

A LOW COST SCANNER FOR SMALL FORMAT TRANSPARENT MATERIAL

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ABSTRACT

A low-cost, high resolution scanner with off-the-shelf CCD-camera for semi-automatic DEM creation from contour maps that are photographically reduced in size and printed on transparent material has been developed at ITC. The paper describes the hardware components of the scanner and their geometric accuracy. The orientation and calibration of the scanner is based on optical and photogrammetric methods. The transparencies are scanned patch-wise and converted into a binary image. The patches are pre-processed and edited, and the contour lines are annotated manually and by means of information from adjacent patches. Reported are accuracies achieved and performance mosaicking of scanned patches.

INTRODUCTION

Data acquisition techniques based on photographic images and line maps usually require costly equipment and a trained operator. In addition there is a significant time lag between the data acquisition and the final products which is unacceptable for many applications. It is the intention of future developments to reduce the cost and to improve the efficiency of the data acquisition process. Increasing processing speed often leads to a decreasing precision of measurements and vice versa (Luhman 1988). Recent advances in solid state cameras and micro computers provide the tools required for automation in data acquisition processes to become reality e.g. the real time systems by means of charge coupled device(CCD) cameras. The accuracy and stability of these cameras are rapidly improving, while the speed and memory capacity of micro computers are constantly increasing. All this with falling prices makes the future of real time data acquisition very promising indeed. In effort to reduce the cost in automating data acquisition from maps and photographs, the image processing division of the international institute for aerospace survey and earth sciences(ITC), has developed a low cost scanner system here afterwards named the ITC_LCS. The prime consideration in developing this system was the use of low cost readily available hardware and software. The scanner incorporates mechanical, optical, electronic and software components, it uses photogrammetric and digital image processing tools. It should be capable of producing digital elevation models (DEM) from contour maps, ortho-image creation and the selection of data from the screen by interpretation as input to an object oriented data base, but in first instance it is developed to create a raster DEM from contour maps that are photographically reduced in size. The input to the system consists of patch-wise grabbed source material (photos,maps). These patches can be stored, transported, processed (enhanced, rectified, mosaicked, merged etc.) or used as input to a combination of these actions. Since the output of the system can be used for various types of products it is important that the geometry of the source material is not changed. To avoid modification of the geometry, the grabbed data is not re-sampled. To enable the system to get a good mosaic of the grabbed and digitised patches the mechanical part of the system can be adapted to that requirement.

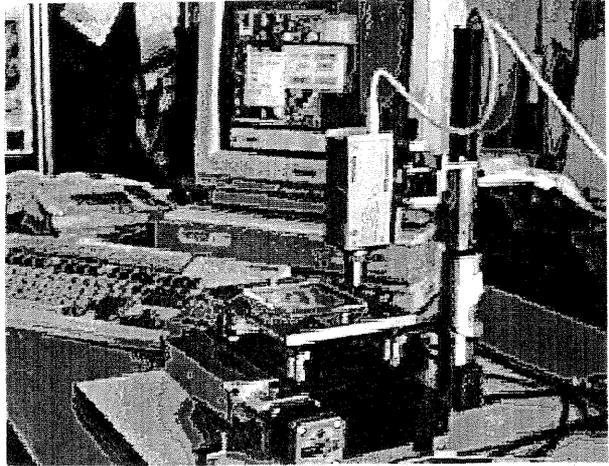


Figure 1: The ITC_LCS

SYSTEM DESCRIPTION

The ITC_LCS system consists as many systems in these days of a hardware and a software component. The hardware component has got the following subsystems:

- Computer system
- Camera system
- Mechanical system
- Electric/Electrical system

Computer system

The heart of the computer is the Archimedes 310. The processor in this computer is the 32 bit Acorn RISC chip, executing four million instructions per second. The memory capacity of the Archimedes 310 is 4M byte RAM and 512K byte ROM. The standard storage capacity is a 3.5 inch floppy disc drive. A hard disc is connected having a capacity of 20M bytes. To display pictures and control a high resolution monitor is connected.

