Kazakhstan International Linguistic College - ”KILC”

REPORT

On The Topic - 'Autonomous Collision Avoidance System'

Content

Autonomous System for Detecting Space Objects and Space Debris Based on Computer Vision

1. Introduction

Modern space exploration is accompanied by a rapid increase in the number of artificial objects in Earth orbit. In addition to active satellites, there are spent rocket stages, fragments of destroyed spacecraft, and small particles of space debris. These objects pose a serious threat to operating space vehicles. For this reason, automatic systems for detecting objects and preventing collisions are becoming increasingly important.

This project is focused on developing a software prototype of an autonomous system that uses computer vision and neural network technologies to detect space objects and provide recommendations to avoid possible collisions.

2. Project Overview

The project represents a software system that analyzes a video stream or a sequence of images obtained from onboard cameras of a spacecraft. The system works in real time, detects objects in the field of view, classifies them, and determines whether they may pose a potential danger.

The core of the system is the YOLOv8 neural network model, which is used for object detection. After analyzing the position of detected objects relative to the direction of movement, the system generates a recommendation for changing the spacecraft's trajectory.

The project has a demonstration and educational purpose, but it is based on real principles used in modern space safety systems.

3. Relevance and Existing Problems

3.1 Space Debris Problem

Currently, millions of space debris fragments of various sizes are located in near-Earth orbit. Even objects with a diameter of a few millimeters can cause critical damage to a satellite due to their high orbital speed.

3.2 Limitations of Traditional Methods

Traditional object tracking systems mainly rely on radar data and ground-based computing. These methods have several limitations:

- data transmission delays;
- high infrastructure costs;
- low accuracy when detecting small objects.

3.3 Importance of Autonomous Systems

Autonomous onboard systems reduce dependence on ground control centers and significantly increase the safety of space missions.

4. Project Goals and Objectives

4.1 Project Goal

The goal of the project is to create a prototype of an autonomous system for detecting space objects and debris that can analyze visual data and generate recommendations to prevent collisions.

4.2 Main Objectives

To achieve this goal, the following tasks were set:

- studying computer vision methods;
- integrating a neural network object detection model;
- developing an algorithm for identifying a danger zone;
- implementing decision-making logic;
- visualizing system results.

5. Theoretical Background

5.1 Computer Vision

Computer vision is a field of artificial intelligence focused on extracting information from images and videos. In space-related tasks, computer vision is used for navigation, docking, surface monitoring, and object detection.

5.2 Neural Network Models

Modern neural networks are capable of recognizing and classifying objects even in difficult lighting and background conditions. The YOLO model belongs to the class of single-stage detectors and is known for its high processing speed.

6. Technologies Used

The following tools and libraries were used in the project:

- Python programming language;
- Ultralytics YOLOv8 library;
- OpenCV for video processing;
- NumPy for numerical calculations;
- Pillow library for displaying text information.

These technologies were chosen due to their availability, flexibility, and wide use in scientific and engineering projects.

7. System Architecture

The system consists of the following logical modules:

- video data capture module;
- object detection module;
- danger zone analysis module;
- decision-making module;
- visualization module.

Each module performs a specific function, which ensures modularity and allows further system expansion.

8. System Operation

8.1 Image Capture and Processing

At the first stage, the system receives video frames from a spacecraft camera or a test video file. The frames are then passed to the processing module.

8.2 Object Detection

Each frame is analyzed by the YOLOv8 neural network, which detects objects and determines their coordinates and classes.

8.3 Selection of Dangerous Objects

From all detected objects, the system selects those that may pose a threat, such as other satellites or space debris fragments.

8.4 Formation of a Danger Zone

A conditional danger zone is formed in the central part of the image, corresponding to the spacecraft's direction of movement.

8.5 Decision-Making Algorithm

If a dangerous object enters the central zone, the system analyzes the distribution of objects on the left and right sides and generates a recommendation for changing the trajectory.

9. Collision Prevention Algorithm

The algorithm of preventing collisions is based off heuristic approaches and it follows these steps:

- Calculation and rating of objects in the area by each side;
- Analysis of its relative distances;
- Search for the safest direction.

This approach allows the system to make fast decisions without using complex orbital calculations.
It is especially useful for real-time processing, where quick reaction is required.

The mentioned algorithm is the simplest depiction of real orbital maneuvers.
Despite its simplicity, it demonstrates the basic logic used in collision avoidance systems.

10. Budget and Cost

Our project is for now a prototype software, and it doesn't require necessary financial support to be used.
The system is mainly focused on software implementation and testing rather than physical deployment.

10.1 Component Costs

- Personal computer for development;
- Usage of open source codes;
- Developers' time;

These components are sufficient for creating and testing a working prototype of the system.

10.2 Estimated Development Cost

Since free libraries and cheap equipment have been used in the plan, the cost of the project is deemed to be minimal and are only spent to development and testing.

This makes the project accessible for small teams and educational environments.

11. System Testing

The system was tested using videos simulating space environments.
Tests focused on detection accuracy, stability, and accuracy of making decisions.

Additional testing scenarios suchlike varying object sizes, different lighting conditions, and increased object density have been used to evaluate the strength of the system.
These tests helped to identify potential weaknesses and improve overall system performance.

12. Project Result

As a result of the project, we have created a functional prototype system that is able to:

- detect space objects and debris;
- identify potentially dangerous threats;
- generate route and maneuver recommendations;
- work in real time;
- work properly in most space situations;
- visualize results and outputs.

The results confirm that the system meets the initial goals set at the beginning of the project.

13. Significance in Practice

This project demonstrates the application of Artificial Intelligence (AI) into problems in the dark space and providing safety.
It shows how modern technologies can be applied to real-world space challenges.

It can be also used for educational purposes to illustrate how computer vision works.
Students can use this project as an example of practical AI implementation.

14. Development Prospects

The system will be improved and we will consider several development aspects in the future, and the following may be included:

- Estimation of object distance, relativity and velocity of objects;
- Incorporation of orbital mechanics;
- Usage of radar or lidar sensors;
- Use of more advanced artificial intelligence for enhanced results.

These improvements can significantly increase the accuracy and reliability of the system.

15. Conclusion

In summary, we have developed a prototype software of an autonomous system for detection of space odjects and debris.
The project demonstrated the effectivity of using computer vision and artificial intelligence to enhance the safety in space missions.

The results obtained approve the potential of autonomous systems as a significant component of future space infrastructure.
Overall, the project confirms the relevance of AI-based solutions in modern space technologies.

15