An Absolute Positioning System for 100 Euros[*]

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1 Introduction

For experiments in robotics it is frequently necessary (and often helpful) to possess a method that allows investigators to determine the absolute position of a robot or other moving objects. Therefore a vision-based positioning system was developed that provides reliable and accurate measurements by tracking a distinctly coloured object. In order to reduce costs, the system uses a number of web-cameras to acquire images from different angles. The object chosen was a coloured "hat" made of cardboard, which can be worn by a person or placed on top of a robot (see Fig. 1).

2 Set-Up

Figure 1: The coloured "hat" that is tracked by the absolute positioning system, worn by a person (left) and placed on a robot (right).

The web-camera-based absolute positioning system ("W-CAPS") was developed such that it can be utilised with an arbitrary number of cameras ($N \geq 2$). To achieve the results presented in this paper, four Philips PCVC 740K web-cameras were used with a resolution of 320 $\times$ 240 pixels. These cameras were mounted at a height of approx. 2 m in the corners of the 10.6 $\times$ 4.5 m laboratory room shown in Fig. 2. The orientation and position was adjusted to cover a large area of interest with as many cameras as possible. All the calculations were performed on a Pentium III PC, which was connected to the web-cameras by a 4 $\times$ USB port.

[*]this is the assumed cost of two web-cameras and connectors, i.e., the minimum hardware required, excluding PC.

3 Determining the 2D Coordinates

W-CAPS is based on triangulation. First, the angle φ_i at which the centre of the coloured object appears is determined for each camera. For every combination of two cameras i, j that both actually sense the whole coloured object, an estimate of the position $\vec{x}_{ij}$ is then calculated by triangulation. Using N cameras up to $N(N-1)/2$ valid position estimates result from each snapshot taken, which are combined to determine the final estimate $\vec{x}$.

To compensate for different lighting conditions, the original colour values (r,g,b) are first normalised as:

$$(r', g', b') = \begin{cases} \frac{(r,g,b)}{r+g+b} & \text{if } r+g+b \geq B_{norm} \\ (r,g,b) & \text{if } r+g+b < B_{norm} \end{cases} . \quad (1)$$

The threshold B_{norm} is used to prevent amplification of noise in dark regions. Then pixels within a given contiguous rgb-colour range are selected, and the median values (X_i, Y_i) of the corresponding pixel-coordinates are calculated for each camera i. An example is indicated on the left side of Fig. 1. In the next step, the angle of the centre of the colour blob φ_i is calculated from the median value X_i. Finally, a list of positions is triangulated for all combinations of two cameras that detected the hat. To avoid ambiguous results, only combinations φ_i, φ_j are considered for which the direction differs sufficiently.

$$\vec{x}_{ij} = \frac{(C_i B_j - C_j B_i, A_i C_j - A_j C_i)}{A_i B_j - A_j B_i} \quad (2)$$

$$A_i = sin(\varphi_i), B_i = -cos(\varphi_i), C_i = A_i X_i + B_i Y_i. \quad (3)$$

Finally, the overall estimate $\vec{x}_t$ is calculated by averaging those estimates $\vec{x}^t_{ij}$ whose validity can be verified as follows: the position of the colour blob is propagated using the last valid estimate $\vec{x}_{last}$ and the speed $\vec{v}_{last}$, which is determined from the most recent valid positions. An estimate $\vec{x}^t_{ij}$ is believed to be valid if it lies inside a circle with radius $r(t)$ around the propagated position. The radius of the circle is increased linearly by $v_{max} \cdot (t - t_{last})$ to enable recovery in the case of lost positions, using an assumed maximum speed (v_{max}) and the time since the last valid estimate was detected ($t - t_{last}$).

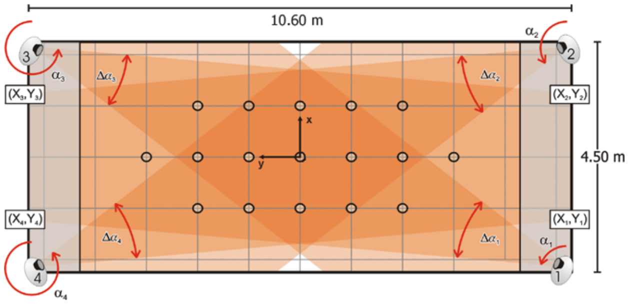

Figure 2: Floor plan of the laboratory room at Örebro University where the experiments were performed. Also shown are the positions that were used for calibration.

