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**CCTag**

**AliceVision**

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# INSTALL

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This library provides the code for the detection of CCTag markers made up of concentric circles [CGGG16]. CCTag markers are a robust, highly accurate fiducial system that can be robustly localized in the image even under challenging conditions. The library can efficiently detect the position of the image of the (common) circle center and identify the marker based on the different ratio of their crown sizes.

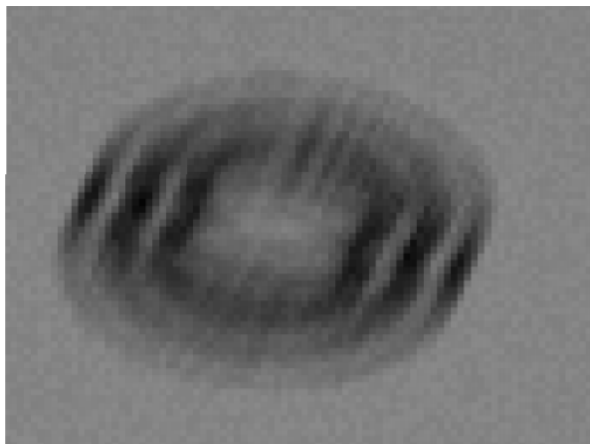


An example of three different CCTag markers with three crowns. Each marker can be uniquely identified thanks to the thickness of each crown, which encodes the information of the marker, typically a unique ID.

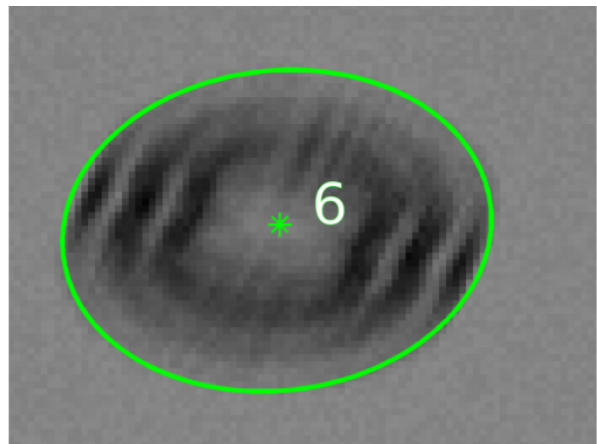
The implementation is done in both CPU and GPU (Cuda-enabled cards). The GPU implementation can reach real-time performances on full HD images.



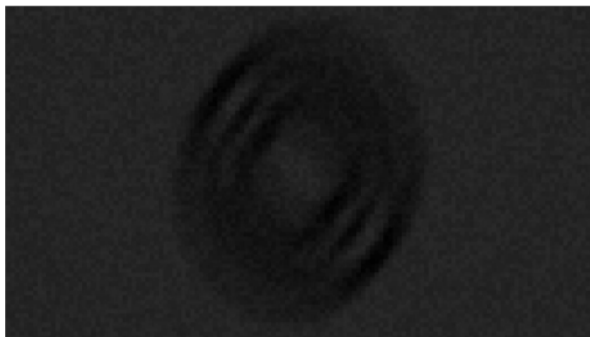
### EXAMPLE OF DETECTION IN CHALLENGING CONDITIONS



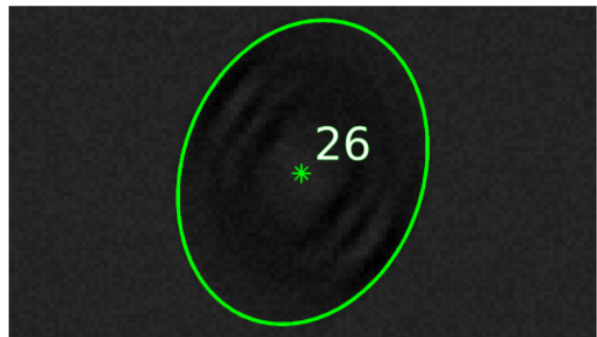
(a)



(b)



(c)



(d)

Examples of synthetic images of circular fiducials under very challenging shooting conditions i.e., perturbed, in particular, by a (unidirectional) motion blur of magnitude 15px. The markers are correctly detected and identified (b,d) with an accuracy of 0.54px and 0.36px resp. in (a) and (c) for the estimated imaged center of the outer ellipse whose semi-major axis (in green) is equal to 31.9px and 34.5px resp.





