direction, and speed (see Figure 2 i).

To decide what type of visual representation to use, we conducted a pilot study with 10 participants, where, given various representations, they were inquired about their preferences. All participants were familiar with geographic visualization, however, none of them had practice on spatio-temporal analysis. Based on the users' feedback, trajectories are represented as a sequence of points connected with lines. The direction of movement is depicted using arrows, located at various points alongside the line. Each line-segment is coloured according to the user's speed, in a four colour scale (green to red). On the other hand, altitude is depicted with point symbols located in areas with high variations of this attribute, where the larger the symbol, the higher the altitude represented. Finally, in the animated map prototypes, two symbols located at the bottom right corner are used to display the current values of speed and altitude (Figure 2 ii).

Despite their similarities in how the data is visually presented, each prototype behaves differently. The first (*AM1*) consists of an animated map with a focus on the movement history, in which the map's centre and zoom level are adapted so that the entire geographical area in which movement was detected is visible as the animation progresses (unless interactively changed through pan/zoom operations) (Figure 2 b). The second prototype (*AM2*) consists of an animated map with a focus on the current moment. During the animation, the map's centre is constantly updated to the position of the current location represented in the animation, emphasizing the *current* state of the user (Figure 2 c). The third consists of a static 2D map (*SM*), representing the entire trajectory, similarly to the end result of playing any of the previous animations.

All prototypes support common pan/zoom map operations. In addition, at the bottom of the screen, users can interact with a temporal slider, allowing users to change the current time represented in the map and providing information about the time of animation passed (when used) and how long to finish (Figure 2 iii). Finally, clicking on any point in the map provides detailed information about the state of the user on the selected location.

3. User Study

This Section describes the comparative user study conducted with the described prototypes, in which we aimed at evaluating the effects of the use of temporal animations over the participants' memory, performance, and interaction, with a visualization of personal trajectory data on a mobile device context. Based on the features of each prototype, our hypotheses were the following: *(H1)* animated maps, in particular with a focus on the movement history, will be preferred over static maps; *(H2)* animated maps will be more adequate in helping users understanding the information displayed; and *(H3)* static maps will be more adequate in helping users analysing detailed information.

A total of 10 participants volunteered to the study, aged between 17 and 63 (Av: 32.3, SD: 16.5). Although all participants
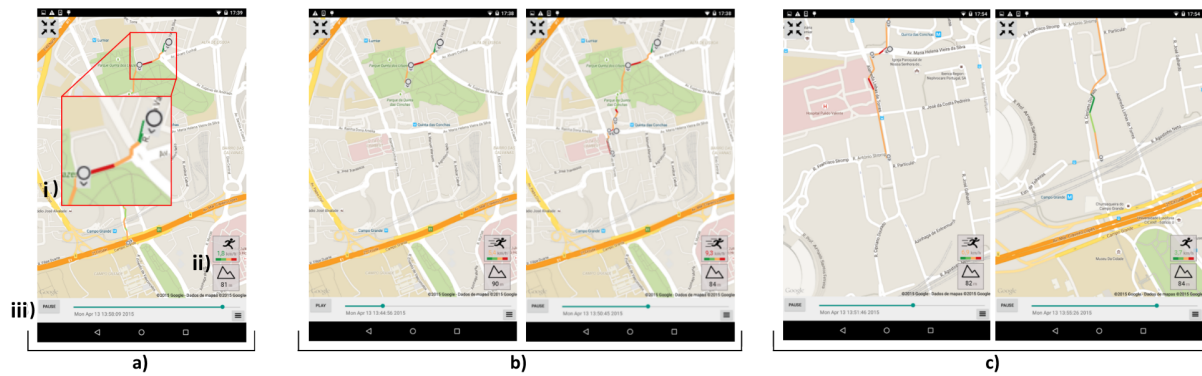
Figure 2: *a) Trajectory data representation: 1) Line colour, elevation symbol size, and direction arrow; 2) Current speed and altitude icons 3) Time slider b)* AM1 *Animated map with focus on the movement history c)* AM2 *Animated map with focus on the current location*

were knowledgeable with computer applications for finding specific points of interest (e.g., Google Maps), none of them were experts with trajectory data analysis, nor had any prior information regarding the datasets that they had to visualize.

To test our hypotheses, the participants performed two tasks based on the most common types of cartographic visualization objectives described in the literature [Rot13]. The first, *identify*, required the participants to describe a trajectory displayed in the prototype in terms of the variation of speed, elevation, and direction, using a set of keywords (e.g., *The variation in speed was <constant/increasing/decreasing>*). The second, *compare*, required the participant to determine in which locations the represented user moved faster and/or over a higher location.

The experiment followed a *within subjects* design and all participants carried out each task individually, in a controlled environment. At the beginning of the study, subjects were briefed about the objectives of the experiment. Before carrying out the tasks, they were asked to interact with the applications and encouraged to clarify any doubts. After the training phase, the participants performed the two tasks, with the different prototypes. In both tasks, participants were given a period of two minutes to freely analyse a random trajectory with the visualization. After that, in the first task, the participants had to complete various sentences to describe the data, with a set of keywords. In the second task, the participants were shown a static representation of the map they had just analysed without any thematic information (i.e., without information regarding speed, altitude, and direction), in which they had to select a region correspondent to the objective of the task.

