Feasibility study for a catadioptric bi-spectral imaging system

Christelle Gée, L. Berret, C. Chardon, Jérémie Bossu, Jean-Philippe Guillemin, G. Jones, Frederic Truchetet

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C. Gée*[a], L. Berret [a], C. Chardon[a], J. Bossu[a], JP. Guillemin[b], G. Jones[a], F. Truchetet[c]
[a]ENESAD/DSI/LGAP'Laboratoire en Génie des Agroéquipements et des procédés', 21, Bd Olivier de Serres F-21800 Quetigny, FR;
[b]ENESAD/DAE/UMR BGA 'Biologie et Gestion des Adventices', Bd Dr Petitjean, F-21000 Dijon, FR ;
[c]Le2i, UMR 5158, uB-CNRS, 12 rue de la fonderie F-71200 Le Creusot, FR

ABSTRACT

In the context of sustainable agriculture, matching accurately herbicides and weeds is an important task. The site specific spraying requires a preliminary diagnostic depending on the plant species identification and localisation. In order to distinguish between weeds species or to discriminate between weeds and soil from their spectral properties, we investigate a spectral approach developing a catadioptric bi-spectral imaging system as a diagnostic tool. The aim of this project consists in the conception and feasibility of a vision system which captures a pair of images with a single camera by the use of two planar mirrors. Then fixing a filter on each mirror, two different spectral channels (e.g. Blue and Green) of the scene can be obtained. The optical modeling is explained to shot the same scene. A calibration based on the inverse pinhole model is required to be able to superpose the scene. The choice of interferential filters is discussed to extract agronomic information from the scene by the use of vegetation index.

Keywords: precision agriculture, imaging system, spectral, pinhole model, crop, weed.

1. INTRODUCTION

In the context of Precision Agriculture and more particularly for a site specific weed management remote sensors are nowadays useful tools to obtain agronomic information like a weed infestation rate in crop field. Moreover in the case of vision systems, agronomists have developed vegetation indices to extract this agronomic information. It consists of the combination of different spectral channels of the camera (i.e.: Blue, Green, Red or Near Infrared). Among them, the more famous index is the NDVI (Normalized Difference Vegetation index =(NIR-R)/(NIR+R)) [1] which informs about the biomass or vegetative vigour and is usually dedicated to satellite images. For post-emergence herbicide applications, imaging systems are embedded in the field and a pre-processing stage, based on other indices, is required to discriminate between plants and soil. Particularly, Woebbecke et al. [2] examined several colour indices for weed image segmentation (r-b, g-b, g-r-b, 2g-r-v).

Most of the time, these commercial multi or hyper spectral imaging systems are complex and expensive tools and they are usually designed for a general use. Many applications can be found in remote sensing or quality control [3]. These systems use different technologies either based on n-CCD [4] or spectrograph [5, 6]. In the case of very simple applications some authors have developed their own multi-spectral imaging systems embedded in mobile vehicles [7, 8]. For instance Vioix et al. have developed a multi-spectral imaging system embedded (CCD camera with a 4 filter wheel) in a small aircraft in order to point out the weed density heterogeneities in crop fields. However, these systems are either expansive or they require a dedicated and complex electronic device [9].

The present study concerns the feasibility of an easy and simple bi-spectral imaging system exclusively based on optics and involving no specific electronic and no moving part. The aim of this project consists in the conception of an optical system which snaps in one shot the same scene in two different spectral channels (e.g. blue and green) by the use of a interferential filters fixed on each mirror. Thus this spectral information can be used in addition to the geometric ones to recognize and to characterize plants. The section 'Materials and Method' explains the optical model of the vision system considering the two planar mirrors. The section 'Results and Discussion' presents an agronomic example to test the

*c.gee@enesad.fr. phone 33(0)3 80 77 27 71; fax 33(0)3 80 77 28 16.

discrimination between soil and plants in the scene. Then the agronomic perspectives of a such system are discussed and a conclusion of this feasibility study is done.