## COMPARISON WITH ARTOOLKITPLUS

The video shows the effectiveness and the robustness of the detection compared to the ARToolKitPlus [WS07]. ARTK-Plus is, among all the available open-source solutions, one achieving better performances in terms of detection rate and computational time.

In the video, 4 markers for each solution are placed on a plane at known positions, so that the relevant plane-induced homography can be estimated. For ARTKPlus once all the markers are detected and identified, the homography is estimated using all the detected marker corners following a DLT approach [HZ04] (note that the homography can be then estimated even if only one marker is detected). For CCTAG, the image of the four centres of the concentric circles is used to compute the homography.

The image placed in between the markers can be then rectified in order to visually assess the quality of the estimated homography. Thanks to the accurate estimation of the image of the four centres of the concentric circles provided by CCTag, the homography can be robustly estimated and the rectified image is not affected by any significant jittering, whereas the rectified image computed with the ARTKPlus homography is more unstable. Moreover, the video shows that the proposed method allows detecting the marker even in very challenging conditions, such as severe motion blur and sudden illumination changes.

## 2.1 Requirements

### 2.1.1 Hardware

CCTag has a CPU and a GPU implementation. The GPU implementation requires an NVIDIA GPU card with a CUDA compute capability  $\geq 3.5$ . You can check your NVIDIA GPU card [CC support here](#) or on the [NVIDIA dev page](#). If you do not have a NVIDIA card you will still be able to compile and use the CPU version.

Here are the minimum hardware requirements for CCTag:

Minimum requirements	
Operating systems	Windows x64, Linux, macOS
CPU	Recent Intel or AMD cpus
RAM Memory	8 GB
Hard Drive	No particular requirements
GPU	NVIDIA CUDA-enabled GPU (compute capability $\geq 3.5$ )

### 2.1.2 Software

CCTag depends on the following libraries:

- Eigen3  $\geq$  3.3.4
- Boost  $\geq$  1.66
- OpenCV  $\geq$  3.1
- TBB  $\geq$  4.0

**Warning:** In order to have Cuda support on Windows, at least Eigen 3.3.9 is required

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## 2.2 vcpkg

vcpkg is a cross-platform (Windows, Linux and MacOS), open-source package manager created by Microsoft.

We are planning to release a port of the library so that it can be easily built using the package manager. Stay tuned!

---

## 2.3 Building the library

### 2.3.1 Building tools

Required tools:

- CMake  $\geq$  3.14 to build the code
- Git
- C/C++ compiler supporting the C++11 standard (gcc  $\geq$  4.6 or visual studio or clang)

Optional tool:

- CUDA  $\geq$  7.0 (CUDA 7.5 is currently not recommended)

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**Note:** On Windows, there are compatibility issues to build the GPU part due to conflicts between msvc/nvcc/thrust/eigen/boost.

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### 2.3.2 Dependencies

#### vcpkg

vcpkg can be used to install all the dependencies on all the supported platforms. This is particularly useful on Windows. To install the dependencies:

```
vcpkg install
  boost-accumulators
  boost-algorithm
  boost-container
  boost-date-time
  boost-exception
  boost-filesystem
  boost-iterator
  boost-lexical-cast
  boost-math
  boost-mpl
  boost-multi-array
  boost-ptr-container
  boost-program-options
  boost-serialization
  boost-spirit
  boost-static-assert
  boost-stacktrace
  boost-test
  boost-thread
  boost-throw-exception
  boost-timer
  boost-type-traits
  boost-unordered
  opencv
  tbb
  eigen3
```

You can add the flag `--triplet` to specify the architecture and the version you want to build. For example:

