IDENTIFYING PEDESTRIAN MOVEMENT BEHAVIOUR USING OBJECT DETECTION METHODS AND LAND-USE AGGLOMERATION ANALYSIS

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KEY WORDS: Pedestrian Behaviour, Human Detection, Land-Use Planning, Public Transits, Accessibility, Spatial Analysis

ABSTRACT:

Urban structure plays a key role in providing available paths for pedestrian flow through urban areas. Land-use planning influences the accessibility behaviours of pedestrian movement controlled by urban structures, activities, and street networks with the unique attributes of each urban area. To improve urban spatial planning in terms of adopting effective land-use options and enhance a better public transportation accessibility, we consider combining the following two techniques; detection of pedestrians using computer vision, and trajectories of crowd movement using land-use agglomeration pattern analysis. Applying the proposed method to a high-density area composed of multi-directional crossings at a T-way junction in front of Hakata station, Fukuoka, Japan, it is shown that the derived correlation coefficient between the closeness value and the volume of commercial building space indicates a strong relationship between these two variables, resulting in the conclusion that the proposed method is useful for application in the design of urban spatial plans.

1. INTRODUCTION

The study of pedestrian movement is crucial for land-use and transportation planning which mostly concentrates on improving the connection between urban places and public transportation. Land use planning influences pedestrian movement behaviour in terms of the element of accessibility that is controlled by urban structure, activities, and street networks, all of which make different cities display the unique urban forms. This is especially the case in the high-density areas such as a central business district or a major transit station district where urban form is planned to support the use of land and potential accessibility between people and places.

Urban structure plays a key role in providing available paths (Anas et al., 1997; Hillier, 2007; Voulgaris et al., 2015; Kim, 2017) for pedestrian flows through urban areas. Public spaces, sidewalks, and street crossings all influence the direction of crowd movement along with the surrounding conditions that have an impact on people making decisions on which access path they select (McCuaig et al., 2016; Nakamura, 2016). Pedestrians create their own path to reach their desired destination through their own choices of transit access routes, which are generated by their estimation and perception of the quickest route whilst also considering secondary factors that include the surroundings of the built-up environment such as the attractiveness of facilities while avoiding negative features. Urban network analysis is useful for describing the interaction between urban structures and street networks which leads to the impact prediction on the project evaluation. The computer analysis is available for the transportation planning on providing important spatial information which is precise data on spatial structure that enables urban planners to see the whole picture of the planning area as well as to understand the impact on both existing and future structures that might be assigned as a result of future policy.

Improvement of accessibility between transit nodes and destination also need to take into consideration the elements of urban agglomeration (Frey & Zimmer, 2001; Brulhart & Sbergami, 2008; Batty, 2013) such as the density or the cluster of activities (Lara, et al., 2016) which make the particular area attractive for a large amount of its users, such as a business district that has emphasis on employment as well as retail space and office and other necessary facilities that are related to the cycle of commercial activity (Sevtsuk, 2014). The development of spatial analysis methods that influence the accuracy of data, prediction and decision-making processes present the balancing between street network accessibility and urban activity density which classifies the characteristics of urban form (Papa et al, 2013). Urban facility designs that relate to pedestrian behaviour might help to improve the potential of accessibility or make the trip more convenient, especially in the last mile area (Lynch, 2003).

Survey methods used to identify pedestrian movement characteristics are questioned in terms of their ability to obtain precise data for proceeding to the next step of spatial analysis. As the development of data technology assists spatial survey methods with lower financial and time costs, surveyors or analysts nowadays are able to conduct data collection processes via their handheld device (Lwin et al, 2012; Calabrese et al., 2013). Although counting the number of people passing by particular area is considered as a traditional method for the study of transportation study, there are not always definitions of precise pedestrian movement or behaviour due to limitations in the data collection process. The integration of data surveying methods which are able to solve such limitations by relying on more accessible devices and computer software are needed to

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https://doi.org/10.5194/isprs-annals-IV-4-W7-123-2018

improve these collection methods. With this measure, the study combines the pedestrian detection system for tracking the actual walking movement which seems to be more precise in terms of identifying how pedestrians actually react to the pedestrian infrastructure within specific land-use conditions.