Camera system

The camera is a CCD video Camera of type LHD 0460/00 produced by Philips. It has a matrix sensor with 256x512 sensor elements. The CCD in conjunction with a power supply unit of type LDH 4460/60 and a lens (C-mount) of own choice will produce fully interlaced black and white television pictures according to CCIR standard (625 lines 50Hz). The power supply of the camera has the following ratings; +12V and 165mA. The lens used is manufactured separately. The choice of a particular lens is determined by the required angle of view, the minimum illumination level, the acceptable amount of lens distortion and the final resolution required. The illumination of the transparent sources is realised by a LED (Light Emission Diode) that is mounted under the plate holder.

Mechanical system

The mechanical system is formed by the following parts;

- Plate holder
- Cross table
- Camera mounting
- Motors

Plate holder

The plate holder is of opal glass, for light diffusion, that is mounted on a cross table. The distance between the plate holder and the cross table can be varied by means of four micro screws that are positioned at the corners of plate holder.

Cross table

The cross table, produced by "Precisie-metaal, A. Aalbers BV", Holland consists of two stable plates on top of each other that are movable in two perpendicular directions. The table can be positioned by means of a connection with a set of spindles that are driven by stepping motors. The spindles have a pitch of 2mm. The accuracy depends on the base material and the way they are manufactured (grind or rolled). The effective range of the table is 75x75mm.

Camera mounting

The camera is mounted at a stable stand, which is fixed connected to the ground plate of the cross table. The mounting of the camera enables a motion in vertical direction and rotations around two perpendicular horizontal axis.

Motors

The stepping motors used in the system are manufactured by SLO SYN. The motors convert electronic signals coming from a controller into mechanical motion. Each time the direction of the current in the motor windings is changed, the motor output shaft a specific angular distance. This motor type offers many advantages as an actuator in a digital controlled positioning system. The motor type used in the scanner system has got a standard step angle of 1.8 degrees, that also can be used in a half step mode. The 1.8 degree steps is according to 200 steps revolution. In the half step mode a rotation of 400 steps/revolution is reached. The accuracy is 3% of a step angle. With the used spindles and 400 steps/revolution a planimetric motion of 5 micron/step is reached.

Electric/Electronic system

This system part has three main functions.

- Power supply
- Motor control
- Video digitizing

Power supply

The power supply for the illumination of the plate holder, the motor-controller and the stepping motors are combined and stored in the motor-controller box. The power supply of the camera that is mentioned before is separate.

Motor control

The motor-controller, a GS-C200, is a product of SGS-Thomson Micro Electronics. It is a programmable intelligent stepper motor controller that coordinates movements and sequential operations. The operation are loaded in program form into the controller by the host computer. The program language has a small number of instructions that provide move, stop, and positioning. Other instructions control the maximum speed for start, stop and constant

movement. The link between the Archimedes host computer and the processor in the motor-controller is made via a RS 423 port that enables serial in- and output.

Video digitizing

The ITC_LCS incorporates the Watford electronics video digitizer which is a versatile add-on for the Acorn Archimedes range of computers, allowing video images from a variety of sources to be captured and manipulated. Facilities are provided for grabbing images which can be displayed, rotated, and scaled to any size and angle, saved to disk or printed. The digitizer podule has 128 K of on board memory (digitizer memory), that is used to store a picture. Pictures are initially grabbed into this memory and then transferred to the Archimedes main memory (usually the screen memory) with optionally scaling and rotation. It is also possible to use this memory as a general purpose picture store, as its contents may be transferred to or loaded from disk or main memory. The video digitizer hardware grabs images that are stored internally with 256x512 image sensor elements and 64 intensity levels per sensor element. The digitizer will accept signals from most video-cameras and video recorders which give a standard one volt video signal.