2. MATERIAL AND METHOD

2.1 Experimental set-up

The vision system has been developed for a particular agronomic application : discriminate between plants and soil. It is firstly composed of a single camera (JAI CV-M50, a black and white camera, 768x576) with 2 planar mirrors (Emund Optics, size : 50x120 mm). Figure 1a shows the mirror/filter holder placed in front of the camera. For this feasibility study, currently no adapter attached to the camera has been realised in order to test different configurations and to estimate the ideal configuration for a best field of view of the camera. The two mirrors (M1, M2) can be inclined along the horizontal axis. For this application the angle (β_1) of the mirror (M1) takes only positive values (Fig. 1b) whereas the angle (β_2) of the mirror (M2) can take all values. Secondly, an interferential filter has been fixed onto each mirror. For agricultural applications, we opt for a blue filter and a green one according to the plant and soil spectral signatures [10]. (Green filter : Schott VG-9 and Blue filter: Schott BG12; size: 25mm square)

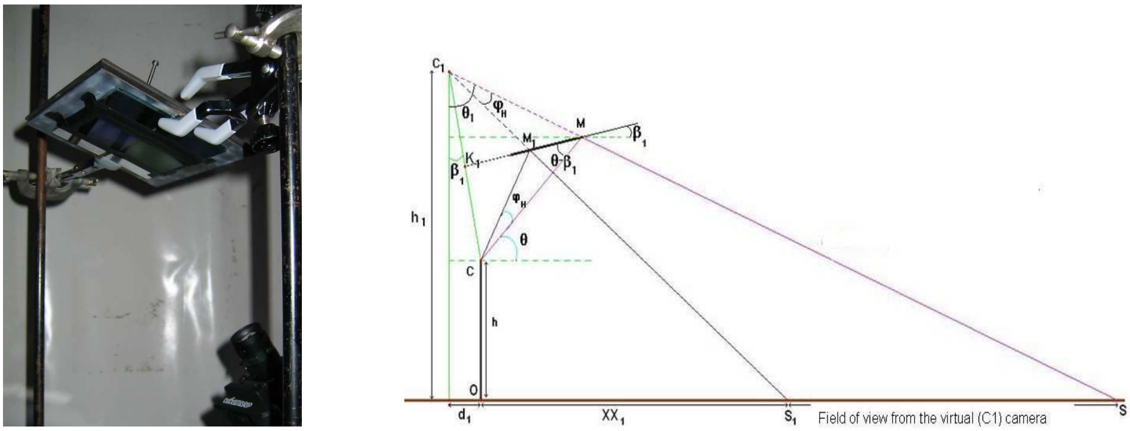

Fig. 1. a) The catadioptric viewer composed of a CCD monochrome camera with 2 mirrors placed above the camera. An interferential filter is fixed on each mirror. b) Optical model of the viewer system considering only one mirror (M1).

2.2 Optical structure

Before describing the requirements for rectified catadioptric vision system, we review the image formation with planar mirrors. As shown in Figure 2a, the field of view of the camera (C) is split in two such as the mirrors reflect the scene onto two different portions of the imaging plane which are correlated to the mirror angle from the horizontal axis. Moreover due to the fact that the camera (C) is inclined from the vertical axis, the resulting field of view is a trapezium. From Figure 2a it can be also noticed that the image issued from each mirror (M1 and M2) is the same image taken by a virtual camera (C1 and C2) located on the opposite side of each mirror. In this case the virtual cameras have the same intrinsic parameters than the initial one (C) and their extrinsic parameters are deduced from those of the initial camera (C) from geometric considerations (Fig. 1b). They are summarized in Table 1.

Table 1: Extrinsic parameters for each camera. *f* : focal lens of the (C) camera, Hccd: the height of a CCD matrix and CM: distance between the (C) camera and the mirrors. (θ) is the camera (C) angle from the horizontal axis.