This study proposed the use of tracking data of pedestrian movement to interpret the crowd movement behaviour in an urban area. Pedestrian movement behavioural was compared with an analysis of urban agglomeration pattern in order to understand the interaction between pedestrian movement behaviour and the surrounding built-up environmental conditions. By suggesting a new approach using a combination of methods between human detection technology and the urban agglomeration pattern which those clusters of activity attracts a large volume of people to travel towards the particular area. Interpretation of the subjected factors is conducted through a statistical analysis in order to indicate the significant relationship of spatial structure and crowd's trajectory as well as people's choices of route which aimed to assist urban planners in developing their decision-making processes. This enhance the integration of public transit systems and land use planning towards urban spatial design to be more effective on urban spatial planning program.

2. METHODOLOGY

This study introduced the methods used to identify pedestrian movement behaviour which integrate object detection application and urban spatial analysis in order to investigate the interaction between built-up urban environments and people's perception of accessible routes. Although the density of each urban activity, location of buildings, and distance from transit nodes are all related to the attractiveness of an area due to the volume of potential destinations and level of accessibility, a pedestrian's route of choice is still needs to be checked according to the change of pedestrian perception (Rodriguez, et al., 2015; Millonig & Schechtner, 2007) of access routes due to surrounding built-up environmental factors area and crowd congestion. Then, the methodology proposed three parts of analysis, including pedestrian movement detection, spatial density and path analysis which can be used to interpret the results into geographical data.

The methods firstly consider the land-use agglomeration and its spatial network in the subject area through spatial density and network analysis in order to define the urban spatial pattern of the area. Spatial agglomeration analysis considers five factors of building-size configuration, such as building count, minimum building space, maximum building space, mean value of building space and total floor area contained within the building calculated in square meter units which investigate separately into urban block-scale which is located along the major street of the study area and district-scale which represents the two different districts that were separated by the major street. Then, the study simulates the potential accessible paths which indicated the probability of each trip that is likely to take along the street network for weighting the ratio of pedestrian route choice accessibility.

Secondly, the study records pedestrian movement using an object detection system on histograms of oriented gradients (HOGs) which have been modified in terms of the size of human detection according to the size of the video frame. Finally, the resulting data will be able to define pedestrian movement behaviour due to the significant trajectory among factors according to correlation coefficient measurement as displayed in Figure 1.

