Improving 3D measurements accuracy with camera information redundancy

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SUMMARY

The accuracy of the Codamotion system for 3D measurement depends mainly on the signal level of the sensors and the resolution of the system at the marker localization. When using several units to cover a large field of view, the estimated position of the different units might differ. We propose a method taking both resolution and signal level in to account, instead of only the signal level as in the built-in weighting process. This new method offers improved accuracy.

INTRODUCTION

Optoelectronic systems are a common way to analyze 3D motions. The Codamotion technology [1], based on active markers, allows the localization of markers with only one unit. However, to cover a large field of view, several units are usually used at the same time. The accuracy of the measure of a single unit depends mainly on the resolution of the system at the point of measure and on light intensity received by the sensors. All units don't measure the marker location with the same accuracy. Therefore, the way estimated locations are weighted acts upon the final measure. This paper aims at comparing several weighting approaches. We will here consider a system composed of two units.

METHODS

The accuracy of the localization measure mainly depends on the resolution (poorest in the range direction [2]) and on the signal level. The signal level has a strong influence on the noise of each sensor. The built-in weighting approach of the system is based on this information only. If I_1 is the intensity of the signal received by the first unit and I_2 the intensity received by the second one, the weighting process is given as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{intensity} = \frac{I_1}{I_1 + I_2}\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{Unit1} + \frac{I_2}{I_1 + I_2}\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{Unit2} \qquad (1)$$

Another approach would be to base the weighting process on the resolution of each unit at the marker localization. In order to do so, a model of the resolution of the unit through space is here presented. Each unit is composed of three sensors. Each sensor measures the angle between the unit and the marker as shown in Figure 1. The equation of the position p of the marker as a function of the three angles $p(\alpha,\beta,\gamma)$ can be expanded as a Taylor series (Equation 2).

$$p(\alpha,\beta,\gamma) = p(\alpha_0,\beta_0,\gamma_0) + \Delta\alpha \left.\frac{\partial p}{\partial \alpha}\right|_{\alpha_0,\beta_0,\gamma_0} + \Delta\beta \left.\frac{\partial p}{\partial \beta}\right|_{\alpha_0,\beta_0,\gamma_0} + \Delta\gamma \left.\frac{\partial p}{\partial \gamma}\right|_{\alpha_0,\beta_0,\gamma_0} + O(\Delta\alpha^2, \Delta\beta^2, \Delta\gamma^2) \qquad (2)$$

$\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$ are the angular resolutions of the three sensors of the unit. These resolutions are equal to the same value Δ. The resolution R can be estimated as:

$$R = p(\alpha,\beta,\gamma) - p(\alpha_0,\beta_0,\gamma_0) \approx \Delta \left.\frac{\partial p}{\partial \alpha}\right|_{\alpha_0,\beta_0,\gamma_0} + \Delta \left.\frac{\partial p}{\partial \beta}\right|_{\alpha_0,\beta_0,\gamma_0} + \Delta \left.\frac{\partial p}{\partial \gamma}\right|_{\alpha_0,\beta_0,\gamma_0} \qquad (3)$$

The relations between *(x,y,z)* and *(α,β,γ)* are easily obtained from figure 1:

$$\begin{cases} \alpha = atan\left(\dfrac{2y}{L+2x}\right) \\ \beta = atan\left(\dfrac{z}{y}\right) \\ \gamma = atan\left(\dfrac{2y}{L-2x}\right) \end{cases} \qquad (4)$$

Then the resolution as a function of the position *[x,y,z]* of the marker (Figure 2) is obtained by using (4) in (3). The exact value of resolution is proportional to the presented values as the value Δ of the angular resolution is unknown.

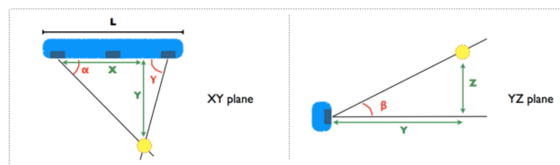

Figure 1: Angles *(α, β, γ)* are measured by the three sensors of the unit to obtain the marker localization *[x, y, z]*.

