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Beyond the Shortest Route: A Survey on Quality-Aware Route Navigation for Pedestrians

PANOTE SIRIARAYA[1], YUANYUAN WANG[2], YIHONG ZHANG[3], SHOKO WAKAMIYA[4], PÉTER JESZENSZKY[5], YUKIKO KAWAI[3,6], AND ADAM JATOWT[7]

[1]Faculty of Information and Human Science, Kyoto Institute of Technology, Kyoto 606-8585, Japan
[2]Graduate School of Sciences and Technology for Innovation, Yamaguchi University, Ube 755-8611, Japan
[3]Department of Multimedia Engineering, Osaka University, Suita 565-0871, Japan
[4]Division of Information Science, Graduate School of Science and Technology, Nara Institute of Science and Technology, Ikoma 630-0192, Japan
[5]Department of Geography, Ritsumeikan University, Kyoto 603-8577, Japan
[6]Faculty of Information Science and Engineering, Kyoto Sangyo University, Kyoto 603-8555, Japan
[7]Department of Social Informatics, Kyoto University, Kyoto 606-8501, Japan

Corresponding author: Panote Siriaraya (spanote@kit.ac.jp)

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ABSTRACT Navigation systems often aid users when traveling in unfamiliar locations. Current navigation systems tend to focus on identifying the shortest or fastest routes between two points. However, path cost expressed in terms of length and distance (i.e., the utilitarian qualities of travel) is only one attribute which could be used in route recommendation. Recent years have seen navigation systems moving beyond such utilitarian attributes. These include systems aimed at providing users with scenic, safe or attractive routes among other dimensions. In this paper, we contribute to the existing research domain by providing an overview of the different quality-aware route navigation systems that have been proposed in past research for pedestrians. In particular, we examine the different qualities which have been used as key criteria in route recommendation. As the outcome of the paper, we provide a categorization of these systems based on our proposed SWEEP taxonomy. In addition, we outline the various data sources, algorithms and evaluation approaches that have been used to implement quality-aware route navigation systems. Afterwards, we conclude by discussing potential problems encountered in previous studies and highlight promising directions for future research.

INDEX TERMS Navigation, route planning, mobile computing, social media services.

I. INTRODUCTION

Automatic route navigation systems have become an essential tool in modern society for people who wish to navigate in physical spaces, especially within unknown areas. Before the advent of Web-based technologies, a common approach in deciding which route to take was to refer to a physical map before or during the travel and the entire trip would generally need to be pre-planned by the travellers. Automatic route navigation systems had begun to emerge and became more popular after the growth of mobile technology and improvements in digital mapping techniques. Currently there are a number of services designed to help users navigate effectively which have been made available to the public. Google Maps in particular which was established in 2005, has grown to become one of the most popular navigation services, helping millions of users find the most cost-effective path towards their desired destinations through driving, public transportation or walking.

Earlier research into route[1] navigation systems tend to focus on such utilitarian aspects of travelling. These navigation systems were generally designed to provide routes which allow users to travel from one point to another while minimizing costs in time, distance and resources [1]–[3]. When calculating the cost of a route, dynamic factors such as congestion, delays in public transportation and the weather were later taken into consideration [4]–[6]. More recent studies have seen the development of navigation systems

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[1]The terms "paths" and "routes" are used interchangeably in this paper.

which go beyond recommending routes purely based on their utilitarian qualities. Instead of recommending routes which only minimize the economical costs of travelling, researchers have been examining algorithms to recommend paths that maximize the enjoyment and positive experiences of users as they travel from one point to another based on the hedonic attributes within the routes (i.e., the aesthetic qualities of a given path or the presence of scenic or fashionable locations) [7]–[9]. Increasing attention is also being given to recommend routes which emphasize on the safety and well-being of users as they travel, such as routes which have less probability of users encountering crime, accidents [10], [11] and pollution [12]. In part, the development of such systems has been made possible through the prodigious growth of information from online social media services and public data sets which have been made available by various governmental and inter-governmental organizations. While prior systems only had data about the objective attributes of a given path (i.e., the distance, inclination or traffic statistics, etc.), modern systems could draw upon data about the opinions, activities and behaviors of various population groups at different locations through online social media services such as Twitter and Foursquare [13] and such data have been used to represent the subjective attributes (i.e., perceived beauty, perceptions of safety, etc.) of a path [14], [15].

Quality-aware route navigation systems are particularly useful for people who travel to unknown locations in foreign countries. The tourism industry contributes to a significant portion of the revenue in many cities, localities and even entire countries (e.g., such as Italy or Greece) [16]. Therefore, attending to the needs of tourists who tend to prefer an enjoyable and safe walking experience is of high importance. As it is generally difficult for travellers to properly plan and select routes if they do not speak the local language, they would benefit considerably from automatic route navigation systems. Other groups such as seniors also share a preference for routes which are aesthetically appealing, safe and contain well managed facilities [17], [18]. Furthermore, quality-oriented route recommendation services resonate well with the growing importance of Mobility-as-a-Service (MaaS), which offers transportation as a rented or metered service to their customers [19]. Since any mobility typically starts with a travel plan (explicit or implicit, full or partial), customized route suggestion as online services could be seen as one of the initial components of MaaS. Given these various use cases, we believe that it is time to focus more on developing route recommendation systems that go beyond simple and traditional cost assessment of routes in terms of length and time.

Despite the growing interests in quality-aware route navigation systems, there has yet to be a comprehensive review of such systems. While there have been reviews of how different data types (such as data from location-based social networks, volunteered geographical information and social media) could be used with regards to geographical studies and spatial planing [20], [21], in general, there is a shortage of works that survey route recommendation methods for pedestrians such that different aspects of route quality (beyond the most economical path) are considered. In a prior publication, Golledge [22] pointed out that route navigation for pedestrians could be quite different from those of car drivers as there are different qualities which pedestrians require from a route. For example, ''pedestrians, especially when having enough time, might prefer different route qualities rather than shortness, e.g., simplicity, safety, attractiveness, and convenience''. Similarly, another study which examined pedestrian behaviour also indicated that while the primary factor influencing route choice was the shortest path, secondary factors such as the presence of attractions were also valued, such as those which contain retail fronts such as cafes and shops along the path [23], [24]. A similar theory was also proposed which suggested that the cost of travelling between a path for pedestrians is not only influenced by travel time but could also be mitigated by factors such as stimulation from the environment and the potential for obstacles while traveling [25]. A more recent review carried out by Gartner *et al.* [26] examined human-centred pedestrian navigation systems. The authors regarded this task as a location-based service (LBS), where context-awareness plays a key role, calling for user modelling, adaptive route planning and route communication. Overall, those earlier papers provided a hint as to the existence of other route qualities beyond the utilitarian aspects.

This paper aims to provide an overview of quality-aware route navigation systems by highlighting the different quality attributes, data sources and algorithms that have been used to implement such systems. We decided to focus the scope of our paper on navigation systems for pedestrians as they tend to be the main target for the quality-aware route recommendation algorithms that have been developed. Overall, this paper contributes to the existing research domain in a number of ways. First, by outlining the different quality-aware route navigation systems, we provide an overview of the various systems proposed in previous studies. We also provide a categorization of such systems based on their underlying purpose and the qualities used to represent value on a specific path. The different types of data that are used to generate features which represent the qualities in the routes are also highlighted as well as the algorithms used in the routing process. This helps researchers and developers become more aware of the building blocks which can be used to create such systems. Finally, based on this survey, we formulate and discuss several observations in the field and propose future directions for researchers looking to develop similar systems.

The reminder of this paper is structured as follows: first, we provide a definition of quality-aware route navigation systems and describe the process used to identify and select publications for this survey paper. We then present the navigation systems identified in our survey through the SWEEP taxonomy and discuss the characteristics and attributes of each system. Afterwards, we provide a summary of the different data types and route search algorithms that have been used to implement the navigation systems. Finally, we provide discussions and propose future directions for research related to quality-aware route navigation systems.

II. QUALITY-AWARE ROUTE NAVIGATION FOR PEDESTRIANS

In this paper, we define a Quality-Aware Route Navigation System for Pedestrians based on the following characteristics:

- The system provides pedestrians with a route which allows them to move from a starting point *A* to destination point *B*. When the user inputs more points to be visited on the route, the task is converted to finding a series of routes between consecutive intermediary locations X_i to X_{i+1} within a route. The starting and destination points could either be pre-determined beforehand or afterwards based on the characteristics of the paths and intermediary locations within a route.
- There are certain user wishes or expectations regarding the preferred route characteristics which go beyond the straightforward route length. The quality of the recommended route should reflect these desired characteristics. Note that while such qualities could be considered as secondary to the basic or primary characteristics (i.e., route length or time), in practice quality-aware route recommendation systems tend to balance the impact of the primary and secondary characteristics.

In summary, the main scenario we consider contains a user who wishes to plan their walk and selects one out of the several possible routes from an origin point to a destination point.

