TOSHKENT AXBOROT TEXNOLOGIYALARI UNIVERSITETI HUZURIDAGI ILMIY DARAJALAR BERUVCHI DSc.13/30.12.2019.T.07.01 RAQAMLI ILMIY KENGASH

MUHAMMAD AL-XORAZMIY NOMIDAGI TOSHKENT AXBOROT TEXNOLOGIYALARI UNIVERSITETI

ATOYEV SUHROB G‘AFUROVICH

UCHUVCHISIZ UCHISH APPARATI YORDAMIDA HARAKATDAGI OBYEKTLARNI ANIQLASH VA KUZATISH ALGORITMLARI VA DASTURIY MAJMUASI

05.01.04 – Hisoblash mashinalari, majmualari va kompyuter tarmoqlarining matematik va dasturiy ta’minoti

TEXNIKA FANLARI BO‘YICHA FALSAFA DOKTORI (PhD) DISSERTATSIYASI AVTOREFERATI

Toshkent – 2025

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Texnika fanlari bo‘yicha falsafa doktori (PhD) dissertatsiyasi avtoreferati mundarijasi

Contents of dissertation abstract of doctor of philosophy (PhD) on technical sciences

Оглавление автореферата диссертации доктора философии (PhD) по техническим наукам

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Toshkent – 2025

Texnika fanlari bo‘yicha falsafa doktori (PhD) dissertatsiyasi mavzusi O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasida B2023.4.PhD/T4170 raqam bilan ro‘yxatga olingan.

Dissertatsiya Muhammad al-Xorazmiy nomidagi Toshkent axborot texnologiyalari universitetida bajarilgan.

Dissertatsiya avtoreferati uch tilda (o‘zbek, ingliz, rus (резюме)) Ilmiy kengashning veb-sahifasida (www.tuit.uz) va “Ziyonet” Axborot ta’lim portalida (www.ziyonet.uz) joylashtirilgan.

Ilmiy rahbar:	**Nishanov Axram Xasanovich** texnika fanlari doktori, professor
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Dissertatsiya himoyasi Toshkent axborot texnologiyalari universiteti huzuridagi DSc.13/30.12.2019.T.07.01 raqamli Ilmiy kengashning 2025-yil “28” mart da soat 14:00 dagi majlisida bo‘lib o‘tadi. (Manzil: 100084, Toshkent shahri, Amir Temur ko‘chasi, 108-uy. Tel.: (99871) 238-64-43, e-mail: iktuit@tuit.uz).

Dissertatsiya bilan Muhammad al-Xorazmiy nomidagi Toshkent axborot texnologiyalari universitetining Axborot-resurs markazida tanishish mumkin (341 raqam bilan ro‘yxatga olingan). (Manzil: 100084, Toshkent shahri, Amir Temur ko‘chasi, 108-uy. Tel.: (99871) 238-64-70).

Dissertatsiya avtoreferati 2025-yil “14” mart kuni tarqatildi.
(2025-yil “14” mart dagi 20 raqamli reestr bayonnomasi).

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KIRISH (falsafa doktori (PhD) dissertatsiyasi annotatsiyasi)

Dissertatsiya mavzusining dolzarbligi va zarurati. Hozirgi kunda sohalardagi turli xil muammolarni chuqur oʻqitishga asoslangan modellar va algoritmlar asosida samarali hal qilish asosiy masalalardan biri boʻlib kelmoqda. Shular qatorida tasvirlar yoki tasvirlar ketma-ketligiga raqamli ishlov berishni ham keltirish mumkin. Tasvirlarga ishlov berish, tasvirlardan muhim obyektlarni aniqlash va ajratish, chuqur oʻqitish algoritmlari asosida avtomatik tanib olish usullarini rivojlantirishga alohida ahamiyat berilmoqda. Sun’iy intellekt texnologiyalari yordamida bunday masalalarni yechish bilan ham iqtisodiy, ham ijtimoiy samaradorlikni oshirish bugungi kunning dolzarb muammosi hisoblanadi.

Soʻnggi yillarda, tez rivojlanayotgan texnologiyalar bilan bir qatorda, uchuvchisiz uchish apparatlari (UUA) tobora ommalashib bormoqda. Bunga asosiy sabab qilib ushbu vositalarning ixchamligi va keng imkoniyatlarga egaligini keltirib oʻtish mumkin. Umuman olganda, UUAlari yordamida obyektlarni tanib olish va ularning harakatini kuzatib borish turli sohalar uchun qimmatli ma’lumotlarni taqdim etadi. Bunday apparatlar kuzatuv tizimlari, qidiruv-qutqaruv, harbiy, atrof-muhit monitoringi, infratuzilmani tekshirish, kinosanoati, qishloq xoʻjaligi va geodeziya kabi sohalarda samarali monitoring, tahlil va qarorlar qabul qilish imkonini beradi. UUAlarning imkoniyatlarini hamda tasvirlarda obyektlarni tanib olish va kuzatish algoritmlarini birlashtirish orqali koʻplab sohalarda, xavfsizlik va resurslarni boshqarish samaradorliklarini oshirish mumkin.

Respublikamizda sun’iy intellekt texnologiyalaridan keng foydalanish va ularni tasvirlardan obyektlarni aniqlash sohasiga joriy qilish, tasvirlardan obyektlarni aniqlovchi va sinflashtiruvchi dasturiy vositalarni rivojlantirish hamda soha boʻyicha olib borilayotgan ilmiy tadqiqot ishlarini qoʻllab quvvatlash davlat darajasida amalga oshirilmoqda. Xususan, Oʻzbekiston Respublikasi Prezidentining “Raqamli Oʻzbekiston – 2030 strategiyasini tasdiqlash va uni samarali amalga oshirish chora-tadbirlari toʻgʻrisida”gi farmonida, jumladan “… axborot texnologiyalari sohasidagi ustuvor yoʻnalishlar boʻyicha fundamental va amaliy tadqiqotlarni olib borish ... istiqbolli innovatsion ishlanmalar va startap loyihalarini amalga oshirish hamda ularni tijoratlashtirish va texnologiyalar transferini qoʻllab-quvvatlash ... raqamli texnologiyalar asosida ilmiy-tadqiqot ishlarini rivojlantirish va ragʻbatlantirish, ularni tashkiliy mexanizmlarini takomillashtirish ...”[1] kabi sohaga doir bir qancha vazifalar belgilangan. Ushbu vazifalarni amalga oshirish, jumladan, jahonda hamda yurtimizda ushbu sohalar boʻyicha olib borilayotgan ilgʻor va zamonaviy texnologiyalar asosida koʻplab ilmiy tadqiqot ishlarini tahlil qilish, ular asosida ishlab chiqarilayotgan aqlli tizimlarni oʻrganish zarur. Shuningdek, UUAlari yordamida obyektlarni tanib olish va ularning harakatini kuzatib borishning neyron tarmoqlariga asoslangan modelini ishlab chiqish muhim hisoblanadi.

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[1] Oʻzbekiston Respublikasi Prezidentining 2020-yil 5-oktyabrdagi PF-6079-son “Raqamli Oʻzbekiston – 2030 strategiyasini tasdiqlash va uni samarali amalga oshirish chora-tadbirlari toʻgʻrisida”gi farmoni

Oʻzbekiston Respublikasi Prezidentining 2021-yil 17-fevraldagi PQ-4996-son “Sun’iy intellekt texnologiyalarini jadal joriy etish uchun shart-sharoitlar yaratish chora-tadbirlari toʻgʻrisida”gi, 2024-yil 14-oktabrdagi PQ-358-son “Sun’iy intellekt texnologiyalarini 2030-yilga qadar rivojlantirish strategiyasini tasdiqlash toʻgʻrisida”gi qarorlari, Oʻzbekiston Respublikasi Vazirlar Mahkamasining 2022-yil 15-noyabrdagi 658-sonli “Oʻzbekiston Respublikasida uchuvchisiz uchadigan apparatlardan foydalanishni tartibga solish boʻyicha qoʻshimcha chora-tadbirlar toʻgʻrisida”gi qarori hamda mazkur faoliyatga tegishli boshqa me’yoriy-huquqiy hujjatlarda belgilangan vazifalarni amalga oshirishda ushbu ilmiy-tadqiqot ishida olingan natijalar muayyan darajada xizmat qiladi.

Tadqiqotning respublika fan va texnologiyalari rivojlanishining ustuvor yoʻnalishlariga mosligi. Mazkur tadqiqot respublika fan va texnologiyalar rivojlanishining IV. “Axborotlashtirish va axborot-kommunikatsiya texnologiyalarini rivojlantirish” ustuvor yoʻnalishi doirasida bajarilgan.

Muammoning oʻrganilganlik darajasi. Tasvirlarga raqamli ishlov berish algoritmlarini ishlab chiqish, tasvirlardagi obyektlarni aniqlash va sinflashtirish usullari va algoritmlari boʻyicha J. Redmon, Yu.I. Juravlev, R. Golsales, S. Divvala, J. Xing, A. Farhadi, J. Cao A. Fawzi, Liang M., Z. Wang H., Ciresan Dan, K.R. Kwon, D.H. Wu, G. Park kabi xorijiy olimlarining ilmiy ishlari tadqiq etilgan.

Shuningdek, mamlakatimizda tasvirlarga ishlov berish va timsollarni tanib olishning nazariy asoslarini rivojlantirishga M.M. Komilov, Sh.X. Fozilov, A.X. Nishanov, X.N. Zaynidinov, N.S. Mamatov, M.X. Xudayberdiyev va boshqalar oʻzlarining katta hissalarini qoʻshganlar.

Hozirgi kunda tasvirlarga ishlov berish, ulardan muhim obyektlarni tanib olish va tahlil qilish uchun avtomatlashtirilgan aqlli tizimlar yaratishning mavjud usul va algoritmlarini takomillashtirish, boʻyicha qator ilmiy tadqiqot ishlari olib borilmoqda. Biroq, ushbu sohada dron texnologiyasi yordamida harakatdagi obyektlarni aniqlash va kuzatish masalalari hozirgi kungacha qoniqarli darajada yechilmagan.

Dissertatsiya tadqiqotining dissertatsiya bajarilgan oliy ta’lim muassasasining ilmiy-tadqiqot ishlari rejalari bilan bogʻliqligi. Dissertatsiya tadqiqoti Muhammad al-Xorazmiy nomidagi Toshkent axborot texnologiyalari universiteti ilmiy-tadqiqot ishlari rejasining 20/1-1278 – “Ichki ishlar vazirligiga tegishli hudud, bino va inshootlarni texnik vositalar yordamida qoʻriqlash” (2021-2023) loyihasi doirasida bajarilgan.

Tadqiqotning maqsadi. Uchuvchisiz uchish apparati yordamida harakatdagi obyektlarni aniqlash va kuzatishning neyron tarmoq modeliga asoslangan gibrid algoritmi hamda dasturiy majmuasini ishlab chiqishdan iborat.

Tadqiqotning vazifalari:

ma’lumotlarni sun’iy koʻpaytirish usullari orqali ma’lumotlar toʻplamini shakllantirish;

qoldiq blokini ishlab chiqish orqali obyektlarni aniqlashning YOLO neyron tarmoq modelini takomillashtirish;

neyron tarmoqlarida yashirin qatlamlar soni oshgani sari yuzaga keladigan o‘qitish xatoligini bartaraf etish usulini ishlab chiqish;

uchuvchisiz uchish apparati yordamida harakatdagi obyektlarni aniqlash va kuzatish uchun takomillashtirilgan YOLO modeli hamda Kalman filtriga asoslangan gibrid algoritmni ishlab chiqish;

taklif qilingan gibrid algoritm asosida obyektni aniqlash va kuzatish dasturiy majmuasini ishlab chiqish.

Tadqiqotning obyekti sifatida harakatdagi obyektlarni aniqlash va kuzatish jarayoni qaralgan.

Tadqiqotning predmetini harakatdagi obyektlarni aniqlash va kuzatish usullari, algoritmlari va dasturiy majmuasi tashkil etadi.

Tadqiqotning usullari. Dissertatsiya ishi tadqiqotlari doirasida tasvirlarga dastlabki ishlov berish usullaridan, ma’lumotlar to‘plamini shakllantirishda ma’lumotlarni sun’iy ko‘paytirish usullaridan, tasvirlar ketma-ketligidan harakatdagi obyektlarni aniqlash va kuzatishda chuqur o‘qitish algoritmlariga asoslangan neyron tarmoq modellaridan foydalanilgan.

Tadqiqotning ilmiy yangiligi quyidagilardan iborat:

qoldiq blokini ishlab chiqish orqali obyektlarni aniqlashning neyron tarmoqlariga asoslangan YOLO modeli takomillashtirilgan;

gradient oqimini kuchaytirish hamda to‘yinganlik effektlarini kamaytirish orqali neyron tarmoqlarida yashirin qatlamlar soni oshgani sari yuzaga keladigan o‘qitish xatoligini bartaraf etish usuli ishlab chiqilgan;

uchuvchisiz uchish apparati yordamida harakatdagi obyektlarni aniqlash va kuzatish uchun takomillashtirilgan YOLO modeli hamda Kalman filtriga asoslangan gibrid algoritm ishlab chiqilgan;

ishlab chiqilgan model va gibrid algoritm asosida harakatdagi obyektlarni aniqlash va kuzatish uchun kross-platformali desktop ilovasining modullari va funksional strukturasi ishlab chiqilgan.

Tadqiqotning amaliy natijalari quyidagilardan iborat:

harakatlanuvchi obyektlarning 6 ta sinfiga tegishli 12000 ta tasvirdan tashkil topgan ma’lumotlar to‘plami yaratilgan.

UUA yordamida harakatlanuvchi obyektlarni aniqlash va kuzatishning chuqur o‘qitishga asoslangan gibrid algoritmni ishlab chiqildi.

UUA yordamida harakatlanuvchi obyektlarni aniqlash va kuzatishni amalga oshiruvchi dasturiy majmuaning funksional strukturasi hamda dasturlararo muloqot interfeysi ishlab chiqildi.

Tadqiqot natijalarining ishonchliligi. Tasvirlar ketma-ketligidan harakatdagi obyektlarni aniqlash va kuzatishning neyron tarmoq modeli ishlab chiqilganligi, dissertatsiyada taklif qilingan model, algoritm va dasturiy vositalarning bosma nashrlar va xalqaro ilmiy konferensiyalar ma’ruzalaridagi aprobatsiyasi, tajribaviy tadqiqotlar va yaratilgan dasturiy vositalarning amaliyotga tadbiq etilganligini asoslovchi guvohnomalar hamda tadqiqot natijalarining joriy etilganlik dalolatnomalari bilan tadqiqot natijalarining ishonchliligi asoslanadi.

Tadqiqot natijalarining ilmiy va amaliy ahamiyati. Tadqiqot natijalarining ilmiy ahamiyati tasvirlar ketma-ketligidan harakatdagi obyektlarni aniqlash va sinflashtirishning neyron tarmoq modeli, chuqur oʻqitish algoritmlari uchun harakatlanuvchi obyektlar maʼlumotlar toʻplami, maʼlumotlar toʻplamini sunʼiy koʻpaytirish usullarining dinamik tasvirlardan muhim obyektlarni aniqlashga yoʻnaltirilgan tadqiqotlarning istiqbolli rivojlanishiga qoʻshadigan hissasi bilan izohlanadi.

Tadqiqot natijalarining amaliy ahamiyati tadqiqot doirasida ishlab chiqilgan dasturiy majmua uchuvchisiz uchish apparati yoki qoʻriqlanadigan hududlarda oʻrnatilgan video kuzatuv apparatlari yordamida harakatdagi turli xil obyektlarni tanib olish va ularni kuzatish ishlarida qoʻllanilishi bilan izohlanadi.