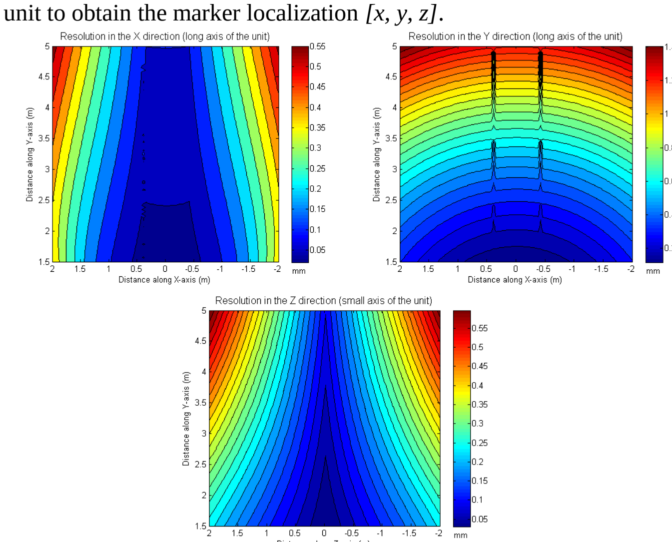

Figure 2: Resolution $r_x(x,y)$, $r_y(x,y)$, $r_z(x,y,z=0)$ in respectively the X, Y and Z direction.

The weight w given to each coordinate of each unit is:

$$\begin{cases} w_{Unit1} = \begin{bmatrix} 1 - \dfrac{{}^{Lab}T_{Unit1} \cdot r^x_{Unit1}}{{}^{Lab}T_{Unit1} \cdot r^x_{Unit1} + {}^{Lab}T_{Unit2} \cdot r^x_{Unit2}} ; \\ 1 - \dfrac{{}^{Lab}T_{Unit1} \cdot r^y_{Unit1}}{{}^{Lab}T_{Unit1} \cdot {}^{Lab}T_{Unit2} \cdot r^y_{Unit1} + r^y_{Unit2}} ; \\ 1 - \dfrac{{}^{Lab}T_{Unit1} \cdot r^z_{Unit1}}{{}^{Lab}T_{Unit1} \cdot r^z_{Unit1} + {}^{Lab}T_{Unit2} \cdot r^z_{Unit2}} \end{bmatrix}^T \\ w_{Unit2} = (1 - w_{Unit1}) \end{cases} \qquad (5)$$

With $r_{Unit} \epsilon\ [r_{Unit}^{x}, r_{Unit}^{y}, r_{Unit}^{z}]$ being the resolution in all three directions and ${}^{Lab}T_{Unit}$ the transformation matrix from the global reference frame of the laboratory to the local reference frame of the unit. The weighting option based on the resolution of each unit at the marker localization is:

$$\begin{bmatrix}x\\y\\z\end{bmatrix}_{resolution} = w_{Unit1}\begin{bmatrix}x\\y\\z\end{bmatrix}_{Unit1} + w_{Unit2}\begin{bmatrix}x\\y\\z\end{bmatrix}_{Unit2} \qquad (6)$$

This way different weight can be assigned to each direction of each unit depending on their relative position.

The last merging process presented in this paper takes into account both signal level and resolution at marker localization. Because of the strong influence of the signal level on the noise, the estimation based on light intensity will be favored when the difference of signal level between the two units is high. When the signal intensities are close, the estimation based on the resolution is preferred. The process is:

$$\begin{bmatrix}x\\y\\z\end{bmatrix}_{merge} = w_{intensity}\cdot\begin{bmatrix}x\\y\\z\end{bmatrix}_{intensity} + w_{resolution}\cdot\begin{bmatrix}x\\y\\z\end{bmatrix}_{resolution} \qquad (7)$$

With the weights defined by:

$$\begin{cases} w_{intensity} = \left[1 - e^{-\frac{(ratio-0.5)^2}{0.02}}\right] \\ w_{resolution} = (1 - w_{intensity}) \end{cases} \quad with\ ratio = \frac{I_1}{I_2} \qquad (8)$$

In order to evaluate the different weighting options, two experiments were realized: (i) two units were placed normally to one another and pointing to a single marker. The marker is kept fixed while both units are progressively moved away from the marker of the same distance (from 1.5 m to 5.0 m) (ii) the units are placed as in the first experiment but this time only the second unit moves away. In the first experiment, the signal level of both units decreases at the same rate whereas in the second one, only the signal level of the second unit decreases.