III. LITERATURE COLLECTION

We undertook a search of published studies between 2004 to 2019 on 5 databases: Scopus, Science Direct, IEEE Xplore, ACM Digital Library, and Springer. The terms which were used in the search include (''map'') OR (''route'') OR (''path'') AND (''navigation system'') OR (''recommendation''). Overall, the inclusion criteria were (1) peer-reviewed academic articles from journals, books, conferences or workshops, which are (2) focused on methods for route recommendation. We decided to exclude studies which (1) are not available online or (2) are without peer review. Studies in languages other than English were also excluded. We have included other papers that we discovered after reading the ones obtained through the keyword search or that we knew about before. Afterwards, we examined the papers and removed those which did not propose a system or algorithm which met the definition of a quality-aware route navigation system as defined earlier in Section II. For example, we excluded papers which did not target pedestrians (such as those targeting car drivers) and those which did not provide a routing solution for users. After removing the papers beyond the scope of our study, we identified 47 papers which met with our inclusion criteria. Table 3 provides details of all the papers included in this survey.

IV. AN OVERVIEW OF QUALITY-AWARE ROUTE NAVIGATION SYSTEMS

Based on the identified literature, we provide an overview of the quality-aware route navigation systems which have been proposed based on (1) the attributes which are used to represent the qualities of a route, (2) the type of data features which have been used to implement such systems, (3) the algorithms used to implement the systems and (4) the evaluation approaches used to implement quality-aware route navigation systems.

A. ROUTE QUALITY ATTRIBUTES

We introduce the SWEEP taxonomy (**S**(afety)-**W**(Health and Well-being)-**E**(ffort)-**E**(xploration)-**P**(leasure)) to classify the different quality-aware route navigation systems that have been proposed in prior studies. This taxonomy was devised to help highlight the different types of quality attributes which have been used in the route recommendation systems in our survey. The categorization was based on the different areas the quality attributes were applied towards and the main problems they attempt to address. When certain quality attributes could be used in multiple domains (i.e. street quality could be considered to be related to both safety and physical effort), we looked at the overall aim of the proposed system as stated by the authors to determine the main problem or goal that the quality attributes aim to address and categorized them accordingly. It should also be noted that some of the systems could be developed to address problems in multiple domains and could utilize quality attributes in multiple categories. For example, the system proposed by Furukawa and Nakamura [27] aimed to recommend routes which both reduce physical load (effort) and helps elderly users avoid obstacles (safety) and the system proposed by Sharker *et al.* [28] aims to identify health-optimal routes (i.e. routes that encourage exercise) that are also safe (i.e. crime).

Overall, we had identified five different categories from the papers in our survey. Navigation systems which emphasize on the quality attribute of **Safety** generally aim to help users travel from one point to another in a safe manner by identifying routes which have a low probability of crime and accidents. Often such systems take into account environmental factors which decrease the likelihood of such occurrences (by examining whether the paths have sufficient lighting, low crime statistics etc) and target general users. In the meanwhile, systems utilizing the quality attribute of **Health and Physical Well-being** refer to those which recommend routes that minimize exposure to external environmental conditions (air pollution, heat etc.) which when exposed, would be detrimental to their health. Included in this category are systems which recommend routes that provide opportunities for users to exercise as a way to improve their overall physical well-being. Systems which emphasize on **Effort** refer to those which recommend routes that minimize the effort of users when travelling from one point to another. In contrast to conventional shortest path route recommendation systems, effort-aware route navigation systems consider factors such as cognitive effort (the memorability of the route etc.) and physical effort not bound only to the length of a given path (based on factors such as changes in elevation etc.). Such systems also tend to take into consideration internal factors related to the users themselves in relation to the environmental factors when recommending an appropriate path (for example, those who are confined to a wheelchair might require more effort traveling in streets with steps). Next, systems emphasizing on **Exploration** are those which maximize the opportunity for users to visit and discover new locations and experiences in an efficient manner. Such systems are often used for the purpose of serendipitous tourism and travel. Finally, navigation systems emphasizing on **Pleasurable Experience** aim to provide routes which maximize the hedonic experience as users travel from one point to another. These include routes which are aesthetically pleasing, in either a visual or olfactory sense. While systems in both the pleasure and exploration categories are similar in that they aim to provide users with hedonic experiences, systems in the pleasure category focus predominantly on the walking experience and often emphasize on qualities along the paths which users need to travel through to reach their destination (i.e. streets which pass through nature or have less noise and bad smell). However, routes in the exploration category tend to focus on providing users with an opportunity to visit and discover new places and unfamiliar sights. The hedonic experience provided by such systems are often based on the Points of Interests or locations (shops, etc.) that are novel to the users which the routes pass through and these systems are often aimed towards users new to the area such as tourists. Figure 1 provides a visual overview of the different types of qualities which have been used in the navigation systems proposed in previous studies based on our taxonomy.

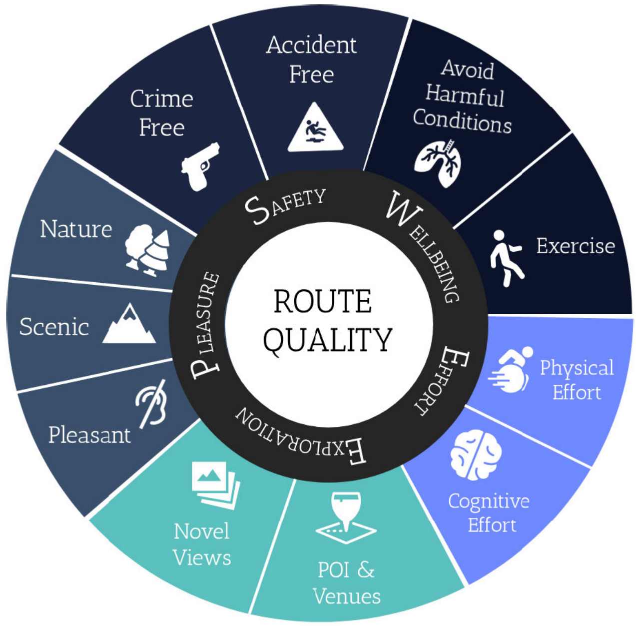

FIGURE 1. An overview of the quality types used in the previously proposed route navigation systems based on the SWEEP taxonomy.

1) SAFETY

Several navigation systems have been proposed to provide routes which allow users to travel safely from one point to another. A number of such systems have considered the risk of criminal activities as one of the qualities which should be minimized. This includes the TREAD system [29] and the PASSAGE system which attempt to find safe routes using data about past occurrences of crime within a city [10]. The system proposed by Elsmore *et al.* [30] operates in a similar manner, although incorporating crowd-sourced data. Other examples are systems proposed by Utamima and Djunaidy [31] which assign a safety index towards a given route and calculate a safety score based on historical occurrences of crime on that route using data from police departments. When crime data is not available, social media data has also been used to infer the safety of a given path. In the SocRoutes system [14] for example, sentiment analysis is carried out on the tweets posted along each path in the route and the quality of a given route is calculated inversely based on the proportion of negative tweets. The belief is that crime would be more likely to occur on streets where users express negative sentiment. Later systems utilized a hybrid approach (such as [32]) in which data from both official government sources (i.e., statistical crime data) and social media (i.e., tweets) were used to identify crime-free routes.

Instead of focusing on crime, other systems have also been proposed to recommend routes which reduce the likelihood of accidents for users on a given path. Notable examples include an approach proposed by Bao *et al.* [33], [34] which considers qualities such as the lighting condition and the width of a road to recommend safe walking paths for users. Goel *et al.* [11] goes a step further and combines data about the lighting conditions, past accidents and road quality from government databases with data from online news sites and crowd-sourced information about perceived safety to recommend safe routes. Some of these systems have been developed specifically for certain user groups such as elderly users, incorporating the physical safety requirements of each user in addition to street safety features when determining safe routes [35].

To identify which routes are physically safe, researchers have generally relied on historical data about the number of crime incidents that had occurred at different locations in the past [11], [29], [32], [36]. Such data is typically obtained from a city or police database and are mapped towards different street segments. The system then attempts to identify a route which passes through streets that have had the lowest occurrence of crime in the past. When data from social media is used to augment predictions of safety, sentiment analysis [14] or semantic analysis (based on crime related word ontologies) [32] is carried out on geo-tagged tweets along the routes to provide a proxy measure of safety. In comparison to statistical crime data, social media data is often used to provide a more dynamic and real-time status in regards to the safety. Finally, crowd-sourced data, such as user reported crime data [30] and perceived ratings of safety [11], [30] have also been used as a subjective proxy of safety for a given path. Such data could be particularly useful when information about past crime occurrences and the safety characteristics of a given street is not available.

2) HEALTH AND PHYSICAL WELL-BEING

In addition to the physical safety aspect described in the previous section, there have also been a number of proposed navigation systems focusing on health and well-being. These generally fall under two sub-categories, (1) navigation systems which help users avoid exposure to harmful substances or environments and (2) navigation systems which aim to help users improve their baseline well-being, mainly by supporting physical exercise.

