DnnOpenVinoDetector C++ library

v1.0.0

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Overview

DnnOpenVinoDetector C++ library version **1.0.0** is designed for automatic detection of objects on videos through the utilization of neural networks. The library is implemented in C++ (C++17 standard) and exclusively relies only on one third-party library, which is Intel's **OpenVINO™** runtime. The library supports various neural network models, if only model is supported by OpenVINO and has standard one-batch output (eg. yolov5). NN model can be specified in detector parameters, library inherits its interface from the **ObjectDetector** class, offering flexible and customizable parameters. It seamlessly integrates into systems of any complexity.

Versions

Table 1 - Library versions.

Version	Release date	What's new
1.0.0	27.09.2023	First version.

Library files

The library supplied by source code or compiled version. The user would be given a set of files in the form of a CMake project (repository). The repository structure is shown below:

```
CMakeLists.txt ------------------------ main CMake file
README.md ----------------------------- Documentation
3rdparty ------------------------------ folder with 3rdparty libraries
    CMakeLists.txt -------------------- CMake file for 3rdpary folder
    ObjectDetector -------------------- files of ObjectDetector interface library
src ----------------------------------- folder with library source code
    CMakeLists.txt -------------------- CMake file
    DnnOpenVinoDetector.h ------------- main library header file
    DnnOpenVinoDetectorVersion.h ------ header file with library version
    DnnOpenVinoDetectorVersion.h.in --- file for CMake to generate version header
    DnnOpenVinoDetector.cpp ----------- C++ implementation file
demo ---------------------------------- folder for demo application files
    CMakeLists.txt -------------------- CMake file for demo app
    3rdaprty -------------------------- folder with 3rdparty libraries
        CMakeLists.txt ---------------- CMake file for 3rdparty folder
```

```
        SimpleFileDialog ------------- file dialog service library
        VSourceOpenCv ---------------- video capture service library
    main.cpp ------------------------- source C++ file of demo app
example ------------------------------ folder for simple example
    CMakeLists.txt ------------------- CMake file of example
    main.cpp ------------------------- source C++ file of example
test ---------------------------------- folder with test app (benchmark)
    CMakeLists.txt ------------------- CMake file of test app (benchmark)
    main.cpp ------------------------- source C++ file of test app
```

DnnOpenVinoDetector library depends on open source **ObjectDetector** (provides interface for object detection), which depends on open source **Frame** library (provides video frame structure and pixel formats description) and open source **ConfigReader** library (provides methods to work with JSON file and structures). Additionally demo application depends on open source **SimpleFileDialog** (provides dialog to open files) and **VSourceOpenCv** (provides method to capture video from files, cameras and streams, supplied as source code under **DnnOpenVinoDetector** license).

Key features and capabilities

Table 2 - Key features and capabilities.

Parameter and feature	Description
Programming language	C++ (standard C++17) using the OpenVINO library (version 2022.3.1).
Supported OS	Compatible with any operating system that supports the C++ compiler (C++17 standard) and the OpenVINO library (version 2022.3.1).
Shape of detected objects	The library is capable of detecting moving objects of various shapes. Users can set the minimum and maximum height and width of the objects to be detected through library parameters.
Supported pixel formats	RBG24, BGR24, GRAY, YUV24, YUYV, UYVY, NV12, NV21, YV12, YU12. The library uses the RGB format for video processing. If the pixel format of the image is different from RGB , the library pre-converts the pixel formats to RGB.
Maximum and minimum video frame size	The minimum size of video frames to be processed is 32x32 pixels, and the maximum size is 8192x8192 pixels. The size of the video frames to be processed has a significant impact on the computational speed.
Coordinate system	The algorithm uses a window coordinate system with the zero point in the upper left corner of the video frame.
Calculation speed	The processing time per video frame depends mostly on loaded neural network model and also on the computing platform used. The processing time per video frame can be estimated with the demo application.

Parameter and feature	Description
Type of algorithm for detection of objects	To detect different objects on current frame interface for obtaining neural network model was implemented. This interface relies on OpenVino implementation and utilizes its features such as: pre-processing of input data, reading and launching neural network model and obtaining output results. Output data is cleaned up from overlapping boxes and correct types are assigned to output vector of objects.
Discreteness of computation of coordinates	The library utilizes the object bounding box for each detected object. If boxes are overlapping and have the same object type, they are merged into one combined. This means discreteness of library is strongly depended on loaded neural network model.
Working conditions	The library is designed to function on a variety of devices. It is optimized for GPU hardware support, which can significantly enhance processing speed. The detector processes each frame independently, so camera movement does not impact the results.