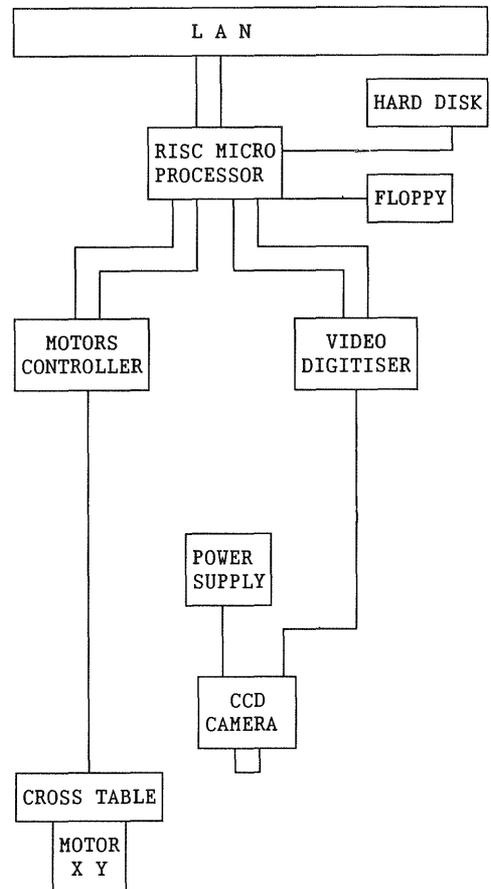


Figure 2: Components of the ITC_LCS

The software characteristics and component are:

- Operating system
- Program language
- Libraries
- System control
- Applications

Operating system

The operating system on the Archimedes is called RISC_OS (Reduced Instruction Set Computer Operating System). It is, as many other often used software tools, located in separate modules in ROM. All these modules provide certain services to the user (programs) and to each other. An important module of the operating system is the WIMP-manager. (WIMP stands for Window Icon Menu Pointer). Many tools of this manager can be used to create application programs in window environment that enables multitasking and a user friendly interfacing.

Program language

The system control- and application programs are all written in C.

Libraries

For reasons of simplicity and flexibility in programming the motor-controller two libraries are created. One library contains functions in C which translate readable commands in calling functions and/or programs into a sequence of characters that are send to the motor-controller to set it in a desired mode or to activate the stepping-motors. The second library consists of a number of standard functions that are needed to initiate the ITC_LCS or to perform diagnostics.

System control

A number of programs are written to initiate the ITC LCS (set it in the required mode and position) and to calibrate the different system parts. More details on these operation will be given.

Applications

These software programs will perform the processing of grabbed patches. The "pilot" program under development will produce a DEM from contour maps that are photographically reduced in size.

SYSTEM CONCEPT

To reach a high resolution sensor system in the ITC LCS, the lens of CCD camera can be a microscope type. Since this lens is mounted at a fixed position relative to the CCD chip and the diameter of the lens is small, the instantaneous field of view (IFOV) is limited. To digitize a source that has got a larger dimension than the IFOV a patch wise scanning process is enabled in the system. These patches can be processed in different ways and before or after these processes be mosaicked. However mosaicking requires mostly a resampling of the input patches and is based on tie_point in overlapping areas or referencing to a master image. A possible solution for reference points is the use of a reseau pattern that is superimposed on the source material. This solution needs additional illumination processes (alternating illumination of source and reseau) or an elimination process of the acquired data. It is also possible to avoid resampling if the patches are scanned in such a way that adjacent patches fit perfect (no overlap and no gaps). To reach this ideal situation it is required that the camera axis is perpendicular to the plate holder of the source material and that the distance between the lens and source is constant at any position. Also the edges of the patches (CCD chip) have to be parallel to the motion-axis of the tracking device. The current construction of the ITC_LCS enables the change of the camera axis around the two non-vertical axis, the motion in a "horizontal" plane and the levelling of the plate holder. With these motions

it is possible to set the camera axis vertical to the plate holder having the lens-source distance constant. For reasons of mechanical stability and to avoid complicated and time consuming orientation processes the camera can not be rotated around its vertical axis. To enable the creation of a complete image in spite of the last mentioned limitations, the tracking device and with it the source material is moved after each patch grabbing in the directions of the patch edges over a distance that is equal to the dimension of the patch edge in the move direction. (Figure 3)

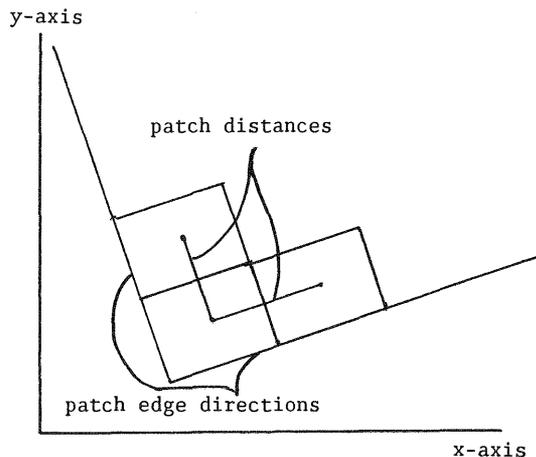


Figure 3: Tracking device coordinate system and patch positions.

