MOVABLE OBJECT PERCEPTION SYSTEM

FIELD OF THE INVENTION

[0001] The present disclosure relates to a movable object perception system, and more particularly to a movable object perception system to detect and track movable objects while estimating distance, speed and orientation for applications related to moving object aware navigation, so that it allows mobile robots to navigate among multiple objects moving in different positions, speeds and orientations with respect to itself.

BACKGROUND OF THE INVENTION

[0002] A key principle of robot navigation sharing the same space as humans is to be aware of oncoming humans and plan its path accordingly. While typical obstacle detection comprises human detection, only a static representation of the detected human at the moment (e.g., at each video frame) of inference is provided. Such inferences lack the ability to represent continuous states of the human agent motion. For robots navigating in a dynamic and crowded public environment such as hospitals, shopping malls, and supermarkets, how to efficiently and safely react in real-time to avoid crowds and re-plan the route accordingly is a key factor to increase competitiveness.

[0003] On the other hand, the conventional perception system needs to use prior information such as a pre-defined map of the environment, recognition-based approaches to detect and track humans. In the case that the conventional perception system is applied to human aware navigation, there will be a lot of data and time required for human-aware path planning.

Furthermore, the conventional perception system cannot be easily adapted to some environments, such as the narrow and crowded walkways.

[0004] Therefore, there is a need of providing a movable object perception system to detect and track moving objects while estimating distance, speed, orientation and width for applications related to moving object aware navigation, so that it allows agents to navigate among multiple objects moving in different positions, speeds, orientations and widths with respect to itself, and overcome the drawbacks of the conventional technologies.

SUMMARY OF THE INVENTION

[0005] The present disclosure provides a movable object perception system to assist an agent (e.g. an intelligent agent which can act in an intelligent manner, also called as "IA"), such as an autonomous mobile robot (AMR), to prepare the route in advance for a safe and efficient navigation in crowded and dynamic spaces. By dealing with the perception source obtained through an image capture module such as an RGBD camera for moving object aware navigation, the movable object perception system on the agent is able to robustly detect moving objects, track them and predict their paths in their paths respectively without any prior knowledge of the scene or the moving objects in the scene. The movable object perception system detects and tracks the moving objects across multiple instances to estimate their distance, speed, orientation and width relative to the position of the agent therewith. In this way, the movable object perception system is able to work in dynamic environment without prior information required (e.g., map of scene, walking pattern of humans, path of robot), able to learn and evolve to detect, track and predict the trajectory of other moving objects

for the purpose of robot navigation, and able to work with a low-cost single camera system to save costs. With the movable object perception system, it facilitates the agent to realize the human detection, the machine design for human safety and the human-aware path planning. Furthermore, it helps the agent such as the AMR to build a virtual boundary for collaborative safety. With the virtual boundary for collaborative safety, the movable object perception system further provides functions of reconfigurable virtual safety boundary and response based on distance from people/obstacles, non-contact detection of people and objects located in the path of the agent, dynamic collision avoidance of moving humans or obstacles, preventive safety to slow down and stop the AMR with imminent danger, and timely voice/display feedback to project to humans around the AMR.

[0006] In accordance with an aspect of the present disclosure, a movable object perception system is provided. The movable object perception system includes an image capture module, a modeler, a tracker, an estimator and a trajectory module. The image capture module captures a continuous image. The modeler receives the continuous image and marks at least one moving object based on the continuous image if at least one exists. The tracker is connected to the modeler and tracks the at least one moving object marked based on the continuous image by the modeler to obtain a tracking result of the at least one moving object. The estimator is connected to the tracker, and estimates a distance, a speed, an orientation, and a width of the at least one moving object based on the tracking result of the at least one moving object. The trajectory module is connected to the estimator, receives the distance, the speed, the orientation, and the width of the at least one moving object, and performing a motion trajectory prediction and a

motion flow integration, so as to obtain a motion region with distance, speed, orientation and width indications of the at least one moving object.

[0007] In an embodiment, the at least one moving object includes a human, a moving object or a combination thereto, wherein the moving object includes an agent, an AMR, a wheelchair, a trolly or a stroller.

[0008] In an embodiment, the perception source is obtained through an agent, an image capture module or a camera.

[0009] In an embodiment, the trajectory module further performs a historical pattern generalization.

[0010] In an embodiment, the movable object perception system further includes a strategist module, connected to the trajectory module, and performing a traffic analysis and a moving strategies estimation based on a motion flow map to obtain one or more possible ways with distance, speed, orientation and width suggested.

[0011] In an embodiment, the modeler further receives an agent width and a map, and performs an obstacle detection through an obstacle detector.

