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Sensor data-based assessment of waste container conditions and automation of regional services

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Abstract: This paper develops an IoT-based smart waste management system for segregating household waste into wet, dry, and metallic categories, remotely monitoring container fill levels, and automatically notifying responsible personnel when a predefined threshold is exceeded. The proposed solution integrates an inductive metal sensor, moisture sensor, ultrasonic distance sensor, ESP32 microcontroller, server-side database, geospatial dashboard, and bot-based alert module. A sequential decision rule is introduced in which metallic objects are detected before moisture-based classification, while the fill level is estimated from the measured distance between the sensor and the waste surface. The software prototype supports regional registration and grouping of waste collection points, map-based visualization, device-status monitoring, and location-linked notifications. Functional verification confirmed the coordinated operation of the principal modules.

Keywords: Internet of Things, smart waste management, waste segregation, wet waste, dry waste, metal detection, fill-level monitoring, geospatial dashboard, bot notification

Chiqindi konteynerlari holatini sensor ma’lumotlari asosida baholash va hududiy xizmatni avtomatlashtirish

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Annotatsiya: Maqolada IoT sensorlari asosida maishiy chiqindilarni ho‘l, quruq va metall turlariga ajratish, konteynerlarning to‘lish darajasini masofadan kuzatish hamda to‘lish chegarasi oshganda mas’ul xodimga avtomatik xabar yuborishga mo‘ljallangan aqlli chiqindi boshqaruv tizimi ishlab chiqilgan. Taklif etilgan yechim induktiv metall sensori, namlik sensori, ultratovush masofa sensori, ESP32 mikrokontrolleri, server ma’lumotlar bazasi, geografik monitoring paneli va bot-xabarnoma modulini yagona arxitekturaga birlashtiradi. Chiqindini tasniflashda metallni birinchi tekshiruvchi ketma-ket qaror qoidasi, konteyner to‘lishini baholashda esa sensor va chiqindi yuzasi orasidagi masofaga asoslangan matematik model taklif etilgan. Dasturiy prototipda chiqindi yig‘ish nuqtalarini hududiy guruhlash, xaritada ko‘rsatish, qurilma holatini kuzatish va belgilangan to‘lish darajasida manzilga bog‘langan xabar yuborish funksiyalari amalga oshirilgan. Funksional sinovlar tizim modullarining o‘zaro bog‘langan holda ishlashini tasdiqladi.

Kalit so‘zlar: Internet buyumlari, aqlli chiqindi boshqaruvi, chiqindini saralash, ho‘l chiqindi, quruq chiqindi, metallni aniqlash, to‘lish darajasi, geografik monitoring, Telegram bot

1. Kirish

Shahar va qishloq hududlarida maishiy chiqindilarni o‘z vaqtida yig‘ish, saralash va olib chiqish ekologik xavfsizlik hamda sanitariya holatini ta’minlashning muhim shartlaridan biridir. An’anaviy boshqaruvda konteynerlar ko‘pincha belgilangan jadval asosida tekshiriladi. Bunday yondashuv konteyner hali to‘lmagan bo‘lsa ham transport yuborilishiga yoki aksincha, tez to‘lgan nuqtada xizmatning kechikishiga olib kelishi mumkin. Natijada ortiqcha yo‘l, yoqilg‘i va mehnat sarfi yuzaga keladi, to‘lib ketgan konteyner esa atrof-muhit va aholi salomatligi uchun salbiy omilga aylanadi.

O‘zbekistonda chiqindilar bilan ishlash sohasini raqamlashtirish, GPS monitoringi, yagona axborot tizimlari va onlayn murojaat xizmatlarini rivojlantirishga alohida e’tibor qaratilmoqda. O‘zbekistonda chiqindilarni boshqarish tizimini raqamlashtirish, maxsus transport vositalarini GPS orqali nazorat qilish, elektron billing va hududiy monitoring mexanizmlarini takomillashtirish davlat siyosatining ustuvor yo‘nalishlaridan biri sifatida belgilangan [1]. Bu jarayonlar joylardagi chiqindi konteynerlaridan olinadigan real vaqt ma’lumotlarini boshqaruv tizimlariga uzatadigan arzon va moslashuvchan IoT yechimlariga ehtiyojni oshiradi.