Navigation systems which aim to help users avoid exposure to harmful substances and environments include those designed to minimize exposure to air pollution [12] and excessive temperatures [37]. Such systems tend to be designed specifically to help population groups who are particularly vulnerable to those environments, such as to help children or people with respiratory conditions avoid exposure to air pollution [12] and elderly users avoid areas with excessive temperatures [37]. Another example is a system designed to help those who are in drug or alcohol rehabilitation to avoid exposure to locations which might stimulate their craving [38]. Finally, while not specifically aimed at helping users avoid exposure to a specific harmful substance or environment, researchers have also proposed a route recommendation algorithm which encourages users to walk along paths to increase their contact with nature (parks, woods, gardens etc.) [39] and decrease chances of contact with unhealthy environments. This was based on the rationale that such locations have been found to help lower blood pressure and cortisone for pedestrians, while unpleasant environments increase blood pressure, muscle tension and may even contribute to suppressing the immune system of pedestrians [40]–[42].

In the second subcategory, navigation systems have also been proposed as a way to support users in improving their health and well-being through physical exercise. For example, Takama *et al.* [43] proposed an algorithm which recommends a walking route based on the amount of calories a user wishes to lose through exercise. A similar system aimed at helping prevent obesity used factors such as time constraint, walking speed, BMI as well as the weather to provide users with appropriate exercise routes [28]. In summary, the systems in both sub categories strive to find routes that either minimize the risk to the health of pedestrians or promote factors that are beneficial to their well-being.

Overall, the studies which help users minimize exposure to harmful environments tend to utilize either historical data or live data from sensors to calculate the degree to which users are exposed to harmful substances and environments (such as heat [37], and air pollution [12]) when traveling on a given route. This information is generally used as the main cost function for a given path. Social media data in combination with machine learning techniques have also been used in cases where the impact or presence of the harmful substances is less clear (such as when determining which path has potential to stimulate cravings [38] or help in relaxation [39]). Finally, systems which encourage physical exercise tend to rely on the path length to judge whether a route meets the exercise criteria of the user, by using information such as the time a user is willing to spend or the amount of calories they wish to lose to calculate the appropriate distance for meaningful exercise.

3) EFFORT

Navigation systems aimed at minimizing travel effort tend to focus either on (1) reducing the cognitive effort or (2) reducing the physical effort of users as they travel between two destinations. Developers of such systems often posit that the route with the shortest path is not necessarily a route that requires the minimum amount of effort to travel in practice, as various factors such as the cognitive complexity of the paths and the presence of steep slopes could require more cognitive and physical effort from travellers.

There have been a number of studies which have explored algorithms that take into account the cognitive cost of a user as they navigate along a given path, leading to the development of navigation algorithms aimed at recommending routes that are easily memorable. An earlier study in this domain used easily recognizable objects (wall clocks, points of interest, etc.) in the user's visual environment as landmarks to recommend easily memorable walking routes for pedestrians [44]. Afterwards, the concept of the least complex route (LCO) was proposed as a route which has a minimal amount of turns and is thus less complex cognitively. A navigation system based on this concept was implemented using user generated content, by asking users to rate the perceived complexity of a given path and this data was used to identify the least complex route [45].

Past studies have also shown how external landmark objects could be used to recommend routes which are more easily navigable. Rousell and Zipf [46] developed a proof-of-concept system which showed how landmarks extracted from OpenStreetMap could be used to provide easy to understand navigation instructions to pedestrians. A similar route planning algorithm that considers the visibility and recognizability of landmarks was also proposed by Furukawa and Nakamura [27], although with an emphasis on helping reduce pedestrian anxiety. Further studies have utilized data from social media to a similar effect, as a way to automatically identify recognizable landmarks from a given path and recommend an easily memorable route [47].

In addition to cognitive effort, there have been a number of studies aimed at reducing the physical effort of users when travelling. A number of these systems were developed to reduce the burden of navigation for a specific population group. For example, route navigation systems specifically for wheelchair users have been proposed, taking into consideration factors such as steepness, slope, the presence of curb ramps, surface type, the conditions of sidewalks and other impediments to wheelchair navigation [48]–[54]. A more generalized algorithm for identifying routes appropriate for people with different types of impairments was proposed in the form of the RouteCheckr system [55], PAM system [56] and Route4All [57]. Users with different impairments (visual or physical impairments etc.) rated various criteria which they felt were important to them when navigating (i.e. blind users might prefer paths which are less crowded or those with easily noticeable landmarks and people with hearing impairments could prefer paths with low traffic noise etc.). These ratings were then used to weigh the importance of different route factors when determining which route is appropriate for each user group with the same impairments. A similar multi-attribute routing system, AccessMap, was also proposed to recommend accessible routes to users with limited mobility based on their selection of criteria which they feel most impact their travels (i.e. wheelchairs users might prefer curb ramps and users with crutches may prioritize a shorter distance route). In a later system proposed by [54], the weights which were derived from these criteria were further re-adjusted based on user ratings given after users had actually walked through the routes.

When determining the quality of the routes for navigation systems in this domain, attributes related to the characteristics of routes themselves are generally used (such as the slope, steepness or number of turns required). Such attributes are often calculated using data from conventional geographical data sets such as OpenStreetMap (or for smaller areas, from manually created and annotated data sets [48]–[50]). Data about the presence of visible landmarks could either be created manually [44], obtained by analyzing data from OpenStreetMap (based on the distance and whether they are visible from the current travel direction [46], etc.) or inferred using social media data (such as examining whether such locations are mentioned in geo-tagged tweets on certain streets [47]). Using this data, the system would then determine the optimal route by selecting paths which contain easily visible landmarks. In other cases, users could also be asked to rate the complexity of a given path [45] or which attribute they find important in an accessible route [55]. These ratings would then be used to adjust the original cost function (based on distance) to identify a more effortless route.

4) EXPLORATION

In exploration based navigation systems, rather than recommending the shortest route to users, the system would attempt to recommend a route which maximizes the opportunity for users to visit and discover new locations and experiences during their travels. Earlier systems in this domain were developed mainly to support sightseeing and tourism related activities. Such systems were typically designed to allow users to visit and enjoy a large number of locations (often referred to as points of interest (POI)) in an efficient manner [58]–[62]. Most POI-based navigation systems are personalized, providing individual users with a travel itinerary to visit different locations that match their personal interests [58], [59]. To determine which locations might be of interest to users, researchers have relied on social media data. For example, the photos uploaded by users on photo sharing sites such as Flickr [61] or other panoramic photo sites [59] could be used to represent their travel history. This information could then be used to predict the quality of attractions on a given route [59]. Contextual information such as the type of venue (museum, nightlife venue, etc.), the weather conditions and the time of the trip could be further incorporated to more accurately determine the attractiveness of the locations [60].

Other types of exploration-based navigation systems are those developed to provide users with routes that contain novel views. One such system was also developed to allow users to walk along different heritage and historic areas within a city (such as a historical neighbourhood or an ancient market area) [63]. By looking at diversity within a route, researchers have also proposed a system which recommends a route that maximizes the diversity of locations and views encountered along that route [64]. The rationale behind such a system is that visually diverse routes are more likely to be interesting to walk through instead of routes with very similar views and that taking diverse walking routes allows users to better explore unfamiliar places.

The quality of the route for navigation systems in this category is generally calculated based on the attractiveness of locations (shops and tourist attractions) and views (scenic sights, landmarks, and diverse locations) which exist alongside the route. To identify such places, researchers have either manually created a list of candidate locations, obtaining such information from a geographical data set such as OpenStreetMap or through social network services such as Foursquare [60], [63] or Jie Pang [62] (a location based social network similar to Foursquare hosted in China). Afterwards, the attractiveness of a given location for each user is generally calculated by taking into account their past travelling experiences and current location [58], [59], using methods such as collaborative filtering [60], [62]. In other cases, the attractiveness of a location or street segment on the route could be calculated based on the overall popularity of that location or route, with the characteristics of geo-tagged photos submitted to photo sharing sites such as Flickr or Panoramio being used as a proxy for popularity [59], [61]. For example, the number of times a photo of a particular location was submitted to Flickr could be used to represent the popularity of that location. In the routing process, the system would then calculate the most optimal route that allows users to pass through the locations deemed to be attractive in an efficient manner.

5) PLEASURABLE EXPERIENCE

The final category of route navigation systems are those which focus on recommending routes that provide users with

TABLE 1. A summary of the key data sources used to implement quality-aware route recommendation systems.

