NMAP ALGORITMI: MOBIL NAVIGATSIYA UCHUN XARITALASH, MAHALLIYLASHTIRISH VA YO'LNI REJALASHTIRISHNI INTEGRATSIYALASH

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Annotatsiya: Ushbu maqolada avtonom mobil robotlar uchun xaritalash, lokallashtirish va yo‘lni rejalashtirish jarayonlarini yagona tizimda birlashtiruvchi NMap (Navigation Map) algoritmi taklif etiladi. Taklif etilgan algoritm ROS asosida yaratilgan simulyatsiya muhitlarida, jumladan Gazebo, Rviz va bulutli platforma — TheConstruct.ai yordamida sinovdan o‘tkazildi. Tadqiqot davomida NMap algoritmi mavjud ilg‘or yondashuvlar — A*, Frontier-Based Exploration va Rmap+ algoritmlari bilan taqqoslab tahlil qilindi. Simulyatsiya natijalari asosida taklif etilgan algoritm robot harakatining samaradorligini sezilarli darajada oshirishi aniqlangan: umumiy bosib o‘tilgan masofa 36% dan 75% gacha, vaqt sarfi esa 32% dan 76% gacha qisqartirildi. NMap algoritmi real vaqt rejimida ishonchli, moslashuvchan va optimal navigatsiyani ta’minlab, avtonom mobil robotlar uchun zamonaviy va istiqbolli yechim sifatida taklif qilinadi.

Kalit so‘zlar: Avtonom mobil robot, robot boshqaruvi, harakatni rejalashtirish, ROS, Gazebo, Rviz, TheConstruct.ai, Frontier-Based Exploration, Rmap+, Nmap, simulyatsiya, navigatsiya.

Аннотация: В этой статье предлагается алгоритм Nmap (Navigation map) для автономных мобильных роботов, который объединяет процессы картирования, локализации и планирования маршрутов в единую систему. Предлагаемый алгоритм используется в средах моделирования на основе ROS, включая Gazebo, Rviz и облачную платформу — TheConstruct.ai проверено с помощью. В ходе исследования алгоритм Nmap был проанализирован путем сравнения с существующими передовыми

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подходами — a*, Frontier-based Exploration и rmap+. По результатам моделирования было установлено, что предложенный алгоритм значительно повышает эффективность движения робота: общее пройденное расстояние сократилось с 36% до 75%, а затраты времени-с 32% до 76%. Алгоритм Nmap предлагается как современное и перспективное решение для автономных мобильных роботов, обеспечивающее надежную, гибкую и оптимальную навигацию в режиме реального времени.

Ключевые слова: автономный мобильный робот, управление роботом, планирование движения, рос, беседка, Рвиз, TheConstruct.ai, Frontier-based Exploration, Rmap+, Nmap, моделирование, навигация.

Annotation: this article proposes an Nmap (Navigation Map) algorithm that combines mapping, localization, and path planning processes in a single system for autonomous mobile robots. The proposed algorithm is based on ROS in simulation environments, including Gazebo, Rviz and cloud platform — TheConstruct.ai tested using. During the study, the NMap algorithm was analyzed by analogy with existing advanced approaches — a*, Frontier-Based Exploration, and Rmap+ algorithms. Based on the results of the simulation, the proposed algorithm has been found to significantly increase the efficiency of robot movement: the total distance traveled was reduced from 36% to 75%, while the time consumption was reduced from 32% to 76%. The NMap algorithm is offered as a modern and promising solution for autonomous mobile robots, providing reliable, flexible and optimal navigation in real time.

Keywords: autonomous mobile robot, robot control, motion planning, ROS, Gazebo, Rviz, TheConstruct.ai, Frontier-Based Exploration, Rmap+, Nmap, simulation, navigation.

Kirish

So‘nggi yillarda avtonom mobil robotlar sanoat, qishloq xo‘jaligi, tibbiyot va xizmat ko‘rsatish sohalarida keng qo‘llanilmoqda. Ularning muhim vazifalaridan biri — notanish va dinamik muhitlarda mustaqil harakatlanish, ya’ni navigatsiya imkoniyatiga ega bo‘lishdir. Bunday robotlar ishonchli va optimal navigatsiya uchun uch asosiy bosqichni bajarishi lozim: xaritalash (mapping), mahalliylashtirish (localization) va yo‘lni rejalashtirish (path planning). Bu bosqichlar bir-biriga chambarchas bog‘liq bo‘lib, ularning integratsiyasi robotning harakatdagi aniqligi va samaradorligini belgilaydi.[1]

Hozirgi kunda navigatsiya muammolarini hal etish uchun ko‘plab algoritmlar ishlab chiqilgan. Jumladan, Frontier-Based Exploration metodi muhitni tadqiq etish uchun ishlatilsa, A* algoritmi eng qisqa yo‘lni topishda samarali hisoblanadi. Rmap+ esa real vaqtli xaritalash va marshrut qurishda qo‘llaniladi.