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Internet buyumlari texnologiyasi fizik obyekt holatini sensorlar orqali o‘lchash, ma’lumotni tarmoq orqali uzatish va dasturiy platformada avtomatik qaror qabul qilish imkonini beradi. Aqlli chiqindi tizimlarida ultratovush sensorlari konteynerning to‘lish darajasini, namlik sensori chiqindining ho‘l yoki quruqligini, induktiv sensor esa metall buyum mavjudligini aniqlashi mumkin. Mikrokontroller ushbu signallarni qayta ishlab, aktuatorlarni boshqaradi va serverga standartlashtirilgan ma’lumot paketini yuboradi.

Mazkur tadqiqotning maqsadi - chiqindilarni ho‘l, quruq va metall turlariga avtomatik ajratish, konteynerlarning to‘lish darajasini real vaqt rejimida baholash, chiqindi nuqtalarini hududiy xaritada kuzatish hamda belgilangan chegaraga yetganda bot orqali avtomatik xabarnoma yuboruvchi integratsiyalashgan tizimni ishlab chiqishdir. Tadqiqotning ilmiy-amaliy hissasi alohida sensor funksiyalarini emas, balki saralash, monitoring, geografik vizualizatsiya va manzilga bog‘langan ogohlantirishni yagona boshqaruv siklida birlashtirishdan iborat.

Adabiyotlar tahlili

Muallif **Michael Edwardsning “**Algoritmik Aqlli chiqindi boshqaruvi bo‘yicha tadqiqotlar asosan besh yo‘nalishda rivojlangan: konteyner to‘lishini masofadan kuzatish, kam quvvatli aloqa tarmoqlari, avtomatik ogohlantirish, chiqindini sensor yoki tasvir asosida tasniflash hamda yig‘ish marshrutini optimallashtirish. Cerchecci va hammualliflar ultratovush sensori hamda LoRa aloqa moduliga asoslangan kam quvvatli sensor tugunini taklif etib, uzoq muddatli avtonom ishlash uchun apparat va dasturiy energiya tejash usullarini tahlil qilgan [2]. Lozano va boshqalar LoRaWAN tugunlari, to‘lish hajmi, og‘irlik va harorat ma’lumotlarini yig‘ish hamda ularni transport marshrutini optimallashtirish bilan bog‘lagan [3].

Vishnu va hammualliflarning arxitekturasida jamoat joylari va xonadon konteynerlari uchun turli sensor tugunlari hamda markaziy monitoring paneli taklif qilingan [4]. Soh va hammualliflar konteyner to‘lganda avtomatik ogohlantirish yuboradigan sodda va amaliy tizimni ishlab chiqqan [5]. Ushbu ishlar real vaqt ma’lumoti chiqindi yig‘ish qarorlarini jadvaldan holatga asoslangan boshqaruvga o‘tkazishini ko‘rsatadi.

Chiqindini manbada saralash bo‘yicha Lingaraju va hammualliflar namlik va metall sensorlari orqali chiqindini ho‘l, quruq va metall kategoriyalariga ajratish, joylashuv va havo sifatini kuzatish imkoniyatini bir tizimda birlashtirgan [6]. Suvarnamma va Adi metall, plastik va shisha chiqindilarni saralash bilan birga hosil bo‘lgan chiqindi miqdorini serverda qayd etuvchi SmartBin tizimini taklif qilgan [7]. Bu tadqiqotlar qayta ishlanadigan material sifatini oshirish uchun saralash jarayonini chiqindi hosil bo‘lgan nuqtaning o‘zida boshlash zarurligini tasdiqlaydi.

Tasvirga asoslangan usullarda Wang va hammualliflar chuqur o‘rganish, bulutli hisoblash va IoT monitoringini birlashtirib, chiqindini bir nechta kategoriyaga ajratish konsepsiyasini ishlab chiqqan [8]. Rahman va boshqalar ham CNN modeli va IoT arxitekturasidan foydalanib, chiqindini real vaqt rejimida tasniflash imkoniyatini ko‘rsatgan [9]. Biroq kamera va chuqur o‘rganish modellariga yorug‘lik, fon, tasvir bazasi va hisoblash resurslari kuchli ta’sir qiladi. Shu sababli arzon prototipning birinchi bosqichida sensorli uch sinfli tasniflash, keyingi bosqichda esa kamera orqali quruq chiqindini qog‘oz, plastik, shisha kabi kichik sinflarga ajratish maqsadga muvofiq.

Tahlil shuni ko‘rsatadiki, ko‘plab xorijiy ishlarda saralash, to‘lish monitoringi, xarita, bot-xabarnoma va xizmat ko‘rsatish natijasini qayd etish alohida modullar sifatida ko‘rilgan. Mahalliy kommunal sharoit uchun esa bu funksiyalarni bitta operatsion platformada birlashtirish, internet uzilishlari, sensor ifloslanishi, texnik xizmat va operator uchun tushunarli interfeys masalalarini birgalikda hal qilish zarur.

