ZESZYTY NAUKOWE AKADEMII MARYNARKI WOJENNEJ
SCIENTIFIC JOURNAL OF POLISH NAVAL ACADEMY

2015 (LVI) 4 (203)

DOI: 10.5604/0860889X.1187600

Jarosław Magiera*

MATCHING TRAJECTORY OF A PERSON TO A MAP IN INERTIAL NAVIGATION SYSTEM

ABSTRACT

Paper describes the method of matching, to a map, trajectories of a person walking indoors, obtained from inertial navigation module. General principle of matching algorithm based on particle filtering is presented. Method of detecting particle collisions is described as well. The last chapter provides test results of map matching related to a true trajectory.

Key words:
inertial navigation, map matching.

INTRODUCTION

Majority of recent research in the field of positioning systems is devoted to solutions, which may be used to determine the object's location in an indoor (closed) environment [4]. The conditions in such environment do not allow for obtaining the position information from Global Navigation Satellite Systems (GNSS). Signals transmitted by GPS or GLONASS satellites may be received in an open (outdoor) environment, but they are highly attenuated by walls and ceilings, so their received power is insufficient to estimate the receiver's position inside buildings, tunnels etc.

Indoor positioning systems may be a based on radio navigation, where the reference stations are: Base Transceiver Stations (BTSs) of cellular networks, wireless local area network access points, Bluetooth devices, nodes of sensor networks etc. [9].

* Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, G. Narutowicza 11/12 Str., 80-233 Gdańsk, Poland; e-mail: Jaroslaw.Magiera@eti.pg.gda.pl

Accuracy of location estimation in such systems is usually worse than in case of GPS. This is due to the fact that precise positioning methods, like time-of-arrival or direction-of-arrival, cannot be applied here because of the frequent Non Line of Sight (NLoS) conditions, where the view between transmitting and receiving antennas is obstructed. The exception is the ultra-wideband (UWB) transmission, where the time of signal propagation may be calculated independent from the visibility of antennas. Another significant problem of radio positioning systems is the limited range of transmission, which may make it impossible to obtain the object's position in some parts of building. For example, positioning based on WiFi signals is possible only in the range of transmission of wireless access points.

Another solution for problem of indoor localization is the three-dimensional inertial navigation. It is a kind of dead reckoning, where the object's displacement vector is evaluated basing on integration of linear and angular accelerations. The instantaneous values of these accelerations are measured by accelerometers and gyroscopes [3]. Indoor inertial positioning is free from the limitations of radio solutions, however its main drawback is that the estimated position is only the offset from the initial one and it is not connected to a, local or global, geographical coordinates system. Moreover, position estimation error, resulting mainly from inaccurate measurements of accelerations, cumulates with motion of localized object.

In the light of this, it may be stated that radio and inertial systems complement each other. The latter are seldom applied as standalone solutions, as they usually are the components of hybrid systems, where the location information is obtained from multiple various sensors. Combining the information from: GPS receivers, accelerometers, gyroscopes, compass, pressure sensor, radar, cameras etc., is called the sensor fusion [2]. Process of estimating object's position, using a set of data from independent sensors, may be performed with the methods based on recursive Bayesian filters, such as: Kalman filter, hidden Markov model or particle filtering [8]. These are probabilistic methods, where various states of an object (ie. it's positions) are analyzed, to find the one with maximum probability.

SYSTEM FOR LOACATING PEOPLE ON BOARD A SHIP

In the Department of Radio Communications Systems and Networks at Gdansk University of Technology, an R&D project is realized, aim of which is to develop a system for locating people in indoor environments, especially on boards of large ships, such as sea ferries. Harsh propagation conditions in such environments (construction made mainly of metal elements) practically eliminates the application of radio signals (except UWB) for navigation purposes. Due to this fact, the main source of location information is the inertial measurement unit (IMU). In the referred system, Orientus IMU from Advanced Navigation is used [5]. This shoe-mounted device provides the instantaneous values of three-dimensional acceleration vector, which, after integration, are used to estimate the displacement from initial position. In order to limit the cumulating of positioning error, special algorithm is applied, which detects the time periods when the foot does not move and then calibrates the accelerometers [6]. Height estimation (Z coordinate of position vector) is based on combined outputs from accelerometers and an atmospheric pressure sensor.

Since the radio navigation solutions cannot be applied in this case, other source of information was necessary to convert the position evaluated by IMU to a position related to a local coordinate system, centered and fixed to a body of a ship. Such conversion requires the knowledge about following parameters: coordinates of object's initial position and orientation of object's trajectory in space. It was decided, that values of these parameters will be estimated basing on matching the object's (person's) trajectory to a map of a ship. The rule of map matching is that, from multiple trajectories with different initial points and different orientations, these which collide with walls, ceilings, floors, pillars etc., are eliminated.

