Looking for Human Footprint in Nature: Collaborative Mapping for Monitoring of Self-organized Patterns in Human Trail Systems

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Abstract. Informal trails are usually disregarded to be depicted in the maps and the different dynamics of human trail system formation have not been fully understood, although they are playing an important role in human transportation and impacting the environment and the neighborhoods dramatically.

To create and enrich a database on formation dynamics of human trail system and mapping of the informal trails in the planned and unplanned environments, this research adopted a collaborative spatio-temporal monitoring and mapping approach. To this end, in this study a web-based multimedia GIS system was employed to handle Volunteered Geographic Information that were produced by the participants in the different multimedia formats as well as the temporal images and videos that were acquired by the UAV system in centralized approach.

1. Introduction

The informal trail or desire path (also known as a desire line and social trail) is a technical term which has been applied for a footpath that formed as a

consequence of pedestrians walking in the formal urban environment by urban planners for almost a hundred year. An informal trail is normally formed by people, in the absence of a designed sidewalk or an official route to the desired destination of pedestrians in the urban areas. Furthermore, when an existed designed rout cannot meet the general principles of human logic in path selection, a desire path may be formed based on human preference. In this case, usually a shortcut is emerged as a consequence of pedestrians' footprints in the urban environment. Not only in the planned urban landscape such as parks and campuses, but also the informal infrastructure (i.e. footpaths and trails) can be observed in the unplanned and self-organized environments such as wild nature or informal settlements.

Informal trails are usually disregarded to be depicted in the maps and the dynamics of human trail system formation are neglected to be understood, although they are playing an important role in human transportation and impacted the environment and the neighborhoods considerably

To develop and enrich a database on formation dynamics of human trail system and mapping of the informal trails in the planned and unplanned environments this research adopted a collaborative spatio-temporal monitoring and mapping approach that will be reviewed and discussed in the upcoming sections of this paper.

2. Spatio-temporal Dimensions of Human Trail Formation in the Natural Environment

Formation of human trail system from an origin to a destination in the environment has a bottom-up nature. Basically, the process starts when a track is created by a single pedestrian in the form of physical signs such as compacted ground, snow or damaged and trampled vegetation. These physical signs as the footprint of human in the nature continuously change the landscape while the pedestrians moving from the origin point to the destination point in the landscape. This track will be developed into a footpath if it has been used frequently by many people.

Bottom up process of growth in trail system is initiated from the different daily behaviours of human in the context of an environment and is influenced by various social, economical and physical factors.

Beside the bottom-up development, it is observed that sometimes there are some top-down interferences in the dynamic of trail system expansion. These formal interferences are mostly related to the upgrading of unpaved

footpaths for increasing of the ease of travel in the formed and frequently used trail.

The emergence of the spatio-temporal patterns in the human trail systems are originated from the presence of collective behavioural patterns evolving from the pedestrians' actions and interactions in the environment.

In the context of human locomotion, a pedestrian can be defined as a goal-oriented individual that aim to reach to the destination from her/his origin point in the space based on the principle rules of human logic for path selection.

The formation mechanism of the complex spatial trail patterns in the uniform and obstacle-free environment is an evolutionary process. In this sense, a "Direct Way System" (i.e. beeline path) is formed at the first stages of trail evolution as the result of travel distance minimization goal of pedestrians. In the course of time, by emergence of the common tracks in the environment, a pedestrian will tend to pass over the common tracks to increase his/her convenience and ease of travel.

However, as the distance traveled by a pedestrian is a major constraint for a him/her, an individual does not like to have a large detour from the beeline path (i.e. shortest path), so he/she tries to find the balance between these two goals (minimization of the travel distance and maximization of convenience and ease of travel). By consolidation of the compromise trail system, a structure is formed in the trail system that could be called "Balanced Way System" (Figure 1). In this sense, the complex compromised patterns in the trail system emerged as result of human-environment interaction.