Camera Parameters	Camera (C)	Virtual camera (C1)	Virtual camera (C2)
Height of the camera	h	$h_1 = h + 2 \times CM \times \sin(\theta - \beta_1) \times \cos(\beta_1)$	$h_2 = h + 2 \times CM \times \sin(\theta - \beta_2) \times \cos(\beta_2)$

Tilt-angle	$\phi = \frac{\pi}{2} + \theta$	$\phi_1 = \theta_1 - \varphi_h$ with $\theta_1 = \frac{\pi}{2} + \lvert 2\beta_1 \rvert - \theta$ and $\varphi_h = \arctan(\frac{Hccd}{2f})$	$\phi_2 = \theta_2 - \varphi_h$ with $\theta_2 = \frac{\pi}{2} + 2\lvert\beta_2\rvert - \theta$ and $\varphi_h = \arctan(\frac{Hccd}{2f})$

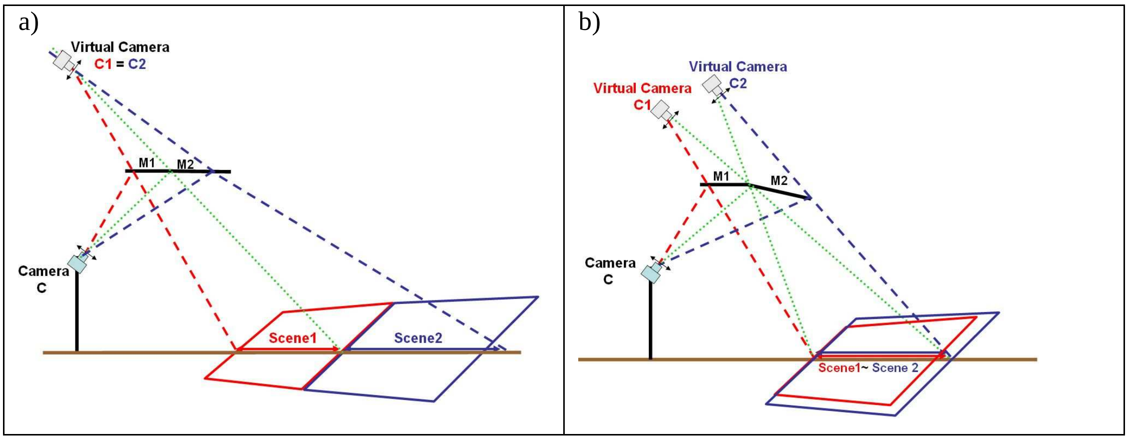

Fig. 2. a) General view of a bi-spectral imaging system based on a single camera (C) with 2 mirrors (M1 and M2). b) Superimposition of the two scenes for particular angles of mirrors (M1 and M2).

A particular configuration of the mirror system is then required in order to observed the same scene in each image issued of the each mirror (Fig. 2b).

The Figure 3 shows an example of an image grabbed through this vision system. This image represents a checkerboard. For this image, the vision system parameters are :

- height of the cameras: $h_{(c)}$ = 1.05m , $h_{(c1)}$ = 1.31m , $h_{(c2)}$ = 1.36m and focal lens f= 50mm,
- θ (camera C angle from vertical axis) = 55°,
- β_1 (mirror M1 angle from horizontal axis) = 12°, β_2 (mirror M2 angle from horizontal axis) = -23°,
- the distance between C and the mirrors: CM= 20cm.

From these parameters the estimated field of view of the each image is 34cm (width) x 40cm (length). The blurring of the center line of the image originates either from the sharpness of the edges of the mirrors or the overlapping of the two views around the center line.