[0012] In an embodiment, the movable object perception system further includes a strategist module, connected to the trajectory module, and performing a traffic analysis and a moving strategies estimation based on a motion flow map and the agent width to obtain one or more possible ways with distance, speed, orientation and width suggested.

[0013] In an embodiment, the trajectory module extends each trajectory of the at least one moving object based on the distance, the speed and the orientation.

[0014] In an embodiment, the trajectory module performs the motion flow integration with considering the width of the at least one moving object to form a motion flow map.

[0015] In an embodiment, the movable object perception system detects and tracks the at least one moving object while estimating the distance, the speed, the orientation and the width of the at least one moving object with respect to an agent, an image capture module or a camera.

[0016] In an embodiment, the modeler includes a learning-based modeler configured to localize the at least one moving object and extract relevant features to generate a tracking ID across frames.

[0017] In an embodiment, the estimator includes a single-frame based mathematical-based estimator utilized to estimate the distance, the orientation (compared to camera position) and the width of each localized one of the at least one moving object.

[0018] In an embodiment, the estimator includes a multi-frame based mathematical-based estimator utilized to estimate the speed and the orientation (compared to moving object itself) at which one of the at least one moving object is moving.

[0019] In an embodiment, the camera is disposed on an autonomous mobile robot, and the distance, the speed, the orientation and the width are converted from camera coordinates to robot coordinates through a camera-to-robot coordinate transformation before execution with the autonomous mobile robot.

[0020] In accordance with another aspect of the present disclosure, a movable object perception system is provided. The movable object perception system includes a modeler, a tracker, an estimator, a trajectory module and a strategist module. The modeler receives a perception source to detect at least one moving object based on the perception source. The tracker is connected to the modeler and tracks the at least one moving object detected by the modeler to obtain a tracking result of the at least one moving

object. The estimator is connected to the tracker, and estimates a distance, a speed, an orientation and a width of the at least one moving object based on the tracking result of the at least one moving object. The trajectory module is connected to the estimator, receives the distance, the speed, the orientation and the width of the at least one moving object, and performs a motion trajectory prediction and a motion flow integration, so as to obtain a motion region with distance, speed, orientation and width indications of the at least one moving object. The strategist module is connected to the trajectory module, and performs a traffic analysis and a moving strategies estimation at least based on a motion flow map formed according to the motion flow integration to obtain a possible way with distance, speed, orientation and width suggested.

[0021] In an embodiment, the strategist module performs the traffic analysis and the moving strategies estimation further based on the motion flow map and an agent width received by the modeler to obtain the possible way with distance, speed, orientation and width suggested.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The above contents of the present disclosure will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, in which:

[0023] FIG. 1 is a schematic diagram illustrating a movable object perception system according to a first embodiment of the present disclosure;

[0024] FIG. 2, FIG. 3, FIG. 4 and FIG. 5 schematically show possible implementations of the movable object perception system of FIG. 1;

[0025] FIGS. 6A to 6C are schematic diagram illustrating examples of the movable object perception system for moving object aware navigation;

[0026] FIG. 7 is a schematic diagram illustrating a movable object perception system according to a second embodiment of the present disclosure; and

[0027] FIGS. 8A to 8E are schematic diagram illustrating examples of the movable object perception system for moving object aware navigation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0028] The present disclosure will now be described more specifically with reference to the following embodiments. It is to be noted that the following descriptions of preferred embodiments of this disclosure are presented herein for purpose of illustration and description only. It is not intended to be exhaustive or to be limited to the precise form disclosed.

[0029] FIG. 1 is a schematic diagram illustrating a movable object perception system according to a first embodiment of the present disclosure. The present disclosure provides a movable object perception system to assist an agent, such as an autonomous mobile robot (AMR), to prepare the route in advance for a safe and efficient navigation in crowded and dynamic spaces. As shown in FIG. 1, the movable object perception system 1 includes a modeler 10, a tracker 20, an estimator 30 and a trajectory module 40. In the embodiment, the modeler 10 receiving a perception source to detect at least one moving object based on the perception source. Preferably but not exclusively, the perception source is continuous images captured through an image capture module (not shown in FIG. 1), such as a RGBD camera disposed on the AMR. Preferably but not exclusively, the image capture module can capture the continuous images with the features of color (RGB) and depth (D). The modeler 10 receives the continuous images and marks at least one moving object based on the continuous images. Preferably but not