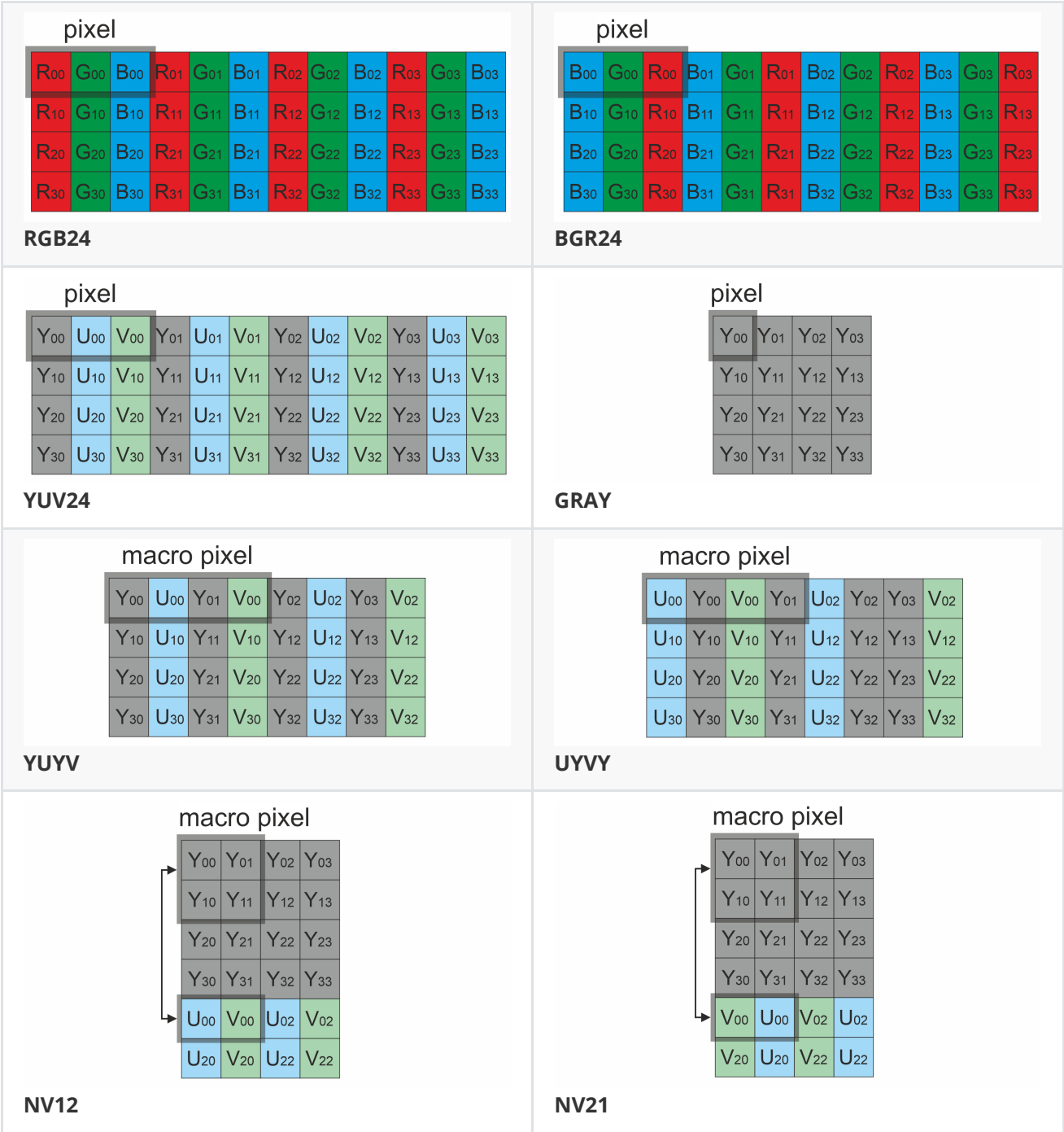
Supported pixel formats

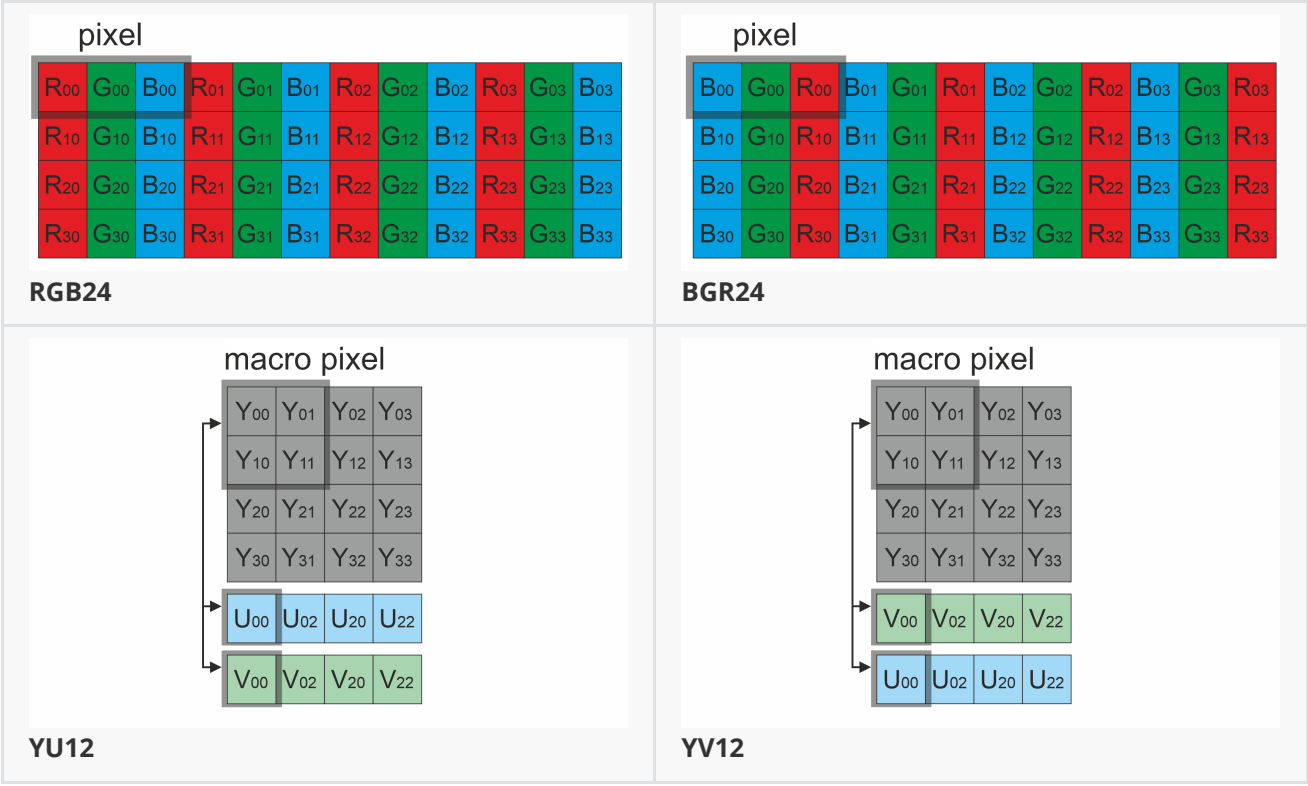
Frame library which included in **DnnOpenVinoDetector** library contains **Fourcc** enum which defines supported pixel formats (**Frame.h** file). **DnnOpenVinoDetector** library supports RAW pixel formats only. The library uses the **GRAY** format for video processing. If the pixel format of the image is different from **GRAY**, the library pre-converts the pixel formats to **GRAY**. **Fourcc** enum declaration:

```
enum class Fourcc
{
    /// RGB 24bit pixel format.
    RGB24 = MAKE_FOURCC_CODE('R', 'G', 'B', '3'),
    /// BGR 24bit pixel format.
    BGR24 = MAKE_FOURCC_CODE('B', 'G', 'R', '3'),
    /// YUYV 16bits per pixel format.
    YUYV  = MAKE_FOURCC_CODE('Y', 'U', 'Y', 'V'),
    /// UYVY 16bits per pixel format.
    UYVY  = MAKE_FOURCC_CODE('U', 'Y', 'V', 'Y'),
    /// Grayscale 8bit.
    GRAY  = MAKE_FOURCC_CODE('G', 'R', 'A', 'Y'),
    /// YUV 24bit per pixel format.
    YUV24  = MAKE_FOURCC_CODE('Y', 'U', 'V', '3'),
    /// NV12 pixel format.
    NV12  = MAKE_FOURCC_CODE('N', 'V', '1', '2'),
    /// NV21 pixel format.
    NV21  = MAKE_FOURCC_CODE('N', 'V', '2', '1'),
    /// YU12 (YUV420) - Planar pixel format.
    YU12 = MAKE_FOURCC_CODE('Y', 'U', '1', '2'),
    /// YV12 (YVU420) - Planar pixel format.
    YV12 = MAKE_FOURCC_CODE('Y', 'V', '1', '2'),
    /// JPEG compressed format.
    JPEG  = MAKE_FOURCC_CODE('J', 'P', 'E', 'G'),
```

```
    /// H264 compressed format.
    H264   = MAKE_FOURCC_CODE('H', '2', '6', '4'),
    /// HEVC compressed format.
    HEVC   = MAKE_FOURCC_CODE('H', 'E', 'V', 'C')
};
```

Table 3 - Bytes layout of supported RAW pixel formats. Example of 4x4 pixels image.





Library Principles

The object detection feature within this library is seamlessly integrated with OpenVINO runtime support, designed to facilitate efficient object detection based on neural network models. The library simplifies the process and provides a straightforward usage sequence for developers. The algorithm primarily consists of the following steps:

1. The library accepts input frames directly and sets proper inputs for compiling neural network model, eliminating the need for any preprocessing.
2. Inference Request is retrieved from compiled model and input frames are forwarded directly into the OpenVINO inference pipeline, utilizing neural network models for object detection.
3. Inference results in output tensor, which is converted (according to detector parameters) to the final vector of objects.
4. Results store not only coordinates but also probability and type - which can be assigned to particular item, according to current network labels.

