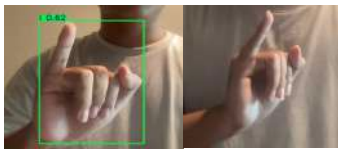

Fig. 5. Detection of letter I at 30 cm (left) and no detection at 60 cm (right).

The background variation testing aims to evaluate the model's performance in detecting BISINDO alphabets under various background conditions, precisely a plain white background and a complex background (patterned or skin-colored). The testing was conducted using a laptop webcam at a distance of 30 cm to measure the model's ability to maintain detection accuracy in different environments.

TABLE VII. BACKGROUND TEST RESULT

| *Background* | *Actual Value* | *Correct Classification* | *False classification* | *Accuracy* |
|---|---|---|---|---|
| White | 78 | 78 | 0 | 100% |
| Complex | 78 | 72 | 6 | 92% |

The model performed very well in detecting the BISINDO alphabet on various backgrounds. The accuracy reached 100% on a plain background, indicating optimal performance. However, on patterned or skin-colored backgrounds, the accuracy decreased to 92% due to misdetections in classes B, I, R, M, and S. This decrease is due to visual distractions, such as color or pattern similarities between the hand and the background, which affect the quality of the features extracted by the model. Here are the detection results on white and complex backgrounds, as shown in Fig. 6 and Fig.7.

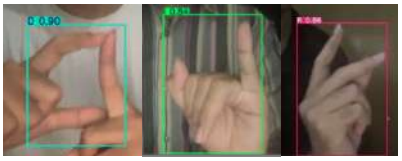

Fig. 6. Test result background

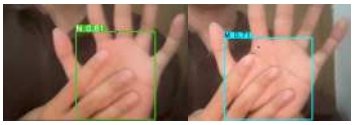

Fig. 7. Misdetection on class M (left) & Correct detection on class M (right)

## V. CONCLUSION

This study successfully developed a classification system for Indonesian Sign Language (BISINDO+) using YOLOv11. The evaluation results on the validation set showed a precision difference of 0.7 and a recall difference of 0.4 compared to YOLOv8. Results on the test set demonstrated a precision of 0.997, a recall of 1.000, and a mAP5 of 0.995. The model was designed with data augmentation techniques, including horizontal flipping, cropping up to 20%, and rotation between -5° and +5°. Additionally, optimal hyperparameter settings, such as 50 epochs, an image size of 640, a batch size of 16, a momentum of 0.95, an initial learning rate of 0.001, and the AdamW optimizer were applied.

Real-time testing achieved 100% accuracy at a distance of 30 cm, which decreased to 97% at 60 cm. The accuracy reached 100% on plain backgrounds, while on patterned backgrounds, it dropped to 92% due to visual interference. Overall, tested on the BISNDO+ dataset, YOLOv11 has proven to be an effective solution for Indonesian Sign Language recognition applications, demonstrating consistent performance and high accuracy under various conditions. However, there is a challenge because there were some detection errors on patterned backgrounds, and future work will involve testing the model under various noise conditions to further enhance its robustness.

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