exclusively, the at least one moving object includes a human, a moving object or a combination thereto, and the moving object includes an agent, an AMR, a wheelchair, a trolly or a stroller. That is, the moving object can be for example but not limited to a human with other moving objects such as the wheelchair, the trolly or a stroller. In the embodiment, the tracker 20 is connected to the modeler 10 and tracks the at least one moving object based on the perception source detected by the modeler 10 to obtain a tracking result of the at least one moving object. The estimator 30 is connected to the tracker 20, and estimates a distance, a speed, an orientation and a width of the at least one moving object based on the tracking result of the at least one moving object. The trajectory module 40 is connected to the estimator 30, receives the distance, the speed, the orientation and the width of the at least one moving object, and performs a motion trajectory prediction and a motion flow integration of the at least one moving object. In this way, a motion trajectory prediction of each moving object is performed, a motion flow integration of each moving object is performed, so that a motion region with distance, speed, orientation and width indications of the at least one moving object is obtained. Preferably but not exclusively, in the embodiment, the motion region includes multiple bounding boxes (e.g., the multiple blocks outside each human), which can be integrated based on a group of moving objects nearby with similar distance, speed, and orientation. Preferably but not exclusively, the trajectory module 40 extends each trajectory of the at least one moving object based on the distance, the speed and the orientation. Furthermore, the trajectory module 40 performs the motion flow integration with considering the width of the at least one moving object to form a motion flow map. In other embodiments, the trajectory module 40 further performs

a historical pattern generalization to generate a historical pattern. Certainly, the present disclosure is not limited thereto.

[0030] In the embodiment, the movable object perception system 1 detects and tracks the movable objects, such as humans, across multiple instances to estimate their distance, speed, orientation and width relative to the position of the AMR therewith. In this way, the movable object perception system is able to work in dynamic environment without prior information required (e.g., map of scene, walking pattern of humans, path of robot, etc.), able to learn and evolve to detect, track and predict the trajectory of other moving objects for the purpose of robot navigation, and able to work with a low-cost single camera system, so as to save costs.

[0031] More specifically, in the embodiment, the movable object perception system 1 detects and tracks the at least one moving object while estimating the distance, the speed, the orientation and the width of the at least one moving object with respect to an agent, an image capture module or a camera, and the perception source is obtained through the agent , an image capture module or a camera. Preferably but not exclusively, the movable object perception system 1 with the image capture module or the camera is disposed on the agent or as a stand-alone sensing node for detecting and tracking the moving objects with respect to the position of the image capture module or camera on the agent or the AMR. Further, in the embodiment, the modeler 10 includes a model of human, agent and/or object detector to detect at least one moving object based on the perception source. Preferably but not exclusively, the modeler 10 includes a learning-based modeler configured to localize the at least one moving object and extract relevant features to generate a tracking ID (for tracking the at least one moving object) across frames. Preferably but not exclusively, the tracker 20 is a human,

agent, object ID tracker which generates the tracking result of the at least one moving object by using extracted relevant features from a frame and continuing to track across later frames. The tracking result can include, for example, information related to the motion behavior or trajectory of the at least one moving object. Thereby, the estimator 30 can estimate information such as position, speed, and direction based on such tracking result. In the embodiment, the estimator 30 includes a single-frame based mathematical-based estimator utilized to estimate the distance, the orientation (compared to the camera's position) and the width of each localized one of the at least one moving object. The orientation mentioned here refers to the information related to the relative position information between the moving object and the camera. The camera's position can be used as a reference point to define the relative position, which can be expressed as an angle. Moreover, in the embodiment, the estimator 30 includes a multi-frame based mathematical-based estimator utilized to estimate the speed and the orientation (compared to the moving object itself) at which one of the at least one moving object is moving. Note that the orientation mentioned in this embodiment refers to information about a moving direction of the moving object, and the moving object itself is used as a reference point to define the moving direction, which can be expressed as an angle. Since the image capture module or the camera is disposed on the agent or the AMR, the distance, the speed, the orientation and the width are converted from camera coordinates to robot coordinates through a camera-to-robot coordinate transformation before execution with the AMR. Certainly, the present disclosure is not limited thereto.

[0032] Dynamically moving people are common in areas where the agent are navigating. With the movable object perception system 1 of the present disclosure, the agent or the sensing node allows the detection and

tracking of the movable objects such as humans along with estimations of their distance, speed, and orientation with respect to the camera-robot position. FIG. 2, FIG. 3, FIG. 4 and FIG. 5 schematically show possible implementations of the movable object perception system of FIG. 1.