2. Tadqiqot metodologiyasi

Dastlab an’anaviy chiqindi boshqaruv tizimlarida uchraydigan axborot uzatishdagi kechikishlar, chiqindilarni saralash mexanizmlarining yetarli emasligi hamda konteynerlarning to‘lish holatini tezkor aniqlash bilan bog‘liq muammolar kompleks ravishda o‘rganildi. Keyingi bosqichda tizimning apparat va dasturiy komponentlari funksional qatlamlarga ajratilib, sensorlardan keluvchi ma’lumotlarni yig‘ish, uzatish, qayta ishlash va ular asosida avtomatik qaror qabul qilish algoritmlari ishlab chiqildi. Yakuniy bosqichda yaratilgan prototipning asosiy funksiyalari oldindan belgilangan nazorat ssenariylari asosida sinovdan o‘tkazilib, uning ishlash barqarorligi, ma’lumotlarni uzatish izchilligi va avtomatik xabarnoma mexanizmining samaradorligi baholandi.

Tizim to‘rtta qatlamdan tashkil topadi: 1) sensor va aktuatorli aqlli konteyner qatlami; 2) ESP32 asosidagi mahalliy boshqaruv qatlami; 3) Wi-Fi, GSM yoki LoRa orqali ma’lumot uzatish qatlami; 4) server, ma’lumotlar bazasi, geografik panel va bot-xabarnomadan iborat amaliy qatlam. Modulli tuzilma laboratoriya sharoitida Wi-Fi, uzoq joylashgan nuqtalarda esa GSM yoki LoRa aloqa texnologiyasidan foydalanish imkonini beradi.

Har bir chiqindi nuqtasi tizimda noyob identifikator, nom, geografik koordinata, hududiy guruh, mas’ul xizmat va qurilma holati bilan ro‘yxatdan o‘tkaziladi. Sensor hodisasi serverga qurilma identifikatori, chiqindi sinfi, to‘lish foizi, vaqt belgisi va holat kodi ko‘rinishida uzatiladi. Bunday format turli qurilmalardan kelayotgan ma’lumotlarni bir xil tuzilishda saqlash va xaritada ko‘rsatish imkonini beradi.

- Chiqindi turini aniqlash ketma-ket qaror qoidasi asosida bajariladi. Avval induktiv sensor metall xususiyatiga ega obyektni tekshiradi. Metall aniqlansa, servo yoki yo‘naltiruvchi mexanizm obyektni metall konteyneriga yuboradi. Metall signal kuzatilmasa, namlik sensori o‘lchovi belgilangan τ chegarasi bilan solishtiriladi. Namlik qiymati chegaradan yuqori bo‘lsa obyekt ho‘l, aks holda quruq chiqindi sifatida tasniflanadi.

Metallni birinchi tekshirishning sababi shundaki, nam yoki elektr o‘tkazuvchan metall buyum namlik sensorida yuqori qiymat hosil qilib, ho‘l chiqindi sifatida noto‘g‘ri tasniflanishi mumkin. Ketma-ket algoritm ushbu xatoni kamaytiradi. Biroq τ universal qiymat emas; u sensor turi, kontakt maydoni, chiqindi harorati va muhit namligiga qarab tajriba orqali kalibrlanishi lozim.

Dasturiy platformada chiqindi yig‘ish nuqtalari hudud, shahar yoki tuman, xizmat ko‘rsatuvchi guruh va qurilma holati bo‘yicha guruhlanadi. Xarita interfeysi operatorga obyektning joylashuvi, so‘nggi ma’lumot vaqti, to‘lish darajasi va aniqlangan chiqindi turini ko‘rish imkonini beradi. Qurilma ma’lum vaqt davomida ma’lumot uzatmasa, u oflayn deb belgilanadi va texnik tekshiruv uchun alohida xabar shakllantiriladi.