Figure 1. A Balanced Way System that was formed in a planned environment (Image courtesy of Google Earth)

The trail system may form at the different spatial scale anywhere, in the planned environment (e.g. open spaces in the street, park, university campus, etc.) or in the unplanned environment (e.g. wild nature, informal settlement) on the grass, bare soil or snow. In this term, different spatial patterns are formed in the trail system as the result of the different social, economical and physical factors which impacted the system.

In addition to spatial characteristics of human trail systems, as it was implicitly mentioned, the temporal dimension of human trail formation is another notable characteristic of trail formation phenomenon. In the course of time, two criteria of minimization of path's length and maximization of walker's convenience have been fulfilled and optimized as the result of the collective optimization approach of the pedestrian to ensure the formation of a compromise trail system in the environment.

Tracks and trials may have a temporary existence in the nature and durability of them are the function of the number of the track or trial users over time. In this sense, the human footprints and the formed trails in the space could be faded or disappeared if the track or trial has been left abandoned for a long time or blocked and not used by the pedestrians frequently as the result of different physical, social or economical factors. In the other words, as the rate of surface weathering or vegetation growth exceeds than the rate surface damaging, compaction and trampling, the track or trail will vanish gradually over time.

For example, the beeline paths that formed between three nodes (origin and destination points) gradually left abandoned (fully or partially) over time as the Direct Way System transit to the Balanced Way System as the result of the collective optimization approach of the pedestrians to form the compromise trail system.

Gradual disappearing of the trails as the result of changes in the security condition of neighborhood or considerable decreasing of the number of daily trips between the origin and destination because of reduction of destination attractiveness are another good examples for this case.

Not only the gradual evolution, but also the abrupt changes in the physical characteristic of the environment may affect the existence or alter spatial structure of trail system sharply.

For example, in the context of informal settlement, the new buildings may be built on the informal track o and block the way if that trail has been used only by a few number of dwellers and not consolidated well in the settlement. So, usually in this case, if an enough space is available around the new

constructed building, the trail's users bypass the obstacle and a new track will be formed gradually around the new building.

Covering the formed trail (fully or partially) by the seasonal flood, swamp etc. and sudden blocking of the trail for the certain period of time in the informal settlements are the good instance for causing of the abrupt changes in spatial formation of the trail system over time.

3. Necessity for Understanding of Human Trail Formation Dynamic

Clear understanding of trail formation dynamic enables the architects and landscape designers to design the formal paths in the open spaces based on the human logic for path formation to prevent the formation of informal shortcuts in the planned environment.

Furthermore, increasing our knowledge about the process of human trail formation enables urban planners and mangers to develop a robust model to simulate the growth pattern of informal infrastructure (trail system) in the informal settlements. The result of this simulation would be very valuable, as the informal infrastructure expansion has a considerable role in the addressing of the informal settlement expansion direction and informal housing pattern. Therefore, by developing a holistic model for simulation of informal infrastructure growth, the informal settlement dynamic can be simulated more realistically

3.1. Spatio-temporal Mapping and Monitoring for Synthesizing and Modeling of the Human Trail Systems

The first contribution for modeling of human trail formation dynamic was conducted by Helbing et al. (1997). Their proposed model was developed based on the concept of Active Walker model in theoretical physics and aimed to reproduce the emerging patterns in the human trail system which are forming between the limited configurations of the points (origin and destination) in the homogeneous and obstacle-free environment.

The main goal of this research was how to adopt and develop the Active Walker model to regenerate the complex patterns that are observable in trail system. In this context, for the simplification of the model, the role of the different physical, social and economical driving forces in the formation of informal trail systems were neglected and a few simple abstract real cases were selected as a case study and the proposed model was configured and adjusted to reproduce the resemble patterns of the trail system that were emerged in the case study. Therefore, consideration of all behaviors of the

individuals and their interactions with each other and environment as well as the systematic analytical validation of the model with the real world were the beyond the scope of this study.

In another study, Goldstone, et al. (2006) studied the nature of the collective behavior of human crowd in formation of the complex trail patterns. To study this dynamic, they developed a software platform for tracking of the virtual movements of the participants of experiment between several points in a plain and homogeneous environment. This experiment was done by participation of a limited number of participants in a short time, and in contrast to the reality, the participant of this study have a global view about the virtual environment and the emergent trail patterns that form in the system. Therefore, it is not an easy task to over-generalize the results of this study to the realistic cases in the natural environment.