The patch-dimensions in units of length depend on the IFOV and the focal length of the lens, and the distance from the CCD chip to the lens. To position the tracking device, the dimensions of the CCD image must be expressed in steps of the stepping motors.

SYSTEM ORIENTATION

To orientate the system we have to process the following steps:

- Lens/mask selection
- Focusing the system
- Levelling the plate holder
- Set the camera axis
- Compute the motion parameters

Lens/mask selection

Lenses with different enlargement factors can be mounted on the camera and enable a variation of geometric resolutions for the scanner. For the system orientation it is necessary to put a mask that is printed on film which is glued on a glass plate on the plate holder at a fixed position. For each lens a mask with adapted size has to be produced. The mask consists of a number of crosses and lines to enable positioning and focusing of the camera (Figure 4).

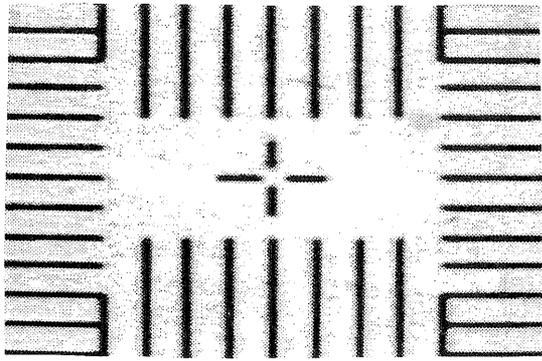


Figure 4: Mask element used for positioning and focusing.

The mask is used for levelling the plate holder and for that reason four crosses plus vertical and horizontal line-pattern are located in the corners of the mask. For the camera axis orientation, a cross with horizontal and vertical line-pattern is located more or less in the center of the mask. To enable a check of the perpendicularity of the camera axis related to the plate holder four crosses building a square are in the mask. Finally an isolated cross in the mask enables the creation of the matrix that will perform the transformation from digitiser-memory vectors into motorsteps vectors.

Focusing the system

To focus the camera, only the variation of the distance from the object to the camera lens is possible. The image of an object can be displayed in almost real time on the monitor and variation in the camera position and height will influence the "sharpness" of the image. A user will have a subjective idea about sharpness of an image and for that reason only a rough setting of the camera is delegated to them. For fine setting of the camera for focusing a quantitative method is used to control this action. The method is based on the following function.

$$S = \sum_{i=1}^k \sum_{j=1}^l (a_{i,j} - a_{i+1,j})^2$$

Where:

- k is the number of lines used;
- l is the number of columns used;
- a(i,j) is the radiometric value of that element;
- S is the sum of the absolute differences between adjacent line or column elements;

If S reaches its maximum value, the camera is in optimum focus (Figure 5).

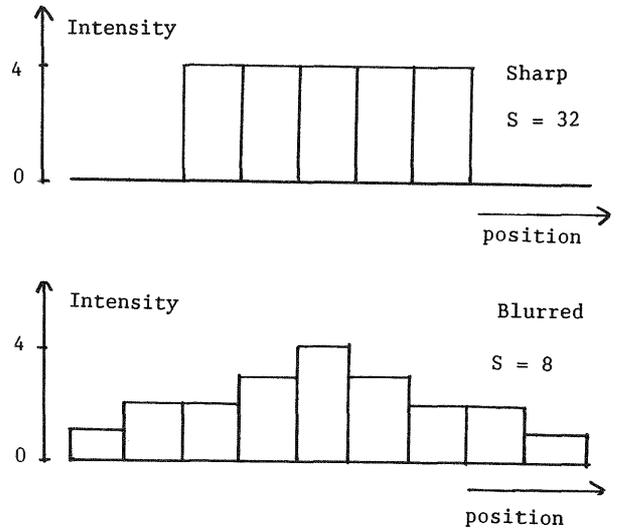


Figure 5: Focusing by first differences.

The value S is displayed on the monitor in a graph that gives also a part of the history of the focusing step. Parallel to this graph the image is displayed in another window to enable the rough setting under operators control (Figure 6).