Tadqiqot natijalarining joriy qilinishi. Tadqiqot doirasida ishlab chiqilgan model va gibrid algoritm asosida yaratilgan “ODDA 1.1” harakatdagi obyektlarni aniqlash va kuzatishning kross-platformali desktop ilovasi asosida:

ilmiy tadqiqot doirasida ishlab chiqilgan harakatdagi obyektlarni aniqlash va kuzatish dasturiy majmuasini Navoiy viloyati IIB Ekspert-kriminalistika markaziga tatbiq etilishi natijasida, viloyatda jinoyatchilarni aniqlash va qidirishga ketadigan vaqt oʻrtacha 16 foizga qisqardi (Oʻzbekiston Respublikasi Raqamli texnologiyalar vazirligining 2024-yil 27-maydagi 33-8/3472-sonli maʼlumotnomasi). Harakatlanuvchi obyektlarni aniqlash va ularni maʼlum bir joyga kuzatib borishning aniqlik darajasi 90-93% ni tashkil qildi;

tadqiqot ishi doirasida taklif etilgan model va algoritmlar asosida olingan ilmiy-amaliy natijalar Ichki ishlar vazirligi Qorovul qoʻshinlari qoʻmondonligi Texnik qoʻriqlash vositalarini joriy etish boʻlimiga joriy etildi (Oʻzbekiston Respublikasi Raqamli texnologiyalar vazirligining 2024-yil 27-maydagi 33-8/3472-sonli maʼlumotnomasi). Tadqiqot doirasida ishlab chiqilgan dasturiy vosita uchuvchisiz uchish apparati yoki qoʻriqlanadigan hududlarda oʻrnatilgan video kuzatuv apparatlari yordamida harakatdagi turli xil obyektlarni tanib olish va ularni kuzatish ishlarida qoʻllanilmoqda. Harakatdagi obyektlarni tanib olish va ularni kuzatib borish ishlarining aniqlik darajalari 89-92%ni tashkil etmoqda. Bu kuzatilgan obyekt maʼlumotlarini tahlil qilish uchun ketadigan vaqtni oʻrtacha 9%ga qisqartirish imkonini berdi;

dissertatsiya doirasida taklif etilgan model va gibrid algoritm asosida yaratilgan dasturiy majmuasi “IT WEBMIN” masʼuliyati cheklangan jamiyati tomonidan foydalanish uchun qabul qilingan (Oʻzbekiston Respublikasi Raqamli texnologiyalar vazirligining 2024-yil 27-maydagi 33-8/3472-sonli maʼlumotnomasi). Dasturiy majmua koʻcha va binolarda oʻrnatilgan video kuzatuv apparatlari yordamida harakatdagi turli xil obyektlarni tanib olish va ularni kuzatish vazifalarini bajarmoqda. Ishlab chiqilgan dasturiy vosita harakatdagi obyektlarni 90-95% aniqlikda tanib olishni amalga oshirmoqda. Bu kuzatilgan obyekt maʼlumotlarini tahlil qilish uchun ketadigan vaqtni oʻrtacha 10%ga qisqartirish imkonini bergan.

Tadqiqot natijalarining aprobatsiyasi. Tadqiqot natijalari 12 ta, jumladan, 8 ta xalqaro va 4 ta Respublika ilmiy-amaliy anjumanlarida muhokamadan o‘tkazilgan.

Tadqiqot natijalarining e’lon qilinganligi. Tadqiqot mavzusi bo‘yicha jami 26 ta ilmiy ishlar chop etilgan bo‘lib, shulardan 7 ta maqola O‘zbekiston Respublikasi Oliy attestatsiya komissiyasining dissertatsiyalarning asosiy ilmiy natijalarini chop etish uchun tavsiya etilgan ilmiy nashrlarda, shu jumladan, 4 ta xorijiy, 3 ta respublika miqyosidagi ilmiy jurnallarda chop etilgan hamda 4 ta EHM uchun yaratilgan dasturiy vositalarini qayd qilish guvohnomalari olingan.

Dissertatsiyaning tuzilishi va hajmi. Dissertatsiya kirish, to‘rtta bob, xulosa, foydalanilgan adabiyotlar ro‘yxati va ilovalardan iborat. Dissertatsiyaning umumiy hajmi 108 betni tashkil etadi.

DISSERTATSIYANING ASOSIY MAZMUNI

Kirish qismida dissertatsiya mavzusining dolzarbligi va zarurati asoslab berilgan, tadqiqot maqsadi va vazifalari belgilab olingan, tadqiqotning obyekti va predmeti aniqlangan. O‘zbekiston Respublikasi fan va texnologiyalari taraqqiyotining ustuvor yo‘nalishiga mosligi ko‘rsatilgan, olingan natijalarning ishonchliligi asoslab berilgan, tadqiqot natijalarining nazariy va amaliy ahamiyati ochib berilgan, tadqiqot natijalarining amaliyotga joriy qilinish holati, chop etilgan ishlar va dissertatsiya tuzilishi to‘g‘risidagi ma’lumotlar keltirilgan.

Dissertatsiyaning “UUA yordamida obyektni tanib olish va kuzatish tushunchasi” deb nomlangan birinchi bobi 4 ta paragrafdan iborat bo‘lib, unda UUAlari haqida umumiy tushunchalar va ularning qo‘llanish sohalari, obyektni tanib olishning chuqur o‘qitishga asoslangan usul va algoritmlari tahlili, harakatlanuvchi obyektlarni aniqlash va kuzatish tizimlarining qo‘llanish sohalari hamda tadqiqot masalasining qo‘yilishi keltirib o‘tilgan. Harakatlanuvchi obyektlarni aniqlash va kuzatish bo‘yicha chuqur o‘qitishga asoslangan yondashuvlar bo‘yicha xorijiy davlatlar va Respublikamizda olib borilayotgan ilmiy va amaliy tadqiqot ishlari atroflicha tahlil qilingan va ushbu tahlillar natijasida obyektlarni tanib olish uchun yechiladigan masalalar ketma-ketligi tanlab olingan.

Ushbu bobning 1.2-paragrafida obyektlarni tanib olishning chuqur o‘qitishga asoslangan yondashuvlari tahlil qilingan. Chuqur o‘qitishga asoslangan CNN (Convolutsion Neural Network) R-FCN (Region-based Fully Convolutional Networks), Fast R-CNN, Faster R-CNN, SSD (Single Shot MultiBox Detector) va YOLO (You Only Look Once) kabi neyron tarmoq arxitekturalari so‘nggi yillarda yuqori natijalarni ko‘rsatmoqda.

Ikkinchi bobda obyektni aniqlash va kuzatish jarayoni tasvirlangan, obyektni aniqlash va kuzatishning bir nechta modellari va algoritmlari ko‘rib chiqiladi. Obyektni aniqlash muammosini hal qilishda asosiy rol o‘ynaydigan tasvirni oldindan qayta ishlashning bir qator yondashuvlari va usullari o‘rganildi. Ular asosida obyektni aniqlash samaradorligini oshirish uchun sun’iy ko‘paytirish usullari yordamida tasvirlar soni oshirildi.

Tasvir o‘lchamini o‘zgartirish rasmning nisbatlarini saqlab qolgan holda uning hajmini o‘zgartirishni o‘z ichiga oladi. Faraz qilaylik, $I(x, y)$asl tasvir M x N o‘lchamiga ega va biz uning o‘lchamini yangi P x Q o‘lchamiga o‘zgartirmoqchimiz. O‘lchamini o‘zgartirish uchun matematik tenglamani quyidagicha yozish mumkin:

$$R_{\mathrm{I}} = Res(I(x, y), P, Q)$$

bunda R_{I} - o‘lchami o‘zgartirilgan tasvir, $Res()$ - asl tasvirni kerakli P x Q o‘lchamga o‘zgartiruvchi funksiya.

Tasvirdan shovqinni olib tashlash texnikasi tasvirdagi shovqinni kamaytirishga qaratilgan. Shovqinni olib tashlashning keng tarqalgan usullaridan biri Gauss filtrlash bo‘lib, u tasvirga Gauss yadrosini qo‘llaydi. Gauss filtrlash tenglamasi:

$$F_{\mathrm{I}} = Convolve(I(x, y), GaussianKernel)$$

bunda F_{I} filtrlangan tasvir, $Convolve()$ tasvir va Gauss yadrosi o‘rtasidagi konvolyutsiya operatsiyasini ifodalaydi.

Rasmni normallashtirish texnikasi tasvirning piksel qiymatlarini standartlashtirishga qaratilgan. Keng tarqalgan usullardan biri piksel qiymatlarini kerakli diapazonga o‘lchaydigan min-max normallashtirishdir. Min-max normalizatsiya tenglamasi quyidagicha:

$$N_{\mathrm{I}} = (I(x, y) - min(I(x, y)))\ /\ (max(I(x, y)) - min(I(x, y)))$$

bu yerda N_{I} normalangan tasvir, $min(I(x, y))$ va $max(I(x, y))$ mos ravishda tasvirdagi minimal va maksimal piksel qiymatlarini ifodalaydi.

Tasvirni aylantirish jarayoni transformatsiya matritsalari yordamida aniqlanishi mumkin. Aylanish uchun 2D aylanish matritsasi ishlatiladi. Tasvirni θ burchakka aylantirish uchun aylanish tenglamasini quyidagicha yozish mumkin:

$$R_{\mathrm{I}} = Rot(I(x, y), \theta)$$

bunda R_{I} - aylantirilgan tasvir.

Ushbu tadqiqotda tasvir ketma-ketligida obyektni tanib olish uchun YOLO modelidan foydalanildi. YOLO modelidagi birinchi konseptsiya qoldiq bloklardir. Arxitekturada ular ma’lum bir tasvirda panjara yaratish uchun 7 × 7 qoldiq bloklardan foydalanilgan. Ushbu panjaralarning har biri markaziy nuqtalar vazifasini bajaradi va bu panjaralarning har biri uchun ma’lum bir bashorat mos ravishda amalga oshiriladi. Panjara katakchasidagi har bir chegaraviy ramka uchun sigmoid funksiya yordamida taxmin qilingan chegara koordinatalari (x, y, w, h) hisoblanadi:

$$b_x = \sigma(t_x) + c_x,$$

$$b_y = \sigma(t_y) + c_y,$$

$$b_w = p_w\, e^{t_w},$$

$$b_h = p_h\, e^{t_h}$$

bunda b_x, b_y - bashorat qilingan markaz koordinatalari; b_w, b_h - bashorat qilingan kenglik va balandlik; t_x, t_y, t_w, t_h - tarmoq prognozlari va c_x, c_y, p_w, p_h - chegaraviy ramkaning parametrlari.

Panjara katakchasidagi har bir chegaraviy ramka obyektni o‘z ichiga olish ehtimolini ko‘rsatadigan ishonch darajasini bashorat qiladi. Ishonch darajasi sigmoid funksiya yordamida hisoblanadi:

$$Conf = \sigma(t_{conf})$$

Har bir katakcha softmax funksiyasidan foydalangan holda P_C sinf ehtimolini bashorat qiladi:

$$P_C = softmax(t_C)$$

bunda t_C - ishonch uchun tarmoq prognozi.

YOLO modelining yakuniy natijasi har bir katakcha uchun taxmin qilingan chegara koordinatalarini, ishonch darajalarini va sinf ehtimolini o‘z ichiga olgan shakl tenzoridir $(S, S, (B5 + P_C))$. Turli baholash ko‘rsatkichlarining asosiy mexanikasi har xil bo‘lishi mumkinligi sababli, ushbu ko‘rsatkichlarning har biri nimani anglatishini va ular qanday ma’lumotlarni yetkazishga harakat qilayotganini tushunish taqqoslash uchun juda muhimdir. Ushbu ko‘rsatkichlarga misollar: aniqlik, eslab qolish, o‘rtacha aniqlik (mAP), birlashma ustidagi kesishma (IoU) va markaz joylashuv xatoligi (CLE).

Taklif etilgan obyektni aniqlash usulini baholash uchun biz aniqlik ko‘rsatkichidan foydalanamiz, u barcha aniqlanishlar orasida haqiqiy ijobiylarning nisbatini o‘lchaydi:

$$\text{Precision} = \frac{TP}{TP + FP}$$

bunda TP - to‘g‘ri pozitiv (aniqlangan obyektlar), FP - noto‘g‘ri pozitiv (noto‘g‘ri aniqlangan obyektlar).

Qayta tiklash ko‘rsatkichi barcha haqiqiy obyektlardan aniqlangan haqiqiy ijobiylarning nisbatini o‘lchaydi:

$$\text{Recall} = \frac{TP}{TP + FN}$$

bunda FN - noto‘g‘ri negativlar (o‘tkazib yuborilgan obyektlar).

O‘rtacha aniqlik (AP) obyektni aniqlash algoritmlarini baholash uchun keng qo‘llaniladigan ko‘rsatkichdir. AP ko‘pincha aniqlik egri chiziqlari va egri chiziq ostidagi maydon yordamida hisoblanadi. O‘rtacha AP (mAP) bir nechta obyekt sinflari uchun hisoblangan AP qiymatlarining o‘rtachasidir:

$$\text{mAP} = \frac{1}{n}\sum_{k=1}^{k=n} AP_k$$

bu yerda AP_k - k sinfining o‘rtacha aniqligi, n - sinflar soni.

Mazkur tadqiqot ishida obyektni kuzatish tizimini baholash uchun CLE ko‘rsatkichidan foydalanildi. CLE obyektning taxminiy markazi va har bir tasvir ramkasidagi haqiqiy markazi o‘rtasidagi Evklid masofasi sifatida aniqlanadi:

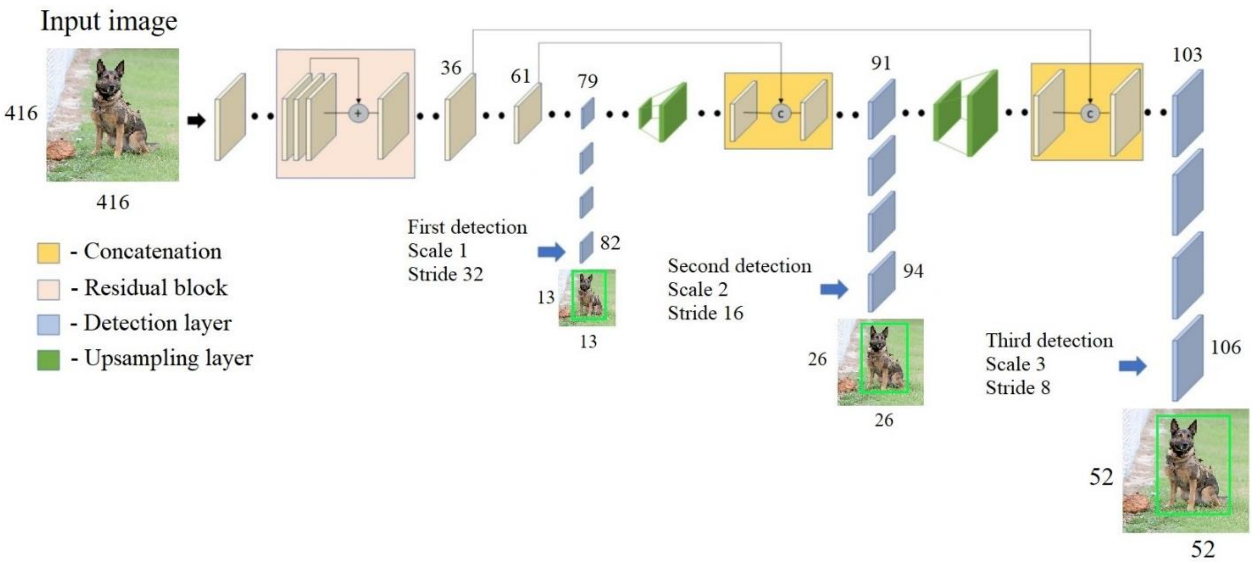
$$CLE = \left\| O_k^E - O_k^{GT} \right\|$$

bu yerda O_k^E va O_k^{GT} obyektning taxminiy va haqiqiy markazlari.

Uchinchi bobda harakatlanuvchi obyektlarni aniqlash va kuzatishning gibrid algoritmi hamda dasturiy majmuasi ishlab chiqilgan. Ushbu bobda quyidagilar keltirilgan:

1. Tasvir yoki tasvir ketma-ketligidagi bir nechta obyektlarni aniqlay oladigan va ularning chegaraviy ramka koordinatalarini sinf ehtimollari bilan ta’minlaydigan neyron tarmoqlariga asoslangan obyektni aniqlashning takomillashtirilgan YOLO modeli taklif etildi. Ushbu tadqiqot ishida YOLO neyron tarmoq modelining 3-versiyasi oddiy blok o‘rniga qoldiq blokdan foydalangan holda takomillashtirildi. Bundan tashqari, Mish faollashtirish funksiyasi obyektni aniqlash tarmog‘ining aniqligini oshirish uchun ishlatildi.