- `--triplet x64-windows` will build the dynamic version for Windows 64 bit
- `--triplet x64-windows-static` will build the static version for Windows 64 bit
- `--triplet x64-linux-dynamic` will build the dynamic version for Linux 64 bit

and so on. More information can be found [here](#)

## Linux

On Linux you can install from the package manager:

For Ubuntu/Debian package system:

```
sudo apt-get install g++ git-all libpng12-dev libjpeg-dev libeigen3-dev libboost-all-
↳dev libtbb-dev
```

For CentOS package system:

```
sudo yum install gcc-c++ git libpng-devel libjpeg-turbo-devel eigen3-devel boost-
↳devel tbb-devel
```

### MacOS

On MacOS using [Homebrew](#) install the following packages:

```
brew install git libpng libjpeg eigen boost tbb
```

### 2.3.3 Getting the sources

```
git clone https://github.com/alicevision/CCTag.git
```

### 2.3.4 CMake configuration

From CCTag root folder you can run cmake:

```
mkdir build && cd build
cmake ..
make -j `nproc`
```

On Windows add `-G "Visual Studio 16 2019" -A x64` to generate the Visual Studio solution according to your VS version (see [CMake documentation](#)).

If you are using the dependencies built with VCPKG you need to pass `-DCMAKE_TOOLCHAIN_FILE=path/to/vcpkg/scripts/buildsystems/vcpkg.cmake` at cmake step to let it know where to find the dependencies.

Otherwise you can specify the path where each dependency can be found (if not installed in system folders) by passing its related path. For example, for OpenCV you can pass `-DOpenCV_DIR=path/to/opencv/install/share/opencv/` to tell where the `OpenCVConfig.cmake` file can be found.

### CMake options

CMake configuration can be controlled by changing the values of the following variables (here with their default value)

- `CCTAG_WITH_CUDA:BOOL=ON` to enable/disable the Cuda implementation
- `BUILD_SHARED_LIBS:BOOL=ON` to enable/disable the building shared libraries
- `CCTAG_ENABLE_SIMD_AVX2:BOOL=OFF` to enable/disable the AVX2 optimizations
- `CCTAG_BUILD_TESTS:BOOL=OFF` to enable/disable the building of the unit tests
- `CCTAG_BUILD_APPS:BOOL=ON` to enable/disable the building of applications
- `CCTAG_BUILD_DOC:BOOL=OFF` to enable/disable building this documentation

So if you do not want to build the Cuda part, you have to pass `-DCCTAG_WITH_CUDA:BOOL=OFF` and so on.

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## 2.4 CCTag as third party

When you install CCTag a file CCTagConfig.cmake is installed in `<install_prefix>/lib/cmake/CCTag/` that allows you to import the library in your CMake project. In your CMakeLists.txt file you can add the dependency in this way:

```

1 # Find the package from the CCTagConfig.cmake
2 # in <prefix>/lib/cmake/CCTag/. Under the namespace CCTag::
3 # it exposes the target CCTag that allows you to compile
4 # and link with the library
5 find_package(CCTag CONFIG REQUIRED)
6 ...
7 # suppose you want to try it out in a executable
8 add_executable(cctagtest yourfile.cpp)
9 # add link to the library
10 target_link_libraries(cctagtest PUBLIC CCTag::CCTag)

```

Then, in order to build just pass the location of CCTagConfig.cmake from the cmake command line:

```
cmake .. -DCCTag_DIR=$CCTAG_INSTALL/lib/cmake/CCTag/
```

## 2.5 Docker image

A docker image can be built using the Ubuntu based Dockerfile, which is based on nvidia/cuda image (<https://hub.docker.com/r/nvidia/cuda/>)

### 2.5.1 Building the dependency image

We provide a Dockerfile\_deps containing a cuda image with all the necessary CCTag dependencies installed.