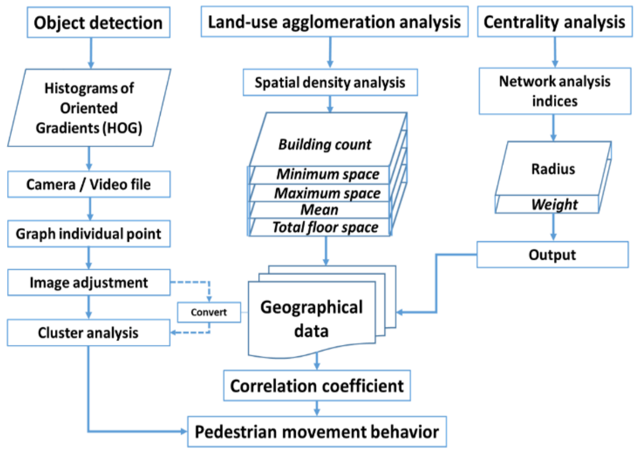

Figure 1. Research framework

2.1 Study area and over all of data

The study aims to identify pedestrian movement behaviour in a district that is influenced by land-use transportation planning as well as to investigate how people are distributed from a major transit station to surrounding destinations by walking. The study was conducted in Hakata ward, Fukuoka city, which is considered the largest transportation hub in Japan's Kyushu region. The majority of the study area consists of commercial activity and is considered as a new central business district of Fukuoka city due to the redevelopment of Hakata station as the hub for major transportation integrated with the commercial district. 96.25 % of land use in the study area is for commercial and commercial-mixed use buildings which indicates a high rate of passengers travel through the area. In this study area, users are encouraged to use public transportation due to the high density of people clustered which causes a high volume of traffic. Analysis of land-use agglomeration which focuses on the density of building-use classified by type of activity and the scale of considered area. Figure 2 shows the land use map with the total floor area calculated which illustrates the volume of land use in the study area.

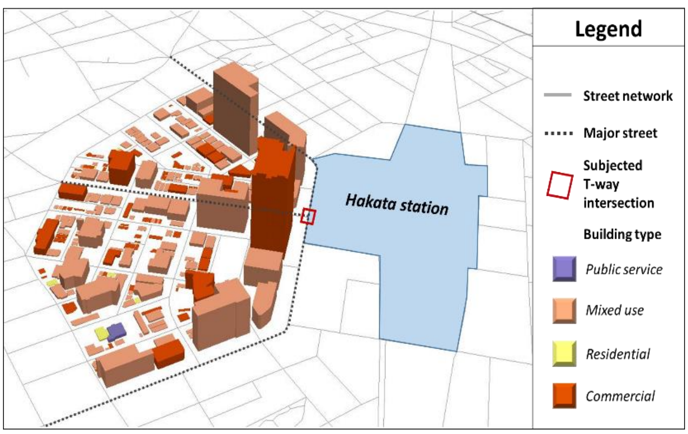

Figure 2. Land use map of study area with the volume of land use illustrated by the total floor area (m^2) in each activity.

The study area is divided into four sub-areas which aims to observe the differences of each area's performance between the north-side and south-side district that is isolated by the major street of Hakata ward. The study also investigated the performance of the urban block area that is located along both sides of the major street which named in this study as north-side block and south-side block as the illustration of the sub-areas displays in Figure 3.

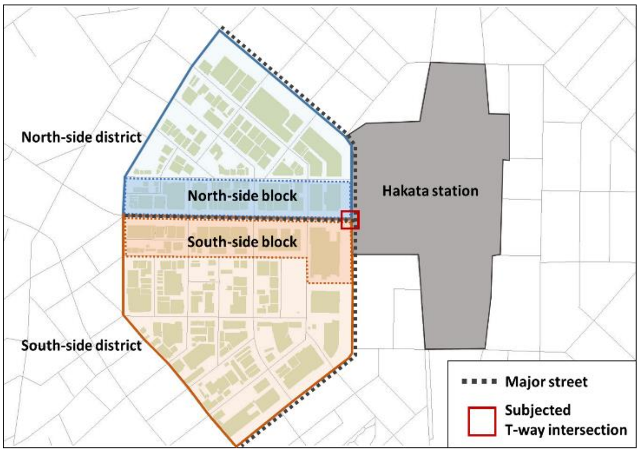

Figure 3. The sub-areas of the urban area in front of Hakata station which are separated into the North-side district, South-side district, North-side block, and South-side block.

For identifying pedestrian movement behaviour, the study selected the street with the most congested crossing in front of the buildings of Hakata station. The crossing is subject to investigation due to the significant role of accessibility from the transit station to surrounding destinations by examining pedestrian movement trajectories from the transit station to surrounding destinations by crossing through the 3-way intersection (Figure 4) as well as investigation of the volume of people accessing in each direction in order to identify the movement pattern that is generated from the actual movement considered along with land-use agglomeration and street network availability. The subject crossing area operates a pedestrian crossing signal that allows pedestrians to cross the street in a variety of different directions independently and not needing to follow the crosswalk's line.