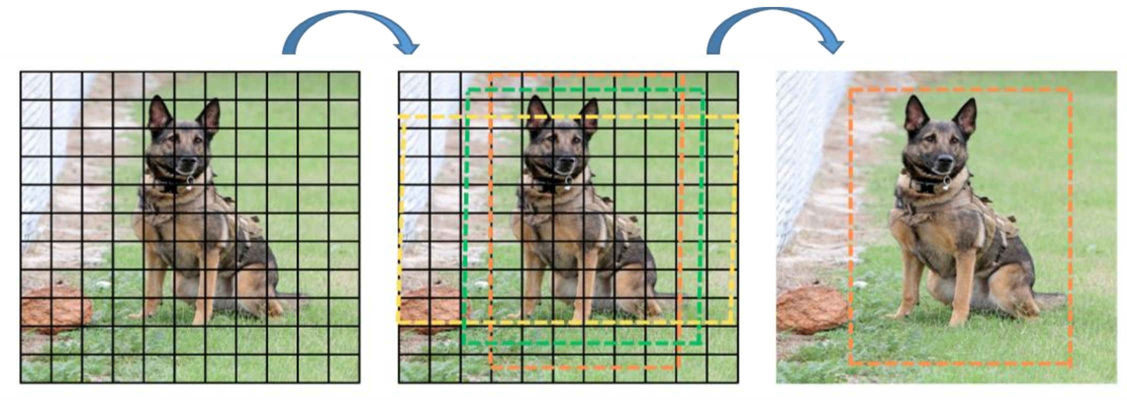
2. Takomillashtirilgan YOLO va Kalman filtriga asoslangan harakatdagi obyektni aniqlash va kuzatishning gibrid algoritmi taqdim etildi. U tasvir ketma-ketligidagi bir nechta obyektlarni aniqlash va kuzatish imkonini beradi. Obyektni kuzatish usuli uchta moduldan iborat: ketma-ketlikning birinchi freymidagi obyektni tanlash moduli, obyektni aniqlash moduli va Kalman filtr moduli.



1-rasm. Takomillashtirilgan YOLO modelining arxitekturasi

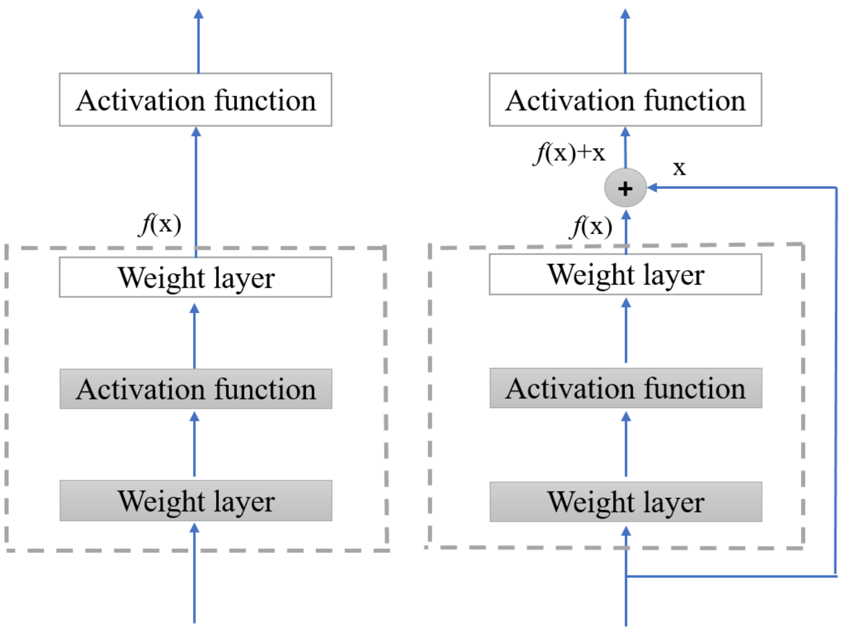
1-rasmda ko‘rsatilganidek, aniqlash moduli 53 qatlamdan iborat bo‘lib, natijalarni to‘liq konvolyutsion 106 chuqur tarmoq qatlamiga birlashtirgan. Takomillashtirilgan YOLO modeli o‘zining asosi sifatida chuqur CNNdan foydalanadi. Magistral tarmoq obyektni aniqlash uchun zarur bo‘lgan past darajali va yuqori darajali xususiyatlarni suratga olgan holda kirish tasviridan boy xususiyatlarni taqdim etadi.

2-rasmda keltirilganidek, obyektni aniqlash jarayoni tasvirni S × S panjarasiga bo‘lishdan boshlanadi (uch xil shkalada S 13, 26 va 52 ga teng). Har bir katakcha chegaralovchi ramkalarni va ular bilan bog'liq sinf ehtimolini bashorat qilish uchun javobgardir. Har bir katakcha ichida takomillashtirilgan YOLO modeli turli o'lcham va shakldagi obyektlarni aniqlash uchun turli o'lchamdagi va tomonlar nisbatidagi chegaralovchi ramkalardan foydalanadi.



2-rasm. YOLO modeli yordamida obyektni aniqlash jarayoni. A: S×S panjarani generatsiyalash, B: chegaraviy ramkalarni yaratish, C: chegaralovchi ramkani bashorat qilish

Takomillashtirilgan YOLO modeli turli masshtablarda bir nechta bashorat qilish qatlamlariga ega. Har bir bashorat qatlami turli o'lchamdagi obyektlarni aniqlash uchun javobgardir. Bashorat qatlamlari o'zlarining tegishli shkalalarida chegaralangan ramkalar, sinf ehtimollari va ishonch ballari uchun bashorat qiladi.



3-rasm. Oddiy konvolyutsion blok va qoldiq blok

Odatda, chuqur neyron tarmoqlarni o'qitish qiyin jarayon hisoblanadi. Chuqurlik oshgani sayin, ba'zida tarmoq aniqligi to'yingan bo'ladi, bu esa yuqori o'qitish xatoligi yuzaga kelishiga sabab bo'ladi. Ushbu muammoni hal qilish uchun qoldiq bloki joriy etildi. Oddiy konvolyutsion bloki va qoldiq blok o‘rtasidagi asosiy farq 3-rasmda ko‘rsatilganidek, yashirin ulanishning qo‘shilishi hisoblanadi. Yashirin ulanish kirishni chuqurroq qatlamlarga yetib borishi ta’minlab beradi. Qolaversa, tarmoq aniqligini maksimal darajada oshirish maqsadida Mish faollashtirish funksiyasidan foydalanildi:

$$f(x) = x \tanh(\ln(1 + e^x))$$

Oxirgi bosqichda YOLO modeli har bir chegaralovchi ramka uchun sinf ehtimolini bashorat qiladi. Model oldindan belgilangan obyekt sinflari to‘plamiga sinf ehtimolini belgilaydi. Sinf ehtimolliklari modelning ma’lum bir sinf obyekti chegaralangan ramka ichida mavjudligiga ishonchini ifodalaydi.

Quyidagi tenglamalardan foydalanib, takomillashtirilgan YOLO modelida gradient oqimini oshirishga va to‘yinganlik effektlarini kamaytirishga erishildi. Bu o‘z navbatida, neyron tarmoqlarida yashirin qatlamlar soni oshgani sari yuzaga keladigan o‘qitish xatoligini bartaraf etishga xizmat qiladi.

Og‘irlikni initsializatsiyalashdan foydalanishdan maqsad, har bir qatlam chiqishidagi farqni kirishlar farqi bilan taxminan bir xil saqlashdir, bu esa gradientlarning yo‘qolishining oldini olishga yordam beradi.

$$W \sim N(0, \sqrt{\frac{2}{n_{in}}})$$

bunda W – og‘irliklar, N - normal taqsimlanish, n_{in} - qatlamdagi kirish neyronlar soni.

Tarmoqni normallashtirish o‘qitish jarayonini barqarorlashtiradi va to‘yinganlikning oldini olishga yordam beradi va bu jarayon quyidagi tenglama orqali amalga oshiriladi:

$$\hat{x} = \frac{x - \mu}{\sqrt{\sigma^2 + \epsilon}}$$

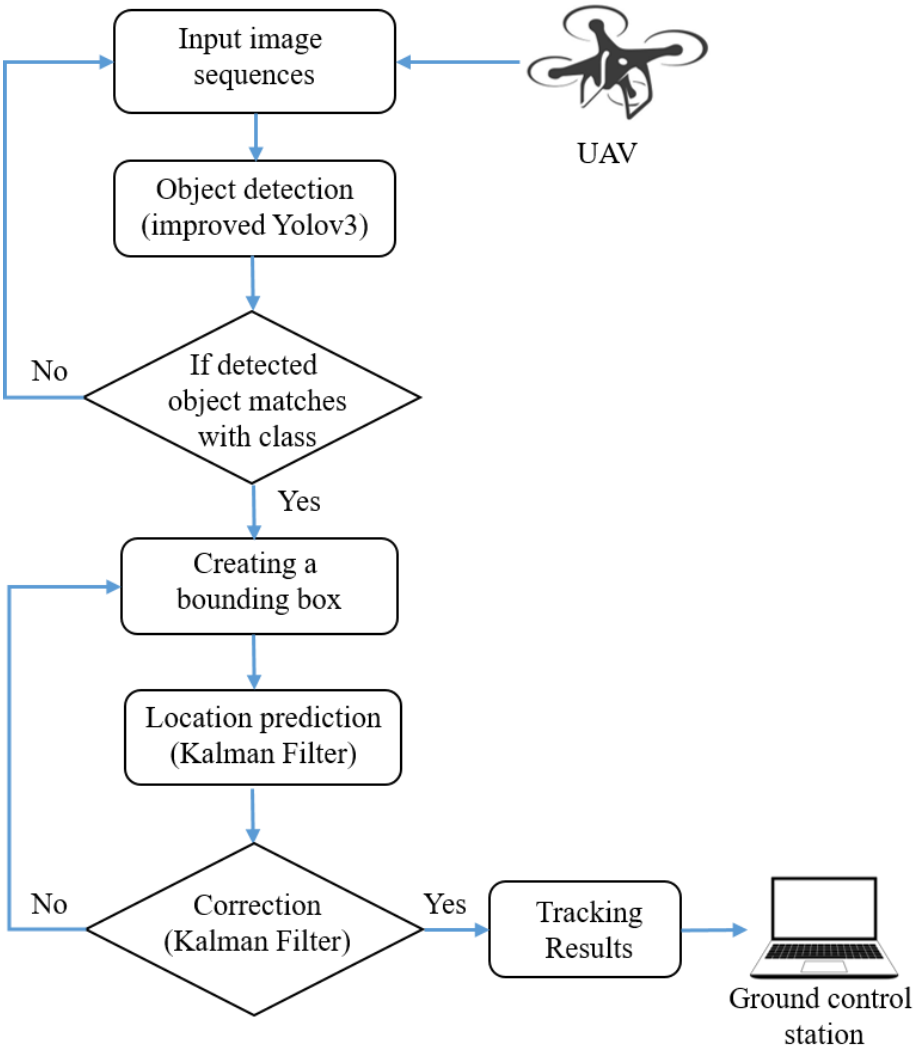
bu yerda x - qatlamga kirish (masalan, oldingi qatlamdan chiqish), μ - tarmoqning o‘rtacha qiymati, σ^2- tarmoq dispersiyasi, ϵ - konstanta, $\hat{x}$- normallashtirilgan chiqish.

Neyron tarmoqlarda o‘qitish paytida gradientlarning (g) haddan tashqari katta bo‘lishini oldini olish uchun gradient kesish usulidan foydalanildi:

$$g = \begin{cases} agar \quad \|g\| \leq \text{bo}'\text{sag}'\text{a}, & g \\ aks\ holda, & \frac{g}{\|g\|} \times \text{bo}'\text{sag}'\text{a} \end{cases}$$

Obyektni kuzatishning asosiy maqsadi tasvir ketma-ketligining har bir freymida uning aniq o‘rnini aniqlash orqali vaqt o‘tishi bilan obyekt trayektoriyasini yaratishdir. 4-rasmda ko‘rsatilganidek, obyektni kuzatish usuli uchta moduldan iborat: tasvir ketma-ketligining birinchi freymidagi obyektni tanlash moduli, obyektni aniqlash moduli va Kalman filtr moduli. Obyektning birinchi kadrdagi o‘rni qidiruv oynasining o‘lchami, kengligi, uzunligini o‘z ichiga olgan ishga tushirish parametrlaridan iborat tanlov moduli tomonidan tanlanadi. Obyektni aniqlash moduli 3.1-bo‘limda tasvirlangan. Obyekt aniqlangandan so‘ng, takomillashtirilgan YOLO modeli mos keladigan chegara ramkasini yaratadi.

Obyektning tasvir ketma-ketligining har bir freymidagi o‘rnini baholash uchun bu ishda Kalman filtridan foydalaniladi. Kalman filtrining kirish parametrlari obyektning k vaqtdagi tasvirdagi holati, obyektning o‘lchami, shuningdek, obyektni qidirish oynasining kengligi va uzunligi bo‘lib, ular tasvir ketma-ketligi davomida obyektning harakatchanligi tufayli o‘zgaradi.



4-rasm. Harakatdagi obyektni kuzatish gibrid algoritmining blok-sxemasi

Kalman filtrining holat vektori va o‘lchov vektori kirish parametrlari bilan ifodalanishi mumkin. Holat vektori mos ravishda t_k vaqtidagi dastlabki pozitsiyadan (x_k, y_k), qidiruv oynasining kengligi W_k va uzunligi L_k va obyektning massa markazidan (x_c, y_c) iborat. Ushbu vektor tomonidan taqdim etiladi:

$$s_k = (x_k, y_k, W_k, L_k, x_c, y_c)$$

O‘lchov vektori obyektni qidirish oynasining t_k vaqtidagi boshlang‘ich holati, kengligi va uzunligidan iborat bo‘lib, bu vektor quyidagicha yozilishi mumkin:

$$z_k = (x_k, y_k, W_k, L_k)$$

Diskret jarayon yordamida Kalman filtri holatni baholaydi. Bu holat chiziqli tenglama bilan modellashtiriladi:

$$s_k = A\, s_{k-1} + w_{k-1}$$

bunda A - o‘tish matritsasi, w_k - jarayon shovqini. O‘lchov modeli esa quyidagicha hisoblanadi:

$$z_k = H\, s_k + v_k$$

bunda H - o‘lchov matritsasi, v_k - o‘lchov shovqini.

Bashorat qilish bosqichida Kalman filtri oldingi holat va tizimning dinamik modeli asosida obyektning kelajakdagi holatini baholaydi. Obyektning k+1 vaqtidagi taxminiy holati quyidagicha hisoblanadi:

$$x_{k+1|k} = A_k x_{k|k} + B_k u_k$$

bunda x_{k+1} obyektning k+1 vaqtidagi taxminiy holati, B - obyekt holatiga har qanday tashqi ta'sirlarni ifodalovchi boshqaruv kirish matritsasi, u - diskretlashtirilgan jarayon shovqinini ifodalaydi. k vaqtdagi holatning bashorat qilingan kovariatsiya matritsasi P quyidagicha hisoblanadi:

$$P_{k+1|k} = A_k P_{k|k} A_k^T + G_k Q_k G_k^T$$

bunda G - jarayon shovqinining kuchayishi matritsasi, Q - kovariatsiya.