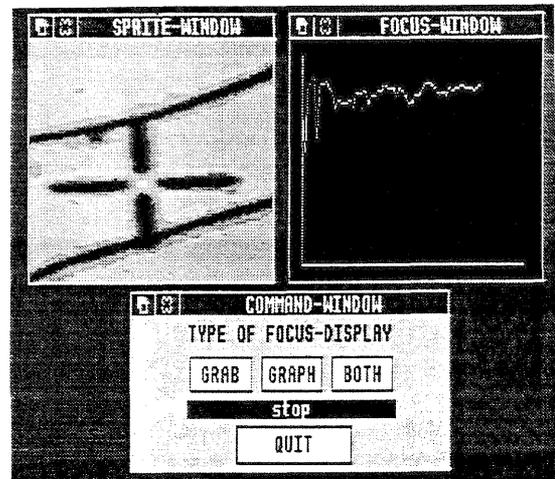


Figure 6: The focusing windows on the display.

Levelling the plate holder

The plate holder is mounted flexible at the tracking device (cross table). To level the plate holder such that it will be equidistant to the lens at all positions of its range, it is sufficient that it has got the same distance to the camera lens in three points which are not collinear. To make the levelling less sensitive to setting errors, these points are located in the corners of the masks. The levelling procedure has the following steps.

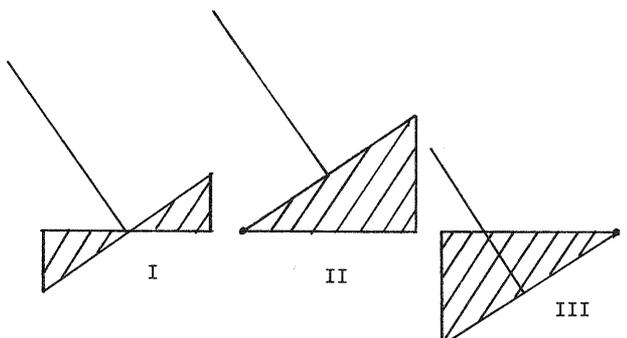
- Set the camera approximately in focus
- Level the plate holder by visual inspection
- Read the data file that describes the mask object positions
- Level, using the focus display windows, the plate holder at two points diagonal to each other
- Level the plate holder in one of the remaining points

- Verify the focusing in the last points and, if the result is not acceptable, repeat the levelling procedure

The situation that during the levelling the camera axis is not perpendicular to the plate holder, will not influence the procedure since the relative "best" focus is indicated in the graph window and not the maximum possible one.

Set the camera axis

As mentioned before the camera has two rotation possibilities. The two axis around which it can move are the non-vertical ones. This freedom of motion enables the correction for a non perpendicularity of the z-axis of the camera. The procedure to set the axis is divided into two separate settings of the axis, one for "omega" rotation and the other for "phi". The setting is based on the following assumption: if two identical line objects are grabbed in the digitizer memory at equal distance from the intersection point of the z-axis of the camera and the plate holder and the focus quantification as mentioned before is used then these values should be identical. The "focus value" is not necessarily the maximum, it can be increased varying the distance from the plate holder to the lens by the vertical motion of the camera (Figure 7).



Focus value(I) > Focus value(II) = Focus value(III)

Figure 7: Axis setting by focusing.

After a correct position in one direction, the same procedure is started for the other one. Since the two rotation axis are in practise not exactly perpendicular to each other an iterative procedure of alternating omega and phi rotation is necessary to create a required result. On the monitor a window is displayed in which the "focus values" are given that belong to the opposite positions in case of phi and omega rotation respectively. Also the total "focus value" is displayed to indicate whether the optimum situation is reached (Figure 8).

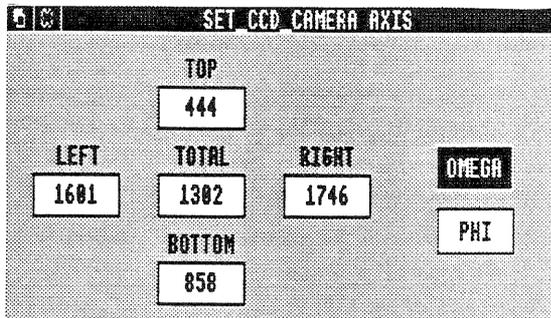


Figure 8: Display window for camera-axis orientation.

The orientation procedure has the following steps.