A parameter CUDA\_TAG can be passed when building the image to select the cuda version. Similarly, OS\_TAG can be passed to select the Ubuntu version. By default, CUDA\_TAG=10.2 and OS\_TAG=18.04

For example to create the dependency image based on ubuntu 18.04 with cuda 8.0 for development, use

```
docker build --build-arg CUDA_TAG=8.0 --tag alicevision/cctag-deps:cuda8.0-ubuntu18.04 -f Dockerfile_deps .
```

The complete list of available tags can be found on the nvidia [dockerhub page](<https://hub.docker.com/r/nvidia/cuda/>)

### 2.5.2 Building the CCTag image

Once you built the dependency image, you can build the cctag image in the same manner using Dockerfile:

```
docker build --tag alicevision/cctag:cuda8.0-ubuntu18.04 .
```

### 2.5.3 Running the CCTag image

In order to run the image nvidia docker is needed: see the [installation instruction](#). Once installed, the docker can be run, e.g., in interactive mode with

```
docker run -it --runtime=nvidia alicevision/cctag:cuda8.0-ubuntu18.04
```

### 2.5.4 Official images on DockerHub

Check the docker hub [CCTag repository](#) for the available images.

## 2.6 Library usage

Detecting the markers requires three main entities:

- the class `cctag::CCTag` modeling a single marker
- and the functions `cctag::cctagDetection()` to process the images and get the list of detected markers.
- the struct `cctag::Parameters` that control the detection algorithm through the various parameters that it exposes.

### 2.6.1 Detection

Here is a minimal sample of code that enable CCTag detection on an image:

```
1 // set up the parameters
2 const std::size_t nCrowns{3};
3 cctag::Parameters params(nCrowns);
4 // if you want to use GPU
5 params.setUseCuda(true);
6
7 // load the image e.g. from file
8 cv::Mat src = cv::imread(image_filename);
9 cv::Mat graySrc;
10 cv::cvtColor(src, graySrc, CV_BGR2GRAY);
11
12 // choose a cuda pipe
13 const int pipeId{0};
14
15 // an arbitrary id for the frame
16 const int frameId{0};
17
18 // process the image
19 boost::ptr_list<ICCTag> markers{};
20 cctagDetection(markers, pipeId, frameId, graySrc, params);
```

@TODO maybe explain what cuda pipe means

## 2.6.2 Process detected markers

Here is a simple example on how to process the detected markers. The function `drawMarkers` takes the list of detected markers and it overlay their information on the original image. From the list of markers, if the detected marker is valid it draws the center of the marker, its ID and the outer ellipse `cctag::numerical::geometry::Ellipse`, all in green. If the marker is not valid, draw the center and the ID in red.

```

1 void drawMarkers(const boost::ptr_list<ICCTag>& markers, cv::Mat& image)
2 {
3     // drawing settings
4     const int radius{10};
5     const int fontSize{3};
6     const int thickness{3};
7     const int fontFace{cv::FONT_HERSHEY_SIMPLEX};
8
9     for(const auto& marker : markers)
10    {
11        // center of the marker
12        const cv::Point center = cv::Point(marker.x(), marker.y());
13        const auto rescaledOuterEllipse = marker.rescaledOuterEllipse();
14
15        // check the status and draw accordingly, green for valid, red otherwise
16        if(marker.getStatus() == status::id_reliable)
17        {
18            const cv::Scalar color = cv::Scalar(0, 255, 0, 255);
19            // draw the center
20            cv::circle(image, center, radius, color, thickness);
21            // write the marker ID
22            cv::putText(image, std::to_string(marker.id()), center, fontFace, ↵
↵fontSize, color, thickness);
23            // draw external ellipse
24            cv::ellipse(image,
25                center,
26                cv::Size(rescaledOuterEllipse.a(), rescaledOuterEllipse.b()),
27                rescaledOuterEllipse.angle() * 180 / ↵
↵boost::math::constants::pi<double>(),
28                0,
29                360,
30                color,
31                thickness);
32        }
33        else
34        {
35            // the same for invalid markers but in red
36            const cv::Scalar color = cv::Scalar(0, 0, 255, 255);
37            cv::circle(image, center, radius, color, thickness);
38            cv::putText(image, std::to_string(marker.id()), center, fontFace, ↵
↵fontSize, color, thickness);
39        }
40    }
41 }

```

Here is an example of possible result:



## 2.7 API References

### 2.7.1 Main Classes

#### **struct** `cctag::Parameters`

Structure containing all the major parameters using in the *CCTag* detection algorithms.