The reviewing the previous literature on the informal human trail formation dynamic shows that so far not enough attention has been paid to understand and modeling of the individual and collective behavior of human in the process of informal path formation in the heterogeneous and complex natural environment.

The lack of enough spatio-temporal information from all steps of the trail formation dynamic and the driving factors in trail formation and evolution is one of the major reasons of the absence of the comprehensive studies on describing the different process of trail system formation and lack of holistic model for simulation of the emergent patterns in the informal trail system.

To have more clear outlook on the role of spatio-temporal information in the understanding and modeling of trail formation dynamic, it is necessary to review the function of the real world data in the procedure of spatial modeling and simulation. Figure 2 illustrates the process of developing a model for simulation of geographical phenomenon in the real world. Acquisition of the accurate spatial-temporal data on the phenomenon is the basic task in the process of spatial modeling as all of the aspects and dynamics of the phenomenon should be fully understood to develop a holistic model from the geographical phenomenon in the real world. Furthermore, in validation and calibration phase of spatial agent-based simulation, the output of the designed model have to be compared with the collected spatial-temporal data about the studied geographical phenomenon (i.e. ground truth) and the model have to be modified if it is necessary in order to guaranty of the accurate representation of the real system by the developed model.
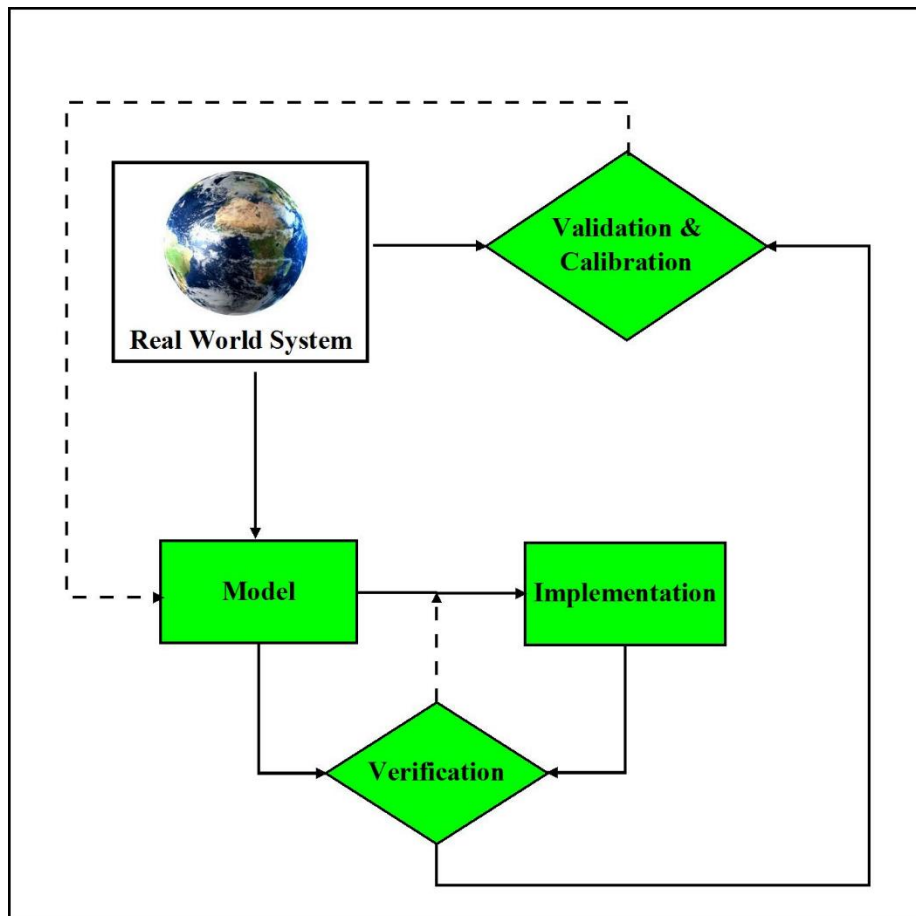
Figure 2. Process of developing a model for simulation of geographical phenomenon

Thus, to understand the role of the different driving forces (i.e. physical, social and economical factors) in the formation of the complex patterns in human trail system in the nature and for filling of the current research gaps, the spatio-temporal mapping and monitoring of the trail systems is a crucial task.