To mitigate sequence effects, the order in which the independent variables were presented was counterbalanced based on a *latin-square* design. Thus, each participant performed a total of 6 tasks, without repetitions: 3 visualization techniques x 2 tasks. Finally, to assess our hypotheses, we considered the following dependent variables: (i) subjective preferences: participants were asked to rate the ease of use of each prototype on 0 to 5 scale; (ii) task accuracy: in the first task, an error corresponds to an incorrectly chosen keyword (percentage between correct and total answers); in the second, accuracy was calculated in function of the distance (in meters)

from the selected location to the correct one; (iii) task completion time; and (iv) number of actions, including pan/zoom operations and temporal slider manipulations.

4. Results

This Section overviews the results obtained in the study, with a focus on the most statistically significant ones. For the analysis of the participants' **task completion times** and **number of actions**, we subjected the data to the Shapiro-Wilk test of normality. Following the results, regarding the **task completion times**, we applied a repeated measures ANOVA, followed by Bonferroni tests for pairwise comparisons. Regarding the **number of actions**, since no normalized dataset was provided, we applied a Friedman's test, followed by a Wilcoxon Signed Rank test, with a Bonferroni correction, for pairwise comparisons, to analyse the differences in the results after each task. Table 1 (a and b) shows the participants' mean results for both tasks. Regarding the **task completion times**, the tests revealed significant differences in the **compare** task ($F(1.3) = 8.514$, $p = 0.01$). The pairwise comparison tests revealed significant lower times after the analysis with *AM1* comparing to *AM2* ($p = 0.014$). Regarding the **number of actions**, the tests revealed significant differences in both tasks ($X^2(2) = 18.2$, $p < 0.001$ and $X^2(2) = 14.2$, $p = 0.001$ for the **identify** and **compare** tasks, respectively). Pairwise comparison tests revealed a significant smaller number of actions when using *AM1*, comparatively to the other two ($p \leq 0.008$ in all cases) and a significant higher number of actions when using *AM2*, comparing to *SM*, in the **identify** task ($p = 0.005$). To analyse the differences between the participants' **preferences**, we followed a similar procedure to the analysis of the **number of actions**. Table 1 (c) shows the average preferences for both tasks, with the different prototypes. In the **compare** task, participants have shown a higher preference ($X^2(2) = 11.7$, $p = 0.003$) towards *AM1* comparatively to *SM* ($Z = -2.69$, $p = 0.007$). These results, in turn, go in agreement with our first hypothesis (*H1: participants would prefer animated representations*). Finally, Table 1 (d) shows the participants' average accuracy for both tasks, with the different prototypes. However, no significant differences were detected in either task.

Table 1: *Mean participants' results in terms of a) task completion time (in seconds), b) number of interactive actions, c) subjective preferences (0 to 5 scale), and d) task accuracy (identify: in percentage values; compare: in meters)*

	Identify			Compare		
	SM	AM1	AM2	SM	AM1	AM2
a) Time (sec)	37.30	44.50	42.10	8.03	**7.69**	15.71
b) N° Actions	20.7	**3.3**	34.1	40.9	**13.6**	56.8
c) Preferences	3.8	4.5	3.1	2.4	**4.8**	3.7
d) Accuracy	58%	64%	64%	334 m	132 m	109 m

5. Discussion

Based on the results of this study, it is not possible to conclude that animated maps improve user's accuracy in identifying or comparing movement features in (personal) trajectory data. However, judging by the average results obtained, it is worth considering the possibility of such differences not being found due to a lack of more test subjects.

On the other hand, the results suggest that the focus of the animation has an effect over its usability, due to the significant differences found comparing the animated map with a focus on the total movement (*AM1*), with the map with focus on the current location (*AM2*). Although it did not affect the participants' preferences, *AM2* forced them to perform more actions, by manipulating the map (pan/zoom) and controlling the temporal flow of the animation (time slider) to obtain and confirm information. In fact, some participants complained that seeing the map constantly changing, due to the update of its centre, was sometimes distracting, making it more difficult and less pleasant to interpret the data displayed in the trajectory lines. On the other hand, *AM1* allowed the participants to acquire and confirm information faster, with fewer actions, which, in turn, was reflected on their preferences. Overall, participants praised this prototype for its ability to provide understandable information on the variations of speed, for being more *interesting*/appealing to look at, compared to a static map (*SM*), and due to its temporal controls allowing to *transform* the animated map into a static one, by pausing the animation at any moment. These results are particularly relevant, considering the potential for personal visualization applications being used in *leisure* scenarios [HTA*15], which may require the visualization to be appealing, informative, and simple to use. In turn, the results suggest that *AM1* possesses these features and the potential to be further explored in larger and more complex studies.

6. Conclusions and Future Work

This paper presented a comparative study between two variants of animated maps and a static map, for the visualization of human trajectories, on a personal context in mobile devices. The results point out that, although no significant differences were found in terms of accuracy, the use of animated maps is preferred over static approaches. Moreover, the focus of the animation can affect the usability of the application, as participants were able to complete the tasks faster and required a smaller number of interactive actions, with animations with a focus on the total trajectory, compared to animations with a focus on the current instant of movement.

Nevertheless, we argue that further studies should still be conducted. As future work, we propose to continue studying the effects of animated maps over trajectory visualization on mobile devices. In particular, we aim at studying the effects of different types of representation and controls over the animation flow, in more complex tasks and with a higher number of test subjects.

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