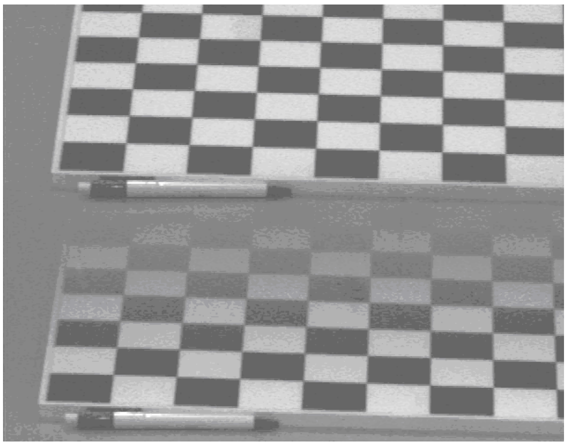

Fig. 3. A pair of images splitted vertically from the vision system composed of a CCD monochrome camera with 2 mirrors placed above the camera.

2.3 Calibration and rectification

Previously, researchers have investigated the geometry of such a catadioptric system composed of 2 mirrors randomly oriented and a single camera [11, 12, 13] and all of these systems have been developed to acquire stereo data with a simple camera [14, 15]. For agronomic applications, no stereo vision has been employed. Only a superimposing of the two images is required in order to extract a vegetation image deduced from a vegetation index. In our case, as the camera is inclined, some perspective effects will be observed so that the field of view of the two images will be not exactly the same as observed in Figure 4a. Consequently, an inverse pinhole model has been applied on each image considering each virtual camera parameters (C1 and C2) in order to match the two images. These parameters are deduced from the equations of the Table 1 depending on the (C) camera parameters. The details of the coordinate transformation can be found in appendix A. Moreover a vertically and horizontal offset must be done to correctly superimpose the two images (Fig.4b).

a) b)

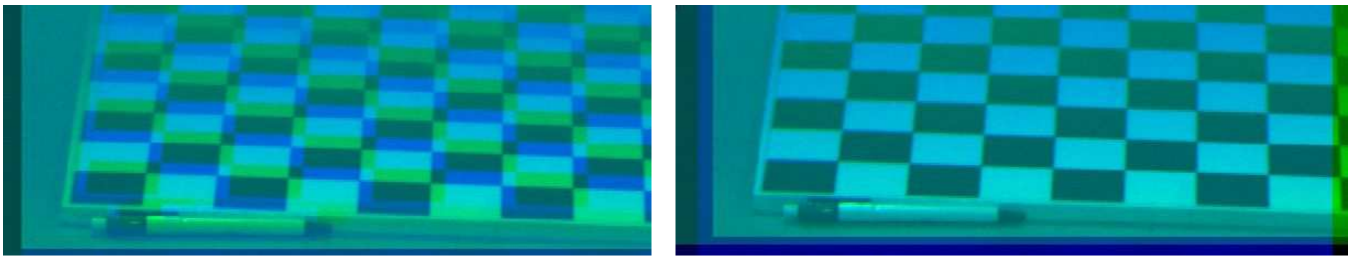

Fig.4: a) Superimposition of a pair of images splitted vertically from the vision system composed of a CCD monochrome camera with 2 mirrors (Green color: image from M1 and Blue color: image from M2) placed above the camera. b) Correction of a vertical offset (13pixels) and an horizontal offset (15pixels).

3. RESULTS AND DISCUSSION

3.1 Agricultural example

Plant species were grown outdoors in portable plots of 30 cm x 40 cm containing local plants. The images issued from each filtered mirror are presented in Figure 5a. Applying the calibration and rectification explained in Section 2.3, we are able to obtain the same field of view of the scene (10cm x 20cm) and the result is presented in Figure 5b.

a) b)