Data Source	Description	Feature type	Modality	Used
OpenStreetMap	A free and editable open source map of the whole world, uploaded, extended and edited by volunteers.	Static street feature	Location data (POI and path characteristics)	[68], [38] [37], [43] [46], [69] [15]
Google Street View	A map service which provides panoramic views from various street positions throughout the world.	Static street feature	Image data (street view)	[39], [38] [64]
Microblogging service (Twitter)	A service where users and organizations share news and opinions.	User experience feature, Dynamic street feature	Text	[14], [32] [38], [47] [66], [15]
Location-based social network service (Foursquare etc.)	A social media service which allows users to share their location and the places they visit as well as their experience at those places.	User experience feature, Static street feature, Dynamic street feature	Location data (POI), Text (User reviews), User rating data, Statistic data (Visitor No.)	[14], [32] [38], [47] [66] [62]
Photosharing services (Flickr, Instagram, Panoramio.com)	Image and video sharing services allow users to post and share photographs with tags and a description.	User experience feature, Dynamic street feature	Image, Text (Tags)	[66], [68] [38], [59] [61]
Open data services (Datasf.org, Data.gov, Data.london.gov.uk, etc.)	Data released by government institutions and corporate entities available in the public domain through open data platforms.	Dynamic street feature, Static street feature	Statistic data (Crime No.), Location data (POI details) Construction data (Ongoing roadwork etc.)	[10], [36] [32], [29] [31], [38] [53]
Crowdsourcing	User perception data about qualities such as safety or aesthetics on a particular route. Such data is generally obtained through questionnaires which are deployed online or through specialized crowd-sourcing platforms.	User experience feature	User rating data	[30], [11] [7], [45]

positive emotions while travelling from one point to another. Such systems aim to maximize the hedonic experience of users as they travel between two locations. These include routes which are aesthetically beautiful, quiet, sociable or provide exposure to areas with nature.

A study carried out by Hochmair and Navratil [65] was perhaps the first to investigate the possibilities of calculating scenic routes from street networks using classical GIS methods such as buffering and intersection. Their proposed method aims to address the multi-objective decision problem of searching for a compromise between routes that strike a balance between attractive scenery and length. Later studies carried out by Quercia *et al.* [7], [66] further examined this problem of how a pleasurable walking experience could be provided for users within cities. In their study, a crowdsourcing platform was implemented to allow users to vote on which areas they felt were more beautiful, quiet and could provide them with happiness. This data was then used to derive the attributes of locations which could invoke pleasurable experiences and routes which provide exposure to locations with such attributes were identified [7]. In later studies, the authors developed an urban smell dictionary which they hinted could be used to identify routes which are pleasing in the olfactory sense [66]. Instead of crowd-sourced data, other systems used information collected from Google Street View, Twitter and OpenStreetMap to determine which routes were bright, contained beautiful views [39] were fashionable [15] or passed through locations that provide a high level of sociability, quietness and are close to nature [67]. Another study in this category proposed a route recommendation algorithm aimed at providing hikers with a sense of solitude while hiking, by generating routes which would allow them to avoid meeting other people along the trail [68].

The type of locations existing on the paths are often used to infer the pleasurable qualities of a route. For example, tag data obtained from OpenStreetMap could be used to determine whether the route contains locations which are noisy (for example, whether there are nearby streets tagged as "highways") or scenic (such as locations tagged as "gardens" or "woods") [67]. In other cases, data from social media such as geo-tagged tweets or photos from Flickr and Google Street View could be analyzed and used to determine whether a route has potential to provide a pleasurable walking experience [39], [66]. For example, image analysis could be carried out to determine the color ratio, object ratio, and color brightness at different points along the route, with the assumption that a pleasant route would have much nature and contain green and bright views [39]. Crowd-sourced data could also be used to help determine which street characteristics are related to pleasant route qualities by analyzing the presence of words and visual textures in streets rated as pleasant and unpleasant by users [66].

B. DATA TYPES

Different types of data have been used to generate features in quality-aware route navigation systems for pedestrians. A summary of these data types is shown in Table 1. Theoretically, any geographical data that can be assigned to a street can be useful for quality-aware routing. The types of data features which have been used in the navigation systems identified from this study could be broadly grouped into three different categories: static street features, dynamic street features and user experience features.

Static street features are those that are related to the static aspects within a path such as the physical attributes of a street (the width, slope and condition of the roads etc.) and the locations which exist nearby (both man-made structures such as shops and schools and geographical features such as lakes and forests). *Dynamic street features* refer to features which are related to the dynamic aspects of a path that generally change based on the time. This includes attributes such as the traffic within the streets, the air or noise pollution, the number of visits to various locations on the street and occurrences of crime and accidents. Finally, *user experience features* refer to those that are related to the perceived opinions and experiences of users towards a given path or its part. Examples include perceived safety, aesthetics and ease of navigation for a given path. Usually, such subjective information is obtained through online social media or crowdsourcing.

Another categorization which could be made on the data type is based on the modality of the data. This includes (a) location data about the position and type of each facility on the street, (b) textual data that generally provides useful information about the perceived characteristics of a street or locations on that street (Tweets, TripAdvisor and Yelp reviews, etc.), (c) image data which provides a visual description of the street and events occurring on the street (e.g., Flickr images, satellite terrain images or Google Street View panorama images), (d) historical data released by local governments which denote or pool events such as instances of crime or others, and (e) user rating data such as those obtained through crowdsourcing where users are asked to rate a street segment on aspects such as aesthetics or perceived accessibility.

It should be noted that in using textual and image data from online sources, it is often necessary to first process the data to make sure it is related to a particular street segment in question and reflects a particular attribute or quality that is needed for routing. For example, indoor images from buildings along a given street segment may need to be discarded as only outdoor images are typically useful, Flickr images with objects that are not typical to the street (such as persons, and mobile objects brought from other places) might also need to be filtered out or processed. Furthermore, tweets that are not directly related to the ambient environment (e.g., tweet about political opinions) would need to be removed. Finally, there is an issue of assigning images, tweets or other social media content to their corresponding street segments which is not always easy (e.g., a tweet can be posted in almost equal distance from two different streets, as well as one needs to decide the maximum distance a tweet can be located from the street segment to be considered as describing it).

1) STATIC STREET FEATURES

A commonly used data source which contains static street features is OpenStreetMap (OSM) which is one of largest user-contributed geographical database. In 2019, OSM contained over 5 billion nodes from around the world, with each node representing a geographical POI.[2] POIs of OSM can include buildings, shops and natural areas such as lakes and forests among many other types of locations and facilities.[3] A street in OSM is defined as a line which is composed of a series of points. OSM data can be easily collected through an Application Programming Interface service or downloaded in bulk for specific cities and countries.[4] Another popular source for static street features is Foursquare venues. Foursquare is a location-based online service that serves as a business directory as well as an activity recording platform. In 2019, Foursquare listed more than 65 million venues in more than 190 countries.[5] Foursquare venues are placed in a category hierarchy, where at the top level, there are 9 categories including food, professional places and shops. At a lower level, there are hundreds of categories such as ''Chinese restaurant'', ''factory'' and ''grocery store''. Overall, studies have shown that user contributed geographical data sets such as OSM and Foursquare have a reasonable degree of accuracy, particularly in dense urban areas [70]. However, they could be less valuable in underpopulated rural areas due to the lack of user contribution [71].

Similar to Foursquare, Google Places[6] also provides detailed information about points of interests (shops, buildings, landmarks, etc.) which exist within a specific area. Alternatively, for smaller areas or for a more specific context (such as tourism or to provide accessible path for people with disabilities), researchers could create their own POI dataset consisting of a list of locations or street features (such as stairs and railings etc.) with latitude and longitude coordinates [56], [63]. Finally, static street features could also be obtained by analyzing image data collected from services such as Google Street View[7] which could be used to infer the characteristics of the surrounding neighbourhood such as whether the location contains green areas or specific landmarks [39], [47].

2) DYNAMIC STREET FEATURES

Dynamic street features reflect the characteristics of the streets which change over time. As such, these features could contain both geographical as well as temporal information. One example is geo-tagged posts in social media. Twitter, a popular microblogging platform which allows users to post short stories and share their opinions about events in their lives, has frequently been used as a source of dynamic street features. Of the more than 500 million tweets per day on Twitter, it is estimated that around 0.9% are geo-tagged [72]. When analyzed, the content from these tweets could be used to identify the various events and activities that had occurred on a given route at a particular time [32], [38]. Twitter data could be collected through the streaming API which allows user to access a random proportion of the tweets on Twitter in real-time.[8] However, as there often are many tweets that are not relevant to the desired routing objective, the tweets would

[2]https://wiki.openstreetmap.org/wiki/Stats

[3]https://wiki.openstreetmap.org/wiki/Map_Features

[4]https://wiki.openstreetmap.org/wiki/API

[5]https://developer.foursquare.com/places

[6]https://cloud.google.com/maps-platform/places/

[7]https://www.google.com/streetview/

[8]https://developer.twitter.com/en/docs/tweets/filter-realtime/overview

generally need to be pre-processed [73]. Alternatively, user behaviour data such as the number of users who visited a specific hotel or shop could be obtained from Foursquare. This data has been used to represent the popularity of a location at a given time which could act as a proxy for the quality of the venue [47]. Data collected from photo sharing sites such as Flickr could also play a similar role in helping identify the presence and activities of users at different locations [59], [61]. For example, the time the photo was taken indicates that there was a user present at that location during that time. Users also generally tag photos posted to the site with the name of the location (Starbucks, etc.) and the activities they were doing (camping etc.). Overall, while such data could be useful in representing user actions and behaviours at a detailed spatial level, researchers have also cautioned that analysis carried out using only such data sets could be biased towards urban populations, young users and those with higher levels of income as they tend to be the main users of these platforms (Flickr, Foursquare and Twitter, etc.) [74], [75].