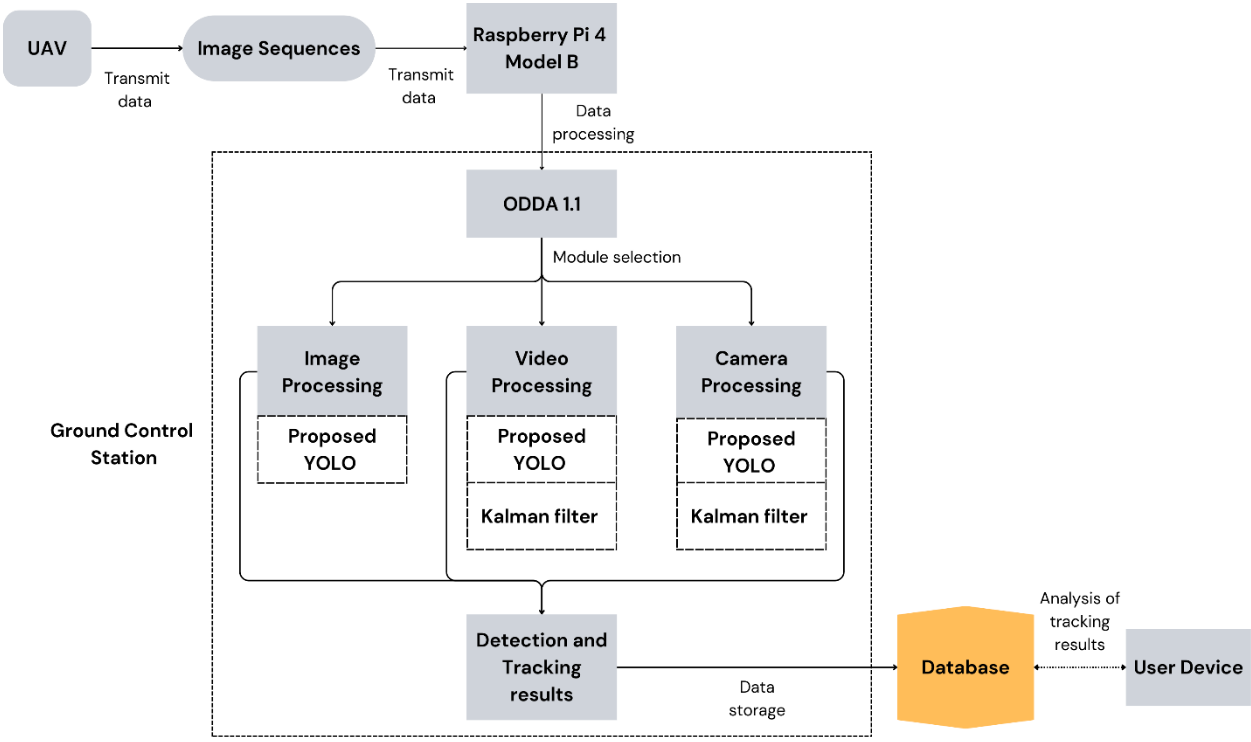
Yangilash bosqichida Kalman filtri sensorlardan olingan o‘lchovlar asosida davlat bahosini yangilaydi. z_k bilan belgilangan o‘lchov qoldig‘i quyidagicha hisoblanadi:

$$z_{k+1|k} = H_{k+1} x_{k+1|k}$$

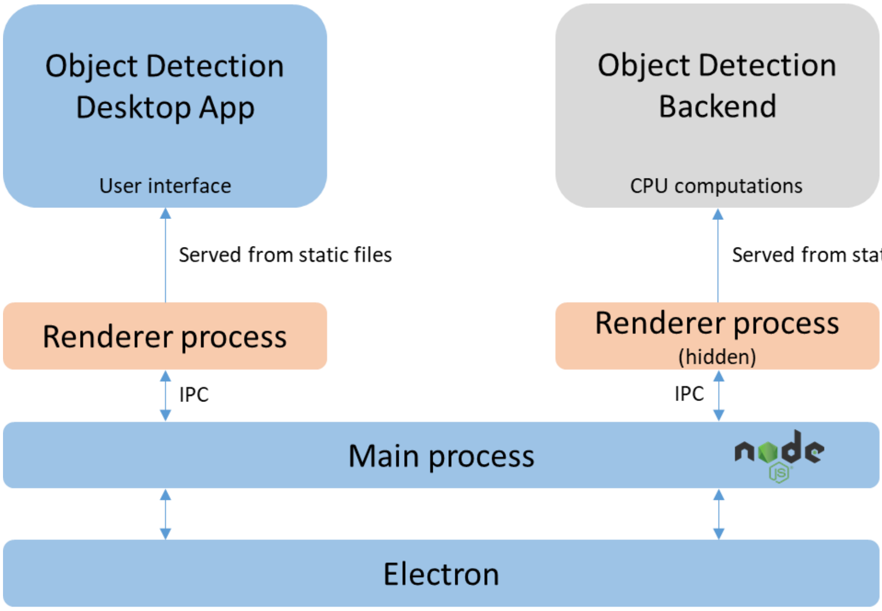
Takroriy ravishda bashorat qilish va yangilash bosqichlarini bajarish orqali Kalman filtri obyekt holatini doimiy ravishda baholaydi va yangilaydi, shovqin va noaniqliklar mavjud bo‘lganda ham aniq kuzatuvni ta’minlaydi.

Obyektlarni aniqlashning eng muhim vazifalaridan biri ma’lumotlar to‘plamini shakllantirishdir. Ushbu tadqiqotda obyektni aniqlash muammosini hal qilish uchun 6 turdagi obyektlar 6 ta sinf sifatida tanlangan. Ushbu sinflarning ma'lumotlar to‘plami 12.000 rangli tasvirlardan, har bir sinf uchun 2.000 ta tasvirdan iborat. Bu ma’lumotlar to‘plami COCO ma’lumotlar to‘plami va jamoamiz tomonidan to‘plangan rasmlardan iborat. Ushbu ma’lumotlar to‘plamidan 80% (9,600) tizimni o‘qitish uchun ishlatilgan va qolgan 20% (2,400) test uchun ishlatilgan. Ushbu tadqiqot ishida Intel(R) Core(TM) i7-8800 protsessorli 3,80 gigagertsli, operativ xotira: 32 GB, SSD: 512, HDD: 1TB, operatsion tizim: Windows 10, 64-bit parametrlarga ega kompyuterdan foydalanildi. Taklif etilgan gibrid algoritmni amalga oshirish uchun Python dasturlash tilidan foydalanildi. ODDA 1.1 desktop ilovasini ishlab chiqish uchun esa Electron.Js freymvorki hamda JavaScript dasturlash tilidan foydalanildi.

Obyektni aniqlash va kuzatish tizimining funksional tuzilishi 5-rasmda keltirilgan. Dastlabki qadamda ma’lumotlarni qaytash ishlash uchun UUA yordamida olingan tasvirlar ketma-ketligi Raspberry Pi 4 mikrokontrolleriga uzatiladi. Qayta ishlangan ma’lumotlar yerdagi boshqaruv qurilmasida (GCS) o‘rnatilgan dasturiy ta’minotga yuboriladi. Shundan so‘ng, “Image Processing”, “Video Processing” va “Camera Processing” modullaridan biri tanlanib, tasvirlar ketma-ketligida obyektni aniqlash va kuzatish jarayoni amalga oshiriladi. Olingan natijalar esa foydalanuvchi tomonidan tahlil qilish uchun ma’lumotlar bazasida saqlanadi.



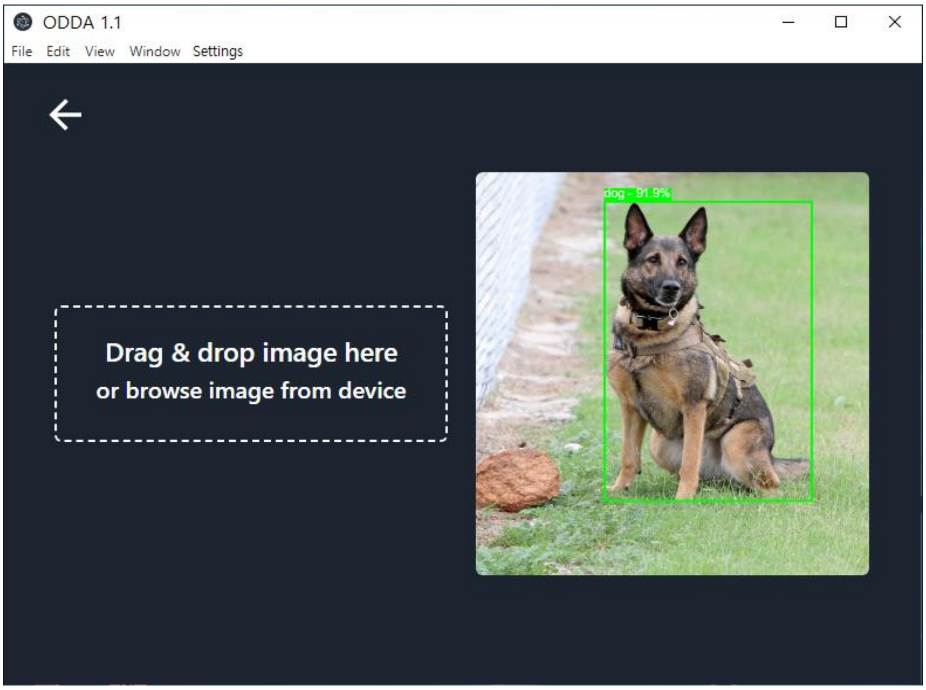
5-rasm. Obyektni aniqlash va kuzatish tizimining funksional tuzilishi



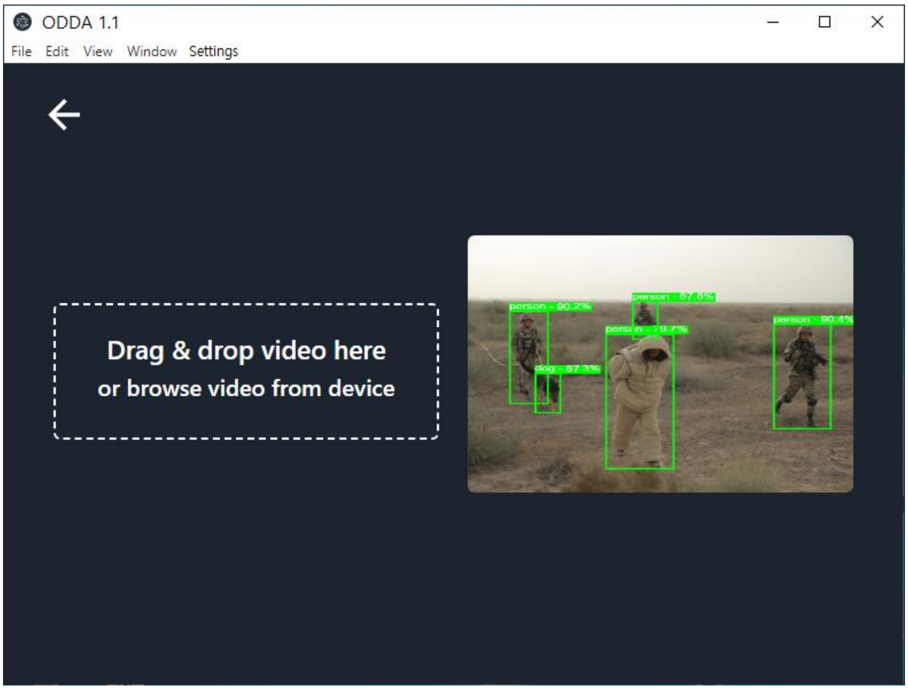
6-rasm. Dasturiy ta’minot arxitekturasi

Ishlab chiqilgan kross-platformali desktop ilovasi real-vaqt rejimida UUA yordamida harakatdagi obyektlarni aniqlash va kuzatish uchun takomillashtirilgan YOLO modeli va Kalman filtridan foydalanadi. Ushbu desktop ilovasining umumiy arxitekturasi 6-rasmda keltirilgan. Ishlab chiqilgan dasturiy majmua “Object Detection Desktop Application (ODDA 1.1)” deb nomlanadi. ODDA 1.1

desktop ilovasining “Imag Processing” oynasi 7-rasmda ko‘rsatilgan. Biz tasvirni bu yerga olib tashlashimiz yoki tasvirdagi obyektni aniqlash uchun qurilmadan tasvirni yuklash mumkin.

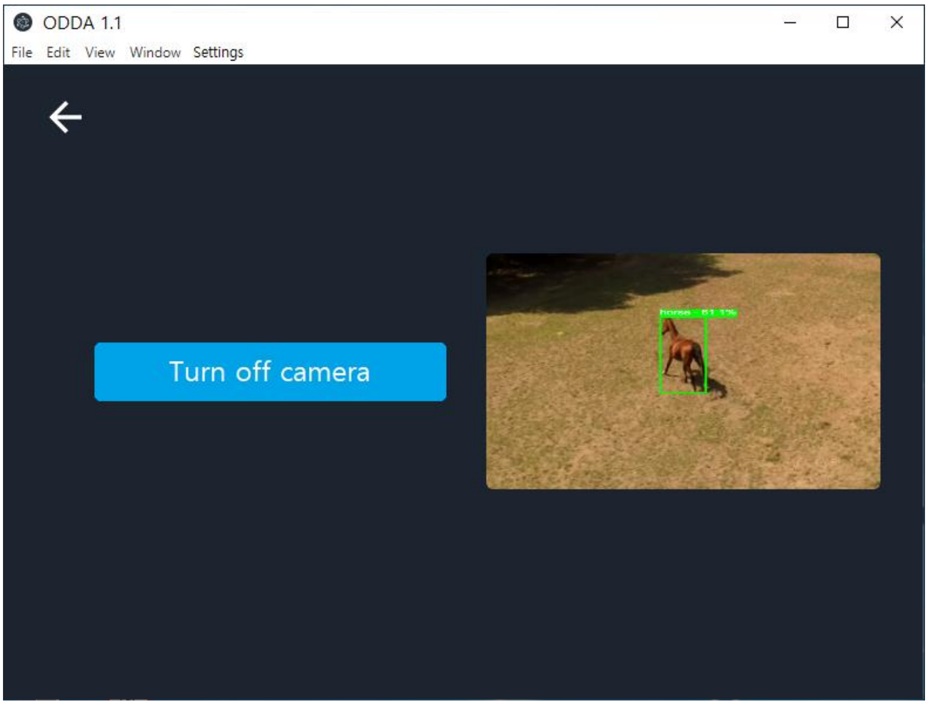


7-rasm. ODDA 1.1 desktp ilovasining tasvirni qayta ishlash oynasi



8-rasm. ODDA 1.1 desktop ilovasining videotasvirni qayta ishlash oynasi

ODDA 1.1 desktop ilovasining “Video Processing” oynasi 8-rasmda ko‘rsatilgan. Videodagi obyektlarni aniqlash va kuzatish uchun qurilmadan videofayl yuklanadi. ODDA 1.1 desktop ilovasining “Camera processing” oynasi 9-rasmda ko‘rsatilgan. “Kamerani yoqish” tugmasini bosish orqali biz real-vaqt rejimida UUA yordamida obyektni aniqlash va kuzatishga ega bo‘lamiz.



9-rasm. ODDA 1.1 desktop ilovasining real-vaqtda videotasvirni qayta ishlash oynasi

Mazkur ilmiy-tadqiqot ishi Ichki ishlar vazirligi Qorovul qo‘shinlari qo‘mondonligi Texnik qo‘riqlash vositalarini joriy etish bo‘limi hamda Navoiy viloyati IIB Ekspert-kriminalistika markazi bilan hamkorlikda olib borildi.

Ishlab chiqilgan model, gibrid algoritm va dasturiy majmuasidan foydalanib, ulardan olingan tadqiqot natijalari 4-bobning asosini tashkil etadi. Kuzatilgan obyekt va UUA o‘rtasidagi masofa d=50 m bo‘lganda, obyektni aniqlashning turli algoritmlari uchun o‘rtacha AP (mAP) natijalari 1-jadvalda ko‘rsatilgan.

1-jadval.

d=50 m bo‘lganda obyektni aniqlash uchun o‘rtacha AP (mAP)

Sequence	R-CNN	Faster R-CNN	YOLOv3	YOLOv5	YOLOv7	YOLOv9	Proposed YOLO
Human	72.1	80.4	82.4	83.3	85.1	89.5	**90.2**
Drone	64	70.3	75.2	84.2	86.2	88.2	**88.7**
Bird	60.2	63.2	78.3	84.3	88.7	89.2	**88.4**
Dog	71.3	82.5	85.6	86.5	89.6	90.6	**91.2**
Car	70.2	84.2	88.4	88.2	90.3	91.5	**92.7**
Horse	68.1	74.7	80	90.3	91.2	92.5	**92.3**

Obyekt va UUA orasidagi masofa 50 m bo‘lganda, obyektni kuzatish algoritmlari uchun markaz joylashuvi xatoligi (CLE) natijalari 2-jadvalda ko‘rsatilgan.

2-jadval.

d=50 m bo‘lganda markaz joylashuvi xatoligi (CLE)

Sequence	MIL	STRUCK	KCF	SORT	GLOM	Proposed
Human	13.2	13.6	11.5	10.3	9.5	**7.5**
Drone	15.6	14.2	12.6	11.5	9.6	**7.4**
Bird	13.7	13.3	12.8	11.7	11.4	**9.6**
Dog	11.4	7.5	8.2	8.2	8.3	**7.5**
Car	11.3	8.3	10.3	9.4	9.5	**6.4**
Horse	12.2	9.6	11.3	11.7	11.6	**8.2**
Average CLE	**12.9**	**11**	**11.1**	**10.5**	**10.9**	**7.7**

XULOSA

Dissertatsiyaning birinchi bobida UUAlari haqida umumiy tushunchalar va ularning qo‘llanish sohalari, obyektni tanib olishning chuqur o‘qitishga asoslangan usul va algoritmlari tahlili, harakatdagi obyektlarni aniqlash va kuzatish tizimlarining qo‘llanish sohalari hamda tadqiqot masalasining qo‘yilishi keltirib o‘tilgan. Harakatdagi obyektlarni aniqlash va kuzatish bo‘yicha chuqur o‘qitishga asoslangan yondashuvlar bo‘yicha xorijiy davlatlar va Respublikamizda olib borilayotgan ilmiy va amaliy tadqiqot ishlari atroflicha tahlil qilingan va ushbu tahlillar natijasida obyektlarni tanib olish uchun yechiladigan masalalar ketma-ketligi tanlab olingan.

Ikkinchi bobda obyektni aniqlash va kuzatish jarayoni tasvirlangan, obyektni aniqlash va kuzatishning bir nechta modellari va algoritmlari ko‘rib chiqildi. Obyektni aniqlash muammosini hal qilishda asosiy rol o‘ynaydigan tasvirni oldindan qayta ishlashning bir qator yondashuvlari va usullari o‘rganildi va ular asosida obyektni aniqlash muammosini hal qilish samaradorligini oshirish uchun amaliy yondashuvlar taklif qilindi.