#### Public Functions

#### **Parameters** (`std::size_t nCrowns = kDefaultNCrowns`)

The constructor, normally the most interesting parameter is the number of crowns.

#### Parameters

- `nCrowns`: The number of crowns that the markers to detect are made up of.

#### template<class **Archive**>

void **serialize** (*Archive* &ar, unsigned int *version*)

Serialize the parameter settings.

#### Template Parameters

- *Archive*: The class to use to store the data.

#### Parameters

- [inout] *ar*: The object where to store the data.
- [in] *version*: The serialization version.

void **setDebugDir** (`const std::string &debugDir`)

Set the debug directory where debug data is stored.

#### Parameters

- [in] *debugDir*:

void **setUseCuda** (`bool val`)

Whether to use the Cuda implementation or not.



**Note** Ignored if the code is not built with Cuda support.

### Parameters

- [in] val: true to use the Cuda implementation, false to use the CPU.

**class** cctag::CCTag: public cctag::ICCTag

Class modeling the *CCTag* marker containing the position of the marker in the image, its ID and its status.

### Public Functions

float **x** () **const override**

Ger the x coordinate of the center of the marker.

**Return** x coordinate of the center.

float **y** () **const override**

Ger the x coordinate of the center of the marker.

**Return** x coordinate of the center.

**const** cctag::numerical::geometry::*Ellipse* &rescaledOuterEllipse () **const override**

Get the rescaled outer ellipse of the marker. The rescaled outerEllipse is in the coordinate system of the input image, while the internal ellipse is relative to a pyramid level.

**Return** the outer ellipse.

MarkerID **id** () **const override**

Get marker ID.

**Return** the marker ID.

int **getStatus** () **const override**

Get the status of the marker.

**Return** the status of the marker.

## 2.7.2 Functions

**Warning:** doxygenfunction: Unable to resolve multiple matches for function “cctagDetection” with arguments (boost::ptr\_list<ICCTag> &markers, int pipeId, std::size\_t frame, const cv::Mat &graySrc, std::size\_t nRings = 3, logtime::Mgmt \*durations = nullptr, const std::string &parameterFile = “”, const std::string &cctagBankFilename = “”) in doxygen xml output for project “CCTag” from directory: ../build/xml. Potential matches:

```
- void cctagDetection(CCTag::List &markers, int pipeId, std::size_t frame, const
↳cv::Mat &imgGraySrc, const Parameters &providedParams, const
↳cctag::CCTagMarkersBank &bank, bool bDisplayEllipses, cctag::logtime::Mgmt
↳*durations)
- void cctagDetection(boost::ptr_list<ICCTag> &markers, int pipeId, std::size_t
↳frame, const cv::Mat &graySrc, const cctag::Parameters &params, logtime::Mgmt
↳*durations = nullptr, const CCTagMarkersBank *pBank = nullptr)
- void cctagDetection(boost::ptr_list<ICCTag> &markers, int pipeId, std::size_t
↳frame, const cv::Mat &graySrc, std::size_t nRings, logtime::Mgmt *durations,
↳const std::string &parameterFilename, const std::string &cctagBankFilename)
```

```
void cctag::cctagDetection (boost::ptr_list<ICCTag> &markers, int pipeId, std::size_t frame, const
                          cv::Mat &graySrc, const cctag::Parameters &params, logtime::Mgmt
                          *durations = nullptr, const CCTagMarkersBank *pBank = nullptr)
    Perform the CCTag detection on a gray scale image.
```

### Parameters

- [out] markers: Detected markers. WARNING: only markers with status == 1 are valid ones. (status available via getStatus())
- [in] pipeId: Choose between several CUDA pipeline instances
- [in] frame: A frame number. Can be anything (e.g. 0).
- [in] graySrc: Gray scale input image.
- [in] params: *Parameters* for the detection.
- [in] durations: Optional object to store execution times.
- [in] pBank: Path to the cctag bank. If not provided, radii will be the ones associated to the CCTags contained in the markersToPrint folder.