Another useful but less known data source for dynamic street features are public data services and open data sets released by government institutions and commercial entities (such as open data sets provided by the US[9] or Japanese government[10]). Cities such as San Francisco also provide open data sets which contain information about various aspects of the city such as real estate price, healthcare metrics and the number of accidents and crime in different areas.[11] Fine-grained crime data (i.e. criminal incidences recorded at a street-level) in particular is available from a number of open data sets such as those provided by the cities of Chicago, New York and London. Such data have been used extensively as features in safety-based route navigation systems [10], [31]. Health-based navigation systems aimed at helping users avoid exposure to harmful environments (such as air pollution or heat) would generally also obtain information about the presence of harmful substances from public weather services or air pollution monitoring stations [12], [37].

3) USER EXPERIENCE FEATURES

User experience features are often used to represent the subjective qualities of a route such as the aesthetics or perceived safety. To obtain data regarding this feature, researchers have generally relied on user ratings. For example, users could be asked to rate the beauty [7], ease of navigation [45], perceived safety [30], or accessibility [54] of a certain route. Such data could be used directly when calculating the quality of a path or as a label for routes which represent those qualities. In the later case, the user rated routes could then be analyzed to determine what components of that route corresponds to the attribute in question. For instance, users could be asked to rate the attractiveness of different streets based on their images and the researchers could then analyze what visual cues from the images would cause it to be perceived as visually appealing. These cues could then be used as features for paths not yet rated [76].

Geo-tagged data from social media services have also been used as user experience features in route navigation systems. For example, by carrying out sentiment analysis on geo-tagged tweets located near a given path, researchers are able to determine whether the path provides users with positive or negative experiences. This in turn could be used as a proxy measure for how enjoyable the route is [30]. Alternatively, the tags from photos submitted to Flickr or Instagram and the words from geo-tagged tweets could be analyzed and used to identify certain user experiences (such as smells) at different locations [66].

C. ROUTING ALGORITHMS

Several algorithms have been used to recommend an appropriate route to users in the papers which we identified. One popular algorithm is Dijkstra's algorithm [77]. Given a starting node s in a weighted graph G, Dijkstra's algorithm finds the shortest path between the node and every other node in the graph. More specifically, Dijkstra's algorithm generates a shortest path tree with a given starting node as the root. The algorithm maintains two sets of nodes, a set of nodes in the shortest path tree and a set of other nodes which have not yet been included in the shortest path tree. At every step of the algorithm, a node which is not in the shortest path tree and has a minimum distance from the starting node is identified and moved to the set of nodes in the shortest path tree [77]. This algorithm or its derivative has been used in a number of navigation systems covered in this paper, with features such as safety, aesthetics and the potential presence of harmful substances representing the cost along edges in the graph [29], [39], [45], [47], [54], [55], [78]. Quercia *et al.* [7] for example utilized Eppstein's algorithm (see [79]), a variant of Dijkstra's algorithm, which aims to find k shortest paths between nodes s and d and considers cases where repeated vertexes are allowed.

Other algorithms used include the pulse algorithm which aims to find the optimal route by pruning away partial paths that cannot generate full efficient paths [10], and the A* algorithm (see [80]), a "best first search" algorithm which utilizes a heuristic function in addition to the cost function to search for an appropriate path [69]. Alternatively, publicly available or commercial routing services could be used in the routing process [46]. Examples include the OpenRouteService which was developed by the Heidelberg Institute for Geoinformation Technology to provide routing services using information from OpenStreetMap[12] or the Direction API provided by the Google Maps platform.[13] Open source libraries such as pgRouting[14] also allow developers to deploy various routing algorithms (such as Shortest Path A*) to find

[9] https://data.gov
[10] https://data.go.jp
[11] https://datasf.org/opendata/
[12] https://maps.openrouteservice.org/
[13] https://cloud.google.com/maps-platform/routes/
[14] https://pgrouting.org/

the path with the lowest cost on geographical datasets hosted on their own databases.

In cases where route planning is dynamic and the environment changes frequently, algorithms such as Genetic Algorithms (GA) could be used (such as in [47], [69]). In this algorithm, a route from a starting node s to a destination node d is represented as a sequential list consisting of N nodes as if a variable-length chromosome was utilized. An evaluation function is then defined and used to determine an appropriate route that can minimize the evaluation function.

While traditional shortest path algorithms tend to focus on travel time as the main cost of a route, quality-aware route navigation systems often incorporate additional features such as safety and aesthetics. In many cases, geo-tagged data items are used to represent these features on a path. For instance, landmark locations have been used to represent whether the route is worth exploring [9], historic crime incidences to represent safety [29], [31], [36] and social media items to represent past user experiences [14], [66]. As such, when identifying a quality-aware route, it is often necessary to map these items onto a given street or area so that they could be used to adjust the cost of related paths. A simple approach that has been used for this purpose is a threshold-based method in which all data items that are located within a set distance from a path would be used to represent a particular quality on that path [38], [47], [66]. A cell-based method has also been used in which a city would be pre-divided into cells and the data items which fall under each cell area are considered to represent the characteristics of that cell [7]. When a data item does not represent a point but rather an area (such as data pooled for certain spatial regions), a variant of this approach could be used in which the street is sectioned according to the areas it is contained in and the length of the section within the area is weighted to reflect the amount of exposure when calculating the cost [37].

D. EVALUATION OF ROUTE NAVIGATION SYSTEMS

Various methods have been used to evaluate whether a system is effective in recommending routes to users based on the different criteria (e.g., pleasure or safety). Table 2 provides a summary of these methods. The most thorough approach would be to ask participants to actually walk through the routes recommended by the system so that the utility and cost aspects could be measured and compared. This way one would be able to test the system with actual users in a realistic context. Often the recommended routes are compared to those proposed by baseline routing methods (e.g., shortest path). Studies which utilized this evaluation method include [27], [47], [68], [78].

However, as such experiments are often costly both in time and effort, the walking experience could also be simulated when evaluating the systems. For example, in a study by Wakamiya *et al.* [47], Google Street View was used to simulate the walking experience. Participants were asked to simulate walks in San Francisco using Google Street View and then report their opinions and feelings about the routes.

TABLE 2. A summary of the methods used to evaluate the navigation systems.

Evaluation	Description	Category	Used
Field evaluation	Users are asked to walk through the routes recommended by the system and report on their experiences.	End-user	[68], [27] [47], [33] [34], [69] [78]
Simulated evaluation	Users are asked to evaluate the routes through a simulated walking experience using digital videos or panoramic views.	End-user	[35], [47]
Prototype evaluation	Users evaluate the routes through a prototype of the system or evaluate the prototype itself on aspects such as usability, usefulness and willingness to use in the future.	End-user	[67], [50] [60], [63] [59], [43] [55], [65]
Back testing	The performance of the method used to recommend the routes is evaluated using a known past sample data set.	Routing method performance	[30], [36] [32], [31] [12], [58] [61], [14] [62]
Manual inspection	The developers manually examine a sample set of the generated routes to determine how well they meet the routing objectives.	Routing method performance	[10], [67] [37], [49] [69], [52]
Agent simulation	A Pedestrian agent (a computer program) is developed to walk through the routes. The routes are then evaluated based on what is encountered by the agent.	Routing method performance	[43], [28] [45] [54]
Feature evaluation	The accuracy and performance of the method used to calculate the features that represent the quality of the routes are evaluated.	Routing method performance	[7], [66] [15], [46] [52]
Technical feasibility	Researchers test whether it is technically feasible to implement the system.	Technical performance	[51]

In another example, participants were asked to evaluate the routes based on videos taken by the researchers while they themselves walked through the routes [35]. Such approaches are particularly useful in cases where the study is difficult to organize logistically (for example, in [47], participants were asked to evaluate routes in a different country and the other study involved elderly participants [35]). An alternative approach is to evaluate a prototype of the developed system in terms of usability, utility, functionality and the level of satisfaction [50], [59], [60], [63], [67]. Such an evaluation approach involves participants using the developed system in a lab setting. They were asked to evaluate factors such as how easy it was to use the system, how useful they felt the system was and whether they would use such a system in the future. In such lab studies, participants were also asked to rate how useful and accurate the routes themselves were by looking at them on a digital map.