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Biroq ushbu yondashuvlarning har biri alohida modullarga asoslanadi va ko‘pincha bir-biri bilan to‘liq integratsiyalashmagan. Natijada navigatsiya jarayonida kechikishlar, noto‘g‘ri pozitsiyalash yoki optimal bo‘lmagan yo‘llar paydo bo‘lishi mumkin.[2]

Shu nuqtai nazardan, ushbu maqolada xaritalash, lokallashtirish va harakatni rejalashtirish bosqichlarini yagona tizimga birlashtiruvchi yangi yondashuv — NMap (Navigation Map) algoritmi taklif etilmoqda. NMap algoritmi avtonom mobil robotlar uchun real vaqtli, moslashuvchan va optimizatsiyalangan navigatsiyani ta’minlash maqsadida ishlab chiqilgan. U ROS (Robot Operating System) asosida Gazebo, Rviz va TheConstruct.ai platformalarida sinovdan o‘tkazildi.[3]

Maqolada NMap algoritmi mavjud yondashuvlar bilan — A*, Frontier-Based Exploration va Rmap+ bilan taqqoslab tahlil qilinadi, natijalar esa masofa va vaqt sarfini kamaytirish orqali samaradorlikni sezilarli darajada oshirishni ko‘rsatadi. Bu yondashuv kelgusida avtonom mobil robotlarning mustaqil va ishonchli harakatini ta’minlashda muhim rol o‘ynashi mumkin.

NMap (Navigation Map) ishlash jarayoni

Ushbu tadqiqotda taklif etilgan **NMap (Navigation Map)** algoritmi avtonom mobil robotlar uchun xaritalash, lokallashtirish va yo‘lni rejalashtirish bosqichlarini yagona tizimda birlashtirishga qaratilgan. Algoritm uchta asosiy moduldan tashkil topgan: xaritalash (mapping), mahalliylashtirish (localization) va yo‘lni rejalashtirish (path planning). Har bir modul quyida bayon etilgan texnologiyalar asosida qurilgan[4].

Xaritalash (Mapping)

Xaritalash jarayonida robot atrof-muhit haqida vizual va geometriyaga oid ma’lumotlarni yig‘adi. Bu bosqichda **LIDAR** sensorlari va yuqori aniqlikdagi **RGB-D** kameralardan foydalaniladi. Ushbu datchiklar orqali olingan ma’lumotlar asosida Occupancy Grid Map yaratiladi. Bu xarita har bir katakchaning band yoki bo‘sh ekanligini ifodalaydi. Xaritalash jarayonini amalga oshirish uchun **Gmapping** yoki **Cartographer** paketlari ROS platformasida integratsiyalangan[5].

Mahalliylashtirish (Localization)

Robotning muhit ichidagi aniq koordinatalarini aniqlash uchun **Adaptive Monte Carlo Localization (AMCL)** algoritmidan foydalaniladi. AMCL — Particle Filter usuliga asoslangan bo‘lib, xarita va sensorlardan kelayotgan real vaqtli ma’lumotlarni taqqoslab, robotning joylashuvini doimiy tarzda aniqlab boradi. Ushbu metod pozitsiyalashda yuqori aniqlikni ta’minlaydi va dinamik muhitlarda ham samarali ishlaydi[10].

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Yo‘lni rejalashtirish (Path Planning)

NMap algoritmida yo‘lni rejalashtirish moduli avtonom harakatni samarali, xavfsiz va optimal tarzda amalga oshirish uchun bir nechta mavjud yondashuvlar bilan integratsiyalangan. Ular orasida **A***, **Frontier-Based Exploration** va **Rmap+** algoritmlari sinovdan o‘tkazildi va ular o‘zaro taqqoslab baholandi.