4.   Multimedia GIS and Collaborative Mapping

Multimedia exploit different types of media to transfer information such as descriptive text and tags, audio, graphics, animation, and video in interactive digital-based approach. Multimedia promotes user experience and facilitate

and increasing the speed of information understanding (Cartwright and Peterson 2007).

Integration of GIS and multimedia technologies were enabled in the recent years by the advancement in IT technology and the paradigm of multimedia GIS became popular in the area of location-based services. Multimedia GIS enables location-based services to incorporate not only with geographic information in conventional formats but also supporting of multimedia geographic information which were disregarded until fairly recently in the world of GIS.

By the current advances of web 2.0 technologies and popularity of bottom-up and decentralized approaches in the world of GIScience, consideration of local knowledge has increased significantly in the recent years in contrast with the former predominant top-down paradigm of expert-driven GIS in the last decades. So, by employing these new web technologies, the citizens have been enabled to produce the content, as well as the user-friendly interfaces for collaborative mapping approaches.

In the light of these developments, the volunteers can produce and develop the maps easily by using of the map editing online tools and digitizing of the geographical features from the provided base maps as well as high resolution airborne and spaceborne images and enriching the spatial data with attribute information. Furthermore, by emerging of GPS-enabled technologies (e.g., smartphones) and equipping of them with a wide variety of different sensors in the recent years, the participation of the individuals in the process of map making has been facilitated and this great advancement empowered the citizens to enrich the maps with the accurate diverse spatial and attribute information(Jokar Arsanjani and Vaz 2015).

In this context, the Volunteered Geographic Information (VGI) is defined as exploiting of tools for creating, assembling, and dissemination of spatial data produced in the voluntarily approach by citizens and it is a special case of the more general concept so-called user-generated content (UGC) in Web 2.0 Paradigm (Goodchild 2007).

By prevalence of GPS-enabled technologies which support different types of sensors in the daily lives of citizens and according to the advances in web technology as well popularity of collaborative mapping solutions among the individuals, the Multimedia GIS has been transited from the traditional expert-oriented Desktop GIS approach to more citizen-oriented WebGIS based approach to support and handle of the tons of multimedia geographic information that are producing continuously by the volunteers around the world in a decentralized and distributed approach.

4.1. 5D World Map (5DWM) System

"5D World Map" (5DWM) system is an location-based context-aware knowledge creation and sharing system that is developed by "Multi Database and Multi Media Database Research Group" at Keio University, Japan (Figure 3). 5DWM system allows spatial, temporal and semantic analysis of multimedia data and it can integrate and visualize the analyzed location-based information as a 5-dimentional dynamic atlas (Kobayashi et al. 2014; Nguyen et al. 2013; Nguyen et al. 2011; Sasaki et al. 2008).
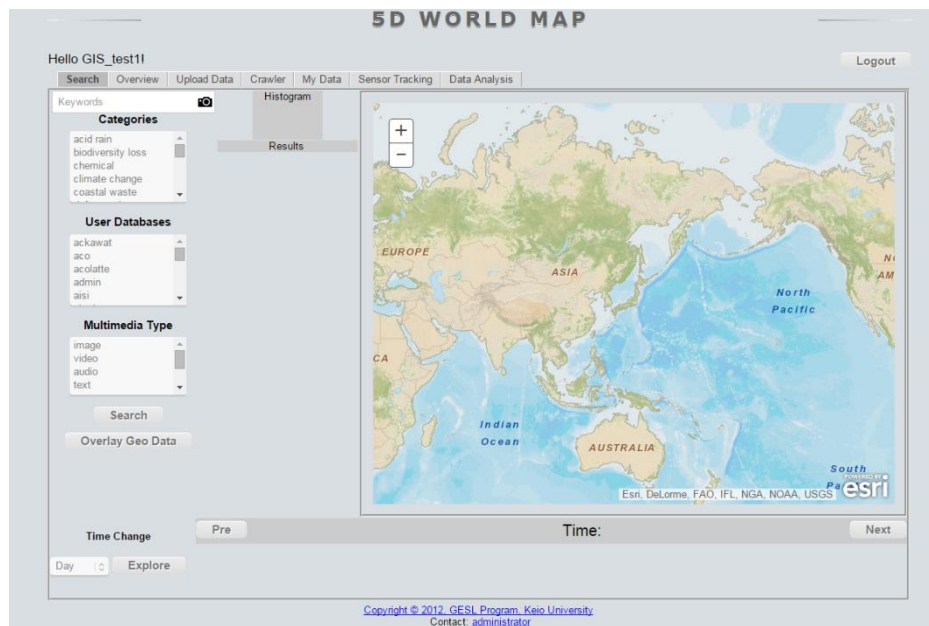
Figure 3. Screenshot of 5D World Map System