3.1 Calibration

The parameters of the cameras (heading α_i, coordinates X_i, Y_i and angular range $\Delta\alpha_i$) were determined by an initial calibration process. This step is crucial because the estimation performance of the whole system depends heavily on the accuracy of the camera parameters.

First, the values of the pixel coordinates $n^{(l)}_{X,i,k}$ of the median were determined from K images taken with each camera $i \in 1,...N$ for L known positions $\vec{p}^{(l)}$ of the coloured object. With this set of input data, position estimates $\vec{x}^{(l)}_{i,k}$ were calculated as described in Section 3, using a particular set of parameters $\{\alpha_i, X_i, Y_i, \Delta\alpha_i\}$. Finally, the average distance $\bar{d}$ between the calculated estimates and the known positions is minimised. Any optimisation technique might be used for this purpose. Here, a hillclimbing algorithm was applied starting from a reasonable set of parameters (determined by hand). It was found to be advantageous to start optimising just the heading of the cameras α_i first, considering the other parameters as fixed. Then, if no improvement is possible any more, all of the parameters were optimised. Despite the comparatively poor horizontal resolution of 320 pixels, a good accuracy of $\bar{d} \approx 1cm$ could be achieved utilising the 17 positions shown in Fig. 2.

4 Determining the Heading

To determine the heading of the object, the cardboard hat was augmented with a differently coloured stripe as shown in Fig. 3. The 2D coordinates of such an object can still be tracked as explained in Section 3 using a combined colour range. In addition, the heading can be determined from each snapshot in three different ways: two estimates can be calculated from the relative position of the vertical centre of both stripes in the middle of the hat. These centres are indicated in Fig. 3 by two crosses while the middle of the hat is indicated by a broken line. The vertical position relative to the height of the hat can be converted to an estimate of the heading by applying a linear transformation.

Another estimate can be calculated from the relative

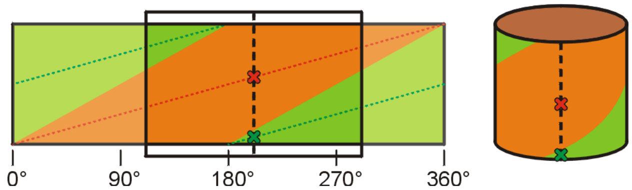

Figure 3: Design of the coloured hat used to determine the heading.

amount of pixels of both colours. Assuming a parallel projection, the relation between the relative number of pixels of colour 1 and colour 2 (N_1, N_2) and the heading ϑ is given by

$$\frac{N_1}{N_1+N_2} = \frac{\int H\frac{|\varphi|}{\pi} \cdot Rcos(\varphi-\vartheta)d\varphi}{2RH} = \frac{1}{2} - \frac{cos(\vartheta)}{\pi}, \quad (4)$$

where H indicates the height, and R the radius of the hat.

Because the quantity considered is symmetric with respect to 0^o and 180^o, the correct branch of the *arccos*-function has to be chosen if ϑ has to be calculated from $N_1/(N_1+N_2)$. This can be done by comparing the above mentioned positions of the centre of both colours in the middle of the hat. Considering the example given in Fig. 3, the inverse function of eq. 4 can be made non-ambiguous by restricting the range to values between 180^o and 360^o. This follows because the centre of the stripe that starts at 0^o (the orange one) is above the other stripe's centre in the middle of the hat.

5 Conclusions

The absolute positioning system W-CAPS was introduced in this paper. Based on an arbitrary number of web-cameras installed at fixed positions, it is possible to track the 2D coordinates and also the heading of a coloured object. A coloured hat made of cardboard was used, which can be easily placed on top of a robot or worn by a person.

W-CAPS has been utilised successfully in a number of experiments with a mobile robot, including gas source localisation [2] and gas distribution mapping [3]. In addition, the system has been used to track the position of people (wearing the hat) in order to train a neural net for person tracking [1].

References

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