TITLE: Method and system for localizing individuals in a monitoring space

The present invention relates to a method for localizing individuals in a monitoring space.

It also relates to an associated localization system and an associated computer program.

The invention is in the general field of video surveillance and finds numerous applications in areas such as infrastructure management, robotics, or autonomous navigation.

The precise localization of individuals likely to move within a monitoring space is useful for ensuring security in general and optimizing various operations. The monitoring space is a commercial or transport infrastructure (station, airport, etc.), for example, or any other place likely to host the public, or the interior of a transport vehicle, or even a road intersection. Of course, this list is not exhaustive.

Various sensor-based systems for localizing individuals allowing for sequences of 2D or 3D images (i.e. videos) of the monitoring space have been proposed. The sensors used specifically comprise optical or infrared surveillance cameras, time-of-flight or TOF cameras, or even 3D Lidar sensors.

The various known sensors have operational weaknesses depending on the application cases and fail to systematically provide sufficient precision. Indeed, some sensors are less effective under certain lighting conditions or crowd density, so they are not robust to all types of situations.

Moreover, the cost of some sensors is particularly high, making it thus difficult to use a large number of them.

To improve the precision of localizing individuals, solutions based on wearing a radio frequency transmitter badge (RFID) or based on other transmitters carried by individuals have been proposed. These solutions are nevertheless intrusive and unsuitable for a public monitoring space.

The invention aims to overcome the drawbacks of the prior art by proposing a solution that allows for more precise localization of individuals and is more robust to contextual changes, while not being intrusive.

To this end, according to one aspect, the invention proposes a method for localizing individuals in a monitoring space comprising a temporal succession of localization data acquisitions, called sensor localization data, of at least one individual, obtained from data acquired by a plurality of distinct sensors, the sensors belonging to at least two distinct categories of sensors. This method includes steps of:

- for at least one chosen pair of sensors, fusion of the sensor localization data provided by the sensors of said pair of sensors at a current moment in time, allowing for obtaining at least one adjusted localization datum associated with the current moment in time and said pair of sensors,
- calculation of at least one consolidated localization datum, associated with the current moment in time, said calculation including:

- obtaining at least one previous consolidated localization datum, associated with a previous moment in time,
- predicting at least one predicted localization datum for the current moment in time, from said at least one previous localization datum,

fusing the at least one predicted localization datum and the at least one adjusted localization datum.

Advantageously, taking into account sensor localization data from a plurality of sensors and at least one predicted localization datum allows for improving the precision of localizing individuals from data from multiple sensors.

The method for localizing individuals in a monitoring space, according to the invention, may also have one or more of the characteristics below, taken independently or according to all technically conceivable combinations.

The method includes an estimation of a confidence score associated with the sensor localization data, the fusion of sensor localization data being a function of said confidence score.

The estimation of a confidence score implements an artificial intelligence engine, previously trained by machine learning to assign a confidence score to the localization data obtained by each sensor, depending on context parameters.

The estimation of a confidence score uses previously recorded confidence score tables.

The fusion of localization data includes steps of calculating a distance matrix between first localization data from a first sensor and second localization data from a second sensor of said pair of sensors, and matching between first and second localization data.

The matching implements a Munkres combinatorial optimization algorithm.

The method further includes a step of calculating adjusted localization data, depending on the result of the matching step and the confidence scores associated with the sensor localization data.

The calculation of adjusted localization data implements a barycenter calculation weighted by the confidence scores associated with the localization data.

With the plurality of distinct sensors comprising at least two pairs of sensors, the fusion of localization data is implemented for each pair of sensors, the method further comprising an iteration of the fusion on the adjusted localization data associated with two distinct pairs of sensors.

The temporal prediction step implements a Kalman filter.

According to another aspect, the invention includes a system for localizing individuals in a monitoring space comprising a plurality of sensors belonging to at least two distinct categories of sensors and a localization device adapted to perform a temporal succession of acquisitions of localization data, called sensor localization data, of at least one individual, obtained from data acquired by the plurality of distinct sensors, the device comprising a processor configured to implement:

- for at least one chosen pair of sensors, a fusion module of the sensor localization data provided by the sensors of said pair of sensors at a current moment in time, allowing for

obtaining at least one adjusted localization datum associated with the current moment in time and said pair of sensors,

- a calculation module of at least one consolidated localization datum, associated with the current moment in time, said calculation comprising
    - o a module for obtaining at least one previous consolidated localization datum, associated with a previous moment in time,
    - o a module for predicting at least one predicted localization datum for the current moment in time, from said at least one previous localization datum,
    - o a module for fusing the at least one predicted localization datum and the at least one adjusted localization datum.