The library is available in two forms: as source code and as a compiled application. Developers can choose the integration method that best suits their project requirements. The recommended usage sequence for the library is as follows:

1. **Integration**: Include the library files in your project, either by incorporating the source code or linking to the compiled application, depending on your preference and project setup.
2. **Initialization**: Create an instance of the `DnnOpenVinoDetector` C++ class for each camera or input source you wish to process. The library supports multiple instances for parallel camera processing.
3. **Customization (Optional)**: If needed, you can customize the library's behavior by using the `setParam()` method. This allows you to adapt the library to specific requirements.
4. **Object Detection**: Create a `Frame` object to represent the input frame, and prepare a vector to store the detected objects.

5. **Detection Process**: Call the `detect(...)` method to initiate the object detection process. This step leverages OpenVINO's neural network inference capabilities to identify objects within the input frame.
6. **Object Retrieval**: Retrieve the detected objects by using the `getObjects()` method. The library provides a vector of `Objects` containing information about the detected objects, such as their positions and attributes.

DnnOpenVinoDetector class description

DnnOpenVinoDetector class declaration

DnnOpenVinoDetector.h file contains **DnnOpenVinoDetector** class declaration. **DnnOpenVinoDetector** class inherits interface from **ObjectDetector** interface class. Class declaration:

```
class DnnOpenVinoDetector : public ObjectDetector
{
public:
    /// Get string of current library version.
    static std::string getVersion();

    /// Class constructor.
    DnnOpenVinoDetector();

    /// Class destructor.
    ~DnnOpenVinoDetector();

    /// Init object detector.
    bool initObjectDetector(ObjectDetectorParams& params) override;

    /// Set object detector param.
    bool setParam(ObjectDetectorParam id, float value) override;

    /// Get object detector param value.
    float getParam(ObjectDetectorParam id) override;

    /// Get object detector params structure.
    void getParams(ObjectDetectorParams& params);

    /// Get list of objects.
    std::vector<Object> getObjects() override;

    /// Execute command.
    bool executeCommand(ObjectDetectorCommand id) override;

    /// Perform detection.
    bool detect(cr::video::Frame& frame) override;

    /// Set detection mask.
    bool setMask(cr::video::Frame mask) override;

    /// Decode command.
```

```
    bool decodeAndExecuteCommand(uint8_t* data, int size) override;
}
```

getVersion method

getVersion() method returns string of current version of **DnnOpenVinoDetector** class. Method declaration:

```
static std::string getVersion();
```

Method can be used without **DnnOpenVinoDetector** class instance. Example:

```
cout << "DnnOpenVinoDetector version: " << DnnOpenVinoDetector::getVersion() << endl;
```

Console output:

```
DnnOpenVinoDetector version: 1.0.0
```

initObjectDetector method

initObjectDetector(...) method initializes object detector. Inside this method also reading network model takes place, because of that it can consume much time when loading big NN models. Method declaration:

```
bool initObjectDetector(ObjectDetectorParams& params) override;
```

Parameter	Value
params	Object detector parameters class. Object detector should initialize all parameters listed in **ObjectDetectorParams**.

Returns: TRUE if the object detector was initialized or FALSE if not.

setParam method

setParam(...) method designed to set new DnnOpenVinoDetector object parameter value. Method declaration:

```
bool setParam(ObjectDetectorParam id, float value) override;
```

Parameter	Description
id	Parameter ID according to **ObjectDetectorParam** enum.
value	Parameter value. Value depends on parameter ID.

Returns: TRUE if the parameter was set or FALSE if not.

getParam method

getParam(...) method designed to obtain object detector parameter value. Method declaration:

```
float getParam(ObjectDetectorParam id) override;
```

Parameter	Description
id	Parameter ID according to **ObjectDetectorParam** enum.

Returns: parameter value or -1 if the parameter is not supported.

getParams method

getParams(...) method designed to obtain object detector params structures as well a list of detected objects. Method declaration:

```
void getParams(ObjectDetectorParams& params) override;
```

Parameter	Description
params	Object detector params object (ObjectDetectorParams)

getObjects method

getObjects() method designed to obtain list of detected objects. User can object list of detected objects via **getParams(...)** method as well. Method declaration:

```
std::vector<Object> getObjects() override;
```

Returns: list of detected objects (see **Object** class description). If no detected object the list will be empty.

executeCommand method

executeCommand(...) method designed to execute object detector command. Method declaration:

```
bool executeCommand(ObjectDetectorCommand id) override;
```

Parameter	Description
id	Command ID according to **ObjectDetectorCommand** enum.

Returns: TRUE if the command was executed or FALSE if not.

detect method

detect(...) method designed to perform detection algorithm. Method declaration:

```
bool detect(cr::video::Frame& frame) override;
```

Parameter	Description
frame	Video frame for processing. Object detector processes only RAW pixel formats (BGR24, RGB24, GRAY, YUYV24, YUYV, UYVY, NV12, NV21, YV12, YU12, see **Frame** class description). The library uses the GRAY format for video processing. If the pixel format of the image is different from GRAY, the library pre-converts the pixel formats to GRAY.

Returns: TRUE if the video frame was processed FALSE if not. If object detector disabled (see **ObjectDetectorParam** enum description) the method should return TRUE.

setMask method

setMask(...) method designed to set detection mask. The user can disable detection in any areas of the video frame. For this purpose the user can create an image of any size and configuration with GRAY (preferable), NV12, NV21, YV12 or YU12 pixel format. Mask image pixel values equal to 0 prohibit detection of objects in the corresponding place of video frames. Any other mask pixel value other than 0 allows detection of objects at the corresponding location of video frames. The mask is used for detection algorithms to compute a binary motion mask. The method can be called either before video frame processing or during video frame processing. Method declaration:

```
bool setMask(cr::video::Frame mask) override;
```

Parameter	Description
mask	Image of detection mask. Must have GRAY (preferable), NV12, NV21, YV12 or YU12 pixel format. The size and configuration of the mask image can be any. If the size of the mask image differs from the size of processed frames, the mask will be scaled by the library for processing.

Returns: TRUE if the the mask accepted or FALSE if not (not valid pixel format or empty).

decodeAndExecuteCommand method

decodeAndExecuteCommand(...) method decodes and executes command on object detector side. **decodeAndExecuteCommand(...)** is thread-safe method. This means that the **decodeAndExecuteCommand(...)** method can be safely called from any thread. Method declaration:

```
bool decodeAndExecuteCommand(uint8_t* data, int size) override;
```

Parameter	Description
data	Pointer to input command.
size	Size of command. Must be 11 bytes for SET_PARAM or 7 bytes for COMMAND.

Returns: TRUE if command decoded (SET_PARAM or COMMAND) and executed (action command or set param command).

encodeSetParamCommand method

encodeSetParamCommand(...) static method of the **ObjectDetector** interface designed to encode command to change any parameter for remote object detector (including motion detectors). To control object detector remotely, the developer has to design his own protocol and according to it encode the command and deliver it over the communication channel. To simplify this, the **ObjectDetector** class contains static methods for encoding the control command. The **ObjectDetector** class provides two types of commands: a parameter change command (SET_PARAM) and an action command (COMMAND). **encodeSetParamCommand(...)** designed to encode SET_PARAM command. Method declaration:

```
static void encodeSetParamCommand(uint8_t* data, int& size, ObjectDetectorParam id, float value);
```

Parameter	Description
data	Pointer to data buffer for encoded command. Must have size >= 11.
size	Size of encoded data. Will be 11 bytes.
id	Parameter ID according to **ObjectDetectorParam** enum.
value	Parameter value. Value depends on parameter ID.