Navigation systems have also been assessed without involving evaluation from participants. Back testing could be carried out in which the developers evaluate the validity of their proposed algorithms by using past data [12], [14], [31], [32], [36], [58], [62]. For example, if the navigation system aims to recommend safe routes, the authors could test whether crime has indeed occurred on the recommended routes by referring to past crime statistics. In other studies, the authors themselves manually evaluated routes generated by the system to see if the objective of their proposed algorithm was met [10], [37], [52] (for example, to see if the generated routes have indeed reduced heat exposure in comparison to the shortest path [37] or to determine whether the trade off in terms of safety is worth the added distance [10]). Alternatively, simulations could be carried out in which agents with pre-programmed sets of behaviours are used to evaluate the quality of the routes [43]. For example, Monte Carlo simulations could be used to randomly generate users with different route preference profiles to walk through routes with random origin and destination points to evaluate them [54]. Such approaches are common in navigation systems in the health and safety domain, as it can be dangerous to carry out actual user evaluations.

Another common evaluation method is to evaluate the features used to generate the routes. For example, a crowdsourcing approach where users are asked to rate the images and locations that were used to calculate the quality of the route was used in [7]. Researchers have also examined how the parameters used to generate features for the routing process influences the overall route recommendation outcome [65] or the performance of the feature extraction methods [46], [52]. The different methods used in the routing could also be evaluated to determine which fits best with the predetermined user preference criteria [49]. Finally, researchers have carried out a pure technical evaluation to determine whether it is technologically feasible to implement such a system [51].

V. DISCUSSION

In this section, we discuss key observations from the papers identified in our survey. We highlight the problems and limitations of the currently proposed systems and provide promising directions for future research into quality-aware route navigation systems.

- Overall, there is a lack of a systematic and comprehensive evaluation approach for route navigation systems. The evaluation methods used in existing literature tend to focus on a single aspect of the system (routing algorithm performance, perceived system value, etc.) and use metrics specific to that domain. For example, studies whose main contribution are to propose a novel routing method tend to evaluate their system using a data-driven approach, by measuring the performance of their method against a known data set using metrics such as accuracy ([30], [32], etc.). Those which employ a user study approach often focus on measuring the experiences of users with the system through metrics such as perceived usefulness and ease of use [50], [59], [67]. In studies where the routes are evaluated (such as in field evaluations or simulated experiments), users often score the routes based on single item metrics specific to their domain (such as perceived safety, general preference, etc.) [35], [69]. As there is no commonly accepted evaluation framework or a measurement scale for user experience which could be shared across different domains, it is difficult to compare the value of the proposed navigation system in an impartial manner. Therefore, we believe that research into quality-aware route navigation systems would benefit greatly from the development of a trans-domain, multi-criteria evaluation framework, similar to those proposed for other digital systems such as web-based learning platforms [81] and games [82].
- Currently, most of the proposed systems focus only on a single quality type (e.g., safety or pleasure). Those which incorporate multiple qualities often target a specific user group (elderly users) or use case (hiking, promoting exercise, etc.) [12], [35], [68], [69], which limits their general applicability. For such systems to be more widely adopted in practice, we believe that they would need to incorporate a wider range of qualities in order to make effective recommendations to general users in everyday life. In such cases, a single user would have a mixture of needs with different levels of preferences that would need to be considered simultaneously (e.g., a safe yet interesting route which allows them to exercise).
- The systems in this survey often assume that the user preferences, the features used to calculate the route qualities and the conditions surrounding the walk would remain static while the system is being used. Most of the proposed systems give non-dynamic final recommendations in the sense that the recommended routes cannot be changed after the initiation of the walk, unless a new route is generated. In a real-life scenario, dynamic systems which could provide adaptive routing that corresponds to changes in the situation and environment of the user would be more useful. Considering safety for example, the initially recommended route may need to be dynamically updated after acquiring information about a public safety risk (a group of hooligans moving towards the area) or based on the latest crime report in the area. Social media data (such as Twitter and Flickr) could be particularly useful for this purpose and while a number of studies have used such data to represent specific features on the route ([14], [15], [66], etc.), they are used in a static manner, namely to precalculate a specific quality on the route. Overall, we lack a mechanism to incorporate real-time changes into the routing process. In addition, the context at the time of the walk would need to be properly considered. Few studies have proposed qualities based on such attributes (i.e. the time and day a user plans to walk and the current weather forecasts, etc.) [28], [33], [34]. Finally, in real-time systems, the degree of the changeability or variability of dynamic street attributes should also be taken into account. For example, while the street width is typically considered constant, the numbers of pedestrians or the colors of building facades may change at a faster or slower pace. Faster changing data attributes would require more constant updating.
- Most of the proposed systems cater to individual users and there is a lack of routing systems which can deal

TABLE 3. A summary of the studies in this paper.

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[14]	Recent crime free, safer, friendlier, and more enjoyable routes	Tweet sentiment mapped on street segments	Tweets	S	Perceived street sentiment	RouteBoxer algorithm	Tested 100 unique routes based on distance and safety
[30]	Safe routes	Vector-based diffusion and interpolation matrix of crowd-sourced safety rating	Crowd-sourced safety rating	S	Safety Crime	Matrix interpolation	Evaluated accuracy in predicting safety in a generated test data set
[10]	Crime free routes	Past crime data mapped on street edge	Crowd-sourced safety rating	S	Crime	Pulse algorithm to prunes partial paths that cannot generate full paths in the efficient set	Compared paths from the proposed system with those from Google Maps to determine if the distance trade-off is worth the added safety benefit
[36]	Crime free routes	Relative probability of a crime modeled on any road segment	Past crime report data	S	Crime	Bi-objective optimization	Tested 100 nodes in Chicago and Philadelphia based on safety
[32]	Crime free routes	Integrated official reports with tweets (using semantic and spatiotemporal analysis)	Tweets Past crime report data	S	Crime	Classify node with onotology then run safe routing	Tested on 5,441 events in Mexico city
[29]	Safe and crime free routes	The number of crime reports within its distanced buffer area mapped to the route	Past crime report data	S	Crime	Dijkstra's algorithm with customized weighting based on distance, crime and POI	None (Demonstration only)
[33] [34]	Accident free routes	A score based on road width, landmarks associated with visibility using a questionnaire and time period (day/night) is calculated for each route	Landmark data Road width data	S	Crime Safety	Construct route from paths with scores exceeding a certain threshold and moves users towards the destination	Simulation with existing algorithms User experiments where participants walked the routes
[11]	Accident and crime free routes	Factors such as light conditions, crowds, ethnic diversity, time, road infrastructure and crime history are used to evaluate a given path	Crime data, accident statistics, data about crime and accidents crawled from online news sites, perceptions of safety through crowdsourcing user feedback	S	Crime Safety	Google directions results re-routed based on safety score	None (Demonstration only)
[35]	Safe and walkable routes with an appropriate physical load for elderly pedestrians	Subjective factors related to walkability, safety and pleasantness are added to the route cost	User evaluations	S, EF, P	Safety	Not specified	Subjectively evaluated with 40 elderly users who asked to watch a video of routes

TABLE 3. ***(Continued)*** **A summary of the studies in this paper.**

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[31]	Crime free routes	The number of crime incidences on the route	Past crime data	S	Safety	Google Maps results re-ranked	Counted the number of crime incidences on routes with different rank
[67]	Routes based on user preferences such as green areas, social places and quite locations	A buffer area is drawn from each street segment, and related POI data collected from OSM is mapped	OpenStreetMap	P	Sociable, quite and green routes	Not specified	User evaluations about the potential utility and usefulness of the system concept Examined randomly generated trips to investigate trade-off benefit between pleasurable quality and length
[7]	Routes which are not only short but also emotionally pleasing	Emotion scores measured from a crowdsourcing platform where users vote on beautiful, quiet, and happy street views are given to streets with similar characteristics	Crowd-sourced votes	P	Beautiful, quiet, and happy	Eppstein-algorithm for shortest routes, average ranking	Evaluated features of crowd-sourced beauty dimensions
[66]	Routes based on urban smell and air quality	Features related to urban smell and air quality are mapped onto streets	Georeferenced picture tags from Flickr and Instagram Georeferenced tweets from Twitter	P	Good smell Bad smell Air quality	Only proposed it could be used in routing	Evaluated robustness of method used to extract smell features through correlation test
[39]	Routes which pass through greenery	Pleasant scores of routes in terms of color ratio and brightness extracted from Google Street View panorama images	Google Street View panorama images	H, P	Green Scenery	Dijkstra's algorithm and re-ranked paths in terms of pleasure aspects	None (Demonstration only)
[68]	Hiking routes which avoid meeting people	Scored path based on how likely it is to meet people and informed users about nearby hikers based on Wi-Fi signals	OpenStreetMap Flickr photos Wi-fi probe requests	P, S	Solitariness	Editing history of OpenStreetMap weighted against shortest path	8 users in the wilderness
[15]	Routes based on user preference such as beauty and fashionability	Categorized geo-tagged tweets using LDA and characterized streets based on categories of tweets assigned to POIs on the street using the Markov random field model	Tweets OpenStreetMap	P, S, Ef, Ex	Characteristics specified from users	Not specified	Evaluated effectiveness of street categorization compared to baseline measures on selected routes