The principle space of this system consists of 5 dimensions of: time (1st dimension), space (2nd, 3rd and 4th dimensions) and finally semantic dimension (as the 5th dimension, which represent a large-scale semantic space) (Kiyoki et al. 2012).

The main feature of 5DWM system is to create and represent various context-dependent spatio-temporal of environmental and social phenomena dynamically according to the different perspectives of service users. The 5DWM system produces multiple views of temporal-spatial and semantic relationships among multimedia in a multidisciplinary environment. (Kobayashi et al. 2014; Nguyen et al. 2013; Nguyen et al. 2011; Sasaki et al. 2008).

In this system, a semantic associative search approach was developed for supporting of the semantics of words, features of multimedia and events. In this context, in addition to the base spatio-temporal data, semantically-evaluated and analyzed multimedia data are also mapped dynamically into space-time. The system has been developed to provide high visibility of semantic correlations among multimedia in temporal and spatial information variation. (Kobayashi et al. 2014; Nguyen et al. 2013; Nguyen et al. 2011; Sasaki et al. 2008) (Figure 4).
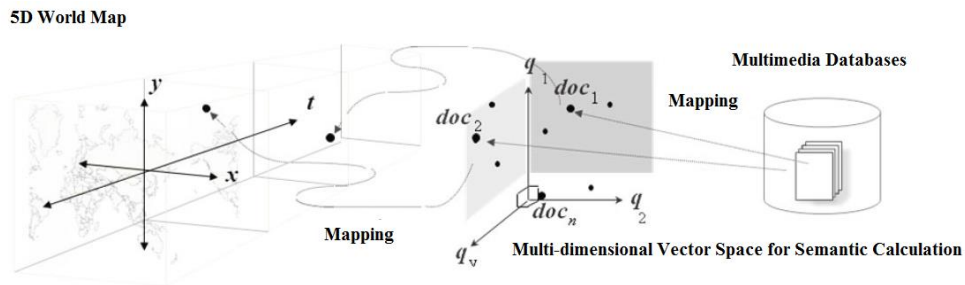

Figure 4. Spatio-temporal and Semantically-evaluated multimedia data dynamical mapping in 5D World Map System (Modified from: Kiyoki et al.(2012))

In the perspective of GIScinece, 5D World Map System can be supposed as a context-aware Multimedia WebGIS system that can be adopted for storing, visualizing, managing and analyzing the different collaboratively collected location-based data (e.g. spatial data layers, GPS data, image, sound ,video and text etc.) on the physical and non-physical characteristics of the observed geographical phenomenon in the real world.

This system can handle the diverse range of studies in the area of environmental sciences such as (1) Cross-topic environmental studies using multimedia retrieval, (2) Time-series based environmental-change observation, and (3) Cross-space environmental-issue overview (Kobayashi et al. 2014).

From the functional and analytical perspective, the 5D World Map System currently supports the different spatial, temporal and semantic functionalities such as Cross-topic multimedia search by semantic similarity calculation, Multimedia database overview by spatio-temporal information, Media data uploader for multi users, Differential computing for spatio-temporal data, spatio-temporal information visualization and sensor tracking.