SET_PARAM command format:

Byte	Value	Description
0	0x01	SET_PARAM command header value.
1	0x01	Major version of ObjectDetector class.
2	0x00	Minor version of ObjectDetector class.
3	id	Parameter ID **int32_t** in Little-endian format.
4	id	Parameter ID **int32_t** in Little-endian format.
5	id	Parameter ID **int32_t** in Little-endian format.
6	id	Parameter ID **int32_t** in Little-endian format.
7	value	Parameter value **float** in Little-endian format.
8	value	Parameter value **float** in Little-endian format.

Byte	Value	Description
9	value	Parameter value **float** in Little-endian format.
10	value	Parameter value **float** in Little-endian format.

encodeSetParamCommand(...) is static and used without **ObjectDetector** class instance. This method used on client side (control system). Command encoding example:

```
// Buffer for encoded data.
uint8_t data[11];
// Size of encoded data.
int size = 0;
// Random parameter value.
float outValue = (float)(rand() % 20);
// Encode command.
ObjectDetector::encodeSetParamCommand(data, size, ObjectDetectorParam::MIN_OBJECT_WIDTH,
outValue);
```

encodeCommand method

encodeCommand(...) static method of the **ObjectDetector** interface designed to encode command for remote object detector (including motion detectors). To control object detector remotely, the developer has to design his own protocol and according to it encode the command and deliver it over the communication channel. To simplify this, the **ObjectDetector** class contains static methods for encoding the control command. The **ObjectDetector** class provides two types of commands: a parameter change command (SET_PARAM) and an action command (COMMAND). **encodeCommand(...)** designed to encode COMMAND (action command). Method declaration:

```
static void encodeCommand(uint8_t* data, int& size, ObjectDetectorCommand id);
```

Parameter	Description
data	Pointer to data buffer for encoded command. Must have size >= 11.
size	Size of encoded data. Will be 11 bytes.
id	Command ID according to **ObjectDetectorCommand** enum.

COMMAND format:

Byte	Value	Description
0	0x00	COMMAND header value.
1	0x01	Major version of ObjectDetector class.
2	0x00	Minor version of ObjectDetector class.
3	id	Command ID **int32_t** in Little-endian format.

Byte	Value	Description
4	id	Command ID **int32_t** in Little-endian format.
5	id	Command ID **int32_t** in Little-endian format.
6	id	Command ID **int32_t** in Little-endian format.

encodeCommand(...) is static and used without **ObjectDetector** class instance. This method used on client side (control system). Command encoding example:

```
// Buffer for encoded data.
uint8_t data[11];
// Size of encoded data.
int size = 0;
// Encode command.
ObjectDetector::encodeCommand(data, size, ObjectDetectorCommand::RESET);
```

decodeCommand method

decodeCommand(...) static method of the **ObjectDetector** interface designed to decode command on object detector side (edge device). Method declaration:

```
static int decodeCommand(uint8_t* data, int size, ObjectDetectorParam& paramId,
ObjectDetectorCommand& commandId, float& value);
```

Parameter	Description
data	Pointer to input command.
size	Size of command. Should be 11 bytes.
paramId	Parameter ID according to **ObjectDetectorParam** enum. After decoding SET_PARAM command the method will return parameter ID.
commandId	Command ID according to **ObjectDetectorCommand** enum. After decoding COMMAND the method will return command ID.
value	Parameter value (after decoding SET_PARAM command).

Returns: 0 - in case decoding COMMAND, **1** - in case decoding SET_PARAM command or **-1** in case errors.

Data structures

ObjectDetectorCommand enum

Enum declaration:

```
enum class ObjectDetectorCommand
{
    /// Reset.
    RESET = 1,
    /// Enable.
    ON,
    /// Disable.
    OFF
};
```

Table 4 - Object detector commands description. Some commands maybe unsupported by particular object detector class.

Command	Description
RESET	Reset algorithm. Clears the list of detected objects and resets all internal filters.
ON	Enable object detector. If the detector is not activated, frame processing is not performed - the list of detected objects will always be empty.
OFF	Disable object detector. If the detector is not activated, frame processing is not performed - the list of detected objects will always be empty.

ObjectDetectorParam enum

Enum declaration:

```
enum class ObjectDetectorParam
{
    /// Logging mode. Values: 0 - Disable, 1 - Only file,
    /// 2 - Only terminal (console), 3 - File and terminal (console).
    LOG_MODE = 1,
    /// Frame buffer size. Depends on implementation.
    FRAME_BUFFER_SIZE,
    /// Minimum object width to be detected, pixels. To be detected object's
    /// width must be >= MIN_OBJECT_WIDTH.
    MIN_OBJECT_WIDTH,
    /// Maximum object width to be detected, pixels. To be detected object's
    /// width must be <= MAX_OBJECT_WIDTH.
    MAX_OBJECT_WIDTH,
    /// Minimum object height to be detected, pixels. To be detected object's
    /// height must be >= MIN_OBJECT_HEIGHT.
    MIN_OBJECT_HEIGHT,
    /// Maximum object height to be detected, pixels. To be detected object's
    /// height must be <= MAX_OBJECT_HEIGHT.
    MAX_OBJECT_HEIGHT,
    /// Minimum object's horizontal speed to be detected, pixels/frame. To be
    /// detected object's horizontal speed must be >= MIN_X_SPEED.
```

```
    MIN_X_SPEED,
    /// Maximum object's horizontal speed to be detected, pixels/frame. To be
    /// detected object's horizontal speed must be <= MAX_X_SPEED.
    MAX_X_SPEED,
    /// Minimum object's vertical speed to be detected, pixels/frame. To be
    /// detected object's vertical speed must be >= MIN_Y_SPEED.
    MIN_Y_SPEED,
    /// Maximum object's vertical speed to be detected, pixels/frame. To be
    /// detected object's vertical speed must be <= MAX_Y_SPEED.
    MAX_Y_SPEED,
    /// Probability threshold from 0 to 1. To be detected object detection
    /// probability must be >= MIN_DETECTION_PROPABILITY.
    MIN_DETECTION_PROPABILITY,
    /// Horizontal track detection criteria, frames. By default shows how many
    /// frames the objects must move in any(+/-) horizontal direction to be
    /// detected.
    X_DETECTION_CRITERIA,
    /// Vertical track detection criteria, frames. By default shows how many
    /// frames the objects must move in any(+/-) vertical direction to be
    /// detected.
    Y_DETECTION_CRITERIA,
    /// Track reset criteria, frames. By default shows how many
    /// frames the objects should be not detected to be excluded from results.
    RESET_CRITERIA,
    /// Detection sensitivity. Depends on implementation. Default from 0 to 1.
    SENSITIVITY,
    /// Frame scaling factor for processing purposes. Reduce the image size by
    /// scaleFactor times horizontally and vertically for faster processing.
    SCALE_FACTOR,
    /// Num threads. Number of threads for parallel computing.
    NUM_THREADS,
    /// Processing time for last frame, mks.
    PROCESSING_TIME_MKS,
    /// Algorithm type. Depends on implementation.
    TYPE,
    /// Mode. Default: 0 - Off, 1 - On.
    MODE,
    /// Custom parameter. Depends on implementation.
    CUSTOM_1,
    /// Custom parameter. Depends on implementation.
    CUSTOM_2,
    /// Custom parameter. Depends on implementation.
    CUSTOM_3
};
```

Table 5 - DnnOpenVinoDetector class params description (from ObjectDetector interface class). Some params may be unsupported by DnnOpenVinoDetector class.