- Select "omega"
- Rotate the corresponding axis until the focus values are equal on top and bottom
- Vary the camera to plate holder distance until the total maximum is reached
- Select "phi"
- Rotate the corresponding axis until the values are equal for left and right
- Vary the camera to plate holder distance until the total maximum is reached
- Repeat the process until the result is satisfactory.

The orientation of the camera is checked by inspection using a square of four crosses. The inclined distance between two crosses on one edge is computed from measured image coordinates. Any two opposite distances should be equal if the camera axis is perpendicular to the plate holder. If the result is not satisfactory the levelling and orientation should be repeated.

Compute the motion parameters

As mentioned before the ITC_LCS has got no screws to adjust for the camera rotation with respect to the direction of the motor motion. But the effect of this rotation can always be corrected by a constant factor in such a way that the direction of the plate holder motion is parallel to the edges of the image. The constant factor is used to convert the number of sensor elements desired to move in the image to its equivalent number of steps to send to the motors. Therefore, the relationship between motorsteps and sensor elements has to be established. In order to establish this relationship, the levelling of the plate holder and the camera axis orientation should be done as described before, then one uniquely marked cross is moved to four different positions inside the IFOV. At each position the image coordinates are computed up to sub-pixel accuracy and their corresponding motor positions are recorded. After this the affine parameters are determined in a least square adjustment.

After the levelling, the orientation and motion parameter computation, the mask is removed and the transparent source material is put under a glass plate on the plate holder. After that the patch-wise scanning of the object can start.

ACCURACY OF THE GEOMETRY OF MOSAICKED IMAGE PATCHES

The geometric accuracy of the mosaicking process is checked in two ways;

- by displacement of a pattern of grid crosses and computing their coordinates at two different positions in the image.
- by visual inspection of mosaicked patches of a contour line map.

Check of a displacement of grid crosses pattern.
Four grid crosses were moved: firstly 35 sensor elements in the image along the X-direction equivalent to (x = -133.14 and y = 1.42) steps, secondly the four crosses were moved 50 sensor elements in the image along the Y-direction equivalent to (x = -1.2 and y = -96.07) steps.

The results of the displacement of four crosses 35 sensor elements in X-direction.

Cross	Initial position		Final position	
	Row	Column	Row	Column
0	219.152	121.240	219.327	85.500
1	216.094	392.341	216.149	357.274
2	125.171	118.249	125.336	82.482
3	122.000	390.827	122.355	355.305

The results of the displacement of four crosses 50 sensor elements in Y-direction are:

Cross	Initial position		Final position	
	Row	Column	Row	Column
0	212.465	124.311	162.074	124.339
1	209.161	393.285	159.047	393.191
2	119.322	121.279	68.433	121.930
3	116.281	391.087	65.115	391.078

From this result it is evident that the correction factor for the camera rotation is capable of maintaining the crosses in the same row or the same column if required. Small differences in decimal numbers are due to the fact that the motor can only be set within one step accuracy, the procedure to detect the centers of the crosses and of course the inaccuracy of the whole system.

Mosaicking of contour line map patches.

Visual inspection was done by mosaicking a contour line map after a motion of 250 sensor elements along the X-direction and also after 127 sensor elements along the Y-direction (Figure 8).

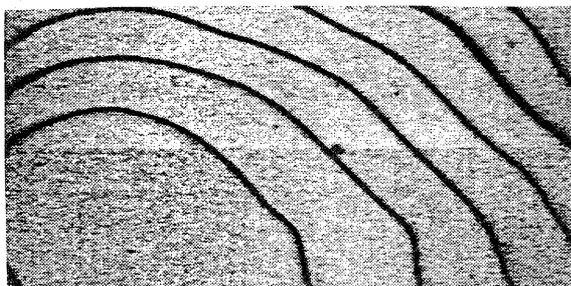


Figure 9: Mosaicked patches in X and Y direction

CONCLUSION

It is possible to create a high resolution scanner (5000 dpi) with of-the-shelf components using an interactive orientation procedure that realizes an accuracy that is sufficient to scan line-data that will be converted into a binary image for further processing. It is necessary that the camera axis passes through the center of the CCD chip, since this is assumed in the orientation procedure. If not a calibration has to be included in the process. Further more a stable mechanical construction is required and the camera should be adapted to the application.

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