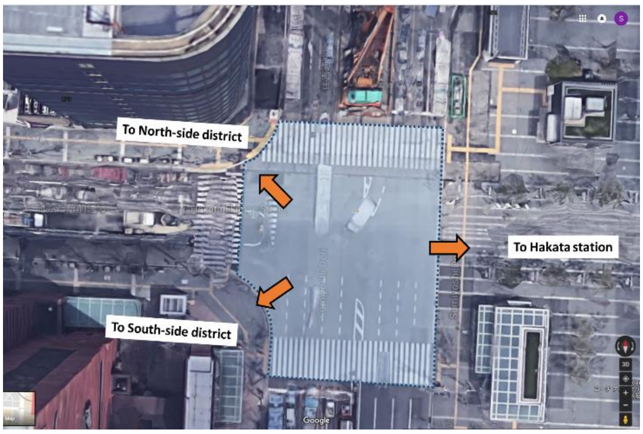

Figure 4. The 3-way intersection in front of Hakata station allows pedestrians to cross the street in different directions according to its signal at any given time.

2.2 Pedestrian detection application

The present study focuses on how different types of technology can be applied in the data collection process regarding pedestrian walking behavior and patterns; the wider aim is to better understand how pedestrians tend to move around urban areas. This study employs an 'object detect system' or 'ODS' because this system has a high potential for accurately detecting and recording the walking behavior of pedestrians, such as patterns of movement and the actual people's moving position when they are walking along a street or across a road at any given time. This system employs ODS by using a 'histogram of oriented gradients' (also referred to as just 'HOG') that can be utilized for identifying the shape of a person, which is a crucial aspect of collecting data about pedestrian movement (according to Dalal & Triggs, 2005). The aspects of HOG can be generated by applying orientation histograms the focus on the intensity of image edges in localized portions (Kobayashi et al., 2007). In terms of the detector frame's size, this study gave limits in accordance with the average size of a person captured by the frame of the camera in place at a given position. The actual moving position of a person can also be identified using HOG, as this system is capable of taking readings of a person's individual footsteps and then generating these into points of data, as shown in figure 5.

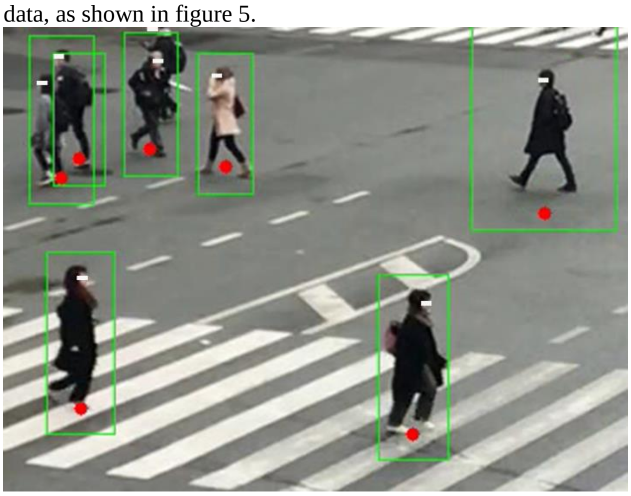

Figure 5. Green blocks are used by the system to identify each individual person (detection frame) while red dots are used to track footsteps as data points.

An XY graph is used to plot the data points in accordance with the video's frame. The video was recorded by one camera with specific scene due to the available of location in Hakata station area. These totaled 62,070 data points collected over a 90-second recording by the camera. The time for the recording was during a busy weekday (peak hour; 08.00 to 09.00). With specialized design software, these data points were then converted and reorganized by the shape of the planes recorded by the camera. This was in order to build up a master plan of Hakata, the Japanese city, by applying common reference points recorded by the video to an accurate spatial map plan. This plan would then be displayed using GIS (geographic information system), as shown in Figure 6. The final process required the conversion of the points of data into a wider system of coordinates (spherical) by rearranged the shape of data layer that contained the recorded points to the master plan of Hakata city using the common reference points. This would be shown by using X and Y points (or latitude/longitude points). Following this, a statistical analysis would be conducted by finding the K-mean and applying this method to generate data cluster areas. These cluster areas would then be able to be used in order to understand pedestrian movement behavior and common walking paths along roads.