METHOD OF MATCHING TRAJECTORIES TO A MAP

Matching algorithm is based on particle filtering method [1]. Particles are points in a three-dimensional space, coordinates of which represent the possible locations of a tracked person. Trajectory of each particle is a translated and rotated version of a raw trajectory from IMU's output. The translation vectors and orientation angles are different for each particle. It was depicted in the figure below.

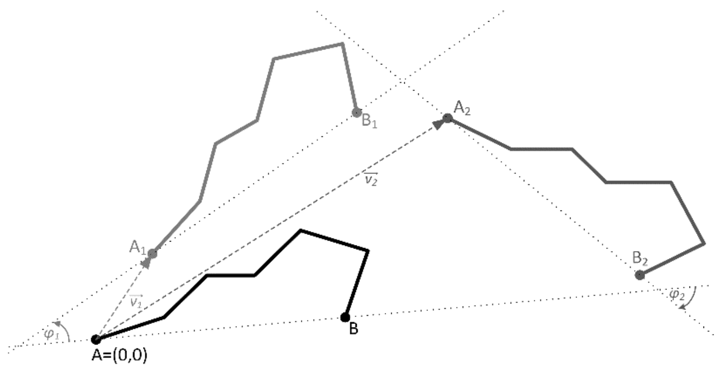

Fig. 1. Concept of particles' trajectories

Stroke line between A and B points represents the raw trajectory evaluated by inertial navigation module. The other stroke lines depict the possible trajectories of two particles. The translation vector of n-th particle initial position from (0,0) point is denoted by v_n symbol, while the orientation (rotation) angle of *n*-th particle's trajectory from raw trajectory is denoted by φ_n symbol.

The matching algorithm may be applied only when the a priori knowledge is available, about the IMU's location in the moment of its activation. There are two reasons why it is necessary. Firstly, allowing arbitrary initial location within the whole ship would require the analysis of a very large number of particles, which, considering the computational complexity, would make it impossible to run the algorithm in real time. Secondly, when the arrangement of rooms is the same on different floors, there is a problem of determination of actual floor (deck), on which a localized person currently is. Therefore it was assumed that the inertial navigation process may be started only when an IMU is located near the point of known coordinates (for example a given entrance to a ship).

In the beginning of trajectory matching procedure, initial particle positions are selected randomly in a few-meters radius from the point with known coordinates. Each time the inertial module provides new position, particles' positions are updated. The length of displacement vector between current and previous position is the same the same as the length of the vector between two last positions calculated by IMU processor. Direction and sense of particle displacement vector depend on orientation of particle's trajectory in relation to its initial position. Particles have memory, which means that, apart from current positions, their trace, containing a certain number of previous positions, is remembered.

Particle's position is updated under condition that its trajectory does not collide with arrangement of walls, ceilings etc. If collision occurs, particle is eliminated and is substituted with a new one. Coordinates of new particle's current position, as well as its orientation (azimuth and elevation angles) are Gaussian random variables. Mean values of these variables are fixed to be the current position and orientation of one of the particles which were not eliminated with the last position update. In case all of the particles collide at the same time, a new set of particles is generated with a constrain that their positions must be contained within the space of the ship model. For each new particle its trace is calculated, according to this particle's position, orientation and set of positions calculated by the IMU. If one or more segments of trace collide with the map, particle generation procedure is repeated until there is no collision.

Current location of a tracked person is assumed to be the position of a particle with the largest life time. The meaning of particle life lime is the number of position updates from the time of its generation. In different time periods of positioning process, there may be different particles with the largest life time. For example, when a tracked person goes along the corridor, one of the particles may follow the true trajectory accurately. However, when the direction of movement changes, orientation of this particle may become incorrect, due to inaccurate estimation of rotation angle in the inertial navigation module. Therefore the whole matched trajectory is not simply a translated and rotated version of raw trajectory, but it is a combination of partial trajectories of different particles, which were subsequently selected to be best fitted to the true trajectory.

DETECTING COLLISTIONS OF PARTICLES WITH OBSTACLES

Particle collision detection algorithm is one of the most important elements of trajectory map matching procedure. Properly designed algorithm should detect every collision as well as it should be computationally effective. The proposed algorithm, described below, complies with both requirements.