Ushbu tadqiqot ishida YOLO neyron tarmoq modeli oddiy blok o‘rniga qoldiq blokdan foydalangan holda takomillashtirildi. Bundan tashqari, Mish faollashtirish funksiyasi obyektni aniqlash tarmog‘ining aniqligini oshirish uchun ishlatildi. Gradient oqimini kuchaytirish hamda to‘yinganlik effektlarini kamaytirish orqali neyron tarmoqlarida yashirin qatlamlar soni oshgani sari yuzaga keladigan o‘qitish xatoligini bartaraf etishga erishildi. Takomillashtirilgan YOLO modeli va Kalman filtriga asoslangan obyektni aniqlash va kuzatishning gibrid algoritmi taqdim etildi, u tasvir ketma-ketligidagi bir nechta obyektlarni aniqlash va kuzatish imkonini beradi. Ishlab chiqilgan gibrid algoritm asosida harakatdagi obyektlarni aniqlash va kuzatishning kross-platformali “ODDA 1.1” nomli desktop ilovasi yaratildi.

Ishlab chiqilgan dasturiy majmua UUA yoki video kuzatuv apparatlari yordamida kuzatilgan obyekt ma’lumotlari ichidan zarurini ajratib olish vazifalarini bajarmoqda. Tajribalar davomida obyektlarni aniqlash va kuzatish tizimi o‘qitishdagi xatolik darajasi, markaz joylashuvi xatoligi va o‘rtacha aniqlik bo‘yicha yuqori natijalarni ko‘rsatdi. Tadqiqot doirasida ishlab chiqilgan dasturiy ta’minot qo‘riqlanadigan hududlarda dronlar yoki o‘rnatilgan videokuzatuv qurilmalari yordamida harakatdagi turli obyektlarni aniqlash va kuzatishda qo‘llanilmoqda. Harakatdagi obyektlarni tanib olish va ularni ma’lum joygacha kuzatib borish ishlarining aniqlik darajalari 90-93%ni tashkil etmoqda. Bu kuzatilgan obyekt ma’lumotlarini tahlil qilish uchun ketadigan vaqtni o‘rtacha 10-15%ga qisqartirish imkonini bergan.

SCIENTIFIC COUNCIL AWARDING SCIENTIFIC DEGREES DSc.13/30.12.2019.T.07.01 AT TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES

TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES NAMED AFTER MUHAMMAD AL-KHWARIZMI

ATOEV SUKHROB GAFUROVICH

ALGORITHMS AND SOFTWARE FOR DETECTION AND TRACKING OF MOVING OBJECTS USING AN UNMANNED AERIAL VEHICLE

05.01.04 – Mathematics and software of computing machines, complexes and computer networks

DISSERTATION ABSTRACT OF THE DOCTOR OF PHILOSOPHY (PhD) ON TECHNICAL SCIENCES

Tashkent – 2025

The theme of dissertation of doctor of philosophy (PhD) on technical sciences was registered at the Supreme Attestation Commission at the Ministry of Higher Education, Science and Innovations of the Republic of Uzbekistan under number B2023.4.PhD/T4170.

The dissertation has been prepared at Tashkent university of information technologies named after Muhammad al-Khwarizmi.

The abstract of the dissertation is posted in three languages (Uzbek, Russian, English (resume)) on the website (www.tuit.uz) and on the website of "Ziyonet" Information and educational portal (www.ziyonet.uz.).

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The defense of dissertation will take place "28" March 2025 y. at 14:00 at the meeting of Scientific council No. DSc.13/30.12.2019.T.07.01 at Tashkent University of Information Technologies (Address: 100084, Tashkent city, Amir Temur street, 108. Ph.: (+99871) 238-64-43, e-mail: iktuit@tuit.uz).

The dissertation can be reviewed at the Information resourse centre of Tashkent university of information technologies named after Muhammad al-Khwarizmi (is registered under No.341). (Address: 100084, Tashkent city, Amir Temur street, 108. Ph.: (+99871) 238-64-70).

Abstract of dissertation sent out on "14" March 2025 y.
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INTRODUCTION (abstract of PhD dissertation)

Relevance and necessity of the dissertation topic. One of the major challenges today is developing effective solutions to problems across various fields using deep learning-based models and algorithms. A key area of focus is the digital processing of images and image sequences. In particular, significant attention is given to developing methods for image processing, identifying and extracting important objects, and enabling automatic recognition through deep learning techniques. Leveraging artificial intelligence technologies to address these challenges can enhance both economic and social efficiency, making it a critical issue in modern times.

In recent years, unmanned aerial vehicles (UAVs), commonly referred to as drones, have become more efficient and considerably less expensive due to the rapid advancement of technology. In general, object detection with UAVs yields useful information for a range of sectors and uses. In fields like surveillance, search and rescue, environmental monitoring, infrastructure inspection, agriculture, and surveying, it enables effective monitoring, analysis, and decision-making. In many domains, we can improve productivity, security, and resource management by fusing the powers of UAVs with object detection algorithms. This dissertation addresses the need for developing a robust detection and tracking system capable of operating in complex environments.

Wide use of artificial intelligence (AI) technologies and their implementation in the field of object recognition from images, development of software tools for identifying and classifying objects from dynamic images, and support for scientific research in the field are being implemented in our republic at the state level. In particular, the Decree of the President of the Republic of Uzbekistan “On approval of the Digital Uzbekistan - 2030 strategy and measures for its effective implementation” , including “... conducting fundamental and applied research on priority directions in the field of information technologies ... implementing promising innovative developments and startup projects and supporting their commercialization and technology transfer ... scientific and research work based on digital technologies development and promotion, improvement of their organizational mechanisms...”[2]. To implement these tasks, it is necessary to analyze many scientific research works on the basis of advanced and modern technologies carried out in these fields in the world and in our country, to study the smart systems produced on their basis. It is also important to develop a neural networks based model for object recognition and tracking using UAVs.

The results obtained in this research work will serve to a certain extent in implementing the tasks outlined in the Resolutions of the President of the Republic of Uzbekistan No. PQ-4996 dated February 17, 2021 “On measures to create conditions for the accelerated introduction of artificial intelligence technologies”, No. PQ-358 dated October 14, 2024 “On approval of the Strategy for the

[2] Decree of the President of the Republic of Uzbekistan No. PF-6079 dated October 5, 2020 “On approval of the Digital Uzbekistan - 2030 Strategy and measures for its effective implementation”

development of artificial intelligence technologies until 2030", Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 658 dated November 15, 2022 "On additional measures to regulate the use of unmanned aerial vehicles in the Republic of Uzbekistan", and other regulatory legal acts related to this research field.

Correspondence of the research to the priorities of the development of science and technology of the republic. This research was carried out in accordance with the "Informatization and development of information and communication technologies" priority direction of the development of Science and technology of the Republic of Uzbekistan.

The degree of study of the problem. The scientific works of foreign scientists J. Redmon, Yu.I. Juravlev, R. Golsales, S. Divvala, J. Xing, A. Farhadi, J. Cao A. Fawzi, Liang M., Z. Wang H., Ciresan Dan, K.R. Kwon, D.H. Wu, G. Park and others on the development and improvement of models, methods and algorithms for image processing and object classification and their implementation in practice are noteworthy.

M.M. Kamilov, Sh.Kh. Fazilov, A.Kh. Nishanov, Kh.N. Zaynidinov, N.S. Mamatov, M.Kh. Khudayberdiev and others contributed to the development of the theoretical foundations of object recognition and classification in Uzbekistan.

Until now, most of the research works have been carried out for visual tracking and classification of moving objects using an UAV. Despite the fact that various visual tracking algorithms have been presented with great performance, most of these algorithms are computationally complex and not suitable for object classification in a UAV communication system. Therefore, the problem of developing reliable and efficient methods and algorithms for object detection using a UAV has not been sufficiently studied.

The connection of the dissertation research with the plans of research work of the higher educational institution where the dissertation was completed. The dissertation research was carried out within the framework of project 20/1-1278 – "Protection of territory, buildings and structures belonging to the Ministry of Internal Affairs using technical facilities" (2021-2023) of the research plan of Tashkent University of Information Technologies named after Muhammad al-Khwarizmi.

The purpose of the research is to develop a hybrid algorithm and software based on a neural network model for detection and tracking of moving objects using an unmanned aerial vehicle.

Research functions:

formation of an image dataset using artificial data augmentation methods;

improving the YOLO neural network model for the object detection by developing a residual block;

development of a technique to eliminate the training error that occurs as the number of hidden layers increases in neural networks;

development of hybrid algorithm based on improved YOLO model and Kalman filter for detection and tracking of moving objects using the UAV;

development of software for the detection and tracking of moving objects based on the proposed hybrid algorithm.

The object of research is considered as the process of detection and tracking of moving objects.

The subject of the research is the methods, algorithms and software for detection and tracking of moving objects.

Research methods. Theoretical studies used probability theory, mathematical statistics, discrete mathematics, image processing, object detection and classification methods.

The scientific novelty of the study is as follows:

by developing a residual block, the YOLO neural network model has been improved for object detection;

by increasing the gradient flow and reducing saturation effects, a method has been developed to eliminate the training error that occurs as the number of hidden layers in neural networks increases;

a hybrid algorithm based on the improved YOLO model and the Kalman filter has been developed for the detection and tracking of moving objects using an unmanned aerial vehicle;

based on the developed model and hybrid algorithm, the modules and functional structure of a cross-platform desktop application for the detection and tracking of moving objects have been developed.

Practical results of the research are as follows: developed a deep learning-based hybrid algorithm for detection and tracking of moving objects using the UAV; based on developed methods and algorithms, "ODDA 1.1" desktop application has been developed.

The reliability of the research results is confirmed by the correct use of the mathematical part of image processing and object detection in the development of algorithms, as well as by the favorable outcomes of experimental studies.

Scientific and practical significance of research results. The scientific significance of the research results is explained by the contribution of the developed algorithms to the prospective development of the theoretical foundations of image processing and object detection.

The practical significance of the research results is explained by the use of the developed software in the creation of automated systems for detection and tracking of moving objects using the UAV.

Implementation of research results. As a result of the implementation of the developed software based on improved YOLO model and Kalman filter to the Criminal investigation department of the DIA of the Navoi region, the time spent on identifying and tracking criminals in the region has reduced by an average of 16% (Certificate of the Ministry of Digital Technologies of the Republic of Uzbekistan dated May 27, 2024 No. 33-8/3472). The accuracy level of detection of moving objects and tracking them to a certain location is 90-93%.

The scientific and practical results obtained on the basis of the proposed method and hybdrid algorithm within the framework of the dissertation are implemented to the department for the implementation of technical tools of protection of the command of the security forces of the Ministry of Internal Affairs (Certificate of the Ministry of Digital Technologies of the Republic of Uzbekistan dated May 27, 2024 No. 33-8/3472). The software developed as part of the research is used to detect and track various objects in motion with the help of drones or video surveillance devices installed in protected areas. The accuracy level of recognition and tracking of moving objects is 89-92%. This allows to reduce the time required for the analysis of the observed object data by an average of 9%.

The cross-platform desktop application created on the basis of the proposed method and hybdrid algorithm is accepted for use by the limited liability company “IT WEBMIN” (Certificate of the Ministry of Digital Technologies of the Republic of Uzbekistan dated May 27, 2024 No. 33-8/3472). The object detection and tracking software performs the tasks of recognizing and tracking various objects in motion with the help of video surveillance devices installed in streets and buildings. The developed software recognizes moving objects with 90-95% accuracy. This made it possible to reduce the time required for the analysis of the observed object data by an average of 10%.

Approbation of research results. The results of this research were presented and discussed at 12 scientific and practical conferences, including 8 international and 4 republican.

Publication of research results. A total of 26 scientific works have been published on the topic of the dissertation. 7 articles were published in scientific publications recommended by the Higher Attestation Commission of the Republic of Uzbekistan for publishing the main scientific results of dissertations, including 4 international and 3 republican scientific journals. 4 certificates were obtained for software products.

The structure and volume of the dissertation. The structure of the dissertation consists of an introduction, four chapters, a conclusion, a list of references and appendices. The volume of the dissertation is 108 pages.

THE MAIN CONTENT OF THE DISSERTATION

The introduction substantiates the relevance and necessity of the dissertation topic, defines the purpose and objectives of the research, defines the object and subject of the research, shows compliance with the priority direction of development of science and technology of the Republic of Uzbekistan, substantiates the reliability of the obtained results, reveals the theoretical and practical significance of the research results, provides the state of implementation of the research results in practice, published works and the structure of information about the dissertation.

The first chapter of the dissertation entitled “The concept of object detection and tracking using the UAV” consists of 4 paragraphs, which contains general concepts about UAVs and their areas of application, analysis of deep learning-based methods and algorithms for object recognition, moving objects the areas of application of detection and monitoring systems and the setting of the research question are mentioned. The scientific and practical research works carried out in foreign countries and our Republic on deep learning-based approaches to the detection and tracking of moving objects were thoroughly analyzed, and as a result of these analyzes, a sequence of problems to be solved for object recognition was selected.

The section on object detection using deep learning delves into the fundamental concepts and techniques of deep learning, specifically focusing on its application to object detection tasks. It explains the underlying neural network architectures, such as CNN (Convolutional Neural Network) are currently R-FCN (Region-based Fully Convolutional Networks), Fast R-CNN, Faster R-CNN, SSD (Single Shot MultiBox Detector) and YOLO (You Only Look Once), and the training processes involved. This section emphasizes the advantages of deep learning-based object detection methods over traditional approaches.

In the second chapter, the process of object detection and tracking is described, several models and algorithms for object detection and tracking are considered. A number of approaches and techniques to image preprocessing, which play a key role in solving the problem of object detection, were considered, and application approaches were proposed to increase the efficiency of solving the problem of object detection based on them.

Image resizing involves changing the size of an image while preserving its aspect ratio. Let's assume the original image $I(x,y)$ has dimensions M x N, and we want to resize it to a new size P x Q. The mathematical equation for resizing can be written as:

$$R_{\mathrm{I}} = Res(I(x,y), P, Q)$$

where R_{I} is the resized image, $Res()$ is a function that resamples the original image to the desired size P x Q.

Image denoising technique aims to reduce noise in an image. One common denoising method is Gaussian filtering, which applies a Gaussian kernel to the image. The equation for Gaussian filtering is:

$$F_{\mathrm{I}} = Convolve(I(x,y), GaussianKernel)$$

where F_{I} is the filtered image, $Convolve()$ represents the convolution operation between the image and the Gaussian kernel.

Image normalization technique aims to standardize the pixel values of an image. One common method is min-max normalization, which scales the pixel values to a desired range. The equation for min-max normalization is:

$$N_{\mathrm{I}} = (I(x,y) - min(I(x,y))) \;/\; (max(I(x,y)) - min(I(x,y)))$$

where N_{I} is the normalized image, $min(I(x,y))$ and $max(I(x,y))$ represent the minimum and maximum pixel values in the image, respectively.

Image rotation and flipping operations can be described using transformation matrices. For rotation, a 2D rotation matrix is used. Let's assume we want to rotate the image by an angle θ. The rotation equation can be written as:

$$R_{\mathrm{I}} = Rot(I(x, y), \theta)$$

where R_{I} is the rotated image.

The first concept in the YOLO model is residual blocks. In the first architectural design, they have used 7×7 residual blocks to create grids in the particular image. Each of these grids acts as central points and a particular prediction for each of these grids is made accordingly. For each anchor box in a grid cell, the predicted bounding box coordinates (x, y, w, h) are computed using the sigmoid function:

$$b_x = \sigma(t_x) + c_x,$$

$$b_y = \sigma(t_y) + c_y,$$

$$b_w = p_w\, \mathrm{e}^{\mathrm{t}_w},$$

$$b_h = p_h\, \mathrm{e}^{\mathrm{t}_h}$$

where b_x, b_y are the predicted center coordinates; b_w, b_h are the predicted width and height; t_x, t_y, t_w, t_h are the network predictions, and c_x, c_y, p_w, p_h are the parameters of the anchor box.

Each anchor box in a grid cell predicts a confidence score indicating the likelihood of containing an object. The confidence score is computed using the sigmoid function:

$$Conf = \sigma(t_{conf})$$

where t_{conf} is the network prediction for confidence.

Each grid cell predicts P_C class probabilities using the softmax function:

$$P_C = softmax(t_C)$$

where t_C is the network prediction for class probabilities.

The final output of the YOLO model is a tensor of shape $(S, S, (B5 + P_C))$, containing the predicted bounding box coordinates, confidence scores, and class probabilities for each grid cell.

In the second technique, each of the central points for a particular prediction is considered for the creation of the bounding boxes. While the classification tasks work well for each grid, it's more complex to segregate the bounding boxes for each of the predictions that are made. The third and final technique is the use of the intersection of union (IOU) to calculate the best bounding boxes for the particular object detection task.