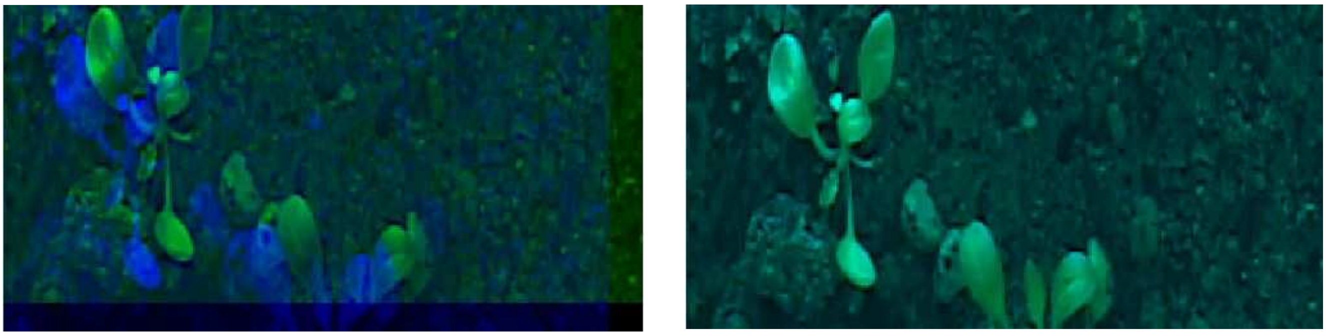

Fig.5: a) Superimposition of a pair of rectified images which have been splitted vertically from the vision system composed of a CCD monochrome camera with 2 mirrors (Green color : image from M1 and Blue color : image from M2). b) Correction with a vertical offset (13pixels) and an horizontal offset (15pixels).

From these pair of images a vegetation image is deduced applying a vegetation index such as (g-b). The result of the subtraction of the two spectral channels, Green and Blue, is presented in Figure 6a. Afterwards the vegetation image (grey level image) can be binarized into black and white image by a dynamic threshold based on the Otsu's method[16] as observed in Figure 6b).

a) b)

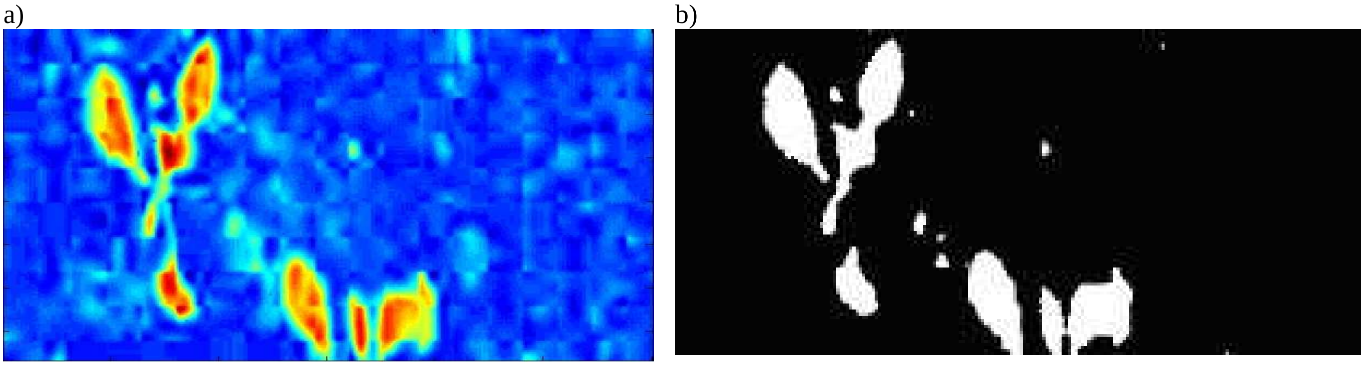

Fig.6. a) Vegetation Image deduced from the (green-blue) vegetation Index. b) Black and White binarization from the vegetation image.

Consequently from this bi-spectral imaging system it is then possible to discriminate the plant from soil form a particular vegetation index depending on a specific configuration of the vision system.