According to one variant, the system for localizing individuals is configured to further implement a module for estimating a confidence score associated with the sensor localization data, with the module for fusing sensor localization data using said confidence scores for each sensor.

According to another aspect, the invention includes an information recording medium, which stores software instructions for executing a method for localizing individuals in a monitoring space, as briefly described above, when these instructions are executed by a programmable electronic device.

According to another aspect, the invention includes a computer program comprising software instructions that implement a method for localizing individuals in a monitoring space, as briefly described above, when implemented by a programmable electronic device.

Brief Description of Drawings

The invention will appear more clearly upon reading the following description, given solely by way of non-limiting example, and made with reference to the drawings in which:

Figure 1 represents the main functional blocks of a system for localizing individuals in a monitoring space according to an embodiment;

Figure 2 is a flowchart of steps of a localization method according to an embodiment;

Figure 3 is a flowchart of steps following the steps of Figure 2 of a localization method according to an embodiment;

Figure 4 is a schematic illustration of localization data at various steps of the localization method.

Figure 1 schematically illustrates a system 2 for localizing individuals in a monitoring space. The monitoring space is not represented.

The system 2 includes at least one pair of distinct sensors, and, in the represented example, includes a plurality of sensors 4A, 4B, 4C, in a variable number.

For example, the sensors belong to several distinct sensor categories and include, for example, two-dimensional image sensors, in particular optical cameras 4A and/or infrared cameras 4B, and/or TOF cameras 4C that provide distance measurements between the camera and a detected individual.

The number of sensors in each category of sensors varies according to the application case.

The respective sensors 4A, 4B, 4C are positioned at various spatial positions of the monitoring space, the spatial positions being chosen to cover the monitoring space by the fields of view of each of the sensors.

The term ‘sensor category’ is understood as referring to sensors having similar operating modes and constituent elements.

Thus, sensors of the same category have a similar performance but vary, depending on external conditions such as lighting conditions or crowd density in the monitoring space, also called the operating context.

The various sensors are configured to acquire temporal data sequences, such as temporal sequences of data forming two-dimensional images when the sensors are optical or infrared cameras.

The system for localizing individuals 2 also includes a localization device 6, configured to communicate with the sensors 4A, 4B, 4C and in particular configured to receive image data and/or sensor localization data from the respective sensors 4A, 4B, 4C.

The localization device 6 is a programmable electronic device, e.g. a computer, and includes, in one embodiment, one or more processors 8, an electronic memory unit 10, an input/output interface 12, and a communication interface 14, these elements being configured to communicate with each other via a communication bus 15 internal to device 6.

The input/output interface 12 specifically includes a display screen and means of data entry (keyboard, mouse, or touchpads) allowing a surveillance operator to perform real-time monitoring of the monitoring space.

In one embodiment, as illustrated in Figure 1, the localization device 6 includes the modules 20A, 20B, 20C for calculating sensor localization data of at least one individual from successive image data obtained by the sensors 4A, 4B, 4C.

In a variant, at least part of the modules 20A, 20B, 20C are integrated into respective sensors 4A, 4B, 4C, and the sensor localization data is provided by each of sensors 4A, 4B, 4C to localization device 6.

The modules 20A, 20B, 20C implement any spatial localization algorithm for individuals, adapted for the considered sensor category, allowing for obtaining sensor localization data $23A_t$, $23B_t$, $23C_t$, associated with moments in times t.

In the following description, the processing of localization data, followed over time, of a given individual is described.

It should be noted that the method and system described here for localizing individuals apply analogously for localizing other entities of interest such as vehicles, animals etc.

The localization device 6 further comprises a module 22 for preprocessing the location data from sensors.

It further comprises a module 24 for estimating a confidence score associated with the sensor localization data for each sensor. According to one unrepresented variant, the module 24 for estimating a confidence score groups several estimation modules, each estimation module being associated with a sensor category. The module 24, for estimating confidence score, or each estimation module allows for estimating a confidence score. depending on the sensor, parameters and context, and additionally, optionally, the implemented localization algorithm.