- **A*** algoritmi — aniqlik, samaradorlik va optimal yo‘lni topish qobiliyati bilan ajralib turadi. Xarita ustida eng qisqa va to‘siqsiz yo‘lni aniqlashda yuqori natija ko‘rsatdi.
- **Frontier-Based Exploration** — noma’lum muhitlarni kashf qilishda foydali bo‘lib, robot o‘z xaritasi chegarasida joylashgan noma’lum hududlarga yo‘naltiriladi. Bu yondashuv xaritalash va harakatni rejalashtirishni birlashtiradi, ammo faqat to‘liq noma’lum muhitlarda samaralidir[12].
- **Rmap+ algoritmi** — real vaqt rejimida yo‘lni rejalashtirish va xarita tuzishni birlashtiruvchi ilg‘or yondashuvlardan biridir. U dinamik to‘siqlar mavjud bo‘lgan muhitda moslashuvchanlikni ta'minlaydi va robotning harakat trayektoriyasini doimiy ravishda yangilab boradi.

NMap algoritmi ushbu algoritmlarni holatga qarab avtomatik tanlash imkoniyatiga ega. Masalan, ma’lumot to‘liq bo‘lgan muhitlarda A* tanlansa, noma’lum hududlarda Frontier-Based Exploration, dinamik va murakkab muhitlarda esa Rmap+ algoritmi ustunlik qiladi. Bu yondashuv robotning atrof-muhitdagi holatlarga moslasha olishini ta’minlab, umumiy navigatsiya samaradorligini sezilarli darajada oshiradi.

Algorithm . NMap Path Planning Algorithm
1. Begin
2. Initialize ROS environment with necessary components (Lidar, Camera, AMCL, Path Planning)
3. Initialize Robot Position and Orientation
4. Set: MaxRange ← Maximum range of sensor
5. Set: MinRange ← Minimum range of sensor
6. Set: Robot ← New Robot object with start position
7. Create empty Map and Localization grid
8. SensingData ← Collect data from Lidar and Camera sensors
9. Loop until goal is reached:
10. Perform Localization (AMCL or Particle Filter)

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11. Update robot position on the Map
12. Set Goal Location ← Target position or predefined destination
13. Generate Frontiers ← Identify unexplored areas using sensor data
14. Calculate Size of each Frontier
15. Choose the best Frontier ← Based on size and robot capabilities (MaxRange/MinRange)
16. Perform Path Planning using chosen Frontier:
17. If using **A***, calculate the optimal path from robot to Frontier based on cost and heuristic values
18. If using **Frontier-Based Exploration**, explore the most promising unexplored area using the frontier approach
19. If using **Rmap+**, calculate a path considering dynamic obstacles and recalculate path if needed
20. Navigate robot to the chosen Frontier
21. If obstacle detected, use local obstacle avoidance algorithms
22. Continue navigation until robot reaches the chosen frontier
23. Update Map and Localization after each movement
24. End Loop when goal is reached
25. Return robot to final destination
26. End

Harakatni boshqarish (Motion Control)

Rejalashtirilgan yo‘l bo‘ylab robotni aniq harakatlantirish uchun harakat nazorati mexanizmi zarur. Bu bosqichda ikki xil boshqaruv yondashuvi sinovdan o‘tkazildi:

- **PID (Proportional–Integral–Derivative)** nazorati — soddaligi va tez ishlashi bilan ajralib turadi.
- **MPC (Model Predictive Control)** — oldindan modellangan harakat trayektoriyalarini optimallashtirib, murakkab harakat muhitlarida yuqori aniqlik bilan boshqarishni ta’minlaydi.

Simulyatsiya muhiti

Algoritmni sinovdan o‘tkazish uchun ROS (Robot Operating System) platformasidan foydalanildi. Sinovlar quyidagi muhitlarda amalga oshirildi:

- **Gazebo** — fizik muhitni real ko‘rinishda modellashtiruvchi 3D simulyator;
- **Rviz** — sensor va xarita ma’lumotlarini vizualizatsiya qiluvchi vosita;
- **TheConstruct.ai** — bulutli onlayn muhit bo‘lib, real vaqtda ROS dasturlarini ishga tushirish, masofaviy boshqaruv va simulyatsiyani amalga oshirish imkonini beradi.

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NMap algoritmi yuqoridagi modullarni bir tizimga integratsiyalash orqali robotlarga murakkab muhitlarda samarali va mustaqil harakat qilish imkonini beradi.