[0033] With the movable object perception system 1 of the present disclosure, the AMR allows detecting and tracking multiple humans at the same time, as shown in FIG. 2. In this example, there are two humans detected and tracked by the movable object perception system 1. The movable object perception system 1 can label them as "Person 1" and "Person 2" respectively, and also estimate their distance, speed, and orientation information with respect to the AMR's position. In this example, for Person 2, the estimated distance, speed, and orientation with respect to the AMR's position are 2.59 meters, 0.05 m/s, and -34 degrees. As for Person 1, the estimated distance, speed, and orientation with respect to the AMR's position are 2.48 meters, 0.58 m/s, and -3 degrees. Further, the movable object perception system 1 can further count the current number of objects in this frame as well as the cumulative number of objects the movable object perception system 1 have detected. As shown in the example of FIG, 2, there are two objects currently detected in this frame, and there are two objects detected in total.

[0034] In the embodiment, the AMR with the movable object perception system 1 of the present disclosure allows continuous tracking of human walking in any direction even if not face the image capture module or camera, as shown in FIG. 3. In this example, the two humans of FIG. 2 are detected and tracked by the movable object perception system 1 continuously. The movable object perception system 1 can label them as "Person 1" and "Person 2" respectively, and also estimate their distance,

speed, and orientation information with respect to the AMR's position. In this example, for Person 2, the estimated distance, speed, and orientation with respect to the AMR's position are 2.6 meters, 0.07 m/s, and -34 degrees. As for Person 1, the estimated distance, speed, and orientation with respect to the AMR's position are 2.296 meters, 0.7 m/s, and 8 degrees. Further, the movable object perception system 1 can further count the current number of objects in this frame as well as the cumulative number of objects the movable object perception system 1 have detected. As shown in the example of FIG, 3, there are two objects currently detected in this frame, and there are two objects detected in total.

[0035] In the embodiment, the AMR with the movable object perception system 1 of the present disclosure allows perception of new humans entering the scene at any time, as shown in FIG. 4. In this example, the movable object perception system 1 continues performing detection and tracking, and there are four humans detected and tracked, including the two people previously detected in the embodiment of FIG. 3 and additional two people detected. The movable object perception system 1 can label them as "Person 1", "Person 2," "Person 3" and "Person 4" respectively, and also estimate their distance, speed, and orientation information with respect to the AMR's position. In this example, for Person 2, the estimated distance, speed, and orientation with respect to the AMR's position are 3.60 meters, 0.36 m/s, and -27 degrees. As for Person 4, the estimated distance, speed, and orientation with respect to the AMR's position are 2.564 meters, 1.77 m/s, and -15 degrees. As for Person 1, the estimated distance, speed, and orientation with respect to the AMR's position are 6.7 meters, 1.26 m/s, and -4 degrees. As for Person 3, the estimated distance, speed, and orientation with respect to the AMR's position are 3.494 meters, 1.29 m/s, and 5 degrees.

Further, the movable object perception system 1 can further count the current number of objects in this frame as well as the cumulative number of objects the movable object perception system 1 have detected. As shown in the example of FIG, 4, there are four objects currently detected in this frame, and there are four objects detected in total.

[0036] Furthermore, in the embodiment, the AMR with the movable object perception system 1 of the present disclosure allows perception of occlusion of humans, as shown in FIG. 5. In this example, the four humans of FIG. 4 are detected and tracked by the movable object perception system 1 continuously. The movable object perception system 1 can label them as “Person 1”, “Person 2” “Person 3” and “Person 4”respectively, and also estimate their distance, speed, and orientation information with respect to the AMR’s position. In this example, for Person 4, the estimated distance, speed, and orientation with respect to the AMR’s position are 2.262 meters, 2.03 m/s, and -22 degrees. As for Person 2, which is obscured by Person 4, so that the estimated distance, speed, and orientation of Person 2 with respect to the AMR’s position are omitted. As for Person 1, the estimated distance, speed, and orientation with respect to the AMR’s position are 6.8 meters, 1.26 m/s, and -4 degrees. As for Person 3, the estimated distance, speed, and orientation with respect to the AMR’s position are 4.6 meters, 0.65 m/s, and -1 degrees. Further, the movable object perception system 1 can further count the current number of objects in this frame as well as the cumulative number of objects the movable object perception system 1 have detected. As shown in the example of FIG, 5, there are four objects currently detected in this frame, and there are four objects detected in total.

[0037] In some embodiments, by dealing with the perception source obtained through an image capture module such as an RGBD camera

disposed on the AMR for moving object aware navigation, the movable object perception system 1 on the AMR is able to robustly detect moving objects, track them and predict their trajectory in their paths, and further integrate all motion flows of the detected moving objects into a motion flow map without any prior knowledge of the scene or the humans in the scene.