TABLE 3. ***(Continued)*** **A summary of the studies in this paper.**

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[65]	Routes which balance scenic areas and path length	A buffer area around scenic locations (parks etc.) If the buffer area intersects with a street intersection, that location is considered to be scenic	Street network data at the Fort Lauderdale area	P, Ex	Scenic views	Not specified	Evaluated different approaches to map scenic features
[12]	Routes which minimize exposure to air pollution for vulnerable population	Air quality index is mapped to each road segment and air pollution exposure is calculated based on time taken to travel along the road	Air pollution data from monitoring stations Road network database	H	Pollution	Weighted road sections based on air quality index using Inverse distance weighting and kriging	Leave-one-out cross-validation on random samples
[38]	Routes which help users avoid stimulating environments for drugs/alcohol	Tweets with alcohol and drug related words, Foursquare venues related to alcohol and drugs and Google Street Views with features related to drug and alcohol crimes are used to score the route	Tweets Flickr OpenStreetMap Foursquare Google Street View	H	Alcohol and drug related stimulus	Dijkstra's algorithm	None (Demonstration only)
[37]	Routes which reduce heat-stress	Heat index calculated based on air temperature and humidity data used to calculate which routes minimize exposure to areas with high heat	OpenStreetMap Weather data	H, S	Heat stress	Dijkstra's algorithm with applied weighting to account for time dependency	Inspected 1000 random routes generated by the algorithm to determine if they result in reduced heat exposure
[43]	Routes based on calorie consumption to facilitates walking related exercises	The walking distance and user weight is used to estimate the calories consumed on a path	OpenStreetMap	H	Calories	Developed algorithm which selects a random destination and finds the shortest path to that destination. Repeats until the calorie expenditure quota has been reach	Agent simulation Comparison of the map-based interface and the hands-free interface by test participants
[28]	Routes which increase physical activity to prevent obesity	Individual factors (BMI etc.) and environment factors (weather conditions) used as a weight to a street segment	Not specified	H, S	Walkability Ability for physical exercise	Not specified	Simulated to determine the feasibility of the proposed features
[44]	Routes based on the visibility of landmarks	Salient and visible landmarks in the environment identified by users mapped to the path	Spatial database of indoor stationary landmarks (wall clocks, escalators)	Ef	Ease of navigation	Created a routing table based on possible travel routes between one visible landmark to another	None
[27]	Routes based on visible and recognizable landmarks	The recognizability and visibility of landmarks are calculated and used to adjust the path cost	Proprietary map data	Ef	Visibility of landmarks	Dijkstra's algorithm	User experiments in the real world by measuring anxiety and time

TABLE 3. ***(Continued)*** **A summary of the studies in this paper.**

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[45]	Least-complex routes and length complexity optimized routes	The ratings of past navigators (people who have navigated in environment before) on the complexity of a path	User ratings of complexity	Ef	Route complexity	Dijkstra's algorithm	Agent simulation
[46]	Routes based on visible and recognizable landmarks	Predefined weights based on place type (bank etc.) used as a proxy for the visibility of landmarks	OpenStreetMap	Ef	Visibility of landmarks	Open route service	Compared the landmarks used in navigation instructions proposed by users with those generated by the system
[47]	Routes based on landmarks	Extracted landmarks by measuring place popularity, direct visibility and indirect visibility and constructed landmark based route graph	Tweets Foursquare venues 3D geographic data	Ef	Ease of navigation	Genetic algorithm Dijkstra's algorithm	User experiments in the real world and simulated world (Google Street view)
[48]	Accessible routes for wheelchair users	Attributes on the streets which makes it appropriate for wheelchair users (side-walk slope etc.) is used to determine the accessibility of a given path	Building data Lighting Accessible sidewalk measures	Ef	Route accessibility	Dijkstra's algorithm	None
[49]	Accessible routes for wheelchair users	Calculated an impedance score for each path based on sidewalk parameters using a fuzzy inference system and the impedance level is used to represent the cost of the path	Self-collected dataset of path characteristics (slope, length etc.) through field surveys and GPS receiver data	Ef	Route accessibility	Dijkstra's algorithm	Compared the performance of the weighting methods used to construct the path and examined if the generated routes matched user preferences
[55]	Routes appropriate for people with different impairments (visual etc.)	Multi-criteria features specific to different population groups are used to calculate the cost of a given path	User rating of accessibility criteria Environmental information	Ef	Multi-criteria route accessibility	Dijkstra's algorithm	Evaluated the routes simulated through a prototype system
[51]	Accessible routes for people with impaired mobility	Routes walked by people with different mobility problems are collected pervasively through mobile devices and is used to decide which route is accessible	Paths walked by users with mobility problems	Ef	Route accessibility	Google Map API	Technical feasibility evaluation

TABLE 3. ***(Continued)*** **A summary of the studies in this paper.**

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[50]	Accessible routes for wheelchair users	Route cost is calculated using factors influencing ease of navigation (slope, curbs, surface types etc.)	Ordnance Survey Panorama dataset and Ordnance Survey Land-line data, measurements of wheelchair resistance levels at different surface types etc.	Ef	Route accessibility	Not specified	Usability testing and assessment of the usefulness of the application with wheelchair users
[52]	Accessible routes for wheelchair users based on surface type	Accessibility of surface type identified from crowd-sensed data and street features are used to calculate path score	Surface type inferred from accelerometer and gyroscope data	Ef, S	Route accessibility safety and difficulty	Generate all possible routes in a specific radius from A to B and identify the best from the top 10. Length is inversely weighted with the accessibility score	Evaluated surface prediction algorithm
[53]	Accessible routes for users with limited mobility	Created a multiple attribute graph by combining sidewalk, street and elevation data etc. Route cost is calculated using factors such as the presence of sidewalks, ramps and construction areas	Elevation data, construction permit data, presence of curb ramps, presence of sidewalks	Ef	Route accessibility	PGRouting	None
[57] [78]	Accessible routes for users with special needs (visual impairments and physical mobility impairments)	Multi-criteria accessibility features (street width, slope, width, presence of landmarks and barriers etc.) are mapped to each pedestrian street segment. A passability value for each street segment is calculated using these features and used to adjust the cost of the path	Slope data, street gap width, surface type, presence of landmarks and barriers (crossing entry points, ramps) etc.	Ef	Route accessibility	Dijkstra's algorithm	16 Visually impaired users were asked to walk landmark enhanced routes versus the traditional route. Subjective evaluations (such as comfort) and Objective evaluations (completion time) were used to measure performance.

TABLE 3. ***(Continued)*** **A summary of the studies in this paper.**

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[54]	Accessible routes for wheelchair users	Various street attributes are used to calculate the accessibility index of the route for wheelchair users. The importance of each attribute is rated by each user and used as a weight for the attributes This value is further adjusted using feedback from the user after travelling through the route.	Street width, length, slope elevation change, surface conditions, traffic	Ef	Route accessibility	Dijkstra's algorithm	Monte Carlo simulation (100,000 times)
[56]	Accessible routes for people with disabilities	Different accessibility attributes for visually, mobile and hearing impaired users are mapped onto each sidewalk path and are used as weights for different users when calculating the optimal route	Sidewalk width, slope, presence of fences, traffic noise, crossings etc.	Ef	Route accessibility	Did not specify	None
[69]	Waking routes which are safe, enjoyable and accessible for elderly users	A shortest route between identified attractive places is weighted using factors related to safety, existing venues and accessibility	OpenStreetMap	Ef, S, P	Route accessibility, safety and appeal	A* Genetic algorithm	Manual inspection to see if generated routes meet criteria User experiments where users walked through generated routes
[58]	Routes which pass through optimal tourist locations	Inferring and ranking of interesting locations	Visited POI of user and other users	Ex	Ability to visit tourist attractions	HITS (Hypertext Induced Topic Search) based inference model	One year real world GPS tracks of 107 users
[59]	Routes which pass through optimal tourist locations	Analyzed geo-tagged photos posted by users to infer travel routes within specific tourist destinations based on desired visit time	Geo-tagged photos from panoramio.com	Ex	Ability to visit tourist attractions	TRS (Travel Route Suggestion Algorithm)	Students scored recommended internal paths
[61]	Routes which pass through landmark locations based on user interest and time	Analyzed geo-tagged photos posted by users to predict landmark interest and generated routes which optimize visits to the landmarks	Flickr	Ex	Ability to visit landmarks	Optimizes visits to landmarks based on time available	Examined the predictive accuracy of landmark interest
[60]	Routes which pass through optimal tourist locations	Identified a route which provides an optimal path through POIs scored using Collaborative Filtering and contextual factors identified through questionnaires	Foursquare	Ex	Ability to visit tourist attractions	Not specified	Usability evaluation A/B used to determine the effect of incorporating user context

TABLE 3. ***(Continued)*** **A summary of the studies in this paper.**

Cite	Recommended Route	Feature Mapping	Data	Taxonomy	Quality	Algorithm	Evaluation
[63]	Routes which pass through optimal tourist locations	A sequence of POIs generated from cultural and architectural elements of urban districts as a tour path	Collection of POI	Ex	Scenic views	Iterated local search meta heuristic	User-centric evaluation of the prototype system (usability, utility, functionality and recommendation value)
[64]	Routes which offer diverse views and facilities along the path	Venue tags from Foursquare and Image tags from Google Street View and color data used to calculate the diversity within each street	Foursquare Google Street View	Ex	Diversity of facilities and views	Dijkstra's algorithm	None (Demonstration only)
[62]	Routes which pass through interesting venues based on past user interests	Utilized collaborative filtering on past user travel history and location popularity to predict interest in nearby venues and generate a travel plan between those venues considering constrains in space and time	Venue tags and visited POI of data of the user and other users from Jie Pang	Ex	Ability to visit interesting venues	Travel Route planing algorithm	Back-tested algorithm with 3106 users, using a 80-20 train test split evaluation

with cases where multiple users wish to walk together as a group. Group-based routing algorithms could be particularly useful in situations such as group tours and group exercise (jogging with friends, etc.). Such systems would need to take into account the interests and characteristics of a group of users instead of a single user. Several key questions would then need to be addressed, such as whether to take a democratic stance and treat all user needs uniformly or otherwise try to give preference (e.g., to guests or senior persons).