Parameter	Access	Description
LOG_MODE	read / write	Not used. Can have any value.
FRAME_BUFFER_SIZE	read / write	Not used. Can have any value.

Parameter	Access	Description
MIN_OBJECT_WIDTH	read / write	Minimum object width to be detected, pixels. Valid values from 1 to 8192. Must be < MAX_OBJECT_WIDTH. To be detected object's width must be >= MIN_OBJECT_WIDTH. Default value is 4.
MAX_OBJECT_WIDTH	read / write	Maximum object width to be detected, pixels. Valid values from 1 to 8192. Must be > MIN_OBJECT_WIDTH. To be detected object's width must be <= MAX_OBJECT_WIDTH. Default value is 128.
MIN_OBJECT_HEIGHT	read / write	Minimum object height to be detected, pixels. Valid values from 1 to 8192. Must be < MAX_OBJECT_HEIGHT. To be detected object's height must be >= MIN_OBJECT_HEIGHT. Default value is 4.
MAX_OBJECT_HEIGHT	read / write	Maximum object height to be detected, pixels. Valid values from 1 to 8192. Must be > MIN_OBJECT_HEIGHT. To be detected object's height must be <= MAX_OBJECT_HEIGHT. Default value is 128.
MIN_X_SPEED	read / write	Not used. Can have any value.
MAX_X_SPEED	read / write	Not used. Can have any value.
MIN_Y_SPEED	read / write	Not used. Can have any value.
MAX_Y_SPEED	read / write	Not used. Can have any value.
MIN_DETECTION_PROPABILITY	read / write	Defines threshold for object detection probability. Only objects with probability greater than MIN_DETECTION_PROPABILITY will be detected. Can have any values from 0 to 1.
X_DETECTION_CRITERIA	read / write	Not used. Can have any value.
Y_DETECTION_CRITERIA	read / write	Not used. Can have any value.
RESET_CRITERIA	read / write	Not used. Can have any value.
SENSITIVITY	read / write	Not used. Can have any value.
SCALE_FACTOR	read / write	Not used. Can have any value.

Parameter	Access	Description
NUM_THREADS	read / write	Not used. Can have any value.
PROCESSING_TIME_MKS	read only	Not used. Can have any value.
TYPE	read / write	Type defines kind of device for neural network model computation. Default 0 - CPU, 1 - integrated GPU (GPU.0), 2 - separate GPU (GPU.1) 3 - both GPUs (MULTI mode). More information - OpenVinoDevices.
MODE	read / write	Mode. Default: 0 - Off, 1 - On. If the detector is not activated, frame processing is not performed - the list of detected objects will always be empty.
CUSTOM_1	read / write	Not used. Can have any value.
CUSTOM_2	read / write	Not used. Can have any value.
CUSTOM_3	read / write	Not used. Can have any value.

Object structure

Object structure used to describe detected object. Object structure declared in **ObjectDetector.h** file and also included in **ObjectDetectoParams** structure. Structure declaration:

```
typedef struct Object
{
    /// Object ID. Must be uniques for particular object.
    int id{0};
    /// Frame ID. Must be the same as frame ID of processed video frame.
    int frameId{0};
    /// Object type. Depends on implementation.
    int type{0};
    /// Object rectangle width, pixels.
    int width{0};
    /// Object rectangle height, pixels.
    int height{0};
    /// Object rectangle top-left horizontal coordinate, pixels.
    int x{0};
    /// Object rectangle top-left vertical coordinate, pixels.
    int y{0};
    /// Horizontal component of object velocity, +-pixels/frame.
    float vX{0.0f};
    /// Vertical component of object velocity, +-pixels/frame.
    float vY{0.0f};
    /// Detection probability from 0 (minimum) to 1 (maximum).
    float p{0.0f};
```

```
} Object;
```

Table 6 - Object structure fields description.

Field	Type	Description
id	int	Object ID on a current frame.
frameId	int	Frame ID. Will be the same as frame ID of processed video frame.
type	int	Object type according to probability for particular label that was returned from neural network model inference output.
width	int	Object rectangle width, pixels. Must be MIN_OBJECT_WIDTH <= width <= MAX_OBJECT_WIDTH (see **ObjectDetectorParam** enum description).
height	int	Object rectangle height, pixels. Must be MIN_OBJECT_HEIGHT <= height <= MAX_OBJECT_HEIGHT (see **ObjectDetectorParam** enum description).
x	int	Object rectangle top-left horizontal coordinate, pixels.
y	int	Object rectangle top-left vertical coordinate, pixels.
vX	float	Not used. Will have value 0.0f.
vY	float	Not used. Will have value 0.0f.
p	float	Probability value for object label, NOT probability of whole set of labels.