Although to obtain a specific configuration of the vision system is a very delicate operation due to the small values of angles of mirrors, other optical system configurations must be explored in order to enlarge the field of view of the camera. Moreover other filters must be tested in order to determine the best discrimination. Indeed, for a plant discrimination or plant/soil discrimination usually an Near Infrared filter is required because the spectral signature of plant and soil are clearly different in this part of the spectral domain. However, we can only used filters which have similar transmission due to the fact we cannot modify the time exposition independently from one image to the other. Consequently, a test with two Near Infrared filters needs to be investigated.

3.2 Prospects for Agriculture

Currently, the bi-spectral system has been tested exclusively in laboratory with plants in pots and the main difficulty of this system is to adjust finely the mirror tilt-angles and location regarding to the initial camera (C) in order to obtain a similar scene from the two mirrors. Then, fixing the vision system with an holder-adapter mounted on the camera would probably be a solution to have a robust system. Then the future work is to embed this vision system in a small trailer in order to move into a crop field for testing it on real conditions. From this system image-based data can be collected in the field. Then, combining these data to a Global Positioning System (GPS) , they can be used in a Geographic Information System (GIS) for a weed mapping for planning weed control measures.

4. CONCLUSION

A catadioptric bi-spectral imaging system has been described in this article. The system has been tested for agronomic applications to discriminate between plants and soil from two spectral channels employing two interferential filters (blue and green) mounted on mirrors. Although the optical system configuration is a delicate operation to find the same scene through the two mirrors, the results are very promising. It is a useful and low-cost system to manipulate compared to optical systems based on electronic devices. Currently, the system must be optimized for large field of view and must be tested in field conditions.

5. APPENDIX A – OPTICAL SYSTEM

In this part, we will present the optical transformation. Indeed, the camera is located at a height H from the ground (millimeter) and it is inclined by a tilt angle ϕ (degree) as shows in Fig.A1.

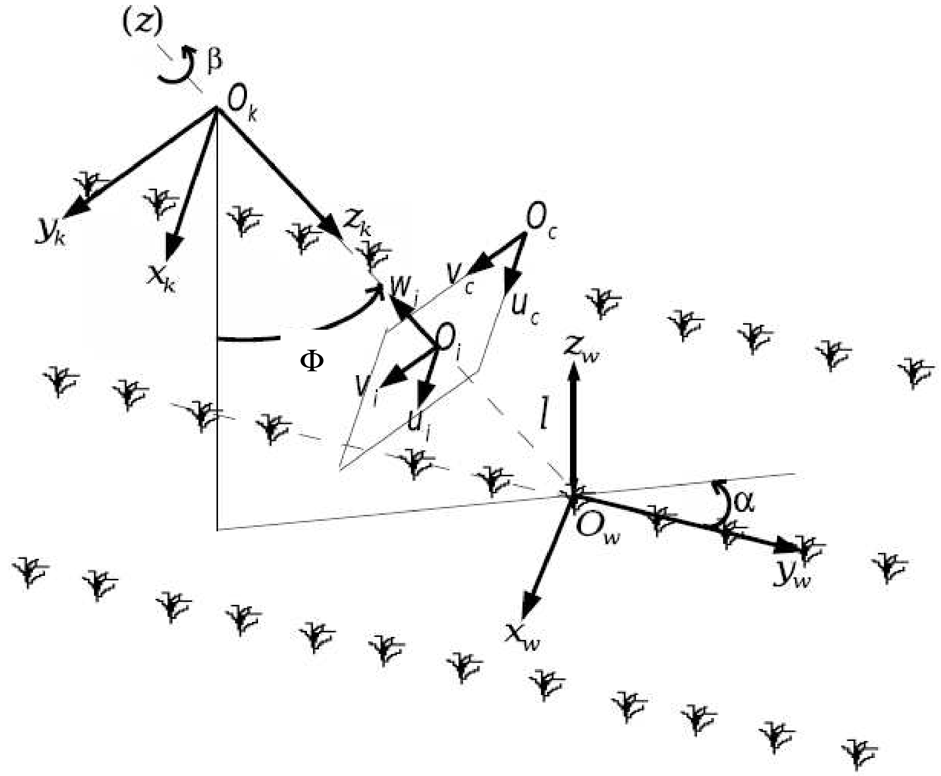

Fig. A1. Optical system with different coordinate systems : camera , image and real world.