[0038] FIG. 6A is a schematic diagram illustrating a first example of the movable object perception system for moving object aware navigation. In the embodiment, the movable object perception system 1 of the present disclosure receives the perception source in view of an agent 11 (or a camera disposed on an AMR). After dealing with the perception source, motion regions with distance, speed, orientation and width indications (not shown in FIG. 6A) of multiple people are obtained. In this example, there are nine people detected by the movable object perception system 1, and nine corresponding motion regions are obtained. Note that in order to make the figure easy to understand, only one of these motion regions is representatively marked with “9” in FIG. 6A, and markings of the other motion regions are omitted. Further, motions of the detected people are respectively indicated with arrows. Similarly, only two arrows in opposite directions of the nine arrows are representatively marked with “91” and "92" in FIG. 6A, while markings of the other arrows are omitted to make the figure clear. Moreover, one or more moving objects that are adjacent and have similar motion behavior can be considered as a group. In this example, based on the detection results at time t1, t2 and t3, the detected people can be divided into four groups, which can be respectively regarded as motion flows MF1-MF4, where two of the motion flows MF1 (including MF1_1, MF1_2 and MF1_3 detected at time t1, t2 and t3, respectively) and MF2 (including MF2_1, MF2_2 and MF2_3 detected at times t1, t2 and t3, respectively) are

representatively marked in FIG. 6A, while for the other two motion flows MF3 and MF4, markings of their immediate detection results at times t1, t2 and t3 are omitted to make the figure clear. Flow direction indicators D1, D2 corresponding to the motion flows MF1-MF4 are further recorded, where the flow direction indicators D1 and D2 respectively point in different directions. Such figure shown as FIG. 6A can be regarded as a motion flow map. By using the motion regions 9 with distance, speed, orientation and width indications of the multiple people, it facilitates the agent 11 with the movable object perception system 1 of the present disclosure to integrate the motion flow map. Different from the typical methods using prior information, the movable object perception system 1 of the present disclosure does not need any such prior information and can be easily adapted to other environments, such an elevator, campus, office building, hospital, shopping mall or hotel.

[0039] FIG. 6B is a schematic diagram illustrating a second example of the movable object perception system for moving object aware navigation. In the embodiment, the movable object perception system 1 of the present disclosure receives the perception source in view of an agent 11 (or a camera disposed on an AMR). After dealing with the perception source, a moving object (e.g. another AMR which is performing other food delivery tasks) can be detected, and a motion region 9a representing the moving object can be obtained along with distance, speed, orientation and width indications (not shown in FIG. 6B) of the another AMR. In this example, a motion flow MF1 can be determined based on the motion behavior of the detected single moving object, and a corresponding flow direction indicator D1 of the moving object is also indicated. By using the motion region 9a with distance, speed, orientation and width indications of the moving object, it facilitates

the agent 11 with the movable object perception system 1 of the present disclosure to integrate the motion flow map.

[0040] FIG. 6C is a schematic diagram illustrating a third example of the movable object perception system for moving object aware navigation. In the embodiment, the movable object perception system 1 of the present disclosure receives the perception source in view of an agent 11 (or a camera disposed on an AMR). After dealing with the perception source, a human and a moving object (e.g. a wheelchair used by the human) can be detected, and motion regions 9, 9a respectively representing the human and the moving object can be obtained along with their distance, speed, orientation and width indications (not shown in FIG. 6C). In this example, a motion flow MF1 can be determined based on the motion behaviors of the detected human and his/her wheelchair as they are adjacent and have similar motion behaviors. A corresponding flow direction indicator D1 of the human with the wheelchair is also indicated. By using the motion regions 9, 9a with distance, speed, orientation and width indications of the human with the moving object, it facilitates the agent 11 with the movable object perception system 1 of the present disclosure to integrate the motion flow map.

[0041] FIG. 7 is a schematic diagram illustrating a movable object perception system according to a second embodiment of the present disclosure. In the embodiment, the structures, elements and functions of the movable object perception system 1a are similar to those of the movable object perception system 1 in FIG. 1, and are not redundantly described herein. Preferably but not exclusively, the movable object perception system 1a is applied to moving object aware navigation of an agent. In the embodiment, the movable object perception system 1a further includes a strategist module 50 connected to the trajectory module 40. In addition to