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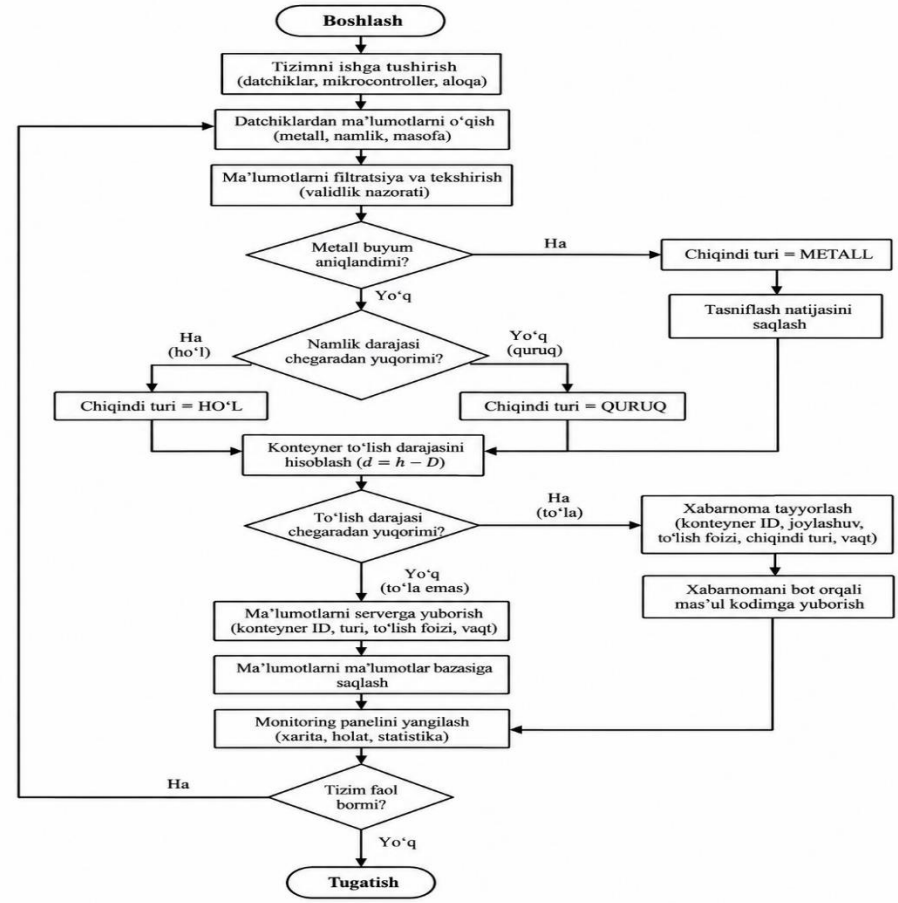

1-rasm. Chiqindilarni sensorli tasniflash va hududiy monitoring qilishning IoT asosidagi integratsiyalashgan algoritmi

Konteyner to‘lish chegarasiga yetganda server botga qurilma nomi, manzil, koordinata, to‘lish foizi, vaqt va tavsiya etilgan harakatni o‘z ichiga olgan xabar yuboradi. Xabar faqat 'konteyner to‘ldi' ma’lumotini emas, mas’ul xodimga obyektni xaritada ochish va xizmat bajarilganini tasdiqlash imkonini ham berishi kerak. Bunday qayta aloqa hodisa hayotiy siklini - aniqlash, xabar berish, qabul qilish, xizmat ko‘rsatish va yopish bosqichlarini raqamli qayd etadi.

Prototipda viloyat hududidagi chiqindi yig‘ish nuqtalarini yagona platformada ro‘yxatlash, ularni guruh va hudud bo‘yicha ko‘rsatish, to‘lish hodisasini bot orqali yuborish hamda obyekt holatini yangilash funksiyalari amalga oshirilgan. Bu yechim oddiy xaritadan farqli ravishda sensor ma’lumotini operatsion harakatga aylantiradi.

3. Natija va muhokamalar

Ishlab chiqilgan prototipning funksional tekshiruvi alohida modullar emas, balki to‘liq hodisa zanjiri bo‘yicha amalga oshirildi. Sinov ssenariylari chiqindi nuqtasini ro‘yxatdan o‘tkazish, xaritada ko‘rsatish, ho‘l, quruq va metall obyektlarni ajratish, to‘lish chegarasini aniqlash, bot orqali xabar yuborish va qurilma aloqasi uzilganda holatni yangilash jarayonlarini qamrab oldi.

Funksional sinovlar asosiy modullarning rejalashtirilgan ketma-ketlikda ishlashini ko‘rsatdi. Metall obyektlarda induktiv sensor asosiy qarorni berdi; metall bo‘lmagan obyektlar namlik qiymatiga ko‘ra ho‘l yoki quruq turga yo‘naltirildi. To‘lish darajasi belgilangan chegaradan oshganda serverda hodisa yaratilib, bot-xabarnoma shakllantirildi. Xarita interfeysida nuqtaning holati yangilandi.