To evaluate the proposed object detection method, we use the precision metric which measures the proportion of true positives among all detections:

$$\text{Precision} = \frac{TP}{TP + FP}$$

where TP is the true positives (correctly detected objects), FP is the false positives (incorrectly detected objects). The recall metric measures the proportion of true positives detected out of all actual objects:

$$\text{Recall} = \frac{TP}{TP + FN}$$

where FN is the false negatives (missed objects).

Average Precision (AP) is a commonly used metric to evaluate object detection algorithms. It considers both precision and recall to measure the algorithm's ability to detect objects accurately. AP is often calculated using precision-recall curves and the area under the curve (AUC) of the curve. Mean Average Precision (mAP) is the mean of AP values calculated for multiple object classes. The mAP is usually calculated as the average of AP values for each class:

$$\text{mAP} = \frac{1}{n} \sum_{k=1}^{k=n} AP_k$$

where AP_k is the average precision of class k, n is the number of classes.

To evaluate the object tracking system in our experiments, we used the center location error (CLE) of the tracked target. CLE is defined as the Euclidean distance between the estimated center of the target and the ground truth center on each image frame, as shown by:

$$CLE = \left\| O_k^E - O_k^{GT} \right\|$$

where O_k^E and O_k^{GT} are the estimated and ground truth centers of the target object.

In third chapter, algorithms and software were developed to detect and track the moving objects. The following were presented in this chapter:

1. Deep learning-based object detection method has been introduced that can detect multiple objects within an image or image sequence and provide their bounding box coordinates along with class probabilities. In this research work, YOLO model is improved by using the residual block instead of regular block. Moreover, Mish activation function is used to increase the accuracy of the object detection network.
2. An improved object detection and tracking method based on YOLO model and Kalman filter was presented, which can detect and track multiple objects in an image sequence. The object tracking system consists of three modules: the target selection module in the first frame of the sequence, object detection module, and the Kalman filter module.
3. The overall structure of the developed cross-platform desktop application was presented in Section 3.3. The ODDA 1.1 desktop application consists of 3 modules: image processing, video processing and camera processing. This application uses the improved YOLO modeil and Kalman filter for detection and tracking of moving objects using the UAV in real-time.

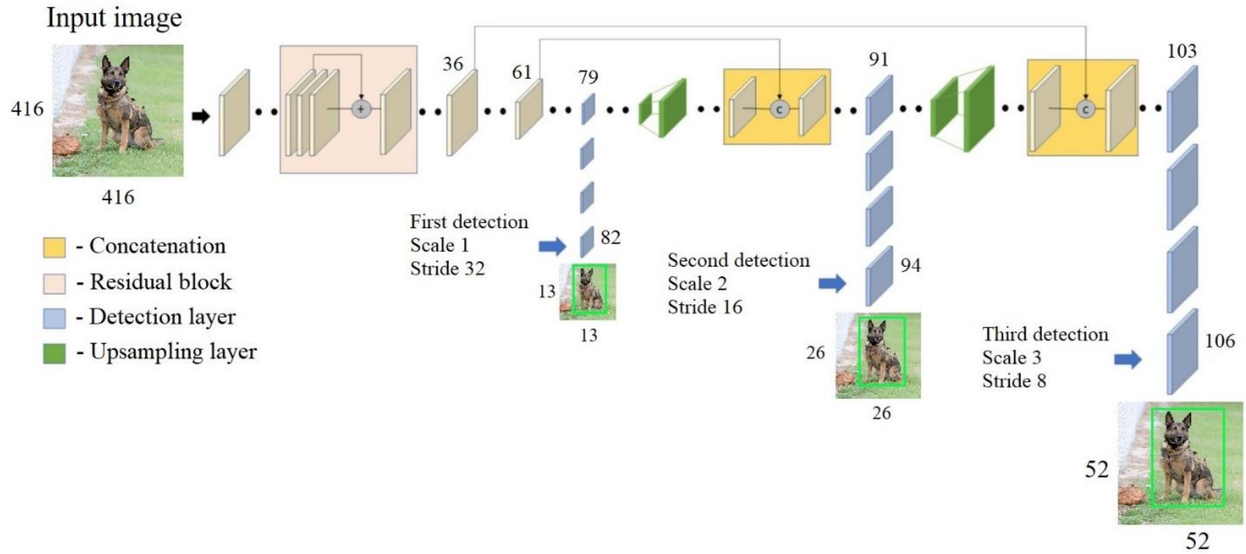

Figure 1. The architecture of an improved YOLO model

In this research work, third version of the YOLO model is improved by using the residual block instead of regular block. Moreover, Mish activation function is used to increase the accuracy of the object detection network. As shown in Figure 1, detection module consists of 53 layers which combined results into a fully convolutional 106 layers of deep network. An improved YOLO model utilizes a deep CNN as its backbone. The backbone extracts rich feature representations from the input image, capturing both low-level and high-level features necessary for object detection.

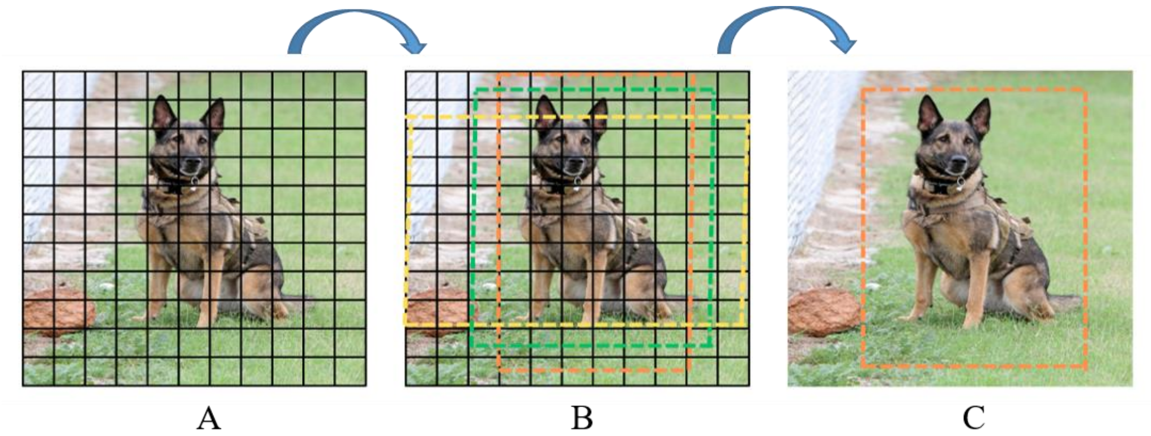

Figure 2. Object detection process using the YOLO model. A: S×S grid generation, B: anchor box generation, C: bounding box prediction

The process is initialized from splitting an image into an S × S grid (at three different scales S is equal to 13, 26 and 52), as shown in Figure 2. Each cell is responsible for predicting bounding boxes and their associated class probabilities. Within each cell, an improved YOLO model uses anchor boxes of different sizes and aspect ratios to detect objects of various scales and shapes. An improved YOLO model has multiple prediction layers at different scales. Each prediction layer is responsible for detecting objects of different sizes. The prediction layers make predictions for bounding boxes, class probabilities, and confidence scores at their respective scales.

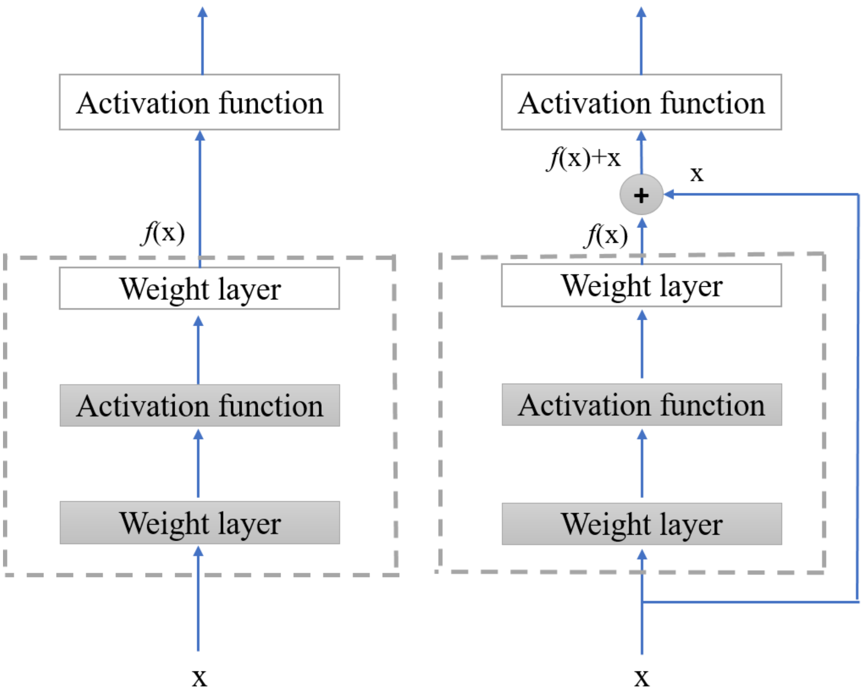

Figure 3. Regular block vs Residual block

The architectural difference between normal convolution block and the residual block is the addition of skip connection, as shown in Figure 3. Skip connection carries the input to the deeper layers. Deep neural networks are difficult to train. With the depth increasing, sometimes network accuracy gets saturated which leads to higher training error. To solve this problem residual block was introduced. In order to maximize the accuracy of the network, the Mish activation function is used:

$$f(x) = x \tanh(\ln(1 + e^x))$$

In the final step, YOLO model predicts class probabilities for each bounding box. The model assigns class probabilities to a predefined set of object classes. The class probabilities represent the confidence of the model that an object of a specific class is present within a bounding box.

By applying following equations and techniques, neural networks can achieve improved gradient flow and reduced saturation effects. Weight initialization is a method used to initialize the weights of neural networks to promote effective training:

$$W \sim N(0, \sqrt{\frac{2}{n_{in}}})$$

where W is the weights of the layer being initialized, N denotes the normal distribution, n_{in} is the number of input units (neurons) in the layer.

Batch normalization normalizes the inputs to each layer by subtracting the batch mean and dividing by the batch standard deviation:

$$\hat{x} = \frac{x - \mu}{\sqrt{\sigma^2 + \epsilon}}$$

where x is the input to the layer, μ is the mean of the batch, σ^2 is the variance of the batch, ϵ is a constant, $\hat{x}$ is the normalized output.

Gradient clipping is a technique used to prevent exploding gradients during training. If the norm of the gradient (g) exceeds a set threshold, it is scaled down to maintain the same direction but within the threshold limit:

$$g = \begin{cases} g, & if \quad \|g\| \leq \text{threshold} \\ \frac{g}{\|g\|} \times \text{threshold}, & otherwise \end{cases}$$

The goal of tracking an object is to generate an object trajectory over time by detecting its exact position in each frame of the image sequence.

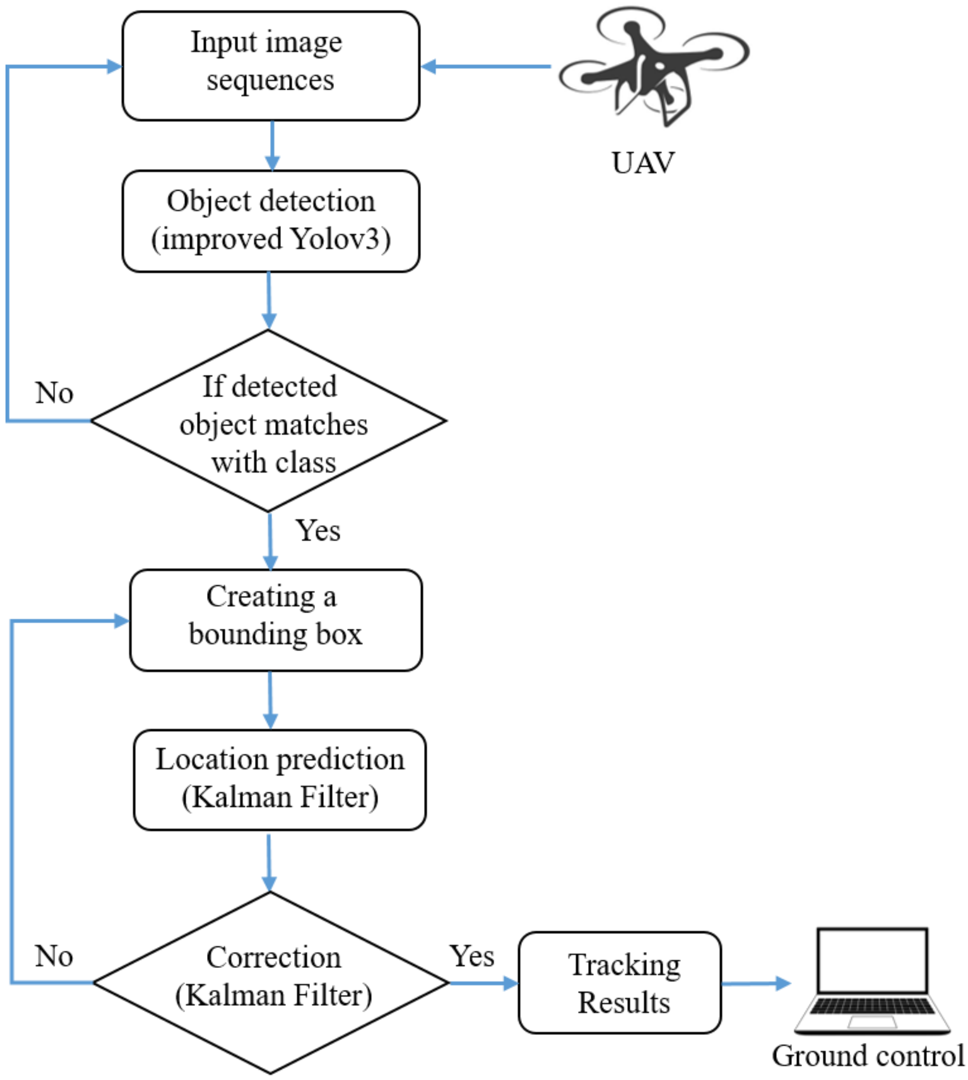

Figure 4. The flowchart of the hybrid method of object tracking

As shown in Figure 4, the object tracking method consists of three modules: the target selection module in the first frame of the sequence, object detection module, and the Kalman filter module. The position of the object in the first frame is selected by the selection module, which consists of initialization parameters, including size, width, length of the search window. Object detection module is described in Section 3.1. Once an object is detected, the improved YOLO model creates the corresponding bounding box. In order to estimate the position of the object in each frame of the sequence, the Kalman filter is used in this work. The input parameters of the Kalman filter are the position of the object in the image at time k, the size of the object, as well as the width and length of the object search window, which change due to the object's mobility during the sequence. The state vector and the measurement vector of the Kalman filter can be represented by input parameters. The state vector consists of the initial position (x_k, y_k), width W_k and length L_k of the search window and the center of mass of the object (x_c, y_c) at time t_k, respectively. This vector is presented by:

$$s_k = (x_k, y_k, W_k, L_k, x_c, y_c)$$

On the other hand, the measurement vector consists of the initial position, width and length of the search window of the object at time t_k, correspondingly and this vector can be written by:

$$z_k = (x_k, y_k, W_k, L_k)$$

Using a discrete process, the Kalman filter estimates the state. This state is modeled by the linear equation, as given by:

$$s_k = A\, s_{k-1} + w_{k-1}$$

where A is the transition matrix, w_k is the process noise. The measurement model can be written as:

$$z_k = H\, s_k + v_k$$

where H is the measurement matrix, v_k is the measurement noise.

In the prediction step, the Kalman filter estimates the future state of the object based on the previous state and the system's dynamic model. The predicted state of the object at time $k + 1$ is calculated as:

$$x_{k+1|k} = A_k x_{k|k} + B_k u_k$$

where x_{k+1} is the estimated state of the object at time $k + 1$, B is the control input matrix that represents any external influences on the object's state, u represents discretized process noise. The predicted covariance matrix P of the state at time k is calculated as:

$$P_{k+1|k} = A_k P_{k|k} A_k^T + G_k Q_k G_k^T$$

where G is the process noise gain matrix, Q is the covariance.

In the update step, the Kalman filter updates the state estimate based on the measurements received from sensors. The measurement residual, denoted by z_k, is calculated as:

$$z_{k+1|k} = H_{k+1} x_{k+1|k}$$

By iteratively performing the prediction and update steps, the Kalman filter continuously estimates and updates the state of the object, providing accurate tracking even in the presence of noise and uncertainties.