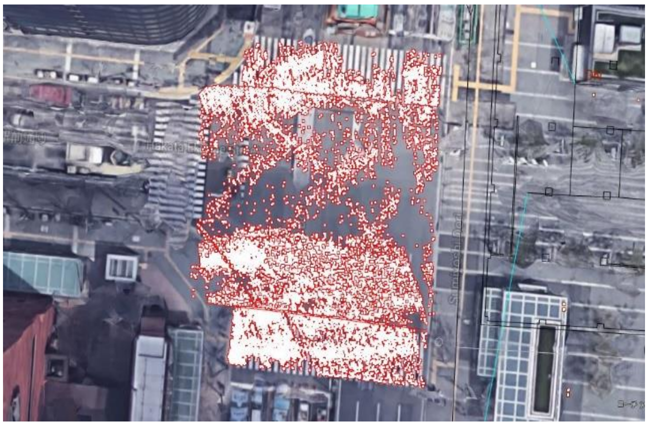

Figure 6. Spatial map employing GIS illustrations of the area of study; pedestrian movement detected by the camera is shown as points of data that have been transformed from the human detection system (HOG).

2.3 Interpretation of pedestrian movement behaviour

The urban form elements (Dempsey, et al., 2010) include density, building activity, spatial arrangement, land use, and transport infrastructure, all of which play a key role for the identification of physical characteristics of an urban area. The study of land-use agglomeration basically interprets the morphological attributes that also refer to economic and social systems of an urban area. People consider these land-use clusters as a center of urban activity which can be differentiated by size of the area, type of activity, and distance between nodes when people consider their route of travel. As pedestrians are forced to reach their destination in different ways due to different conditions (Cao et al., 2017) such as high densities of people, traffic congestion or to avoid any other negative features along the street. In comparison, the built environment impacts on pedestrian movement clustering and the volume of space in use indicates the significant impact that might attract a high volume of pedestrians to access the particular area but one other factor that might affect the flow of pedestrian trajectory as a distance between transit node and surrounding destinations is also taken into account. To investigate the relationship between the location of a specific destination and the distance from major transit nodes (i.e. Hakata station), the Closeness index from urban centrality analysis, which was developed by (Sevtsuk & Kalvo, 2015), is employed to indicate how close the commercial buildings are to Hakata station which considered by the shortest path along street network as defined as equation (1).

$$Closeness[i]^r = \frac{\sum j \in G-\{i\}, d[i,j] \leq r \frac{W[j]}{d[i,j]}}{n} \quad (1)$$

where $d[i, j]$ = distance between origin (i) and destination (j) through the shortest possible path
$W[j]$ = the weight of the destination (j)
n = total considered destinations;

The nodes in this study were represented by the buildings within the observed boundaries as a block scale and district scale from both sides of the major street in front Hakata station. As the purpose of this analysis was to investigate the relationship between activity nodes and the transit station, we then assigned the location of the destination as the destination node and Hakata station as the origin node. Moreover, to avoid the limitation of distance assignment, this study assigned a 5,000-meter radius for the closeness analysis in order to make sure that all of the considered buildings were not affected from unreachable issue according to the closeness calculation. At last, land-use agglomeration, which was considered by building space characteristics and the closeness analysis results were measured by the significant values of each scale and pedestrian trajectories to identify the relationship of continuous variables as a correlation coefficient.