5. Prototype Implementation

A prototype project was initiated by using of 5DWM system to conduct a collaborative approach for mapping of informal trails in the nature. The participant were asked to use the multi-media functionalities of 5DWM system to map the informal paths in the Shonan Fujisawa Campus (SFC) of Keio University, Fujisawa, Japan. The project members might use the smartphones, tablets, handheld GPS or digital camera for collecting the multimedia data in the formats that are supported by 5DWM system (.txt, .pdf, .csv, .jpg, .png, .gif, .mpeg, .kml).

In this study, the spatial component of the studied phenomenon could be acquired by using GPS, manual digitizing or geo tagging on the base map.

The attribute data and temporal component of the studied feature could be assigned to the spatial data by using of the developed interface in 5DWM system (Figure 5, Figure 6 and Figure 7).
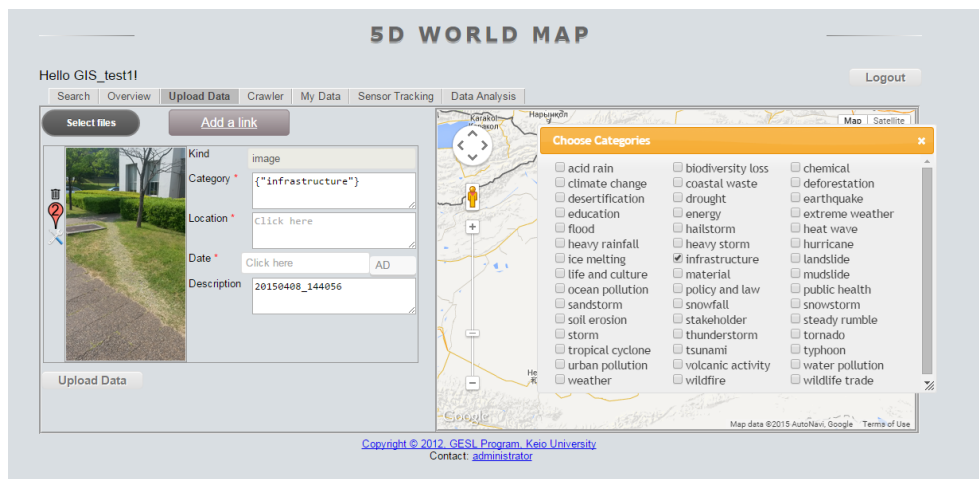

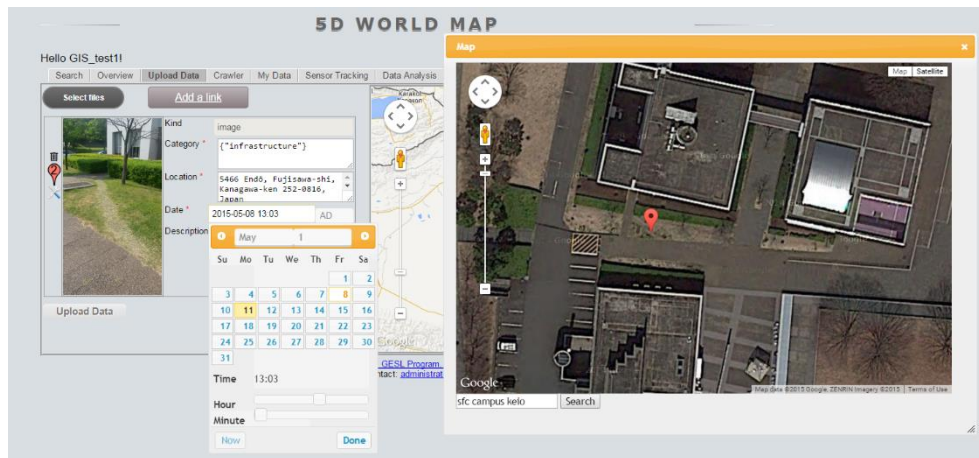**Figure 5.** Adding the attribute data (category) to the uploaded multimedia data in 5DWM system