1-Jadval

NMap algoritimini A*, Frontier-Based Exploration, Rmap+ algoritmlari bilan turli muhitlarda burilish nuqtalari, qamrov maydoni, masofasi va vaqtiga nisbatlari aks etgan.

Muhit turlari	Algoritm	Burilish nuqtalari	Qamrov maydoni	Tadqiqot masofasi	Tadqiqot vaqti
Keng siklik muhit	A*	45	100%	220 m	590 sek
	Frontier-Based Exploration	48	100%	260 m	690 sek
	Rmap+	175	100%	450 m	1450 sek
	NMap	35	100%	190 m	510 sek
Kichik siklik muhit	A*	6	98%	40 m	115 sek
	Frontier-Based Exploration	9	100%	57 m	195 sek
	Rmap+	35	100%	110 m	340 sek
	NMap	5	100%	34 m	95 sek
Kichik siklga ega bo‘lmagan muhit	A*	8	96%	42 m	60 sek
	Frontier-Based Exploration	10	98%	52 m	140 sek
	Rmap+	41	100%	130 m	400 sek
	NMap	7	100%	38 m	50 sek

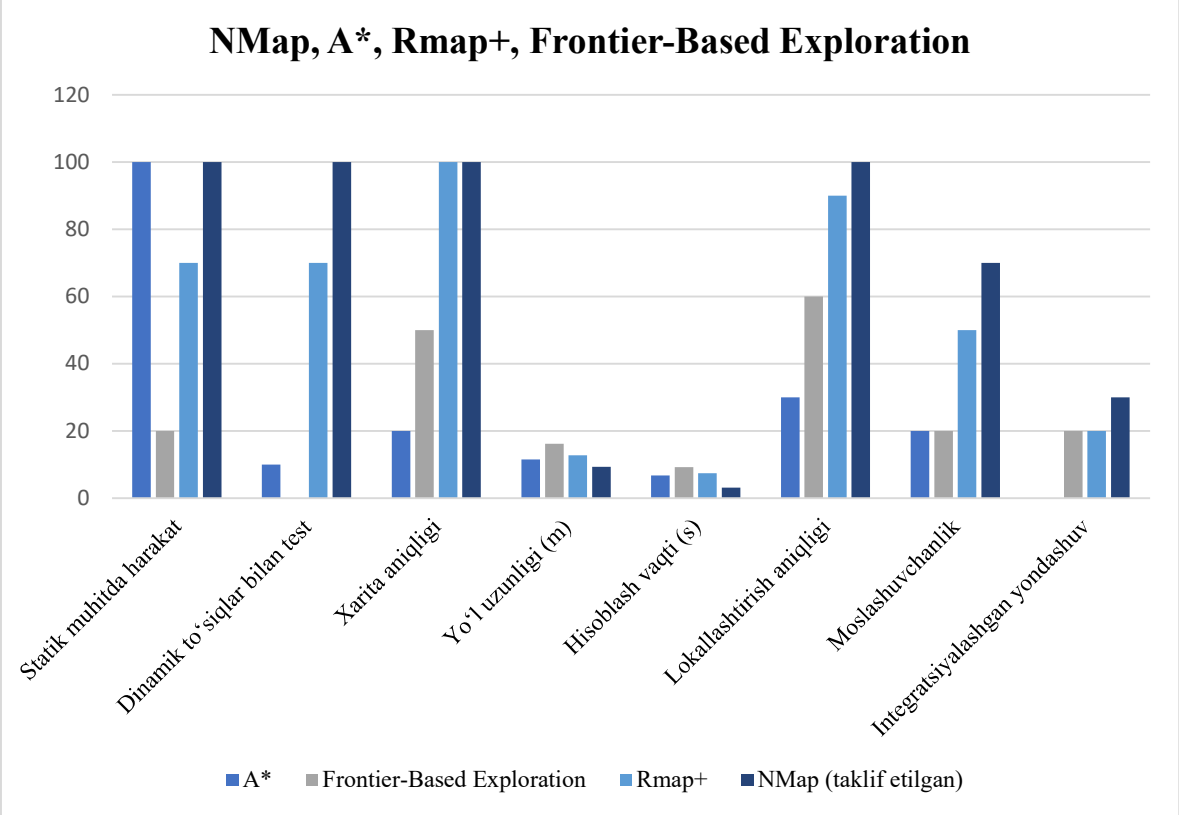
2-Jadval

NMap algoritimini A*, Frontier-Based Exploration, Rmap+ algoritmlarini turli ko‘rsatkichlar orqalisamaradorligi aks ettirilgan.

