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O'ZBEKISTON MILLIY UNIVERSITETINING
JIZZAX FILIALI

ZAMONAVIY INNOVATSION TADQIQOTLARNING DOLZARB MUAMMOLARI VA RIVOJLANISH TENDENSIYALARI: YECHIMLAR VA ISTIQBOLLAR

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ANALYSIS OF EXISTING APPROACHES TO LOCAL NAVIGATION AND CONTROL OF LOGISTICS MOBILE ROBOTS IN DYNAMIC ENVIRONMENTS

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Abstract: This study provides a critical analysis of contemporary approaches to local navigation and motion control for logistics mobile robots operating in dynamically changing environments. Logistics mobile robots are increasingly deployed in manufacturing facilities, warehouse systems, service infrastructures, healthcare institutions, and other indoor technological domains to support automated

material handling, object delivery, and service-oriented operations. However, the coexistence of mobile robots with humans, moving carts, other robotic platforms, and temporarily appearing obstacles substantially increases the complexity of ensuring safe, stable, and smooth motion. Under such conditions, conventional navigation and control strategies are often limited in maintaining reliable obstacle avoidance, motion continuity, and real-time adaptability to environmental uncertainties. Accordingly, the systematic investigation of SLAM-based localization and mapping, local navigation algorithms, and adaptive motion control methods is of considerable scientific and practical relevance for enhancing the autonomy, robustness, and operational reliability of logistics mobile robots.

Keywords: logistics mobile robot, dynamic environment, SLAM, local navigation, DWA, TEB, MPC, adaptive control, localization uncertainty, motion safety.

Introduction

In recent years, autonomous mobile robots have become an important technological tool for automating logistics processes. Logistics mobile robots are widely used to reduce human involvement, accelerate material transportation, improve service efficiency, and support real-time operation in indoor environments [1]. In relatively static conditions, such robots can follow a predefined trajectory; however, in real operating environments, surrounding conditions may change continuously.

Figure 1. Logistics mobile robot operating in a human-shared warehouse environment

Figure 2. Autonomous logistics mobile robots in an indoor warehouse system

During robot motion in a dynamic environment, different risky situations may occur. For example, a person may suddenly cross the robot's path, a moving cart may block the passage, the robot's motion area may intersect with that of another robot, or sensor data may contain noise and delay [2]. In such situations, relying only on a prebuilt map is not sufficient. The robot must continuously evaluate the surrounding environment, detect dynamic obstacles, maintain a safe distance, and adapt its linear and angular velocities in real time.

In real logistics environments, mobile robots often operate together with humans, carts, and manually controlled transport devices. Such interaction increases the need for safe local navigation and real-time motion control (Figure 1).

Therefore, the problem of local navigation and motion control for logistics mobile robots is relevant not only to robotics, but also to system analysis, control theory, and information processing. Developing reliable approaches for safe and adaptive robot motion in dynamic environments remains an important scientific and practical task [3].

Relevance of the problem and analysis of existing approaches

Efficient motion of a logistics mobile robot in a dynamic environment depends on its ability to determine its own position, evaluate surrounding obstacles, and generate control decisions according to the current situation. In this process, SLAM enables the robot to perform localization and mapping simultaneously [4]. Algorithms such as SLAM Toolbox, Cartographer, GMapping, RTAB-Map, and ORB-SLAM are widely used for this purpose.

For local navigation and motion control, approaches such as DWA/DWB, TEB, VFH, MPC, PID, and Pure Pursuit are commonly applied. These algorithms support obstacle avoidance, local trajectory selection, and the control of linear and angular velocities [5].

Logistics mobile robots are increasingly used in indoor warehouse systems for automated material handling, object delivery, and transportation tasks. In such environments, several robots may operate simultaneously among shelves, boxes, and moving objects (Figure 2).

However, in dynamic environments where humans, moving carts, other robots, or temporary obstacles may appear, some aspects of these approaches require further improvement. In particular, predicting the future state of moving obstacles, considering SLAM localization uncertainty, maintaining a safe distance, and adapting the robot's velocity in real time remain important issues [6].

Therefore, based on the strengths of existing algorithms, developing an adaptive local navigation and motion control algorithm that integrates SLAM data, dynamic obstacle risk, and the kinematic constraints of the robot is an important scientific and practical task.

Logistics mobile robot as a control object

A logistics mobile robot can be considered a complex technical control object. Its operation is based on the integration of mechanical components, sensors, a control unit, software tools, and navigation algorithms. The robot's motion is carried out through wheels, actuators, sensors such as LiDAR, camera, IMU, and encoders, as well as motion control algorithms [7].

The main task of a logistics mobile robot is to transport loads or objects safely within a given environment, avoid obstacles, and adapt its motion mode according to environmental conditions. In this process, technical parameters such as wheel radius, wheelbase, maximum linear velocity, angular velocity, sensor detection range, and computational capacity play an important role.

In dynamic environments, robot control becomes more complex. This is because the robot must consider not only its own kinematic constraints, but also the motion of surrounding objects, safe distance requirements, sensor errors, and information delays. Therefore, the development of adaptive local navigation and motion control algorithms for logistics mobile robots in real time is an important scientific and practical task.