Figure 6. Adding the spatial and temporal data to the uploaded multimedia data in 5DWM system
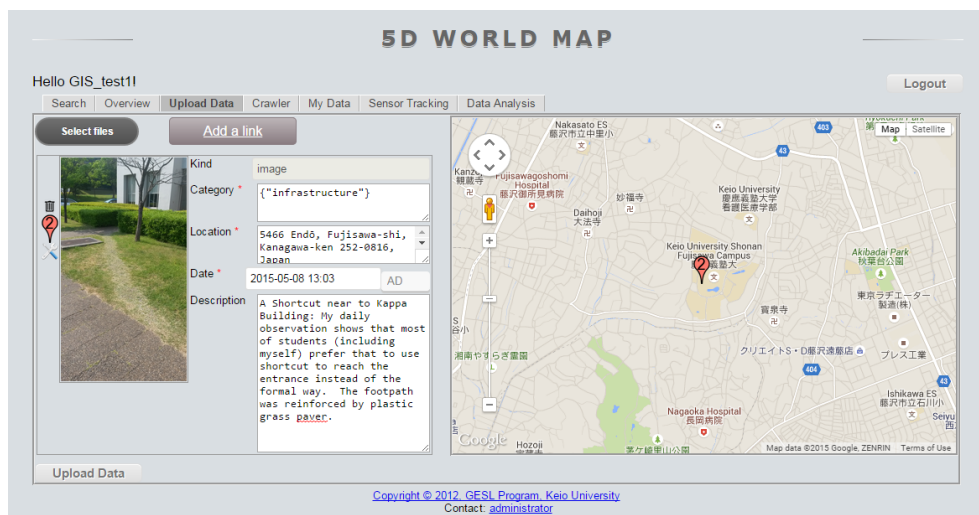

Figure 7. Adding the attribute data (description) to the uploaded multimedia data in 5DWM system

In addition to collecting the data by the ground-based sensors, one of the large scale trail systems within the campus was selected to be mapped by low-cost UAV system (fall 2014 and spring 2015) and uploaded to the system to enrich the collected multimedia GIS database on informal trail system in the study area (Figure 8).
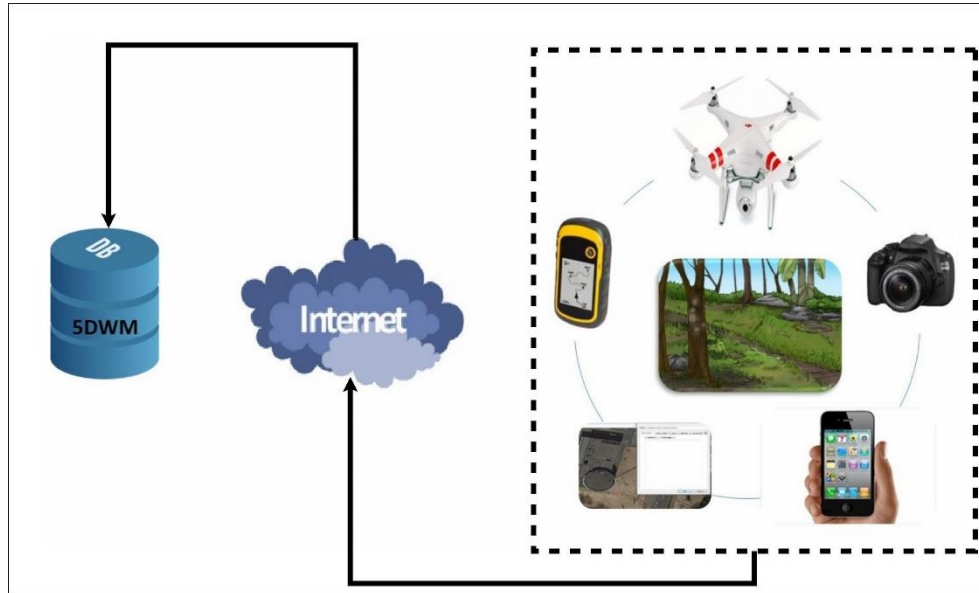
Figure 8. Collective Sensing and Collaborative Mapping for mapping and monitoring of human trail system

The UAV-based remote sensing method was employed: (1) to monitor the possible changes and evolution of the trail system during the different time-spans of the year via RGB high resolution imagery and (2) to study and track the pedestrians' locomotion patterns in the informal infrastructure system by using of UAV video. Moreover, the possibility of conducting the collective mapping projects and fusion of ground-based sensors with air-borne sensors in the context of 5DWM system was investigated.