3. RESULTS AND DISCUSSION

Pedestrian movement behaviour was illustrated by combining methods of actual pedestrian movement detection and analysis of urban agglomeration that influences crowd movement trajectory which enhances urban spatial planning in terms of adopting effective land-use options along with public transportation accessibility improvement. The pedestrian movement pattern illustrated the trajectory of crowd movement through a multi-directional crossing area which connects a transit station to surrounding buildings. Figure 7. illustrates the recorded data from the actual movement of pedestrian crowds in the study area which is able to be used to interpret the pattern of crowd movement by the number of detected points in a 50 square cm cell grid in geographic information system platform. The highest density area covered around a 5-meter radius at the south-left part of the crossing area which indicated 20.9% of the total detected points.

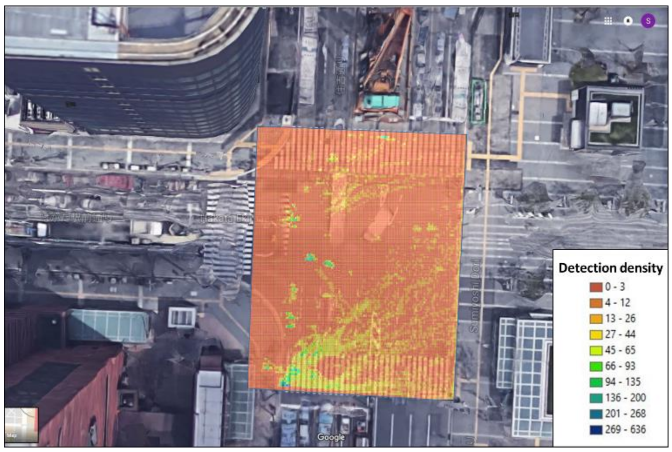

Figure 7. Pedestrian movement pattern at the T-way junction crossing area which was recorded by the pedestrian detection system and proceeded with image adjusting methods.

This interpretation showed the estimation of pedestrian movement behaviour in a multi-directional flow through the cluster pattern of detected data determined the trend-line which is represented by a loess regression curve. The trend-line on Figure 8. shows the most common route of connection based on the relationship between location and volume of data that was generated from HOGs object detection system. As a result, the spatial map indicates that pedestrians are greatly clustered in specific areas. It shows that pedestrians are more likely to choose the south-side crosswalk in order to easily reach the transit station building. Moreover, the crowd movement flows along the crosswalk's mark and tends to avoid going through the center of the crossing area.

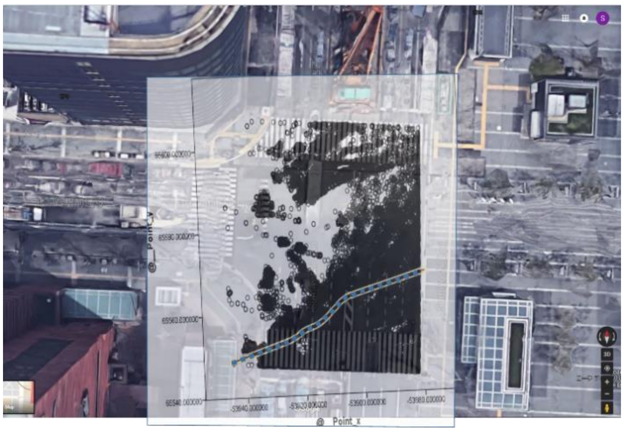

Figure 8. The most common path that pedestrians took detected on the multi-directional crossing area interpreted by the trend-line of the loess regression curve

According to urban land-use agglomeration analysis, the study found that pedestrian movement behaviour is significantly related to the density of commercial activity. The results from both the urban block-scale and the district-scale can be used to interpret the relationship between the total-floor-area of commercial activity and pedestrian movement tendency. Pedestrian's choice of path is made at the crossing area in order to decide the best trajectory to take in order to access the destination. As a result of urban agglomeration comparison which separated the study area into a north-side and south-side according to the trajectory in which the street is crossed by pedestrians making a decision each time. Table 9. also indicates that there is more space used in the commercial activity of the south-side than that of the north-side of the major street as 729,862 square meters over 517,934 square meters for the district scale comparison and 134,720 square meters over 117,533 square meters for the block scale comparison.