ObjectDetectorParams class description

ObjectDetectorParams class declaration

ObjectDetectorParams class used for object detector initialization (**initObjectDetector(...)** method) or to get all actual params (**getParams()** method) including list of detected objects. Also **ObjectDetectorParams** provides structure to write/read params from JSON files (**JSON_READABLE** macro, see [ConfigReader] class description) and provide methos to encode and decode params. Class declaration:

```
class ObjectDetectorParams
{
public:
    /// Init string. Depends on implementation.
    std::string initString{""};
    /// Logging mode. Values: 0 - Disable, 1 - Only file,
    /// 2 - Only terminal (console), 3 - File and terminal (console).
    int logMode{0};
    /// Frame buffer size. Depends on implementation.
    int frameBufferSize{1};
    /// Minimum object width to be detected, pixels. To be detected object's
    /// width must be >= minObjectWidth.
    int minObjectWidth{4};
```

```
    /// Maximum object width to be detected, pixels. To be detected object's
    /// width must be <= maxObjectWidth.
    int maxObjectWidth{128};
    /// Minimum object height to be detected, pixels. To be detected object's
    /// height must be >= minObjectHeight.
    int minObjectHeight{4};
    /// Maximum object height to be detected, pixels. To be detected object's
    /// height must be <= maxObjectHeight.
    int maxObjectHeight{128};
    /// Minimum object's horizontal speed to be detected, pixels/frame. To be
    /// detected object's horizontal speed must be >= minXSpeed.
    float minXSpeed{0.0f};
    /// Maximum object's horizontal speed to be detected, pixels/frame. To be
    /// detected object's horizontal speed must be <= maxXSpeed.
    float maxXSpeed{30.0f};
    /// Minimum object's vertical speed to be detected, pixels/frame. To be
    /// detected object's vertical speed must be >= minYSpeed.
    float minYSpeed{0.0f};
    /// Maximum object's vertical speed to be detected, pixels/frame. To be
    /// detected object's vertical speed must be <= maxYSpeed.
    float maxYSpeed{30.0f};
    /// Probability threshold from 0 to 1. To be detected object detection
    /// probability must be >= minDetectionProbability.
    float minDetectionProbability{0.5f};
    /// Horizontal track detection criteria, frames. By default shows how many
    /// frames the objects must move in any(+/-) horizontal direction to be
    /// detected.
    int xDetectionCriteria{1};
    /// Vertical track detection criteria, frames. By default shows how many
    /// frames the objects must move in any(+/-) vertical direction to be
    /// detected.
    int yDetectionCriteria{1};
    /// Track reset criteria, frames. By default shows how many
    /// frames the objects should be not detected to be excluded from results.
    int resetCriteria{1};
    /// Detection sensitivity. Depends on implementation. Default from 0 to 1.
    float sensitivity{0.04f};
    /// Frame scaling factor for processing purposes. Reduce the image size by
    /// scaleFactor times horizontally and vertically for faster processing.
    int scaleFactor{1};
    /// Num threads. Number of threads for parallel computing.
    int numThreads{1};
    /// Processing time for last frame, mks.
    int processingTimeMks{0};
    /// Algorithm type. Depends on implementation.
    int type{0};
    /// Mode. Default: false - Off, on - On.
    bool enable{true};
    /// Custom parameter. Depends on implementation.
    float custom1{0.0f};
    /// Custom parameter. Depends on implementation.
    float custom2{0.0f};
    /// Custom parameter. Depends on implementation.
    float custom3{0.0f};
    /// List of detected objects.
```

```
    std::vector<Object> objects;

    JSON_READABLE(ObjectDetectorParams, initString, logMode, frameBufferSize,
                  minObjectWidth, maxObjectWidth, minObjectHeight, maxObjectHeight,
                  minXSpeed, maxXSpeed, minYSpeed, maxYSpeed, minDetectionProbability,
                  xDetectionCriteria, yDetectionCriteria, resetCriteria, sensitivity,
                  scaleFactor, numThreads, type, enable, custom1, custom2, custom3);
    /**
     * @brief operator =
     * @param src Source object.
     * @return ObjectDetectorParams object.
     */
    ObjectDetectorParams& operator= (const ObjectDetectorParams& src);
    /**
     * @brief Encode params. Method doesn't encode initString.
     * @param data Pointer to data buffer.
     * @param size Size of data.
     * @param mask Pointer to parameters mask.
     */
    void encode(uint8_t* data, int& size,
                ObjectDetectorParamsMask* mask = nullptr);
    /**
     * @brief Decode params. Method doesn't decode initString;
     * @param data Pointer to data.
     * @return TRUE is params decoded or FALSE if not.
     */
    bool decode(uint8_t* data);
};
```

Table 7 - ObjectDetectorParams class fields description. Some params may be unsupported by DnnOpenVinoDetector class.

Field	Type	Description
initString	string	Has to include path to neural network model that is supported by OpenVino and has standard one-batch layout. Also has to include dimension (width;height) of neural network input images, everything separated by semicolon. E.g.: "./model.onnx;640;640". If neural network model consists of 2 files it should be as this exmaple: "./model.xml;./model.bin;256;480".
logMode	int	Not used. Can have any value.
frameBufferSize	int	Not used. Can have any value.
minObjectWidth	int	Minimum object width to be detected, pixels. Valid values from 1 to 8192. Must be < maxObjectWidth. To be detected object's width must be >= minObjectWidth. Default value is 4.

Field	Type	Description
maxObjectWidth	int	Maximum object width to be detected, pixels. Valid values from 1 to 8192. Must be > minObjectWidth. To be detected object's width must be <= maxObjectWidth. Default value is 128.
minObjectHeight	int	Minimum object height to be detected, pixels. Valid values from 1 to 8192. Must be < maxObjectHeight. To be detected object's height must be >= minObjectHeight. Default value is 4.
maxObjectHeight	int	Maximum object height to be detected, pixels. Valid values from 1 to 8192. Must be > minObjectHeight. To be detected object's height must be <= maxObjectHeight. Default value is 128.
minXSpeed	float	Not used. Can have any value.
maxXSpeed	float	Not used. Can have any value.
minYSpeed	float	Not used. Can have any value.
maxYSpeed	float	Not used. Can have any value.
minDetectionProbability	float	Defines threshold for object detection probability. Only objects with probability greater than MIN_DETECTION_PROPABILITY will be detected. Can have any values from 0 to 1.
xDetectionCriteria	int	Not used. Can have any value.
yDetectionCriteria	int	Not used. Can have any value.
resetCriteria	int	Not used. Can have any value.
sensitivity	float	Not used. Can have any value.
scaleFactor	int	Not used. Can have any value.
numThreads	int	Not used. Can have any value.
processingTimeMks	int	Not used. Can have any value.
type	int	Type defines kind of device for neural network model computation. Default 0 - CPU, 1 - integrated GPU (GPU.0), 2 - separate GPU (GPU.1) 3 - both GPUs (MULTI mode). More information - OpenVinoDevices.
enable	bool	Mode: false - Off, true - On. If the detector is not activated, frame processing is not performed - the list of detected objects will always be empty.
custom1	float	Not used. Can have any value.
custom2	float	Not used. Can have any value.

Field	Type	Description
custom3	float	Not used. Can have any value.
objects	std::vector	List of detected objects.

Note: *ObjectDetectorParams class fields listed in Table 7* ***must*** *reflect params set/get by methods setParam(...) and getParam(...).*

Serialize object detector params

ObjectDetectorParams class provides method **encode(...)** to serialize object detector params (fields of ObjectDetectorParams class, see Table 5). Serialization of object detector params necessary in case when you need to send params via communication channels. Method provides options to exclude particular parameters from serialization. To do this method inserts binary mask (3 bytes) where each bit represents particular parameter and **decode(...)** method recognizes it. Method doesn't encode initString. Method declaration:

```
void encode(uint8_t* data, int dataBufferSize, int& size, ObjectDetectorParamsMask* mask
= nullptr);
```

Parameter	Value
data	Pointer to data buffer. Buffer size should be at least **99** bytes.
dataBufferSize	Size of data buffer. If the data buffer size is not large enough to serialize all detected objects (40 bytes per object), not all objects will be included in the data.
size	Size of encoded data. 99 bytes by default.
mask	Parameters mask - pointer to **ObjectDetectorParamsMask** structure. **ObjectDetectorParamsMask** (declared in ObjectDetector.h file) determines flags for each field (parameter) declared in **ObjectDetectorParams** class. If the user wants to exclude any parameters from serialization, he can put a pointer to the mask. If the user wants to exclude a particular parameter from serialization, he should set the corresponding flag in the ObjectDetectorParamsMask structure.