Dynamic environment and problematic situations

A dynamic environment refers to an environment in which objects change their position over time. In such conditions, people, other mobile robots, moving carts, temporarily placed loads, or suddenly appearing obstacles may exist around the robot [8].

For logistics mobile robots, several problematic situations may occur in dynamic environments. These include an object crossing the robot's path, an obstacle moving toward the robot, motion in narrow spaces with nearby objects, delays in sensor data, SLAM localization errors, sudden stopping or oscillatory motion of the robot, and violation of the safe distance.

In such situations, conventional local navigation algorithms may not always provide sufficient smoothness, safety, and stability of robot motion. As a result, the robot may perform unnecessary turns, stop unexpectedly, or approach obstacles at an unsafe distance. Therefore, an adaptive local navigation and control approach that considers SLAM data, dynamic obstacle risk, and the robot's kinematic constraints is required for reliable robot motion in dynamic environments.

SLAM-based localization and mapping in mobile robots

SLAM technology enables mobile robots to simultaneously build a map and estimate their own position in unknown or partially known environments [9]. This approach is especially important for logistics mobile robots, since they usually operate in indoor and changing environments where GPS signals are unavailable.

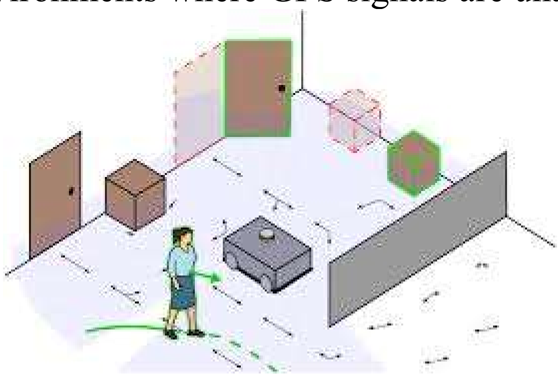

Figure 3. SLAM-based perception and mapping of obstacles in a dynamic indoor environment

In practice, LiDAR-based SLAM, visual SLAM, and LiDAR–IMU integrated approaches are widely used. LiDAR-based SLAM provides stable mapping in indoor environments, while visual SLAM relies on camera images to detect environmental features. LiDAR–IMU integration helps reduce drift and sensor noise in robot state estimation [10].

SLAM enables a mobile robot to perceive surrounding objects, estimate its own position, and construct a map of the environment. In dynamic indoor conditions, the robot must distinguish static elements from moving or temporary obstacles **(Figure 3).**

However, SLAM results are not always absolutely accurate. Sensor noise, wheel slip, repetitive environmental structures, lighting conditions, and dynamic obstacles can affect localization accuracy. Therefore, localization uncertainty obtained from SLAM should be considered in local navigation and motion control algorithms.

Local navigation algorithms and their limitations

Local navigation is the process of selecting a safe and smooth motion trajectory by considering obstacles in the robot's nearby environment. It is based on real-time sensor data and plays an important role in generating the robot's linear and angular velocity commands.

Currently, local navigation algorithms such as DWA/DWB, TEB, MPC, and VFH are widely used. DWA/DWB evaluates a set of possible robot velocities and selects a suitable motion option [11]. TEB aims to ensure smooth motion by optimizing a time-dependent trajectory. MPC optimizes control actions by predicting future robot states. VFH selects a safe direction based on obstacle density.

Although these approaches are effective under certain conditions, further improvement is required for dynamic environments. In particular, predicting the future state of moving obstacles, considering SLAM localization uncertainty, maintaining a safe distance, reducing robot oscillations, and generating stable control decisions in real time remain important issues [12].

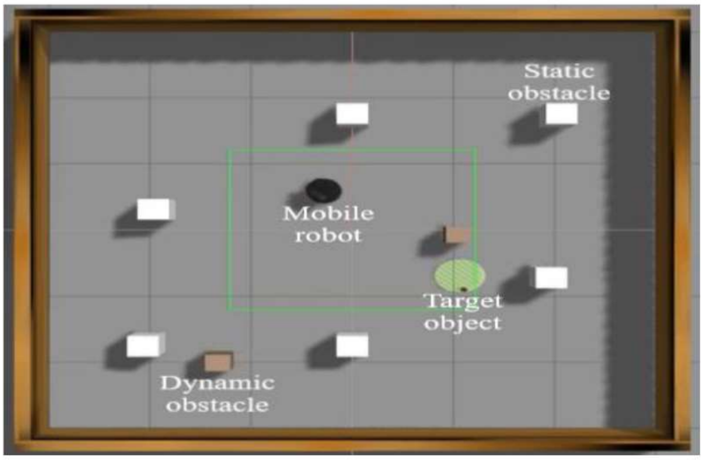

Figure 4. Local navigation scenario with static and dynamic obstacles

Therefore, developing an adaptive local navigation and motion control algorithm that integrates SLAM data, dynamic obstacle risk, and the kinematic constraints of logistics mobile robots is an important scientific and practical task.