Criteria	Block scale		District scale	
	South	North	South	North
Number of building	48	53	328	146
Minimum building area (m^2)	33.03	24.81	22.04	24.435
Maximum building area (m^2)	44957.825	16606.33	44957.825	52713.17
Total floor area (m^2)	134720.14	117532.79	729862.045	517934.175
Mean (m^2)	2806.669	2217.60	2225.1891	3547.4943

Table 9. Urban space usage configuration of the study area considered separately by block-scale and district-scale from both sides of the major street

Along with the closeness analysis result that show the influence of street network patterns and relationship with a distance from Hakata station to each building in study area. The statistical relationship between closeness analysis and total-floor-space indicated that the most significant coefficient value on the south-side block was 0.888, followed by the south-side district, north-side block, and north-side district scale which indicated the coefficient value as 0.580, 0.530, and 0.233 respectively which is interpreted in Table 10. These values imply that the urban agglomeration pattern clustered along the major street of the study area. Especially, the axial line segment which connected to Hakata station where there was isolation in the north-side and south-side of the study area.

Area	N	Coeff.	Std. Deviation	*p*-value
North-side district	124	0.233	5327.36	9.317×10^{-3}
South-side district	200	0.580	5654.91	0.000
North-side block	51	0.530	3792.40	6.2×10^{-5}
South-side block	48	0.888	7255.66	6.2×10^{-5}

Table 10. Estimated coefficients for the total floor area (m^2) used and closeness measurement according to area scale

The overall results show that there was a significant relationship between pedestrian movement trajectories and urban agglomeration characteristics which can thus be used to identify pedestrian movement behaviour in high-density urban areas, especially in commercial districts where people mainly use the public transit as a major mode of transportation.

This interpretation concentrated on the combination of undersigned walking areas as the T-way junction which operate the multi-directional access and free-flow accessibility along the urban layout that is found in above-ground environments which is able to explain the influences from surrounding urban structures and transport infrastructure such as a railway station, street network, and traffic facilities. There is also a discussion on the underground space that is available for pedestrians to use in order to access specific buildings. In this study area, some buildings from the north-side block are linked to the subway station (Fukuoka airport line) and are also connected to the inter-city train station (JR Hakata station) through a bi-directional connecting corridor. This multi-floor connection could lead to the pattern of pedestrian movement in above-ground areas as well as in terms of volume of crowd-flow in particular trajectories.

4. CONCLUSIONS

The methods of spatial survey to identify pedestrian movement behavioral could be more functional by combining methods of collecting actual pedestrian movement and the calculation of space used along with the distance aspect. This paper aimed to identify pedestrian behaviour in the central business district of Hakata city by developing a framework of surveying methodology that combined pedestrian movement tracking methods using an object detection system on HOGs and the relationship between building space usage of commercial activity and accessibility to transit nodes using a closeness index on urban centrality analysis. Closeness values referred to a matter of distance from street network where pedestrians move along in order to access specific destinations via the shortest possible path. The values assist in explaining the probability of pedestrian movement trajectory which significantly relates to urban forms, especially on the density of urban activity and the accessibility through the layout of the study area. The coefficient correlation between closeness value and volume of spatial space use indicates a strong relationship among these two variables which specifies the most significant value at the south-side block where the object detection system illustrated the most common path that linked the urban block and Hakata station through the multi-directional crossing at the T-way junction in front of Hakata station. This process was able to predict pedestrian trajectory crowd flow by providing a double confirmation of the trajectory of pedestrian crowd flow which able to be developed in several aspects as a fundamental analysis such as the application of spatial surveying, urban design on spatial redevelopment project, or even the mathematical model on pedestrian crowd movement behaviour.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number JP17K14781.

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