One of the most important tasks in the detection of objects is the formation of a dataset. In order to solve the problem of the object detection in this research, 6 types of objects have been selected as 6 classes. The dataset of these classes consists of 12.000 color images, 2.000 images for each class. This dataset consists of COCO dataset and images collected by our team. From this dataset, 80% (9.600) were used to train the system, and the remaining 20% (2.400) were used for testing. In this research work, we used a computer with an Intel(R) Core(TM) i7-8800 CPU 3.80 GHz, RAM: 32 GB, SSD: 256, HDD: 1TB, operating system: Windows 10, 64-bit to evaluate the complexity of the proposed approach in terms of CLE and mAP. In order to implement the proposed method, we used the Python programming language. Electron.Js framework and JavaScript programming language are used to develop ODDA 1.1 desktop application.

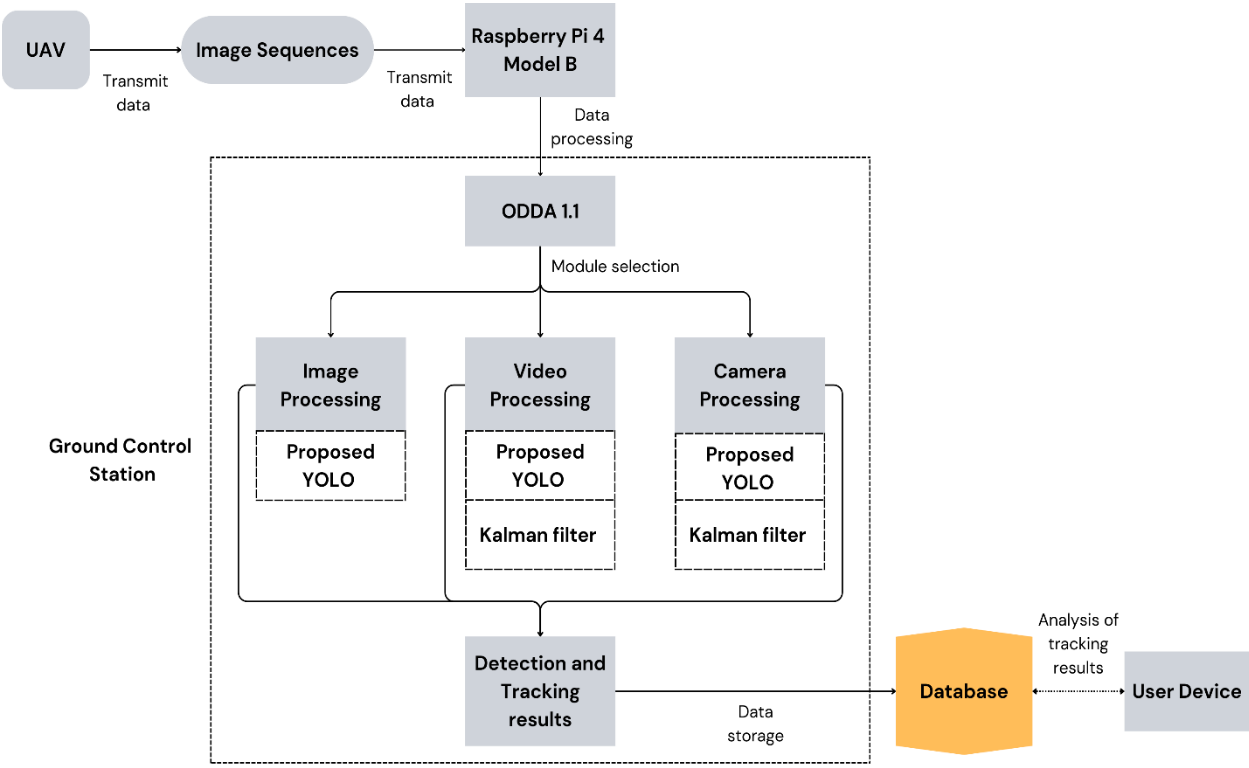

Figure 5. Functional structure of the object detection and tracking system

The functional structure of the object detection and tracking system is presented in Figure 5. Initially, the sequence of images obtained using the UAV is transmitted to the Raspberry Pi 4 microcontroller for data processing. The processed data is sent to the software installed on the ground control station (GCS). After that, one of the "Image Processing", "Video Processing" and "Camera Processing" modules is selected, and the object detection and tracking process is performed in the image sequence. The obtained results are stored in the database for analysis by the user. The overall architecture of the developed desktop application is presented in Figure 6. The developed software is named as "Object Detection Desktop Application (ODDA 1.1)".

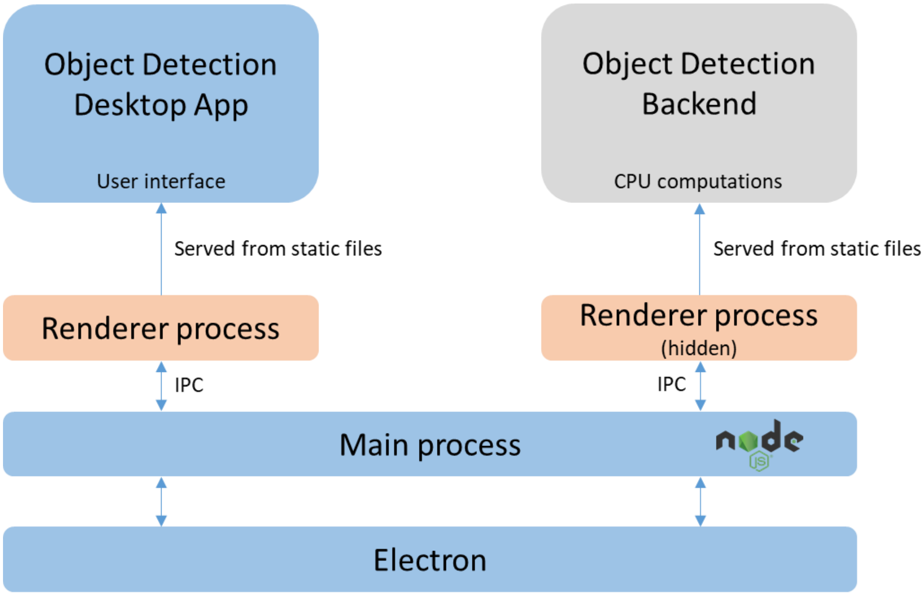

Figure 6. Software architecture

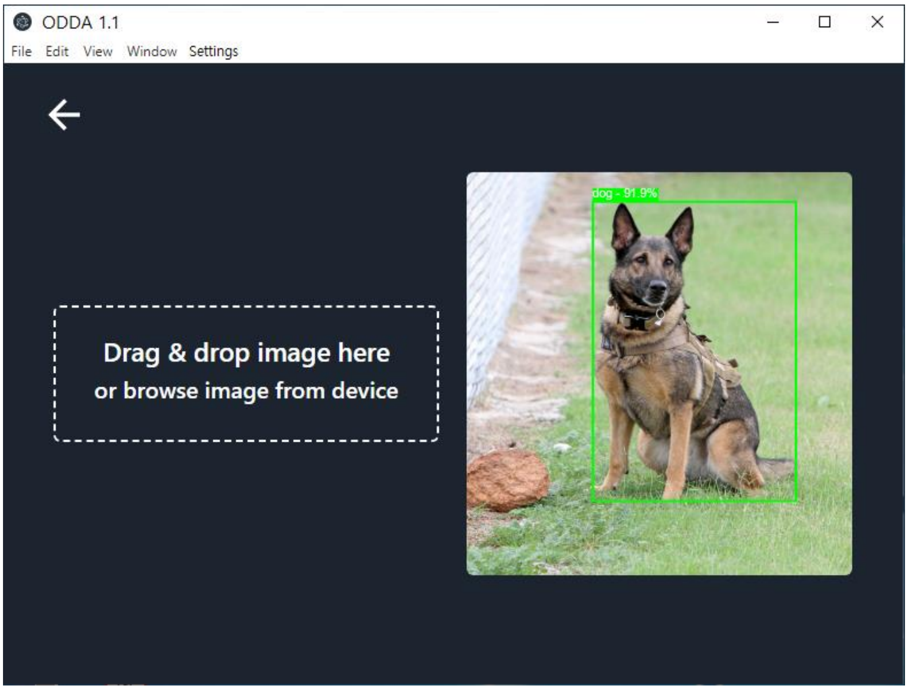

Figure 7. Image processing window of the ODDA 1.1 desktop application

The "Image processing" window of the ODDA 1.1 desktop application is shown in Figure 7. We can drag and drop an image here or browse an image from device to detect the object in the image. The "Video processing" window of the ODDA 1.1 desktop application is shown in Figure 8. We can drag and drop the video file here or browse the video file from device to detect and track the objects in the video. The "Camera processing" window of the ODDA 1.1 desktop application is shown in Figure 9. By clicking the "Turn on camera" button, we will have real-time object detection and tracking using the UAV.

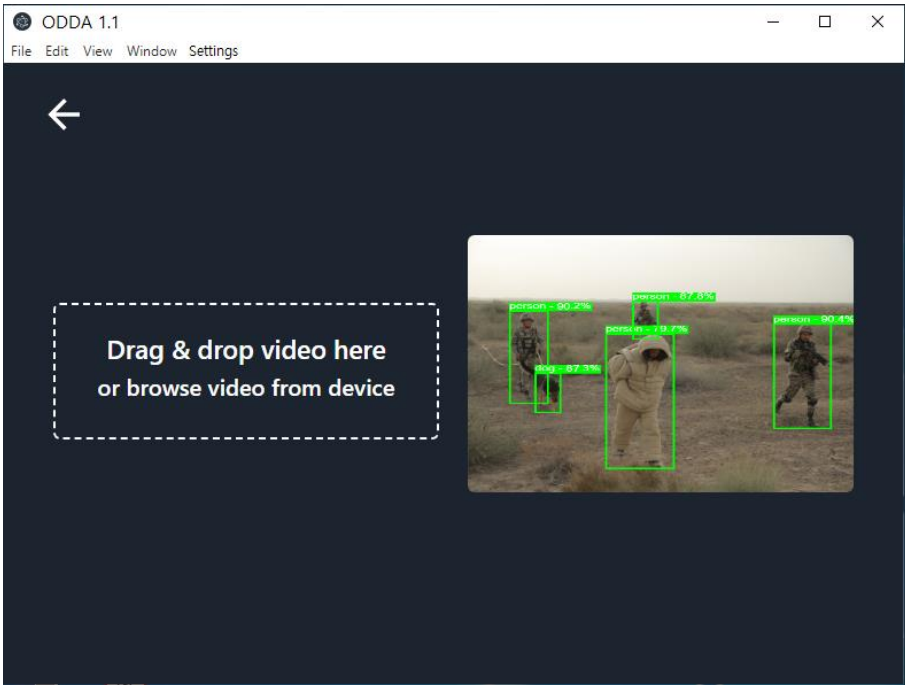

Figure 8. Video processing window of the ODDA 1.1 desktop application

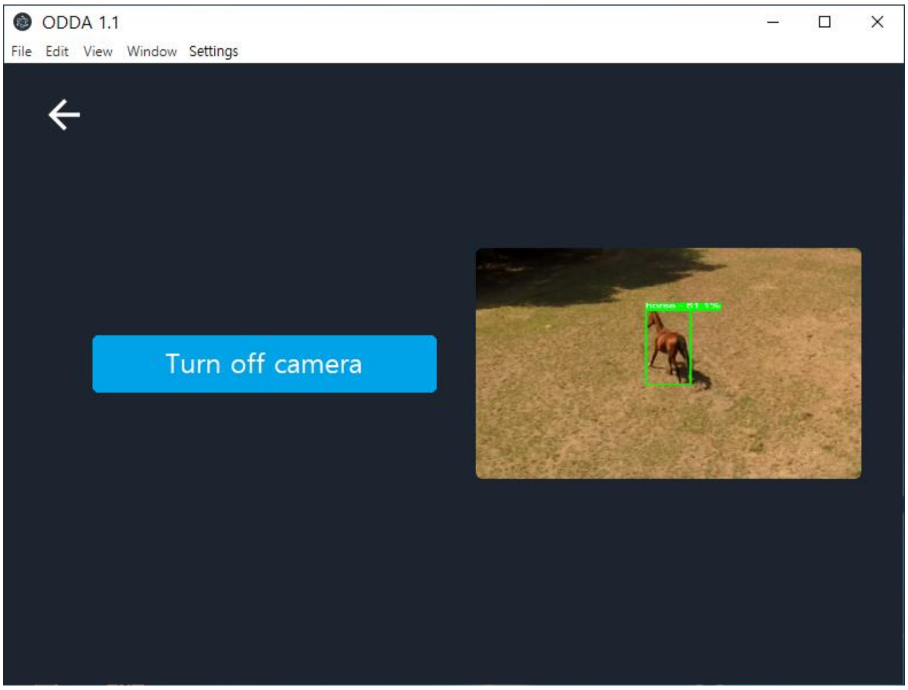

Figure 9. Camera processing window of the ODDA 1.1 desktop application

As shown Table 1 and Table 2, the detection results based on the distance (d) between the object and the UAV. Mean Average Precision (mAP) results for different object detection algorithms are shown in Table 1, when the distance between the object and the UAV is 30m.

Mean Average Precision (mAP) results for different object detection algorithms are shown in Table 2, when the distance between the object and the UAV is 50m. From the tracking results shown in Table 3 and Table 4, we can observe that proposed method demonstrated great performance for each image sequence. Moreover, we can assume that the improved YOLO model represented a significant advancement in object detection, providing a robust and accurate framework for detecting objects in images. Further research and development continue to refine and extend the capabilities of YOLOv9 and other versions of YOLO, addressing its limitations and pushing the boundaries of object detection performance.

Table 1.

Mean Average Precision (mAP) for object detection (d=50 m)

Sequence	R-CNN	Faster R-CNN	YOLOv3	YOLOv5	YOLOv7	YOLOv9	Proposed YOLO
Human	72.1	80.4	82.4	83.3	85.1	89.5	**90.2**
Drone	64	70.3	75.2	84.2	86.2	88.2	**88.7**
Bird	60.2	63.2	78.3	84.3	88.7	89.2	**88.4**
Dog	71.3	82.5	85.6	86.5	89.6	90.6	**91.2**
Car	70.2	84.2	88.4	88.2	90.3	91.5	**92.7**
Horse	68.1	74.7	80	90.3	91.2	92.5	**92.3**

The center location error (CLE) for object tracking algorithms are shown in Table 2, when the distance between the object and the UAV is 50m.

Table 2.

Center location error (CLE) results for object tracking (d=50 m)

Sequence	MIL	STRUCK	KCF	SORT	GLOM	Proposed
Human	13.2	13.6	11.5	10.3	9.5	**7.5**
Drone	15.6	14.2	12.6	11.5	9.6	**7.4**
Bird	13.7	13.3	12.8	11.7	11.4	**9.6**
Dog	11.4	7.5	8.2	8.2	8.3	**7.5**
Car	11.3	8.3	10.3	9.4	9.5	**6.4**
Horse	12.2	9.6	11.3	11.7	11.6	**8.2**
Average CLE	**12.9**	**11**	**11.1**	**10.5**	**10.9**	**7.7**

Here, MIL – Multiple Instance Learning, STRUCK – Structured output tracking with kernels, KCF – Kernelized Correlation Filters, SORT - Simple online and real-time tracking, GLOM – Global-Local Object Model.

This research work was carried out in cooperation with the department for the implementation of technical tools of protection of the command of the security forces of the Ministry of Internal Affairs and the criminal investigation department of the DIA of the Navoi region.

CONCLUSION

With a particular focus on object detection tasks, the first chapter of this dissertation on object detection using deep learning explores the core ideas and methods of deep learning. It offers a thorough overview of the subjects of UAVs, deep learning-based object recognition, object detection and tracking system applications, and a research problem statement.

In this research work, YOLO model is improved by using the residual block instead of regular block. Moreover, Mish activation function is used to increase the accuracy of the object detection network. Multiple objects in an image sequence can be detected and tracked using an enhanced object detection and tracking technique based on YOLO model and the Kalman filter. Based on the obtained results, it can be assumed that the improved YOLO model represents a significant step forward in object detection, providing a robust and accurate basis for detecting objects in image sequences. Moreover, this study demonstrates that even in challenging environments with numerous obstacles (such as foreground objects) surrounding the target object, the proposed method can still function effectively.

The YOLO family of models, particularly improved YOLO and YOLOv9, stands out for their high inference speeds and shorter training times, making them ideal for applications that demand rapid processing and efficiency. Further research and development continue to refine and extend the capabilities of YOLO models, addressing its limitations and pushing the boundaries of object detection performance. Conversely, R-CNN and Faster R-CNN, while effective, are less suited for real-time scenarios due to their slower speeds and longer training requirements.