ObjectDetectorParamsMask structure declaration:

```
typedef struct ObjectDetectorParamsMask
{
    bool logMode{true};
    bool frameBufferSize{true};
    bool minObjectWidth{true};
    bool maxObjectWidth{true};
    bool minObjectHeight{true};
    bool maxObjectHeight{true};
    bool minXSpeed{true};
    bool maxXSpeed{true};
    bool minYSpeed{true};
    bool maxYSpeed{true};
```

```
    bool minDetectionProbability{true};
    bool xDetectionCriteria{true};
    bool yDetectionCriteria{true};
    bool resetCriteria{true};
    bool sensitivity{true};
    bool scaleFactor{true};
    bool numThreads{true};
    bool processingTimeMks{true};
    bool type{true};
    bool enable{true};
    bool custom1{true};
    bool custom2{true};
    bool custom3{true};
    bool objects{true};
} ObjectDetectorParamsMask;
```

Example without parameters mask:

```
// Prepare random params.
ObjectDetectorParams in;
in.logMode = rand() % 255;
in.objects.clear();
for (int i = 0; i < 5; ++i)
{
    Object obj;
    obj.id = rand() % 255;
    obj.type = rand() % 255;
    obj.width = rand() % 255;
    obj.height = rand() % 255;
    obj.x = rand() % 255;
    obj.y = rand() % 255;
    obj.vX = rand() % 255;
    obj.vY = rand() % 255;
    obj.p = rand() % 255;
    in.objects.push_back(obj);
}

// Encode data.
uint8_t data[1024];
int size = 0;
in.encode(data, size);
cout << "Encoded data size: " << size << " bytes" << endl;
```

Example with parameters mask:

```
// Prepare random params.
ObjectDetectorParams in;
in.logMode = rand() % 255;
in.objects.clear();
for (int i = 0; i < 5; ++i)
{
    Object obj;
    obj.id = rand() % 255;
    obj.type = rand() % 255;
```

```
    obj.width = rand() % 255;
    obj.height = rand() % 255;
    obj.x = rand() % 255;
    obj.y = rand() % 255;
    obj.vX = rand() % 255;
    obj.vY = rand() % 255;
    obj.p = rand() % 255;
    in.objects.push_back(obj);
}

// Prepare mask.
ObjectDetectorParamsMask mask;
mask.logMode = false;

// Encode data.
uint8_t data[1024];
int size = 0;
in.encode(data, size, &mask)
cout << "Encoded data size: " << size << " bytes" << endl;
```

Deserialize object detector params

ObjectDetectorParams class provides method **decode(...)** to deserialize params (fields of ObjectDetectorParams class, see Table 5). Deserialization of params necessary in case when you need to receive params via communication channels. Method automatically recognizes which parameters were serialized by **encode(...)** method. Method doesn't decode initString. Method declaration:

```
bool decode(uint8_t* data);
```

Parameter	Value
data	Pointer to encode data buffer.

Returns: TRUE if data decoded (deserialized) or FALSE if not.

Example:

```
// Prepare random params.
ObjectDetectorParams in;
in.logMode = rand() % 255;
for (int i = 0; i < 5; ++i)
{
    Object obj;
    obj.id = rand() % 255;
    obj.type = rand() % 255;
    obj.width = rand() % 255;
    obj.height = rand() % 255;
    obj.x = rand() % 255;
    obj.y = rand() % 255;
    obj.vX = rand() % 255;
    obj.vY = rand() % 255;
    obj.p = rand() % 255;
```

```
    in.objects.push_back(obj);
}

// Encode data.
uint8_t data[1024];
int size = 0;
in.encode(data, size);
cout << "Encoded data size: " << size << " bytes" << endl;

// Decode data.
ObjectDetectorParams out;
if (!out.decode(data))
{
    cout << "Can't decode data" << endl;
    return false;
}
```

Read params from JSON file and write to JSON file

ObjectDetector library depends on **ConfigReader** library which provides method to read params from JSON file and to write params to JSON file. Example of writing and reading params to JSON file:

```
// Prepare random params.
ObjectDetectorParams in;
in.logMode = rand() % 255;
in.objects.clear();
for (int i = 0; i < 5; ++i)
{
    Object obj;
    obj.id = rand() % 255;
    obj.type = rand() % 255;
    obj.width = rand() % 255;
    obj.height = rand() % 255;
    obj.x = rand() % 255;
    obj.y = rand() % 255;
    obj.vX = rand() % 255;
    obj.vY = rand() % 255;
    obj.p = rand() % 255;
    in.objects.push_back(obj);
}

// Write params to file.
cr::utils::ConfigReader inConfig;
inConfig.set(in, "ObjectDetectorParams");
inConfig.writeToFile("ObjectDetectorParams.json");

// Read params from file.
cr::utils::ConfigReader outConfig;
if(!outConfig.readFromFile("ObjectDetectorParams.json"))
{
    cout << "Can't open config file" << endl;
    return false;
}
```

```
ObjectDetectorParams out;
if(!outConfig.get(out, "ObjectDetectorParams"))
{
    cout << "Can't read params from file" << endl;
    return false;
}
```

ObjectDetectorParams.json will look like:

```
{
    "ObjectDetectorParams": {
        "custom1": 57.0,
        "custom2": 244.0,
        "custom3": 68.0,
        "enable": false,
        "frameBufferSize": 200,
        "initString": "sfsfsfsfsf",
        "logMode": 111,
        "maxObjectHeight": 103,
        "maxObjectWidth": 199,
        "maxXSpeed": 104.0,
        "maxYSpeed": 234.0,
        "minDetectionProbability": 53.0,
        "minObjectHeight": 191,
        "minObjectWidth": 149,
        "minXSpeed": 213.0,
        "minYSpeed": 43.0,
        "numThreads": 33,
        "resetCriteria": 62,
        "scaleFactor": 85,
        "sensitivity": 135.0,
        "type": 178,
        "xDetectionCriteria": 224,
        "yDetectionCriteria": 199
    }
}
```

Build and connect to your project

On Windows

Start with cloning **DnnOpenVinoDetector** to your local directory on Windows:

```
git clone https://github.com/ConstantRobotics-Ltd/DnnOpenVinoDetector.git
cd DnnOpenVinoDetector
git submodule update --init --recursive
```

Necessary step before building **DnnOpenVinoDetector** library is to download **OpenVino** runtime library. Current tested and working perfectly with **DnnOpenVinoDetector** library **OpenVino** runtime library version is **2022.3.1**. DOCS

Steps for connecting OpenVino to **DnnOpenVinoDetector** project:

1. Create directory "C:\Program Files (x86)\Intel".
2. Download OpenVINO compressed library from this link -> LINK
3. Extract .zip file to "C:\Program Files (x86)\Intel" and rename extracted folder to 'openvino'.
4. Add paths to Path in "Edit the system environment variables":

```
- C:\Program Files (x86)\Intel\openvino\runtime\bin\intel64\Release
- C:\Program Files (x86)\Intel\openvino\runtime\bin\intel64\Debug
- C:\Program Files (x86)\Intel\openvino\runtime\3rdparty\tbb\bin
- C:\Program Files (x86)\Intel\openvino\runtime\3rdparty\hddl\bin
```

5. Run the 'cmake' command while specifying the location of the OpenVino CMake configuration and build the entire solution:

```
mkdir build
cd build
cmake .. -D CMAKE_PREFIX_PATH=/opt/intel/openvino_2022.3.1/runtime/cmake
make
```

On Linux

Start with cloning **DnnOpenVinoDetector** to your local directory on Linux:

```
git clone https://github.com/ConstantRobotics-Ltd/DnnOpenVinoDetector.git
cd DnnOpenVinoDetector
git submodule update --init --recursive
```

Necessary step before building **DnnOpenVinoDetector** library is to download **OpenVino** runtime library. Current tested and working perfectly with **DnnOpenVinoDetector** library **OpenVino** runtime library version is **2022.3.1**. DOCS

1. Make sure you have the latest updates.

   ```
   sudo apt-get update
   sudo apt-get upgrade
   ```

2. Get OpenVINO 2022.0 and place it in opt/intel directory.

   ```
   cd <user_home>/Downloads
   sudo apt-get install curl
   curl -L
   https://storage.openvinotoolkit.org/repositories/openvino/packages/2022.3.1/linux/l_o
   penvino_toolkit_ubuntu20_2022.3.1.9227.cf2c7da5689_x86_64.tgz --output
   openvino_2022.3.1.tgz
   tar -xf openvino_2022.3.1.tgz
   sudo mkdir /opt/intel
   sudo mv l_openvino_toolkit_ubuntu20_2022.3.1.9227.cf2c7da5689_x86_64
   /opt/intel/openvino_2022.3.1
   ```