The localization device 6 further includes a distance matrix calculation module 26, a matching module 28, and a post-processing module 30, which implements a calculation of adjusted localization data. The modules 26, 28, 30 interact to perform a fusion of localization data from two distinct sources, such as from a pair of sensors, allowing for obtaining adjusted localization data 25_t associated with the moment in time t.

The localization device 6 also includes a prediction module 32 for a predicted localization datum 27_t for a current moment in time from at least one previous localization datum, associated with a previous moment in time t-k, with k being an integer greater than or equal to 1, for example, and a calculation module 34 for at least one consolidated localization 29_t associated with a current moment in time.

In one embodiment, the modules 20, 22, 24, 26, 28, 30, 32, 34 are implemented as software instructions forming a computer program, which, when executed by a programmable electronic device, implements a method for localizing individuals in a monitoring space as described.

In an unrepresented variant, the modules 20, 22, 24, 26, 28, 30, 32, 34 are each implemented as programmable logic components, such as FPGAs (Field Programmable Gate Array), microprocessors, GPU components (general-purpose processing on graphics processing), or even dedicated integrated circuits such as ASICs (Application Specific Integrated Circuit).

The computer program comprising software instructions is also capable of being recorded on a non-transitory, computer-readable information recording medium. This computer-readable medium is a medium capable of storing electronic instructions and being coupled to a bus of a computer system, for example. For example, this medium is an optical disk, a magneto-optical disk, a ROM memory, a RAM memory, any type of non-volatile memory (e.g., EPROM, EEPROM, FLASH, NVRAM), a magnetic card or an optical card.

Figure 2 is a flowchart of the steps of the method for localizing individuals in a monitoring space, implemented to perform a first phase of localization data fusion.

The method includes a first step 40 of acquiring sensor localization data, coming from a plurality of distinct sensors, belonging to at least two distinct categories of sensors.

Depending on the embodiments, either localization data is directly provided by the sensors, or an algorithm calculates sensor localization data of at least one individual from successive image data obtained by sensors 4A, 4B, 4C.

The sensor localization data include Cartesian coordinates (x_i,y_i,z_i) of at least one point belonging to the individual in a 3D reference frame.

In practice, for each sensor, the sensor localization data includes a plurality of points corresponding to one or more individuals.

Step 40 is followed by a preprocessing step 42 of normalization comprising distortion correction, coordinate alignment and unit normalization, ensuring that the sensor localization data from distinct sensor categories is comparable.

The method then comprises processing sensor localization data D_1t, D_2t by sensor pairs.

The sensor pairs have already been chosen.

For example, a sensor pair groups sensors of the same category in a first processing phase.

The method then comprises a step 44 of estimating a confidence score associated with the sensor localization data D_1t, D_2t.

A confidence score is associated with the localization data, in other words, a confidence score allows for evaluating the reliability of the localization data obtained from the considered sensor.

The estimation 44 of a confidence score is a function of the sensor category for each sensor of the considered sensor pair, as well as the context of each sensor such as the lighting conditions or crowd density in the monitoring space.

Advantageously, the estimation 44 of a confidence score is performed dynamically, so as to take into account possible context changes likely to impact the performance of each sensor.

Thus, for example, under low lighting conditions, the localization data obtained from images provided by an optical camera have a low confidence score, while the localization data obtained from images provided by an infrared camera have a high confidence score.

In one embodiment, the step 44 implements an artificial intelligence engine, previously trained by machine learning to assign a confidence score to localization data obtained by each sensor depending on the sensor category, context parameters, such as depending on the time of day, lighting conditions (i.e., sensor exposure to a light source), weather conditions when the sensor is positioned outdoors, etc.

For example, the artificial intelligence engine implements a neural network.

In a variant, the estimation 44 of a confidence score uses previously recorded tables, developed with experts, providing a confidence score depending on context parameters, such as depending on the time of day, weather conditions when the sensor is positioned outdoors.

The context parameters are obtained from suitable distinct sensors, for example, or obtained from an external server such as a weather data server, via a communication link with localization device 2.

The method then comprises a step 46 of fusion (or first fusion) of the first sensor localization data D_1t and the second localization data D_2t.

In practice, for each sensor of the sensor pair, the sensor localization data D_1t, D_2t include different numbers of points represented by Cartesian coordinates, such as M points for a first sensor of the sensor pair, N points for a second sensor of the sensor pair, with M and N being distinct integers.