During the experiments, the system performed excellent results in terms of CLE and mAP. The detection and tracking system of moving objects demonstrated an accuracy of 90-93%. Based on the developed models and algorithms, a desktop application for object detection and tracking has been developed. As a result of the implementation of the software to the Criminal investigation department of the DIA of the Navoi region, the time spent on identifying and tracking criminals in the region has reduced by an average of 16%. The software developed as part of the research is used to detect and track various objects in motion with the help of drones or video surveillance devices installed in protected areas. The accuracy level of recognition and tracking of moving objects is 89-92%. This allows to reduce the time required for the analysis of the observed object data by an average of 10-15%.

НАУЧНЫЙ СОВЕТ DSc.13/30.12.2019.T.07.01 ПО ПРИСУЖДЕНИЮ УЧЕНЫХ СТЕПЕНЕЙ ПРИ ТАШКЕНТСКОМ УНИВЕРСИТЕТЕ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ

ТАШКЕНТСКИЙ УНИВЕРСИТЕТ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ ИМЕНИ МУХАММАДА АЛЬ-ХОРЕЗМИ

АТОЕВ СУХРОБ ГАФУРОВИЧ

АЛГОРИТМЫ И ПРОГРАММНОЕ ОБЕСПЕЧЕНИЕ ДЛЯ ОБНАРУЖЕНИЯ И ОТСЛЕЖИВАНИЯ ДВИЖУЩИХСЯ ОБЪЕКТОВ С ПОМОЩЬЮ БЕСПИЛОТНОГО ЛЕТАТЕЛЬНОГО АППАРАТА

05.01.04 – Математическое и программное обеспечение вычислительных машин, комплексов и компьютерных сетей

АВТОРЕФЕРАТ ДИССЕРТАЦИИ
ДОКТОРА ФИЛОСОФИИ (PhD) ПО ТЕХНИЧЕСКИМ НАУКАМ

Ташкент – 2025

Тема диссертации доктора философии (PhD) по техническим наукам зарегистрирована в Высшей аттестационной комиссии при Министерстве Высшего Образования, Науки и Инноваций Республики Узбекистан за B2023.4.PhD/T4170.

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Автореферат диссертации на трех языках (узбекский, английский, русский (резюме)) размещен на веб-странице (www.tuit.uz) и на Информационно-образовательном портале «Ziyonet» (www.ziyonet.uz).

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ВВЕДЕНИЕ (аннотация диссертации доктора философии (PhD))

Целью исследования является разработка гибридного алгоритма и программного обеспечения на основе нейросетевой модели для обнаружения и отслеживания движущихся объектов с помощью беспилотного летательного аппарата.

Задачи исследования:

формирование набора данных изображений с использованием методов искусственного дополнения данных;

совершенствование модели нейронной сети YOLO для обнаружения объектов путем разработки остаточного блока;

разработка метода устранения ошибки обучения, возникающей при увеличении количества скрытых слоев в нейронных сетях;

разработка гибридного алгоритма на основе улучшенной модели YOLO и фильтра Калмана для обнаружения и отслеживания движущихся объектов с помощью беспилотного летательного аппарата;

разработка программного обеспечения для обнаружения и отслеживания движущихся объектов на основе предложенного гибридного алгоритма.

Объектом исследования является процесс обнаружения и отслеживания движущихся объектов.

Предметом исследования являются методы, алгоритмы и программное обеспечение для обнаружения и отслеживания движущихся объектов.

Научная новизна исследования заключается в следующем:

усовершенствована модель нейронной сети YOLO для обнаружения объектов за счет разработки остаточного блока;

за счет увеличения градиентного потока и снижения эффектов насыщения был разработан метод устранения ошибки обучения, возникающей при увеличении числа скрытых слоев в нейронных сетях;

на основе усовершенствованной модели YOLO и фильтра Калмана разработан гибридный алгоритм обнаружения и отслеживания движущихся объектов с помощью беспилотного летательного аппарата;

на основе разработанной модели и гибридного алгоритма разработаны модули и функциональная структура кроссплатформенного десктопного приложения для обнаружения и отслеживания движущихся объектов.

Практические результаты исследования заключаются в следующем:

разработан гибридный алгоритм обнаружения и отслеживания движущихся объектов с использованием БПЛА на основе глубокого обучения; на основе разработанных методов и алгоритмов создано десктопное приложение «ODDA 1.1».

Достоверность результатов исследования. Достоверность результатов исследования подтверждается корректным использованием математической части обработки изображений и обнаружения объектов при разработке алгоритмов, а также благоприятными результатами экспериментальных исследований.

Внедрение результатов исследования. В результате внедрения разработанного программного обеспечения на основе усовершенствованной модели YOLO и фильтра Калмана в Управлении уголовного розыска УВД Навоийской области время, затрачиваемое на выявление и отслеживание преступников в регионе, сократилось в среднем на 16% (справка Министерства цифровых технологий Республики Узбекистан от 27 мая 2024 года № 33-8/3472). Уровень точности обнаружения движущихся объектов и их отслеживания до определенного местоположения составляет 90-93%.

Полученные на основе предложенной модели и гибридного алгоритма в рамках диссертационной работы научные и практические результаты внедрены в отдел внедрения технических средств охраны командования силовых структур МВД (справка Министерства цифровых технологий Республики Узбекистан от 27 мая 2024 года № 33-8/3472). Разработанное в рамках исследований программное обеспечение применяется для обнаружения и сопровождения различных объектов в движении с помощью беспилотных летательных аппаратов или средств видеонаблюдения, установленных на охраняемых территориях. Уровень точности распознавания и сопровождения движущихся объектов составляет 89-92%. Это позволяет сократить время, необходимое для анализа данных о наблюдаемых объектах, в среднем на 9%.

Кроссплатформенное десктопное приложение, созданное на основе предложенной модели и гибридного алгоритма, принято к использованию обществом с ограниченной ответственностью «IT WEBMIN» (справка Министерства цифровых технологий Республики Узбекистан от 27 мая 2024 года № 33-8/3472). Программное обеспечение обнаружения и отслеживания объектов выполняет задачи распознавания и отслеживания различных объектов в движении с помощью устройств видеонаблюдения, установленных на улицах и в зданиях. Разработанное программное обеспечение распознает движущиеся объекты с точностью 90-95%. Это позволило сократить время, необходимое для анализа данных о наблюдаемых объектах, в среднем на 10%.

Апробация результатов исследования. Результаты исследований были доложены и обсуждены на 12 научно-практических конференциях, в том числе 8 международных и 4 республиканских.

Опубликованность результатов исследования. По теме диссертации опубликовано 26 научных работы, из них 7 в научных изданиях, рекомендованных ВАК Республики Узбекистан для публикации основных научных результатов диссертаций, в том числе 4 зарубежном, 3 республиканских научных журналах, и также, получено 4 свидетельств на программы для ЭВМ.

Структура и объем диссертации. Диссертация состоит из введения, четырех глав, заключения, списка литературы и приложений. Общий объем диссертации составляет 108 страницы.

E’LON QILINGAN ISHLAR RO‘YXATI
LIST OF PUBLISHED WORKS
СПИСОК ОПУБЛИКОВАННЫХ РАБОТ

I bo‘lim (I part; I часть)

1. Sukhrob Atoev, Ki-Ryong Kwon, Kwang-Seok Moon, Suk-Hwan Lee. Data Analysis of the MAVLink Communication Protocol. // IEEE International Conference on Information Science and Communications Technologies (ICISCT 2017): Applications, Trends and Opportunities. Tashkent-2017. -P. 1-3. (05.00.00; OAK Rayosatining 31.10.2017 yildagi 243/3-son qarori).
2. Sukhrob Atoev, Ki-Ryong Kwon, Oh-Heum Kwon, Suk-Hwan Lee. An Efficient SC-FDM Modulation Technique for a UAV Communication Link. // Electronics – SCIE indexed journal, 7(12), 352, 2018. 18p. (05.00.00; № 3; IF=2.6).
3. Sukhrob Atoev, Oh-Jun Kwon, Chee-Yong Kim, Suk-Hwan Lee, Young-Rak Choi, Ki-Ryong Kwon. The Secure UAV Communication Link Based on OTP Encryption Technique. // The 11th International Conference on Ubiquitous and Future Networks. Zagreb, Croatia-2019. 3p. doi: 10.1109/ICUFN.2019.8806165 (05.00.00; № 3).
4. Nishanov A.X., Atoyev S.G‘. Uchuvchisiz uchish apparati aloqa kanali uchun samarali SC-FDM modulyatsiya usuli. // Informatika va energetika muammolari ilmiy jurnali. №1/2021 Toshkent-2021. –B. 88-101. (05.00.00; № 5).
5. Sukhrob Atoev, Akhram Nishanov, Fakhriddin Abdirazakov. Object Tracking Method Based on Kalman Filter and Camshift Algorithm for UAV Applications. // International Conference on “Information Science and Communications Technologies: Applications, Trends and Opportunities, ICISCT 2021,” Tashkent- 2021. -4p. (05.00.00; OAK Rayosatining 30.10.2021 yildagi 308/6-son qarori).
6. Nishanov A.X., Achilov U.Sh., Atoyev S.G‘., Rayimov T.G., Sobirov B.T. Uchuvchisiz uchish apparati uchun obyekt harakatini kuzatishning samarali usuli. // Innovation Technosystems ilmiy-texnik jurnali. №2(2)/2021 Toshkent-2021. –B. 119-125. (05.00.00; OAK Rayosatining 31.01.2023 yildagi 332/5-son qarori).
7. Sukhrob Atoev, Akhram Nishanov. An Object Tracking Method Based on Improved Yolov3 Model and Kalman Filter for Uav Applications. // Raqamli Transformatsiya va Sun’iy Intellekt ilmiy jurnali. №2(4)/2024 Toshkent-2024. 7b. (05.00.00; OAK Rayosatining 03.07.2023 yildagi 340/3-son qarori).

II bo‘lim (II part; II часть)

8. Sukhrob Atoev, Ha-Joo Song, Oh-Jun Kwon, Suk-Hwan Lee, Ki-Ryong Kwon. The Secure Drone Communication Protocol using Blowfish Algorithm. // Korean Multimedia Society Fall conference. Korea-2017. -P. 53-54.

9. Sukhrob Atoev, Jin-Hyeok Park, Oh-Heum Kwon, Suk-Hwan Lee, Eung-Joo Lee, Ki-Ryong Kwon. Data Analysis of the DJI Phantom 4 Drone. // 30th Image Processing and Image Understanding (IPIU) Conference. Jeju, Korea-2018. 3p.

10.Sukhrob Atoev, Ki-Ryong Kwon, Oh-Heum Kwon, Ha-Joo Song, Oh-Jun Kwon, Suk-Hwan Lee. An Efficient UAV Communication Link based on SC-FDM Modulation Technique. // 14th International Conference on Multimedia Information Technology and Applications (MITA). Shanghai, China-2018. 3p.

11.T. T. P. Thanh, Caleb Vununu, Sukhrob Atoev, Suk-Hwan Lee, Ki-Ryong Kwon. Leukemia Blood Cell Image Classification Using Convolutional Neural Network. // International Journal of Computer Theory and Engineering, Vol. 10, No. 2, 2018. -P. 54-58.

12.Rafiul Hasan Khan, Sukhrob Atoev, Xurshid Farhodov, Kyung-Min Lee, Ki-Ryong Kwon. Binary Classification of Horse Face from Animal Face using Deep Convolutional Neural Network. // 6th Korea-Japan Joint Workshop on Complex Communication Sciences. Jozankei, Hokkaido, Japan-2018. 2p.

13.Nishanov A.X., Atoyev S.G‘. Uchuvchisiz uchish apparati uchun obyekt harakatini kuzatishning samarali usuli. // “Iqtisodiyot tarmoqlarining innovatsion rivojlanishida axborot-kommunikatsiya texnologiyalarining ahamiyati” Respublika ilmiy-texnik anjumani ma’ruzalar to‘plami, 2-qism. Toshkent-2021. -B. 418-420.

14.Sukhrob Atoev, Akhram Nishanov, Fakhriddin Abdirazakov. Object Tracking based on Weighted Centroid Shifting Method with Superpixel Confidence Map. // International Scientific and Technical Conference on “Digital Technologies: Problems and Solutions for Practical Implementation in an Industry”, Tashkent-2022. -P. 36-37.

15.Nishanov A.X., Atoyev S.G‘. Uchuvchisiz uchish apparatining qo‘llanish sohalari. // “Iqtisodiyot tarmoqlarining innovatsion rivojlanishida axborot-kommunikatsiya texnologiyalarining ahamiyati” Respublika ilmiy-texnik anjumanining ma’ruzalar to’plami, Toshkent-2022. –B 454-456.

16.Sukhrob Atoev, Akhram Nishanov, Fakhriddin Abdirazakov, Ruslan Baydullaev. An efficient object tracker based on superpixel confidence map and weighted centroid shifting. // “Matematik modellashtirish, axborot - kommunikatsiya texnologiyalarining dolzarb masalalari” mavzusidagi Respublika ilmiy-texnik anjumanining ma’ruzalar to’plami, Nukus-2022. -B. 345-348.

17.Sukhrob Atoev, Akhram Nishanov, Fakhriddin Abdirazakov, Ruslan Baydullaev. Object tracking based on weighted centroid shifting method with superpixel confidence map. // Proceedings of International conference on Recent advances in intelligent information and communication technologies ISPC-2022, Tashkent-2022. –P. 82-85.

18.Shakhzodbek Najmiddinov, Sukhrob Atoev. Real-time object detection method based on YOLOv7 model. // “Raqamli texnologiyalar va sun’iy intellektni rivojlantirishning zamonaviy holati va istiqbollari” mavzusidagi Respublika ilmiy-amaliy anjumani materiallari to‘plami, Guliston-2022. –P. 90-92.

19.Sukhrob Atoev. A hybrid method for detection and tracking of moving objects using the UAV. // Central Asian Journal of Education and Computer Sciences (CAJECS) scientific journal. Vol. 2, Issue 3, 2023. -P. 10-14.

20.Shakhzodbek Najmiddinov, Sukhrob Atoev. Object detection method using Faster R-CNN. // Central Asian Journal of Education and Computer Sciences (CAJECS) scientific journal. Vol. 2, Issue 3, 2023. -P. 19-22.

21.Otakhonova Bakhrikhon, Yuldoshev Yusuf, Atoev Sukhrob. Development of a Hybrid Module and Algorithm for Classification of Text Data. // International Conference on “Information Science and Communications Technologies: Applications, Trends and Opportunities, ICISCT 2023,” Tashkent- 2023. –P. 270-274.

22.Sukhrob Atoev, Fakhriddin Abdirazakov, Ruslan Baydullaev. Development of Software for Speech-to-Text Conversion. // International Conference on “Information Science and Communications Technologies: Applications, Trends and Opportunities, ICISCT 2023,” Tashkent- 2023. –P. 310-313.

23.Atoyev S.G‘., Abdurazzoqov F.B., Baydullayev R.T., Shaazizova M.E. Mashinali o‘qitish algoritmlari yordamida obyektlarni tasniflashning dasturiy ta’minoti. // O‘zbekiston Respublikasi Adliya vazirligi huzuridagi Intellektual mulk agentligining elektron hisoblash mashinalari uchun yaratilgan dasturning rasmiy ro‘yxatdan o‘tkazilganligi to‘g‘risidagi guvohnomasi. № DGU 18660. 07.10.2022.

24.Muxamediyeva D.T., Muxamediyeva D.K., Shaazizova M.E., Abdurazzoqov F.B., Atoyev S.G‘. Klassifikatsiya masalalarini yechishning immun algoritmlarga asoslangan dasturiy ta’minoti. // O‘zbekiston Respublikasi Adliya vazirligi huzuridagi Intellektual mulk agentligining elektron hisoblash mashinalari uchun yaratilgan dasturning rasmiy ro‘yxatdan o‘tkazilganligi to‘g‘risidagi guvohnomasi. № DGU 21108. 26.12.2022.

25.Ismoilov J. N., Atoyev S.G‘., Najmiddinov Sh.Sh. ODDA 1.1 – Object Detection Desktop Application. // O‘zbekiston Respublikasi Adliya vazirligi huzuridagi Intellektual mulk agentligining elektron hisoblash mashinalari uchun yaratilgan dasturning rasmiy ro‘yxatdan o‘tkazilganligi to‘g‘risidagi guvohnomasi. № DGU 25105. 27.05.2023.

26.Atoyev S.G‘., Najmiddinov Sh.Sh., Baydullayev R.T. “Object Tracking” mobil ilovasi. // O‘zbekiston Respublikasi Adliya vazirligi huzuridagi Intellektual mulk agentligining elektron hisoblash mashinalari uchun yaratilgan dasturning rasmiy ro‘yxatdan o‘tkazilganligi to‘g‘risidagi guvohnomasi. № DGU 28108. 17.10.2023.

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