## 2.7.3 Utility Classes

**class** cctag::numerical::geometry::**Ellipse**

It models an ellipse with standard form  $\frac{x^2-x_c}{a^2} + \frac{y^2-y_c}{b^2} = 1$ , centered in `_center` ( $x_c, x_y$ ) and rotated clockwise by `_angle` wrt the x-axis. Note that, arbitrarily, the representation with the major axis aligned with the y-axis is chosen.

Subclassed by cctag::numerical::geometry::Circle

### Public Functions

**Ellipse** () = default

Default constructor, set all parameters to zero.

**Ellipse** (const Matrix &matrix)

Build an ellipse from a 3x3 matrix representing the ellipse as a conic.

**Note** By default, the representation with the major axis aligned with the y-axis is chosen.

### Parameters

- [in] matrix: The 3x3 matrix representing the ellipse.

**Ellipse** (const Point2d<Eigen::Vector3f> &center, float a, float b, float angle)

Build an ellipse from a set of parameters.

### Parameters

- [in] center: The center of the conic.
- [in] a: The length of the semi-axis x.
- [in] b: The length of the semi-axis y.

- [in] `angle`: The orientation of the ellipse wrt the x-axis as a clock-wise angle in radians.

**const** Matrix &**matrix** () **const**

Return the matrix representation of the ellipse.

**Return** 3x3 matrix representation of the ellipse.

Matrix &**matrix** ()

Return the matrix representation of the ellipse.

**Return** 3x3 matrix representation of the ellipse.

**const** Point2d<Eigen::Vector3f> &**center** () **const**

Return the center of the ellipse.

**Return** 3 element vector with the homogeneous coordinates of the ellipse.

Point2d<Eigen::Vector3f> &**center** ()

Return the center of the ellipse.

**Return** 3 element vector with the homogeneous coordinates of the ellipse.

float **a** () **const**

Return the length of the x-semi axis of the ellipse.

**Return** the length of the x-semi axis of the ellipse.

float **b** () **const**

Return the length of the y-semi axis of the ellipse.

**Return** the length of the y-semi axis of the ellipse.

float **angle** () **const**

Return the orientation of the ellipse.

**Return** the clock-wise orientation angle in radians of the ellipse wrt the x-axis

void **setA** (float *a*)

Set the length of the x-semi axis of the ellipse.

**Parameters**

- [in] *a*: the length of the x-semi axis.

void **setB** (float *b*)

Set the length of the y-semi axis of the ellipse.

**Parameters**

- [in] *b*: the length of the y-semi axis.

void **setAngle** (float *angle*)

Set the orientation angle of the ellipse.

**Parameters**

- [in] `angle`: the clock-wise orientation angle in radians.

void **setCenter** (**const** Point2d<Eigen::Vector3f> &*center*)  
Set the center of the ellipse.

**Parameters**

- [in] `center`: the new center of the ellipse.

void **setMatrix** (**const** Matrix &*matrix*)  
Update the ellipse from a matrix representing a conic.

**Parameters**

- [in] `matrix`: 3x3 matrix representing the ellipse.

void **setParameters** (**const** Point2d<Eigen::Vector3f> &*center*, float *a*, float *b*, float *angle*)  
Update the ellipse from its parameters.

**Parameters**

- [in] `center`: The center of the conic.
- [in] `a`: The length of the semi-axis x.
- [in] `b`: The length of the semi-axis y.
- [in] `angle`: The orientation of the ellipse wrt the x-axis as a clock-wise angle in radians.

*Ellipse* **transform** (**const** Matrix &*mT*) **const**  
Return a new ellipse obtained by applying a transformation to the ellipse.

**Return** the transformed ellipse.

**Parameters**

- [in] `mT`: a 3x3 matrix representing the transformation.

void **getCanonicForm** (Matrix &*mCanonic*, Matrix &*mTprimal*, Matrix &*mTdual*) **const**  
Compute the canonical form of the conic, along with its transformation.