- The studies in our survey have utilized data from various sources when calculating the qualities on a given path. Data collected from location based social media such as Twitter, Foursquare and Instagram have been particularly useful in representing the behaviour and experience of general users at a large scale (such as what venues are popular or which streets are safe, etc.). However, it is generally more difficult to utilize data from such sources when calculating qualities which are more specific to certain user groups, such as when determining which street is accessible for older people or people with disabilities (as these users tend to be under-represented on social media platforms [75]). In such cases, a crowd-sensing approach is often used, which involves collecting data about the qualities of path while target user participants (wheelchair users etc.) travel along the routes [51], [52]. While it had previously been difficult to implement routing systems based on such qualities in scale due to the effort required by participants, recent improvements in machine learning have led to the development of techniques which allow various accessibility and safety qualities to be inferred automatically from public data sets (such as identifying zebra-crossings from satellite images [83], [84]) or with less effort by participants (such as a passive crowd-sensing approach proposed by Kamaldin *et al.* [85] which automatically detects surface type conditions for wheelchair users or the Moving Wheels [86] which automatically detects obstacles such as steps or ramps from crowd-sourced wheelchair users). A particularly promising research direction that we believe should be further investigated is the use of a semi-automatic approach where users are asked to verify the result of less certain predictions from machine learning models [87]. Such an approach would help ensure both scale and accuracy in the development of a routing system.
- Researchers should be aware of the temporal characteristics of the data they use to calculate the qualities of the routes. For example, Google Street View images for the same city or even district are sometimes taken at different days and times when conditions such as daylight levels or street crowdedness may differ. Additionally, unique dynamic events (such as public demonstrations or irregular sporting events) may influence the nature of conversations in geo-tagged tweets, the characteristics of photos from Flickr and visit numbers on Foursquare Swarm. Hence, when constructing machine learning models to predict route quality from such data (e.g., object and color detection for street quality estimation

and semantic or sentiment analysis from tweet data [14], [15], [39], etc.), the outlier data points would need to be removed and the data would need to be normalized.

- The categories of qualities which we identified from existing studies should by no means be considered as an exhaustive list, but more as an overview of potential areas where quality-aware navigation systems could be applied towards. By providing this basic categorization, we hope to create more awareness about the different areas that have benefited from such systems and promote further development into similar systems in the future. Indeed, we can imagine a range of scenarios that future route navigation systems could consider. In health and physical well-being domain for instance, systems which could recommend routes with hygiene related facilities (e.g., toilets, nursery rooms or facilities providing medical care like hospitals) could be especially useful for the elderly, sick people or mothers with babies or toddlers. Furthermore, existing route recommendation algorithms could also be applied to benefit the community in novel ways. For example, the algorithms developed to help hikers avoid other pedestrians [68] or help users avoid crowds [11] could be useful to people suffering from agoraphobia and could even be applied to protect users in the cases of epidemics such as Covid-19.

VI. CONCLUSION

The recent developments in online maps and routing systems serve as a testimony to their growing demand. While traditional route recommendation is still based on utilitarian factors such as distance and time cost, there have been an increasing number of systems proposed in recent literature which go beyond helping users find the shortest route and consider other qualities such as safety and well-being. In this paper, we provide a survey into such quality-aware route navigation systems.

The different systems which were identified in this paper are presented in detail in Table 3. Overall, we identified five key categories (Safety, Health and Well-being, Effort, Exploration, and Pleasure) based on the quality attributes which have been proposed in existing literature. The data sources used to generate the features that represent these qualities range from location data obtained from OpenStreetMap (used to represent static street features) to social media and crowd-sourced data obtained from services such as Twitter, Foursquare, and Flickr (used to represent dynamic and user experience features). Through this survey, we have provided an overview into the characteristics of these data sources as well as a summary about how they were used in the route recommendation process. Afterwards, the different algorithms which have been used in the routing process as well as the methods that researchers have employed to evaluate their proposed systems were discussed in detail. Common approaches used to evaluate the systems include field and prototype evaluations, back testing and a manual inspection of the routes.

In the discussion, we highlighted the limitations and proposed future research directions for quality-aware navigation systems. Such limitations include the lack of a comprehensive evaluation method for quality-aware navigation systems and the tendency for such systems to assume that user preferences and street features remain static while the system is being used. In addition, most systems tend to focus on a single route quality type and are designed to cater only to individual users. Therefore, to further improve quality-aware navigation systems, we propose that researchers should investigate the development of multi-quality, group-based routing algorithms, a trans-domain evaluation framework and routing algorithms which are able to adapt to changes from street features and user preferences in real-time. This we believe would allow such systems to be more widely adopted by general users in daily life. Finally, we should also note that due to the scope of our survey, our review focused on literature which describe route navigation systems designed for pedestrians and the results from this study would not be generalizable to other types of navigation systems such as those targeting car drivers.

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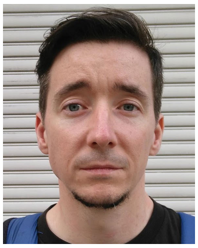
PANOTE SIRIARAYA received the Ph.D. degree in electronics from the University of Kent, Canterbury, U.K., in 2013. He has worked as a Postdoctoral Researcher with the Faculty of Industrial Design Engineering, Delft University of Technology, from 2014 to 2017. He is currently an Assistant Professor with the Faculty of Information and Human Science, Kyoto Institute of Technology, Japan. His main research interests include human–computer interaction and machine learning, which includes topics such as virtual environments, recommender systems, and designing technologies for the aging population.

YUANYUAN WANG received the Ph.D. degree in human science and environment from the University of Hyogo, Japan, in 2014. She has worked as a Researcher with Kyoto Sangyo University, in 2014, and Nagoya University, in 2015. She is currently an Assistant Professor with the Graduate School of Sciences and Technology for Innovation, Yamaguchi University, Japan. Her research interests include e-learning systems, data mining, and human–computer interaction.

YIHONG ZHANG received the Ph.D. degree in computer science from The University of Adelaide, Australia, in 2016. Since then, he has worked as a Postdoctoral Researcher with Kyoto University, Japan, and Nanyang Technological University, Singapore. He is currently a Postdoctoral Researcher with the Department of Multimedia Engineering, Osaka University. His research interests include social computing, data mining, and statistical modeling.

SHOKO WAKAMIYA received the Ph.D. degree in human science and environment from the University of Hyogo, Japan, in 2013. She has worked as a Postdoctoral Researcher with Kyoto Sangyo University. Since 2015, she has been working as a Postdoctoral Researcher and an Assistant Professor with the Nara Institute of Science and Technology, Japan, where she is currently an Associate Professor. Her research interests include social computing, medical and health informatics, and applied natural language processing.



PÉTER JESZENSZKY received the Ph.D. degree in geographic information science from the University of Zurich. He was a Postdoctoral Researcher, funded by the Swiss National Science Foundation, with the Department of Geography, Ritsumeikan University, Kyoto, while assembling this study. He is currently working as a Postdoctoral Researcher with the Center for the Study of Language and Society, University of Bern, Switzerland. His research interests include spatial data science, linguistic geography, and cartography.

YUKIKO KAWAI received the M.S. and Ph.D. degrees in information science and technology from the Nara Institute of Science and Technology, in 1999 and 2001, respectively. She has worked as a Postdoctoral Researcher with the National Institute of Information and Communications Technology (NICT), Japan. She is currently a Professor with the Faculty of Information Science and Engineering, Kyoto Sangyo University. Her research interests include data mining, visualization, Web mining, GIS, and information retrieval.

ADAM JATOWT received the Ph.D. degree in information science from The University of Tokyo. He then worked as a Postdoctoral Researcher with the National Institute of Information and Communications Technology (NICT), Japan. Since 2006, he has been working as an Assistant and an Associate Professor with Kyoto University, where he is currently an Associate Professor with the Department of Social Informatics. His research interests include information retrieval, natural language processing, digital libraries, and digital history.