For both experiments, the position of the static marker was acquired during 5 s for all positions of the two units. The peak to peak values in X, Y and Z directions were then computed. The results are expressed in the local reference frame of the first unit.

RESULTS AND DISCUSSION

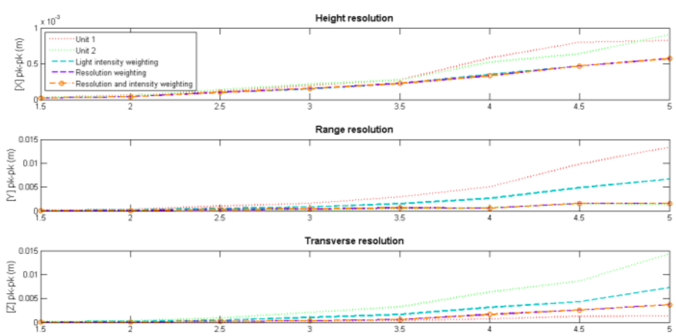

Figure 3: Peak to peak value of the marker localization during the first experiment.

Figure 3 presents the results for the first experiment. Because results are expressed in the first unit reference frame and the units are perpendicular, the range direction is Y for the first unit and Z for the second. We can clearly see that the accuracy is lower in the range direction. In the first experiment, the signal level of both units is similar at a given distance. Therefore the main influence on accuracy is resolution. Both methods taking into account the resolution are better than the one based on the light intensity. It is however important to notice that by placing the two units in a perpendicular position, we choose the best configuration to make the most of the resolution differences.

The results of the second experiment (Figure 4) show the importance of the light intensity on the noise. Indeed, the method based only on the resolution is now a lot worse than the one based on intensity. The reason is that the gain in resolution of the second unit in one direction does not compensate for the signal intensity loss on the global noise. The method based on both resolution and intensity is again really good. Indeed, in this estimation, the estimation based on intensity has a stronger weight because the signal level ratio between the units is high.

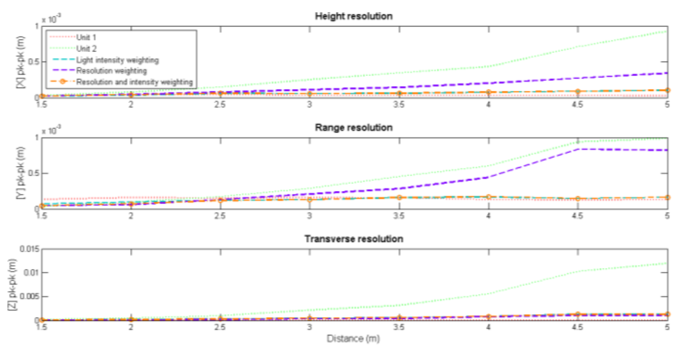

Figure 4: Peak to peak value of the marker localization during the second experiment.

The normal working range of the Codamotion system is from 2.0 m to 4.5 m. It is clear that in this field of view taking into account both resolution and light intensity improves the accuracy of the results.

CONCLUSIONS

We have seen that the light intensity have the strongest influence on the accuracy of the system. The approach of Codamotion to weight the different estimations of the marker position by taking into account the light intensity is therefore interesting. However, when the signal levels are quite similar for both units, taking into account the resolution can further improve the accuracy. The method based on both resolution and light intensity improves the overall accuracy in all cases.

REFERENCES

1. Mitchelson DL. US patent 5408323, 1995.
2. Coda CX1 User guide