In this project, the spatio-temporal multimedia records were collected from the trails within the campus. The participants produced their data in the format of image (.jpg), video (.mpeg), vector data (.kml) and observation report (.txt) (Figure 9).

Figure 9. A trail was mapped by GPS and various multimedia data about the feature were added to the system in a collaborative approach.

6.   Conclusion and Future Works

This study reviewed the necessity of enriching of a multimedia GIS database in a collaborative approach for understanding of trail formation dynamics and mapping of informal trails. In this sense, by incorporation of the local knowledge of citizens with different geospatial technologies, the informal trails can be mapped and monitored over time in decentralized and distributed approach. The collaborative method enable stakeholders to map the informal trails and collect the data on trail formation dynamic in a wide spatial scale in the time, labor and cost effective manner.

In this study, a prototype project was run in a limited spatial scale with a limited number of participants and the collected multimedia spatio-temporal data were stored and visualized by 5DWM system.

However, to increase our understanding from the different dynamics of informal trail formation, it is crucial to collect large amount of spatio-temporal data from the different planned and unplanned environments

in urban and rural areas as well as wild nature. Furthermore, for fulfilling this goal, it is necessary to enrich the database with socio-economical information from the study area. To continue this research, in the future steps we will design a spatio-temporal and semantic analysis framework for processing of the multimedia data by using of the functionalities of 5DWM system to find the driving forces of informal trail system formation and analyze and interpret the different spatio-temporal emerging patterns in the human trail systems.

References

Cartwright W, Peterson MP (2007) Multimedia cartography. Springer

Goldstone RL, Jones A, Roberts ME (2006) Group path formation. Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on 36(3):611-620

Goodchild MF (2007) Citizens as sensors: the world of volunteered geography. GeoJournal 69(4):211-221

Helbing D, Keltsch J, Molnar P (1997) Modelling the evolution of human trail systems. Nature 388(6637):47-50

Jokar Arsanjani J, Vaz E (2015) An assessment of a collaborative mapping approach for exploring land use patterns for several European metropolises. International Journal of Applied Earth Observation and Geoinformation 35, Part B(0):329-337 doi:http://dx.doi.org/10.1016/j.jag.2014.09.009

Kiyoki Y, Sasaki S, Trang NN, Diep NTN (2012) Cross-Cultural multimedia computing with impression-based semantic spaces Conceptual Modelling and Its Theoretical Foundations. Springer, p 316-328

Kobayashi A, Sasaki S, Kiyoki Y (2014) An Analytical Visualization of Global Political Effects with 5D World Map System: Cases of Anti-governmental Movement to Regional Upheaval in the Middle East. In: The Third Indonesian-Japanese Conference on Knowledge Creation and Intelligent Computing (KCIC) 2014, Malang, Indonesia.

Nguyen DT-N, Sasaki S, Kiyoki Y (2013) Wee: A Mashup System Using Social Networks For Collaborative Environmental Monitoring Education With Spatiotemporal Analysis And Visualization. In: The 10th IASTED International Conference on Web-based Education (WBE 2013), Innsbruck, Austria

Nguyen T, Sasaki S, Kiyoki Y (2011) 5D World PicMap: Imagination-based Image Search System with Spatiotemporal Analyzers. In: Proceedings of IADIS e-Society 2011 Conference, Avila, Spain, vol 8. p 253-261

Sasaki S, Takahashi Y, Kiyoki Y (2008) Futuristext: The 4D world map system with semantic, temporal and spatial analyzers. In: Proceedings of the IADIS e-Society 2008 Conference, Algarve, Portugal, vol 8