The fusion 46 then comprises a step 48 of calculating a distance matrix between the localization data D_1t, D_2t, then a step 50 of matching (or assignment) between the sensor localization data D_1t from the first sensor and the sensor localization data D_2t from the second sensor.

Advantageously, the step 50 of matching implements a Munkres combinatorial optimization algorithm, known for solving the problem of assignment between entities of different cardinal sets, in this case between the M points from the first sensor and the N points from the second sensor.

Advantageously, the Munkres combinatorial optimization algorithm allows for solving the assignment problem in polynomial time.

The fusion 46 then comprises a step 52 of calculating the adjusted localization data D_a,t depending on the result of the step 50 of matching and confidence scores associated with the sensor localization data for each sensor.

In one embodiment, the step 52 implements a weighted barycenter calculation by the confidence scores associated with the localization data.

For example, consider two respective points P1 with Cartesian coordinates (x1,y1,z1) and P2 with Cartesian coordinates (x2,y2,z2) that have been matched in step 50, with P1 being a sensor localization datum from the first sensor and P2 being a sensor localization datum from the second sensor.

During step 52, the confidence score S1, S2 associated with each sensor is taken into account. For example, a new point P3, which is an adjusted localization datum, is obtained, the Cartesian coordinates (x3, y3, z3) of P3 being calculated by the weighted average of the Cartesian coordinates of the points P1 and P2, with weighting coefficients derived from the confidence scores.

For example, the following formulas are applied:

$$x_3 = \frac{S_1 x_1 + S_2 x_2}{S_1 + S_2}$$

$$y_3 = \frac{S_1 y_1 + S_2 y_2}{S_1 + S_2}$$

$$z_3 = \frac{S_1 z_1 + S_2 z_2}{S_1 + S_2}$$

The point P3 is then the barycenter of the points P1 and P2, calculated with the confidence scores S1, S2 as weighting (or weight) coefficients.

At the end of the fusion step 46, adjusted localization data is thus obtained. The adjusted localization data is stored.

The steps 44, of estimating confidence scores, and 46, of fusion of localization data, are repeated for each chosen sensor pair.

At the end of this first processing phase, in a second processing phase, if applicable (i.e. if the number of sensor pairs is strictly greater than 1), the step 46 of fusion of localization data is repeated to fuse previously calculated adjusted localization data, until at least one adjusted localization datum D'_a,t, corresponding to the plurality of sensors, is obtained.

The confidence scores are also fused when the adjusted localization data from two distinct sources are fused, with the associated confidence score being the average of the confidence scores of each data source, for example.

The method then includes calculating at least one consolidated localization datum, as explained below with reference to Figure 3.

The method then comprises acquiring at least one previous consolidated localization datum D_c,t-k, associated with a previous moment in time t-k, such as t-1, and a temporal prediction 60 of at least one predicted localization datum Dpred_t, for the current moment in time t, from the at least one previous consolidated localization datum D_c,t-k.

The temporal prediction step 60 implements a Kalman filter, for example.

In other words, for each point P1(t-k), P2(t-k), P3(t-k) corresponding to the consolidated localization data at the moment in time t-k, a predicted point P1-pred(t), P2-pred(t), P3-pred(t) is obtained, as schematically illustrated in Figure 4.

The at least one adjusted localization datum D'_a,t corresponding to the plurality of sensors and the at least one predicted localization datum Dpred_t are provided as input to a fusion step 62 (second fusion).

The fusion step 62 includes a step 64 of calculating a distance matrix between the adjusted localization data D'_a,t and the predicted localization data Dpred_t, similar to the step 48 described above, then a step 66 of matching (or assignment) similar to the step 50 described above.

It then includes a step 68 of calculating at least one consolidated localization datum D_c,t, associated with the current moment t.

In one embodiment, during the step 68, when an association has been made during the matching step 66 between a predicted localization datum Dpred_t and an adjusted localization datum D'_a,t, the adjusted localization datum is retained as consolidated localization datum D_c,t.

According to one variant, the Cartesian coordinates of the consolidated localization datum D_c,t are calculated by averaging the Cartesian coordinates of the adjusted localization datum D'_a,t and the predicted localization datum Dpred_t.