№	Ko‘rsatkichlar	A*	Frontier-Based Exploration	Rmap+	NMap (taklif etilgan)
1	**Statik muhitda harakat**	Juda samarali	Chegaralangan	Yaxshi	Juda samarali
2	**Dinamik to‘siqlar bilan test**	Zaif moslashadi	Moslashmaydi	Yaxshi	**Yuqori moslashuvchanlik**
3	**Xarita aniqligi**	Faqat mavjud xarita	Yangi hududlarni o‘rganadi	Yuqori	**Yuqori aniqlik**

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4	**Yo‘l uzunligi (m)**	1150 m	1620 m	1280 m	**930 m** (36–75% qisqaroq)
5	**Hisoblash vaqti (s)**	6.8 s	9.2 s	7.4 s	**3.1 s** (32–76% tezroq)
6	**Lokallashtirish aniqligi**	O‘rtacha (GPS kerak)	Past (muvofiqlashtirilmagan)	Yuqori	**Yuqori aniqlik** (AMCL bilan)
7	**Moslashuvchanlik**	Past	Past	Yaxshi	**Juda yuqori**
8	**Integratsiyalashgan yondashuv**	Yo‘q	Qisman	Qisman	**To‘liq integratsiyalangan**



1-rasm: NMap, A*, Rmap+, Frontier-Based Exploration algorimlarining turli ko‘rsatkichlar bo’yicha tahlili

NMap algoritmi yuqori samaradorlikka ega, hisoblash vaqtini sezilarli darajada qisqartiradi. Yuqori aniqlikda xaritalash va lokallashtirish, AMCL algoritmi yordamida robot harakati aniq nazorat qilinadi. Xaritalash, lokallashtirish va yo‘lni rejalashtirish alohida modullarda ishlaydi, bu esa moslashuvchanlikni ta’minlaydi. A* Algoritmi aniqlikni yuqori ta’minlaydi, ammo dinamik to‘siqlar bilan ishlashda kamchiliklarga ega. NMap bu holatlarni samarali hal qildi. Frontier-Based

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Exploration algoritmi yangi hududlarni o‘rganishda foydali, ammo cheklangan joylarda samaradorligi pasayadi. NMap bu nuqtada yanada moslashuvchan. Rmap+ algoritmi yuqori aniqlik, ammo hisoblash vaqti ko‘proq. NMap tezroq ishlaydi va samarali navigatsiyani ta’minlaydi.

Murakkab muhitlarda moslashuvchanlikni yaxshilash va energiya samaradorligini oshirish kerak. Ko‘p robotli tizimlar va adaptiv o‘rganish orqali NMap samaradorligini yanada oshirish mumkin. NMap algoritmi yuqori samaradorlikni ta’minlab, kelajakda yanada takomillashishi mumkin.

Xulosa

Ushbu maqolada avtonom mobil robotlar uchun xaritalash, lokallashtirish va yo‘lni rejalashtirishni birlashtiruvchi NMap (Navigation Map) algoritmi taklif etildi. Algoritm ROS asosida ishlab chiqilgan simulyatsiya muhitlarida, jumladan Gazebo, Rviz va TheConstruct.ai platformalarida sinovdan o‘tkazildi. Tadqiqot davomida NMap algoritmi ilg‘or A*, Frontier-Based Exploration va Rmap+ algoritmlari bilan taqqoslanib, uning samaradorligi baholandi.

Simulyatsiya natijalari shuni ko‘rsatdiki, NMap algoritmi robot harakatining samaradorligini sezilarli darajada oshiradi: masofa 36% dan 75% gacha qisqartirilib, vaqt sarfi 32% dan 76% gacha kamayadi. NMap algoritmi yuqori aniqlik, ishonchlilik va tezlikni ta’minlab, real vaqt rejimida samarali navigatsiyani amalga oshiradi.

NMap algoritmi avtonom mobil robotlar uchun zamonaviy va istiqbolli yechim bo‘lib, kelajakda uning samaradorligini yanada oshirish uchun qo‘shimcha takomillashtirishlar kiritish imkoniyati mavjud. Algoritmning modulli va integratsiyalangan tuzilishi uning kengaytirilishi va yangi texnologiyalar bilan integratsiya qilinishiga imkon yaratadi.

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