the perception source, the modeler 10 further receives an agent width and a map (e.g. an environment map). Preferably but not exclusively, the modeler 10 includes a model of human, agent and/or object detector and a model of obstacle detector for detecting human, agent, object and/or obstacle based on the perception source. Preferably but not exclusively, the tracker 20 is a human, agent, object and/or obstacle ID tracker. In the embodiment, the tracker 20 is connected to the modeler 10 and tracks the at least one moving object and/or the obstacle detected based on the perception source by the modeler 10 to obtain a tracking result of the at least one moving object and/or the obstacle. Similarly, the estimator 30 connected to the tracker 20 estimates a distance, a speed, an orientation and a width of the at least one moving object and/or the obstacle. The trajectory module 40 connected to the estimator 30 performs a motion trajectory prediction and a motion flow integration of the at least one moving object and/or the obstacle. In the embodiment, the strategist module 50 further performs a traffic analysis and a moving strategies estimation at least based on a motion flow map optionally with an agent width and environment map to obtain a possible way with distance, speed, orientation and width suggested. Preferably but not exclusively, the motion flow map is formed according to the motion flow integration, and the agent width is received by the modeler. With the movable object perception system 1a, it facilitates the AMR to realize the moving object detection, the machine design for human safety and the human-aware path planning. Certainly, the present disclosure is not limited thereto.

[0042] FIG. 8A is a schematic diagram illustrating a fourth example of the movable object perception system for moving object aware navigation. In the embodiment, the movable object perception system 1a of the present

disclosure receives the perception source in view of an agent 11 (or a camera disposed on an AMR). After dealing with the perception source, motion regions with distance, speed, orientation and width indications (not shown in FIG. 8A) of multiple people are obtained. In this example, there are nine people detected by the movable object perception system 1a, and nine corresponding motion regions are objected. Notably, in order to make the figure easy to understand, only one of these motion regions is representatively marked with "9" in FIG. 8A, and markings of the other motion regions are omitted. Further, motions of the detected people are respectively indicated with arrows. Similarly, only two arrows in opposite directions of the nine arrows are representatively marked with "91" and "92" in FIG. 8A, while markings of the other arrows are omitted to make the figure clear. Moreover, one or more moving objects that are adjacent and have similar motion behavior can be considered as a group. In this example, based on the detection results at time t1, t2 and t3, the detected people can be divided into four groups, which can be respectively regarded as motion flows MF1-MF4, where two of the motion flows MF1 (including MF1_1, MF1_2 and MF1_3 detected at time t1, t2 and t3, respectively) and MF2 (including MF2_1, MF2_2 and MF2_3 detected at times t1, t2 and t3, respectively) are representatively marked in FIG. 8, while for the other two motion flows MF3 and MF4, markings of their immediate detection results at times t1, t2 and t3 are omitted to make the figure clear. Flow direction indicators D1, D2 corresponding to the motion flows MF1-MF4 are further recorded, where the flow direction indicators D1 and D2 respectively point in different directions. Such figure shown in FIG. 8A can be regarded as a motion flow map. By using the motion regions 9 with distance, speed, orientation and width indications of the multiple people, it facilitates the agent 11 with the movable

object perception system 1a to make a navigation plan. In the embodiment, the strategist module 50 further provides several navigation plans P1, P2, P3 of possible ways with distance, speed, orientation and width suggested for the agent 11 based on the motion flow map (and/or with the agent width). The agent 11 with the movable object perception system 1a can select one of possible ways while taking into account all motion flow maps and historical patterns. Herein, the navigation plan P1 suggests the agent 11 to move with the motion flow MF4. The navigation plan P2 suggests the agent 11 to move along a path which is sufficiently wide among motion flows, such as the path between MF4 and MF3. The navigation plan P3 suggests the agent 11 to move with the motion flow MF2.

[0043] FIG. 8B is a schematic diagram illustrating a fifth example of the movable object perception system for moving object aware navigation. In the embodiment, the agent 11 (or a camera disposed on an AMR) with the movable object perception system 1a has to navigate narrow walkways. In this example, there are four people detected by the movable object perception system 1a. As shown in FIG. 8B, motion of the detected four people are respectively indicated with four arrows, and one flow direction indicator D1 towards the agent 11 is shown. The detected four people are considered as a group and regarded as a motion flow MF1. By using the motion regions 9 with distance, speed, orientation and width indications of the multiple people, it facilitates the agent 11 with the movable object perception system 1a to provide several navigation plans P0, P1, P2 of possible ways with distance, speed, orientation and width suggested for the agent 11 based on the motion flow map with the agent width. In the navigation plan P1 or P2, it suggests the agent 11 to slowly move to the side. In the navigation plan P0, it suggests the agent 11 to wait for object passing. Preferably but not exclusively, the

agent 11 can select one of possible ways while taking into account all motion flow maps and historical patterns with a virtual boundary, such as a warning zone, a slowdown zone and a stop zone built with respect to the agent 11 for collaborative safety. With the virtual boundary for collaborative safety, the movable object perception system 1a can further provide functions of reconfigurable virtual safety boundary and response based on human/ obstacle distance, non-contact detection of moving objects located in the passible ways for the agent 11, dynamic collision avoidance of moving human or obstacles, preventive safety to slow down and stop the agent 11 with imminent danger, and timely voice/display feedback to project to humans around the agent 11.