A map, which is used for trajectory matching purposes, is represented by a 3D model which is stored in a text file compliant with *Wavefront.OBJ* format [7]. Vertices of this model create a three-dimensional mesh composed of triangles. Particle collision is detected when a segment, connecting two consecutive positions of this particle, passes through one or more triangles which represent the elements of object's structure (walls, floors etc.). Firstly, coordinates of intersection point, between the analyzed segment and a plane spanned on vertices of a triangle, are calculated. If such point does not exists, there is no collision. Otherwise, collision occurs if the calculated point belongs to the triangle.

An important matter is the selection of triangles, which should be considered during the collision detection procedure. Checking possible collisions for each triangle in a model is unacceptable due to large computational burden, especially in case of complex models and long traces of particles.

In order to limit the number of triangles analyzed by collision detection algorithm, three-dimensional model space is divided into equal cuboid sectors. Each sectors is assigned triangles, which have any common part with this sector. When the algorithm checks whether collision occurs or not, it analyzes the triangles assigned to each sector which contains the part (or whole) of the segment of trajectory connecting two consecutive positions of the particle.

In order to ensure the good performance of collision detection, small dimensions of sectors are preferred, which, in turn, increases their number. Time of execution of tringles' assignment procedure depends both on the number of sectors and on the total number of triangles in a model. For instance, a model was processed of dimensions 113 m x 36,5 m x 55 m, composed of over 41 thousands of triangles. The model space was divided into nearly 232 thousands of cubic sectors of 1 m edge length. It took over ten hours to assign the triangles to the sectors. Because of such long duration, this procedure is executed only once for each new model. The information about mapping triangles to sectors is stored in a file. This file is read each time the model is imported in the trajectory matching program. When particle position is known, the sector which contains it may be easily identified. Knowing the sector number, information about the triangles which are assigned to it may be read directly from the memory.

FIELD TESTS OF TRAJECTORY MAP MATCHING

In order to verify the performance of developed trajectory matching algorithm, a series of test was conducted with use of inertial navigation module. A person, who was equipped with this module, was moving inside the building of Faculty of Electronics, Telecommunications and Informatics at Gdansk University of Technology. During the movement, the navigation processor, basing on output data from IMU, was calculating the coordinates of the offset of current position from the beginning of the path. Recorded raw data were subsequently passed to the map matching algorithm. Performance of this algorithm was assessed basing on the observation of matched trajectory, which was overlaid on the plan of the building.

Overview of the raw trajectory in horizontal plane, estimated by the inertial navigation module, was presented in figure 2. It was obtained for the following walk path: walk forward for about 18m along the corridor, turn left by 90 degrees, walk forward for about 35 m, turn left by 180 degrees, return to the beginning of the path along the same route, turn by 180 degrees, walk 18m forward, turn right by 90 degrees, walk 15 m forward, enter the room on the left hand side, turn left, walk about 3 m. As one may see, the raw trajectory keeps the distances, but it shows errors of azimuth angle what is clearly visible in case of sudden change of direction.

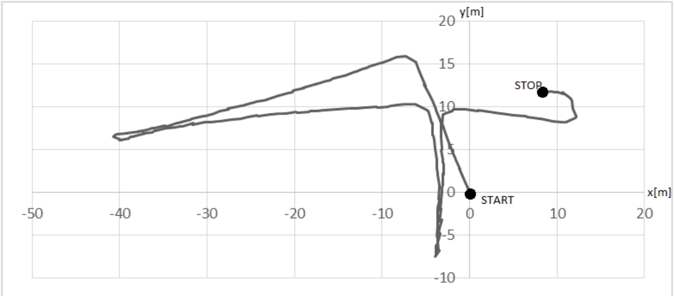

Fig. 2. Raw trajectory from the output of the inertial navigation module

Overview of the raw trajectory in horizontal plane, estimated by the inertial navigation module, was presented in figure 2. It was obtained for the following walk path: walk forward for about 18 m along the corridor, turn left by 90 degrees, walk forward for about 35 m, turn left by 180 degrees, return to the beginning of the path along the same route, turn by 180 degrees, walk 18m forward, turn right by 90 degrees, walk 15 m forward, enter the room on the left hand side, turn left, walk about 3 m. As one may see, the raw trajectory keeps the distances, but it shows errors of azimuth angle what is clearly visible in case of sudden change of direction.

In figure 3, the result of matching the mentioned trajectory to the building's floor plan was presented. Refractions of this trajectory are caused by collisions of particles with largest life time and, as a result, changes of tracked particle. Despite the fact that the matched trajectory does not coincide exactly with the true one, it is possible to determine in which part of the corridor or in which room the localized person is at certain time. Such level of accuracy is usually acceptable in systems which are used for pedestrian localization.