3. Install required system dependencies on Linux.

```
cd /opt/intel/openvino_2022.3.1
sudo -E ./install_dependencies/install_openvino_dependencies.sh
```

4. Configure the environment.

```
source /opt/intel/openvino_2022.3.1/setupvars.sh
```

5. Add libs for GPU devices.

```
sudo apt-get install -y ocl-icd-libopencl1 intel-opencl-icd
```

6. Run cmake command with pointing where OpenVino cmake is placed and build whole solution:

```
cd <project_dir>/DnnOpenVinoDetector/
mkdir build
cd build
cmake .. -D CMAKE_PREFIX_PATH=/opt/intel/openvino_2022.3.1/runtime/cmake
make
```

Connect as source code

If you want to connect **DnnOpenVinoDetector** library to your CMake project as source code, you can do the following. For example, if your repository has structure:

```
CMakeLists.txt
src
    CMakeList.txt
    yourLib.h
    yourLib.cpp
```

You can add repository **DnnOpenVinoDetector** as git submodule by commands (only if you have access to GitHub repository):

```
cd <your respository folder>
git submodule add https://github.com/ConstantRobotics-Ltd/DnnOpenVinoDetector.git
3rdparty/DnnOpenVinoDetector
git submodule update --init --recursive
```

In your repository folder, a new **3rdparty/DnnOpenVinoDetector** folder will be created, which contains files from **DnnOpenVinoDetector** repository along with its subrepository **ObjectDetector** and its subrepositories **Frame** and **ConfigReader**. If you don't have access to GitHub repository, copy **DnnOpenVinoDetector** repository folder to **3rdparty** folder to your repository. Remember to add OpenVino library as above. The new structure of your repository will be as follows:

```
CMakeLists.txt
src
    CMakeList.txt
    yourLib.h
    yourLib.cpp
3rdparty
    DnnOpenVinoDetector
```

Create CMakeLists.txt file in **3rdparty** folder. CMakeLists.txt should be containing:

```
cmake_minimum_required(VERSION 3.13)

###############################################################################
## 3RD-PARTY
## dependencies for the project
###############################################################################
project(3rdparty LANGUAGES CXX)

###############################################################################
## SETTINGS
## basic 3rd-party settings before use
###############################################################################
# To inherit the top-level architecture when the project is used as a submodule.
SET(PARENT ${PARENT}_YOUR_PROJECT_3RDPARTY)
# Disable self-overwriting of parameters inside included subdirectories.
SET(${PARENT}_SUBMODULE_CACHE_OVERWRITE OFF CACHE BOOL "" FORCE)

###############################################################################
## CONFIGURATION
## 3rd-party submodules configuration
###############################################################################
SET(${PARENT}_SUBMODULE_DNN_OPENVINO_DETECTOR           ON  CACHE BOOL "" FORCE)
if (${PARENT}_SUBMODULE_DNN_OPENVINO_DETECTOR)
    SET(${PARENT}_DNN_OPENVINO_DETECTOR                 ON  CACHE BOOL "" FORCE)
    SET(${PARENT}_DNN_OPENVINO_DETECTOR_TEST            OFF CACHE BOOL "" FORCE)
    SET(${PARENT}_DNN_OPENVINO_DETECTOR_DEMO_APP        OFF CACHE BOOL "" FORCE)
    SET(${PARENT}_DNN_OPENVINO_DETECTOR_EXAMPLE         OFF CACHE BOOL "" FORCE)
endif()

###############################################################################
## INCLUDING SUBDIRECTORIES
## Adding subdirectories according to the 3rd-party configuration
###############################################################################
if (${PARENT}_SUBMODULE_DNN_OPENVINO_DETECTOR)
    add_subdirectory(DnnOpenVinoDetector)
endif()
```

File **3rdparty/CMakeLists.txt** adds folder **DnnOpenVinoDetector** to your project and excludes test applications and examples from compiling. The new structure of your repository will be:

```
CMakeLists.txt
src
    CMakeList.txt
    yourLib.h
    yourLib.cpp
3rdparty
    CMakeLists.txt
    Ged
```

Next, you need to include the '3rdparty' folder in the main **CMakeLists.txt** file of your repository. Add the following string at the end of your main **CMakeLists.txt**:

```
add_subdirectory(3rdparty)
```

Next, you have to include DnnOpenVinoDetector library in your **src/CMakeLists.txt** file:

```
target_link_libraries(${PROJECT_NAME} DnnOpenVinoDetector)
```

Done!

Simple example

A simple application shows how to use the DnnOpenVinoDetector library. The application opens a video file "test.mp4" and copies the video frame data into an object of the Frame class and performs objects detection.

```
#include <opencv2/opencv.hpp>
#include "DnnOpenVinoDetector.h"

int main(void)
{
    // Open video file "test.mp4".
    cv::VideoCapture videoSource;
    if (!videoSource.open("./video/test.mp4"))
        return -1;

    // Create detector and set params.
    cr::detector::DnnOpenVinoDetector detector;
    cr::detector::ObjectDetectorParams params;
    params.initString = "./model/yolov5n.onnx;640;640";
    params.maxObjectHeight = 96;
    params.maxObjectWidth = 96;
    params.minObjectHeight = 4;
    params.minObjectHeight = 4;
    params.type = 1;
    detector.initObjectDetector(params);

    // Create frames.
    cv::Mat frameBgrOpenCv;
    cr::video::Frame frameBgr =
    cr::video::Frame((int)videoSource.get(cv::CAP_PROP_FRAME_WIDTH),
```

```
                    (int)videoSource.get(cv::CAP_PROP_FRAME_HEIGHT),
                    cr::video::Fourcc::BGR24);

    // Main loop.
    while (true)
    {
        // Capture next video frame.
        videoSource >> frameBgrOpenCv;
        if (frameBgrOpenCv.empty())
        {
            // If we have video file we can set initial position to replay.
            detector.executeCommand(cr::detector::ObjectDetectorCommand::RESET);
            videoSource.set(cv::CAP_PROP_POS_FRAMES, 0);
            continue;
        }

        // Copy frame data from OpenCv frame to Frame.
        memcpy(frameBgr.data, frameBgrOpenCv.data, frameBgr.size);

        // Detect objects.
        detector.detect(frameBgr);

        // Get list of objects.
        std::vector<cr::detector::Object> objects = detector.getObjects();

        // Draw detected objects.
        for (int n = 0; n < objects.size(); ++n)
        {
            rectangle(frameBgrOpenCv, cv::Rect(objects[n].x, objects[n].y,
                      objects[n].width, objects[n].height),
                      cv::Scalar(0, 0, 255), 1);
            putText(frameBgrOpenCv, std::to_string(objects[n].p),
                    cv::Point(objects[n].x, objects[n].y),
                    1, 1, cv::Scalar(0, 0, 255));
        }

        // Show video.
        cv::imshow("VIDEO", frameBgrOpenCv);
        // Wait ESC.
        if (cv::waitKey(1) == 27)
            return -1;
    }

    return 1;
}
```