[0044] FIG. 8C is a schematic diagram illustrating a sixth example of the movable object perception system for moving object aware navigation. In the embodiment, the agent 11 with the movable object perception system 1a has to navigate narrow walkways with an obstacle B. In this example, there are four people and one obstacle B are detected by the movable object perception system 1a. As shown in FIG. 8C, motion of the multiple people and the position of the obstacle B are indicated, and one flow direction indicator D1 towards the agent 11 is shown. The detected four people are considered as a group and regarded as a motion flow MF1. By using the motion regions 9 with distance, speed, orientation and width indications of the multiple people and the position of the obstacle B, it facilitates the agent 11 with the movable object perception system 1a to provide several navigation plans P0, P1, P2 of possible ways with distance, speed, orientation and width suggested for the agent 11 based on the motion flow map with the agent width. In the navigation plan P1, it suggests the agent 11 to move slowly and weave around obstacles B. In the navigation plan P2, it

suggests the agent 11 to slowly move to the side. In the navigation plan P0, it suggests the agent 11 to wait for object passing. Preferably but not exclusively, the agent 11 can select one of possible ways. The present disclosure is not limited thereto.

[0045] FIG. 8D is a schematic diagram illustrating a seventh example of the movable object perception system for moving object aware navigation. In the embodiment, the agent 11 with the movable object perception system 1a has to navigate narrow walkways. In this example, a moving object (e.g., another AMR which is performing other food delivery tasks) can be detected, and a motion region 9a representing the moving object can be obtained along with distance, speed, orientation and width indications (not shown in FIG. 8D) of another AMR. Moreover, a motion flow MF1 can be determined based on the motion behavior of the detected single moving object, and a corresponding flow direction indicator D1 of the moving object is also indicated. In the case of the agent 11 with the movable object perception system 1a perceives the moving object occupying the entire narrow walkway and moving towards the agent 11, a navigation plan P0 of possible ways with distance, speed, orientation and width is suggested for the agent 11 based on the motion flow map with the agent width. The agent 11 is suggested to wait for object passing. Certainly, the present disclosure is not limited thereto.

[0046] FIG. 8E is a schematic diagram illustrating an eighth example of the movable object perception system for moving object aware navigation. In the embodiment, the agent 11 with the movable object perception system 1a has to navigate narrow walkways. In this example, a human with a moving object (such as wheelchair, trolley, stroller, etc.) are detected, and motion regions 9, 9a respectively representing the human and the moving object can be obtained along with their distance, speed, orientation and width

indications. A motion flow MF1 can be determined based on the motion behaviors of the detected human and the moving object as they are adjacent and have similar motion behaviors. A corresponding flow direction indicator D1 of the human with the moving object is also indicated. In case of that the agent 11 with the movable object perception system 1a perceives the human with the moving object occupying the entire narrow walkway and moving towards the agent 11, a navigation plan P0 of possible ways with distance, speed, orientation and width is suggested for the agent 11 based on the motion flow map with the agent width. The agent 11 is suggested to wait for object passing. Certainly, the present disclosure is not limited thereto.

[0047] In summary, the present disclosure provides a movable object perception system to assist an agent such as an autonomous mobile robot (AMR) to prepare the route in advance for a safe and efficient navigation in crowded and dynamic spaces. By dealing with the perception source obtained through an image capture module such as the RGBD camera for moving object aware navigation, the movable object perception system on the agent is able to robustly detect moving objects, track them and predict their paths in its path without any prior knowledge of the scene or the moving objects in the scene. The movable object perception system detects and tracks the moving objects across multiple instances to estimate their distance, speed, orientation and width relative to the position of the agent therewith. In this way, the movable object perception system is able to work in dynamic environments without prior information required (e.g., map of scene, walking pattern of humans, path of robot), able to learn and evolve to detect, track and predict the trajectory of other moving objects for the purpose of robot navigation, and able to work with a low-cost single camera system to save costs. With the movable object perception system, it facilitates the

agent to realize the human detection, the machine design for human safety and the human-aware path planning. Furthermore, it helps the agent such as the AMR to build a virtual boundary for collaborative safety. With the virtual boundary for collaborative safety, the movable object perception system further provides functions of reconfigurable virtual safety boundary and response based on distance from people/obstacles, non-contact detection of people and objects located in the path of the agent, dynamic collision avoidance of moving humans or obstacles, preventive safety to slow down and stop the AMR with imminent danger, and timely voice/display feedback to project to humans around the AMR.