Figure 4 schematically illustrates, by way of example, in the same 2D spatial reference frame: points P1_a,t, P2_a,t, P3_3,t (reference 70 in Figure 4) corresponding to adjusted localization data calculated for the moment t; points P1(t-k), P2(t-k), P3(t-k) corresponding to the consolidated localization data at the moment in time t-k and the corresponding predicted points at the moment in time t, noted P1-pred(t), P2-pred(t), P3-pred(t) (reference 72 in Figure 4). The results of the matching 66 are illustrated in reference 74 of Figure 4.

Finally, the points P1-c(t), P2-c(t), P3-c(t) corresponding to the consolidated localization data associated with the current moment, calculated from the matched points, are illustrated in reference 76 of Figure 4.

Of course, the example in Figure 4 is schematic and simple, with the localization data to be processed in practical cases being much more numerous.

CLAIMS

1. A method for localizing individuals in a monitoring space, including a temporal succession of acquisitions of localization data, called sensor localization data ($23A_t$, $23B_t$, $23C_t$), of at least one individual, obtained from data acquired by a plurality of distinct sensors (4A, 4B, 4C), the sensors belonging to at least two distinct categories of sensors, the method being characterized in that it includes steps of:

- for at least one chosen pair of sensors, fusion (46) of the sensor localization data provided by the sensors of said pair of sensors at a current moment in time, allowing for obtaining at least one adjusted localization datum associated with the current moment in time and said pair of sensors,
- calculation of at least one consolidated localization datum, associated with the current moment in time, said calculation including
    - o obtaining at least one previous consolidated localization datum, associated with a previous moment in time,
    - o a temporal prediction (60) of at least one predicted localization datum for the current moment in time, from said at least one previous localization datum,
    - o fusing (62) the at least one predicted localization datum and the at least one adjusted localization datum.

2. The method according to claim 1, comprising an estimation (44) of a confidence score associated with the sensor localization data, the fusion (46) of sensor localization data being a function of said confidence score.

3. The method according to claim 2, wherein the estimation (44) of a confidence score implements an artificial intelligence engine, previously trained by machine learning to assign a confidence score to the localization data obtained by each sensor depending on context parameters.

4. The method according to claim 2, wherein the estimation (44) of a confidence score uses previously recorded confidence score tables.

5. The method according to any one of claims 2 to 4, wherein the fusion (46) of localization data includes steps of calculation (48) of a distance matrix between first localization data from a first sensor and second localization data from a second sensor of said pair of sensors, and of matching (50) between first and second localization data.

6. The method according to claim 5, wherein said matching (50) implements a Munkres combinatorial optimization algorithm.

7. The method according to one of claims 5 or 6, further comprising a step of calculating the adjusted localization data (52) depending on the result of the matching step and the confidence scores associated with the sensor localization data.

8. The method according to claim 7, wherein calculating the adjusted localization data (52) implements a weighted barycenter calculation by the confidence scores associated with the localization data.

9. The method according to any one of claims 1 to 8, the plurality of distinct sensors comprising at least two pairs of sensors, in which the fusion (46) of localization data is implemented for each pair of sensors, the method further comprising an iteration of the fusion on the adjusted localization data associated with two distinct pairs of sensors.

10. The method according to any one of claims 1 to 9, wherein the step of temporal prediction (60) implements a Kalman filter.

11. A computer program, comprising software instructions which, when executed by a programmable electronic device, implement a method for localizing individuals in a monitoring space according to claims 1 to 10.

12. A system for localizing individuals in a monitoring space, comprising a plurality of sensors (4A, 4B, 4C) belonging to at least two distinct categories of sensors and a localization device (6) adapted to perform a temporal succession of acquisitions of localization data, called sensor localization data, of at least one individual, obtained from data acquired by the plurality of distinct sensors, the device (6) being characterized in that it includes a processor (8) configured to implement:

- for at least one chosen pair of sensors, a fusion module (26, 28, 30) of the sensor localization data provided by the sensors of said pair of sensors at a current moment in time, allowing for obtaining at least one adjusted localization datum associated with the current moment in time and said pair of sensors,
- a calculation module (34) of at least one consolidated localization datum, associated with the current moment in time, configured to implement:
    - o a module for obtaining at least one previous consolidated localization datum, associated with a previous moment in time,
    - o a module for predicting at least one predicted localization datum for the current moment in time, from said at least one previous localization datum,
    - o a module for fusing the at least one predicted localization datum and the at least one adjusted localization datum.

13. A system for localizing individuals according to claim 12, configured to further implement a module (24) for estimating a confidence score associated with the sensor localization data, the module for fusing sensor localization data using said confidence scores.