Tadqiqotning ilmiy ahamiyati ko‘p sensorli tasniflash qoidasi bilan hududiy operatsion boshqaruv o‘rtasidagi bog‘lanishni formal ifodalashda namoyon bo‘ladi. Tasniflash natijasi faqat mexanik yo‘naltirish uchun emas, balki serverdagi statistik yozuv, konteyner holati va kelajakdagi qayta ishlash rejasini shakllantirish uchun ham ishlatiladi. To‘lish darajasiga ketma-ket o‘lchovlar medianasini qo‘llash notekis chiqindi yuzasidan kelib chiqadigan yolg‘on ogohlantirishlarni kamaytirishga xizmat qiladi.

Amaliy ahamiyat tizimning bosqichma-bosqich joriy etilishi bilan bog‘liq. Dastlab muammosi ko‘p va tez to‘ladigan nuqtalarga sensor o‘rnatish mumkin. Keyingi bosqichda butun hudud bo‘yicha sensor tugunlari, LoRa yoki GSM aloqa, xizmat bajarilganini tasdiqlash va dinamik marshrut moduli qo‘shiladi. Tizimning modulli tuzilishi mahalliy ishlab chiqariladigan korpus, arzon sensorlar va ochiq dasturiy vositalardan foydalanish imkonini beradi.

Taklif etilayotgan yechim farrosh yoki sanitar tozalash xodimini to‘liq almashtirishga emas, takroriy tekshiruvni avtomatlashtirishga qaratilgan. Xodimlar to‘lgan konteyner, nosoz sensor yoki xavfli holat haqida aniq manzilli ma’lumot oladi va vaqtini haqiqiy xizmat talab qiladigan obyektlarga yo‘naltiradi.

Namlik sensori chiqindining kimyoviy yoki biologik turini aniqlamaydi; u faqat namlik bilan bog‘liq fizik signal beradi. Nam karton, ho‘l metall yoki elektr o‘tkazuvchan

aralash materiallar xato tasniflanishi mumkin. Shu bois kalibrlash, sensor kontaktini standartlashtirish va shubhali holat uchun alohida kategoriya kiritish talab etiladi. Ultrasonik sensorning natijasiga konteyner shakli, chiqindi yuzasining burchagi, chang va namlik ta'sir qiladi.

Kelgusida kamera va yengil neyron tarmoq modeli orqali quruq chiqindini qog'oz, plastik, shisha va boshqa sinflarga ajratish, to'lish tarixiga asoslangan prognozlash, transport sig'imini hisobga oluvchi dinamik marshrut, harorat va tutun sensori orqali yong'in xavfini erta aniqlash rejalashtiriladi. Qimmatbaho metall yoki pirotexnik modda haqida funksiyalar 'aniq identifikatsiya' emas, 'shubhali obyekt yoki xavf belgisi bo'yicha erta ogohlantirish' sifatida ishlab chiqilishi kerak; yakuniy tasdiq maxsus asbob va mutaxassis tomonidan amalga oshiriladi.

4. Xulosa

Maqolada IoT sensorlari asosida chiqindilarni ho'l, quruq va metall turlariga ajratish, konteyner to'lish darajasini aniqlash, chiqindi nuqtalarini hududiy xaritada kuzatish va to'lish chegarasi oshganda mas'ul xodimga avtomatik bot-xabarnoma yuborishga mo'ljallangan integratsiyalashgan tizim ishlab chiqildi.

Tizimda metall obyektni birinchi aniqlash va undan so'ng namlikka ko'ra ho'l-quruq tasniflash qoidasi taklif etildi. Konteyner to'lish darajasi ultratovush sensori bilan o'lchangan masofaga asoslangan matematik model yordamida baholandi, yolg'on xabarlarni kamaytirish uchun ketma-ket o'lchovlar medianasidan foydalanish tavsiya qilindi. Sensor, ESP32, server, ma'lumotlar bazasi, geografik panel va bot modullari yagona axborot oqimiga birlashtirildi.

Dasturiy prototipda chiqindi yig'ish nuqtalarini ro'yxatlash va guruhlash, xaritada ko'rsatish, ho'l-quruq-metall holatini qayd etish, to'lish darajasida xabar yuborish va qurilma holatini monitoring qilish funksiyalari tekshirildi. Olingan natijalar tizimning amaliy ishlash imkoniyatini ko'rsatdi. Keyingi bosqichda real konteynerlarda uzoq muddatli dala sinovlari o'tkazilib, tasniflash aniqligi, o'lchash xatosi, aloqa barqarorligi va xizmat xarajatlaridagi o'zgarish miqdoriy baholanishi lozim.

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