[0048] While the disclosure has been described in terms of what is presently considered to be the most practical and preferred embodiments, it is to be understood that the disclosure needs not be limited to the disclosed embodiment. On the contrary, it is intended to cover various modifications and similar arrangements included within the spirit and scope of the appended claims which are to be accorded with the broadest interpretation so as to encompass all such modifications and similar structures.

WHAT IS CLAIMED IS:

1. A movable object perception system disposed on an autonomous mobile robot (AMR), wherein the movable object perception system comprises:

a modeler receiving a perception source to detect a plurality of moving objects based on the perception source;

a tracker connected to the modeler and tracking the plurality of moving objects detected by the modeler to obtain a tracking result of the plurality of moving objects;

an estimator connected to the tracker, and estimating a distance, a speed, an orientation and a width of the plurality of moving objects relative to a position of the AMR based on the tracking results of the plurality of moving objects; and

a trajectory module connected to the estimator, receiving the distance, the speed, the orientation and the width of the plurality of moving objects relative to a position of the AMR, and performing a motion trajectory prediction and a motion flow integration, so as to obtain motion regions with distance, speed, orientation and width indications of the plurality of moving objects in a dynamic space.

2. The movable object perception system according to claim 1, wherein the plurality of moving objects includes a human, a moving object or a combination thereto, wherein the moving object includes an agent, an AMR, a wheelchair, a trolly or a stroller.

3. The movable object perception system according to claim 1, wherein the perception source is obtained through an agent, an image capture module or a camera.

4. The movable object perception system according to claim 1, wherein the trajectory module further performs a historical pattern generalization.

5. The movable object perception system according to claim 1, further comprising a strategist module, connected to the trajectory module, and performing a traffic analysis and a moving strategies estimation based on a motion flow map to obtain a possible way with distance, speed, orientation and width suggested.

6. The movable object perception system according to claim 1, wherein the modeler further receives an agent width and a map, and performs an obstacle detection through an obstacle detector.

7. The movable object perception system according to claim 6, further comprising a strategist module, connected to the trajectory module, and performing a traffic analysis and a moving strategies estimation based on a motion flow map and the agent width to obtain a possible way with distance, speed, orientation and width suggested.

8. The movable object perception system according to claim 1, wherein the trajectory module extends each trajectory of the plurality of moving objects based on the distance, the speed and the orientation.

9. The movable object perception system according to claim 1, wherein the trajectory module performs the motion flow integration with considering the width of the plurality of moving objects to form a motion flow map.

10. The movable object perception system according to claim 1, wherein the movable object perception system detects and tracks the plurality of moving objects while estimating the distance, the speed, the orientation and the width of the plurality of moving objects relative to a position of an image capture module or a camera on the AMR.

11. The movable object perception system according to claim 10, wherein the modeler comprises a learning-based modeler configured to localize the plurality of moving objects and extract relevant features to generate a

tracking ID across frames.

12. The movable object perception system according to claim 11, wherein the estimator comprises a single-frame based mathematical-based estimator utilized to estimate the distance, the orientation and the width of each localized one of the plurality of moving objects.

13. The movable object perception system according to claim 12, wherein the estimator comprises a multi-frame based mathematical-based estimator utilized to estimate the speed and the orientation at which one of the plurality of moving objects is moving.

14. The movable object perception system according to claim 13, wherein the camera is disposed on the AMR, and the distance, the speed, the orientation and the width are converted from camera coordinates to robot coordinates through a camera-to-robot coordinate transformation before execution with the AMR.

15. A movable object perception system disposed on an AMR, wherein the movable object perception system comprises:

a modeler receiving a perception source to detect a plurality of moving objects based on the perception source;

a tracker connected to the modeler and tracking the plurality of moving objects detected by the modeler to obtain a tracking result of the plurality of moving objects;

an estimator connected to the tracker, and estimating a distance, a speed, an orientation and a width of the plurality of moving objects relative to a position of the AMR based on the tracking results of the plurality of moving objects;

a trajectory module connected to the estimator, receiving the distance, the speed, the orientation and the width of the plurality of moving objects

relative to a position of the AMR, and performing a motion trajectory prediction and a motion flow integration, so as to obtain motion regions with distance, speed, orientation and width indications of the plurality of moving objects in a dynamic space; and

a strategist module, connected to the trajectory module, and performing a traffic analysis and a moving strategies estimation at least based on a motion flow map formed according to the motion flow integration to obtain a possible way with distance, speed, orientation and width suggested.

16. The movable object perception system according to claim 15, wherein the strategist module performs the traffic analysis and the moving strategies estimation further based on the motion flow map and an agent width received by the modeler to obtain the possible way with distance, speed, orientation and width suggested.