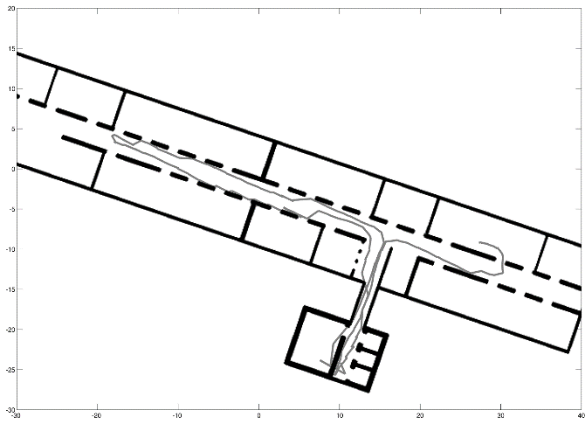

Fig. 3. Trajectory matched to the plan of a building

CONCLUSION

Presented algorithm for matching trajectory to a map makes it possible to map a sequence of positions calculated by inertial navigation module to a trace of a localized person in indoor environment.

The article presents only the results obtained for a two-dimensional scenario, where the person remained on the same floor. Nevertheless the algorithm works correctly also in case of paths, where the vertical change of position occurs. In such scenario, height estimation is based on measurement of accelerations and atmospheric pressure. Obtained accuracy is better than 0.5 m, which is sufficient to determine the floor number.

The time required for presented map matching algorithm to converge is dependent from shape and dimensions of the object (building, ship etc.) and from the arrangement of its interior walls. The plan of an object should allow to make a unique match of a possibly short trajectory, which may be difficult in case of large rooms of regular shapes.

Apart from tests inside buildings, tests onboard a passenger ferry during the cruise will be conducted. It is planned to be done in the next stage of the project.

Acknoledgements

This work was financially supported by Polish National Centre for Research and Development under grant no. DOBR-BIO4/058/13045/2013.

REFERENCES

[1] Beauregard S. et al., *Indoor PDR performance enhancement using minimal map information and particle filters*, Position, Location and Navigation Symposium, IEEE/ION, Monterey 2008, pp. 141–147.

[2] Chen L. et al., *Intelligent Fusion of Wi-Fi and Inertial Sensor-Based Positioning Systems for Indoor Pedestrian Navigation*, 'IEEE Sensors Journal', 2014, Vol. 14, No. 11, pp. 4034–4042.

[3] Chiou Y. et al., *A Dead-Reckoning Positioning Scheme Using Inertial Sensing for Location Estimation*, 10th International Conference in Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP), Kitakyushu, Japan, 2014, pp. 377–380.

[4] Deng Z. et al., *Situation and Development Tendency of Indoor Positioning*, 'China Communications', March 2013, pp. 42–55.

[5] *Orientus — miniature orientation sensor*, [online], http://www.advancednavigation.com.au/product/orientus, [access 27.08.2015].

[6] Rajchowski P., *Stanowisko do badania algorytmów stosowanych w nawigacji inercyjnej*, ‘Przegląd Telekomunikacyjny i Wiadomości Telekomunikacyjne’, 2014, No. 12, pp. 1448-1452 [*Stand for investigation of algorithms used in inertial navigation* — available in Polish].

[7] *Wavefront OBJ File Format*, [online], http://www.fileformat.info/format/wavefrontobj/egff.htm, [access 27.08.2015].

[8] Xiao Z. et al., *Lightweight Map Matching for Indoor Localisation using Conditional Random Fields*, 13th International Symposium on Information Processing in Sensor Networks (IPSN-14), IEEE, Berlin 2014, pp. 131–142.

[9] Yassin M., Rachid E., *A survey of positioning techniques and location based services in wireless networks*, 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), Kozhikode, India, 2015.

DOPASOWANIE TORU RUCHU OSOBY DO MAPY STATKU W SYSTEMIE NAWIGACJI INERCYJNEJ

STRESZCZENIE

W artykule scharakteryzowano metodę dopasowywania do mapy toru ruchu osoby w środowisku zamkniętym, wyznaczanego przez układ nawigacji inercyjnej. Zaprezentowano ogólną zasadę działania algorytmu dopasowania, opartego na tzw. filtracji cząsteczek. Omówiono również metodykę wykrywania kolizji cząsteczek z przeszkodami. W ostatniej części przedstawiono wyniki testu działania algorytmu z użyciem trajektorii zarejestrowanej w warunkach rzeczywistych.

Słowa kluczowe:

nawigacja inercyjna, dopasowanie do mapy.