In local navigation, the robot must select a safe motion trajectory by considering both static and dynamic obstacles in its nearby environment. The presence of moving obstacles may lead to sudden stopping, oscillation, or unsafe distance reduction if the control strategy is not sufficiently adaptive **(Figure 4).**

Mobile robot motion control methods

Motion control of a logistics mobile robot is mainly based on generating its linear velocity v and angular velocity ω in real time. In this process, the robot's current state, surrounding obstacles, motion direction, safe distance, and kinematic constraints should be considered.

In practice, PID, Pure Pursuit, MPC, and adaptive velocity control are widely used for mobile robot motion control. PID control has a simple structure and is effective for stabilizing robot motion. Pure Pursuit is suitable for trajectory tracking, while MPC optimizes control actions by predicting future robot states under given constraints [13]. Adaptive velocity control allows the robot to adjust its speed according to the current environmental conditions.

However, motion control becomes more complex in dynamic environments. Moving obstacles, delays in sensor data, SLAM localization uncertainty, and the requirement to maintain a safe distance demand more flexible and adaptive control strategies. Therefore, adaptive motion control based on the level of environmental risk is important for logistics mobile robots operating in real time.

Formulation of the scientific problem based on existing studies

Existing studies have widely investigated SLAM, local navigation, and motion control algorithms as separate components of mobile robot systems. SLAM enables the robot to build a map and estimate its position. Local navigation algorithms select a feasible trajectory by considering nearby obstacles, while motion control algorithms generate the robot's velocity and turning commands [14].

At the same time, organizing these components as a unified adaptive system remains an important issue in dynamic environments. If moving obstacles, localization uncertainty, real-time constraints, and the robot's kinematic limitations are not considered together, robot motion may not be sufficiently safe, smooth, and stable.

The main scientific problem can be formulated as follows: although a logistics mobile robot can obtain local environmental information through SLAM, existing local navigation and control algorithms are not always sufficiently adaptive in jointly considering moving obstacle risk, localization uncertainty, and robot kinematic constraints [15].

Therefore, it is necessary to develop an adaptive local navigation and motion control algorithm that integrates SLAM data, dynamic obstacle risk, and robot control parameters.

Conclusion

A logistics mobile robot can estimate its position and build an environmental map using SLAM. However, moving obstacles, sensor errors, localization uncertainty, and real-time constraints complicate the process of local navigation and motion control in dynamic environments.

Algorithms such as DWA/DWB, TEB, VFH, MPC, PID, and Pure Pursuit are widely used for obstacle avoidance, trajectory selection, and motion parameter control in mobile robots. Nevertheless, in dynamic environments, evaluating the risk of moving objects, maintaining a safe distance, considering SLAM uncertainty, and adapting the robot's linear and angular velocities in real time require a more specialized approach.

Based on this, the need to develop an adaptive local navigation and motion control algorithm is justified. Such an algorithm should jointly consider SLAM data, dynamic obstacle risk, sensor errors, and the kinematic constraints of the robot in order to ensure safe, smooth, and stable motion of a logistics mobile robot in dynamic environments. This direction can serve as the basis for further algorithmic development and experimental validation.

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TRANSPORT-LOGISTIKA XIZMATLARIDA RAQAMLI AXBOROT-KOMMUNIKATSIYA TEXNOLOGIYALARIDAN FOYDALANISHNING IQTISODIY SAMARADORLIGI

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Annotatsiya: Quyidagi maqolada transport-logistika xizmatlarining iqtisodiy samaradorligini oshirishda raqamli texnologiyalarning o‘rni yoritib o‘tilgan. Shuningdek, logistika tizimida GPS monitoring, elektron hujjat aylanishi, ERP va TMS tizimlari, sun’iy intellekt hamda raqamli platformalardan foydalanishning afzalliklari tahlil qilingan. Maqolada O‘zbekiston va xalqaro tajriba asosida logistika sohasini raqamlashtirishning iqtisodiy samaradorlikka ta’siri ochib berilgan.

Kalit so‘zlar: transport logistikasi, raqamlashtirish, AKT, ERP, TMS, GPS monitoring, raqamli logistika, iqtisodiy samaradorlik, aqlli omborlar.

Bugungi kunda transport-logistika tizimi mamlakat iqtisodiyotining strategik tarmoqlaridan biri hisoblanadi. Ayniqsa, O‘zbekistonning geografik joylashuvi jihatidan Markaziy Osiyoda muhim tranzit hudud sifatida joylashgani transport-logistika xizmatlarini rivojlantirish zaruratini yanada oshirmoqda. Shu sababli logistika tizimida zamonaviy raqamli axborot-kommunikatsiya texnologiyalarini joriy etish iqtisodiy samaradorlikni oshirishning asosiy omillaridan biri sifatida qaralmoqda.

Xususan, O‘zbekiston Respublikasi Prezidentining “O‘zbekiston Respublikasining transport-logistika tizimini yanada rivojlantirish chora-tadbirlari to‘g‘risida”gi qarorida “xalqaro axborot tizimlari bilan integratsiya qilgan holda mamlakatning logistika tizimi platformalarini shakllantirish, xalqaro yuk tashishlarda