**Parameters**

- [out] `mCanonic`: 3x3 diagonal matrix representing the ellipse in canonical form.
- [out] `mTprimal`: 3x3 transformation matrix such that  $C = mTprimal.transpose() * mCanonic * mTprimal$
- [out] `mTdual`: 3x3 inverse transformation matrix ( $= mTprimal.inv()$ )

## Friends

**friend** `std::ostream &operator<<` (`std::ostream &os`, `const Ellipse &e`)  
Print the ellipse in matrix form in Matlab notation.

**Return** the stream with appended the matrix representation of the ellipse.

### Parameters

- [inout] `os`: the stream where to output the ellipse.
- [in] `e`: the ellipse

**struct** `cctag::logtime::Mgmt`

**class** `Measurement`

## 2.8 Markers usage

You can find the pdf of the marker to use in the `markersToPrint` of the project root directory.

### 2.8.1 Print the markers

We recommend to print the markers on a hard, flat and matt surface.

The size of the marker can be chosen considering the minimum size of the marker image that can be detected. The image of the marker should be roughly no less than 30 pixel of radius for the external ring. The size of the actual marker to print can be computed considering the distance of the camera w.r.t the marker, the focal length and the resolution of the image.

To **roughly** estimate the (minimum) radius  $R$  of the marker to print you can use the formula:

$$R = \frac{m u}{f} d$$

where:

- $m$  is minimum size in pixel for the radius (e.g. 30 pixel)
- $u$  is the pixel size in mm (that can be found on the specs of the camera)
- $f$  is the focal length in mm
- $d$  is the distance between the camera and the marker.

For example, for the marker to have a  $m = 75$  pixels radius using a camera with a pixel size of  $u = 0.00434$  mm and a focal length of  $f = 24$  mm and seeing the marker from a distance of  $d = 5$  m, the estimated radius of the actual marker to print is  $R = \frac{75 * 0.00434}{24} * 5000 = 67.81$  mm.

## 2.8.2 Generate the markers

In the `markersToPrint` directory you can also find a python program `generate.py` to generate the svg file of the markers. You can customize the size and print the id of the marker on the corner.

Here is the usage and options:

```
usage: generate.py [-h] [--rings N] [--outdir dir] [--margin N] [--radius N]
                  [--addId] [--addCross] [--generatePng] [--generatePdf]
                  [--whiteBackground]

Generate the svg file for the markers.

optional arguments:
  -h, --help            show this help message and exit
  --rings N             the number of rings (possible values {3, 4}, default: 3)
  --outdir dir         the directory where to save the files (default: ./)
  --margin N           the margin to add around the external ring (default: 400)
  --radius N           the radius of the outer circle (default: 500)
  --addId              add the marker id on the top left corner
  --addCross           add a small cross in the center of the marker
  --generatePng        also generate a png file
  --generatePdf        also generate a pdf file
  --whiteBackground   set the background (outside the marker) to white instead
                      of transparent
```

For example, calling:

```
./generate.py --outdir markers3 --margin 100 --addId
```

it will create a directory `markers3` where it saves an svg file for each marker with a margin around the marker of 100 and with the ID of the marker printed on the top left corner.

To generate pdf and/or png file, use the flags `--generatePdf` and `--generatePng`.

## 2.9 About

### 2.9.1 License

CCTag is licensed under [MPLv2 license](#).

More info about the license and what you can do with the code can be found at [tldrlegal website](#)

### 2.9.2 Contact us

You can contact us on the public mailing list at [alicevision@googlegroups.com](mailto:alicevision@googlegroups.com)

You can also contact us privately at [alicevision-team@googlegroups.com](mailto:alicevision-team@googlegroups.com)

### 2.9.3 Cite us

If you want to cite this work in your publication, please use the following

```
@inproceedings{calvet2016Detection,  
  TITLE = {{Detection and Accurate Localization of Circular Fiducials under Highly_  
↪Challenging Conditions}},  
  AUTHOR = {Calvet, Lilian and Gurdjos, Pierre and Griwodz, Carsten and Gasparini,_  
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## 2.10 Bibliography





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