In order to compute the coordinates of a point in the real world (x_w, y_w) from its coordinates in the image world (x_c, y_c), we must characterize the matrix projection. The transformation of a position expressed in the camera coordinate system *k* to a position expressed in the world coordinate system *w* is given by:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}^w = R_k^w \begin{bmatrix} x \\ y \\ z \end{bmatrix}^k + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}_{k_{org}}^w$$

Where R is the rotation matrix between real world system *w* and the camera system *k*. In our case, R is function of ϕ:

$$R_k^w = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi+180) & -\sin(\phi+180) \\ 0 & \sin(\phi+180) & \cos(\phi+180) \end{bmatrix}$$

In our case, the translation vector is a function of *H* and ϕ:

$$t_x = 0$$
$$t_y = -H \tan\phi$$
$$t_z = H$$

So, the extrinsic parameter matrix is equal to:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}^w = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\cos\phi & \sin\phi \\ 0 & -\sin\phi & -\cos\phi \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}^k + \begin{bmatrix} 0 \\ -H\tan\phi \\ H \end{bmatrix}$$

Moreover to determine a position expressed in the camera coordinate system *k*, the intrinsic parameters of the camera are required. We use the CCD image benchmark *i* where coordinates in meters are:

$$x_k = \frac{x_i}{z_i} z_k$$

$$y_k = \frac{y_i}{z_i} z_k$$

The determination of the coordinates in the CCD image benchmark *i*, based on the coordinates expressed in pixel in the image benchmark *c*:

$$x_i = (x_c - C_x) d_x$$
$$y_i = (y_c - C_y) d_y$$
$$z_i = f$$

Where f in millimeters corresponds to the focal length of the camera. *Cx* and *Cy* are the coordinates of the optical centre of the camera expressed in pixel, that corresponds to half size of the image. *dx* and *dy* are the dimensions of a CCD element, horizontally and vertically respectively.

$$x_k = \frac{(x_c - C_x) d_x}{f} z_k$$

$$y_k = \frac{(y_c - C_y) d_y}{f} z_k$$

If $s = \frac{z_k}{f} \Rightarrow z_k = fs$, then:

$$\begin{aligned} x_k &= x_c d_x s - C_x d_x s \\ y_k &= y_c d_y s - C_y d_y s \\ z_k &= fs \end{aligned}$$

So, the intrinsic parameter matrix is given by:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}^k = \begin{bmatrix} d_x & 0 & -C_x d_x \\ 0 & d_y & -C_y d_y \\ 0 & 0 & f \end{bmatrix} \begin{bmatrix} sx \\ sy \\ s \end{bmatrix}^c$$

If we use the homogeneous matrix, we can directly define the transformation of a position expressed in the image coordinate system *c* to a position expressed in the world coordinate system *w*.

$$\begin{bmatrix} kx \\ ky \\ kz \\ k \end{bmatrix}^w = \begin{bmatrix} d_x & 0 & -C_x d_x & 0 \\ 0 & -d_y \cos\varphi & C_y d_y \cos\varphi + f \sin\varphi & -H \tan\varphi \\ 0 & -d_y \sin\varphi & C_y d_y \sin\varphi - f \cos\varphi & H \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} sx \\ sy \\ s \\ 1 \end{bmatrix}^c$$

Then:

$$\begin{aligned} y_w &= -\frac{2Hd_y(y_c - C_y)}{(y_c - C_y)d_y \sin(2\varphi) + f(1+\cos(2\varphi))} \\ x_w &= \frac{(x_c - C_x)d_x H}{(y_c - C_y)d_y \sin\varphi + f \cos\varphi} \\ z_w &= 0 \end{aligned}$$

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