Parallax and Trigonometry: Using Stereo Vision to Determine the Distance of an Object
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1 Introduction

Computer-generated stereo vision provides opportunities in several areas: positioning and terrain assessment to model three-dimensional topographical maps of planetary surfaces[1] and urban environments,[2] obstacle avoidance[3] for the visually impaired and the vehicles they might drive,[4] and for human head detecting and tracking for interactions with humanoid robots.[5] Because of its ability to provide a three-dimensional view, stereo vision is also important in satellite reconnaissance[6] and video surveillance.[7]

This 3D simulation, using mathematical models and algorithms, allows for the special effects used in such movies as the Harry Potter and Lord of the Rings series.[8] Stereo vision has also been developed in inexpensive image sensor chips to measure distances—potential technology for robotics, game consoles, automobile navigation, and enhanced security.[9] Stereo vision cameras are also used in plastic surgery, orthopedics, prosthetics, and wound healing.[10]

Because stereo vision approximates human sight, it is a highly versatile and dynamic field of study. Depth perception and distance approximation can especially enhance robotics. Applied to Botball, stereo vision can locate objects and obstacles on a Botball table using trigonometry to provide distance and direction information.

2 Stereo Vision Robot

Two XBCs mounted on a turntable with their cameras 5 inches apart, face a reference target ten inches away. Using an adapted male-to-male serial cable (a null-modem cable), the XBCs communicate with each other to exchange angular readings. The turntable rotates the cameras together to keep both pointed at the object, centering the view between the cameras.

To calibrate the vision system, the XBCs measure the horizontal position of the reference target in the camera’s view, convert the measurements to angles, and keep the angles for later calculations. Then, as the target moves about, the system calculates and displays the new distance to the target, while keeping the target in view by rotating the turntable.

3 Stereo Vision Ranging Trigonometry

Trigonometry calculations determine the distance between the cameras and the object on the table. The following figure shows the geometric relationships between the two cameras and a target:

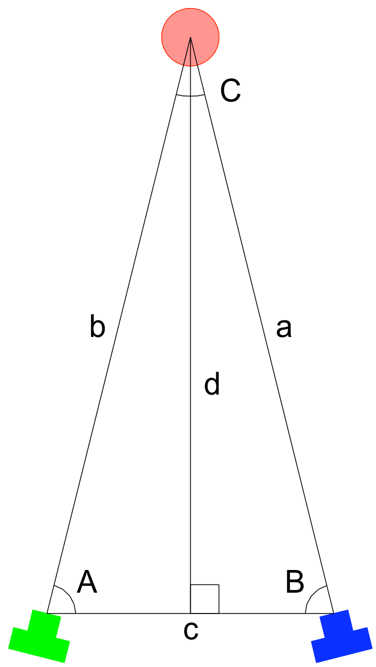

Figure 1: Geometric relationships between two cameras and a target:

The baseline, **c,** is the known distance between the cameras. Angle **A** is the angle between the baseline and the object as measured by the left camera. Angle **B** is the angle between the baseline and the object as measured by the right camera. Distance **d** is the perpendicular distance from the baseline to the target.

The solution is to find **d** as a function of **A**, **B**, and **c**:

$a / \sin(A) = b / \sin(B) = c / \sin(C)$ (law of sines)

$a = c * \sin(A) / \sin(C) = c * \sin(A) / \sin(A+B)$

$d = a * \sin(B) = c * \sin(A) / \sin(A+B) * \sin(B)$

Finally:

$d = c * \sin(A) * \sin(B) / \sin(A+B)$

4 Calibration

In Introduction to AI Robotics, Robin R., Murphy cautions that

> in practice, robots move, bump, and suffer alignment drifts, plus the cameras may have some flaws in their optics. The alignment can be periodically compensated for in software through a camera calibration process, where the robot is presented with a standard and then creates a calibration look up table or function.[11]

The vision system may be calibrated to a reference target centered at a known distance in front of the cameras. The system determines the apparent angles and subtracts the expected angles to get calibration offsets, or angular errors. Later, as the target moves, the vision system determines the new angles, adjusts them using the calibration offsets, and calculates and displays the new distance to the target.

5 Limited View

Each camera's view is limited, and the distance can be calculated only when the target is in view from both cameras. In the figures 2 and 3, the cross-hatched areas represent each camera's view. Distance can be calculated only in the region where the camera views cross. The turntable under the cameras rotates to help keep the target in that area.

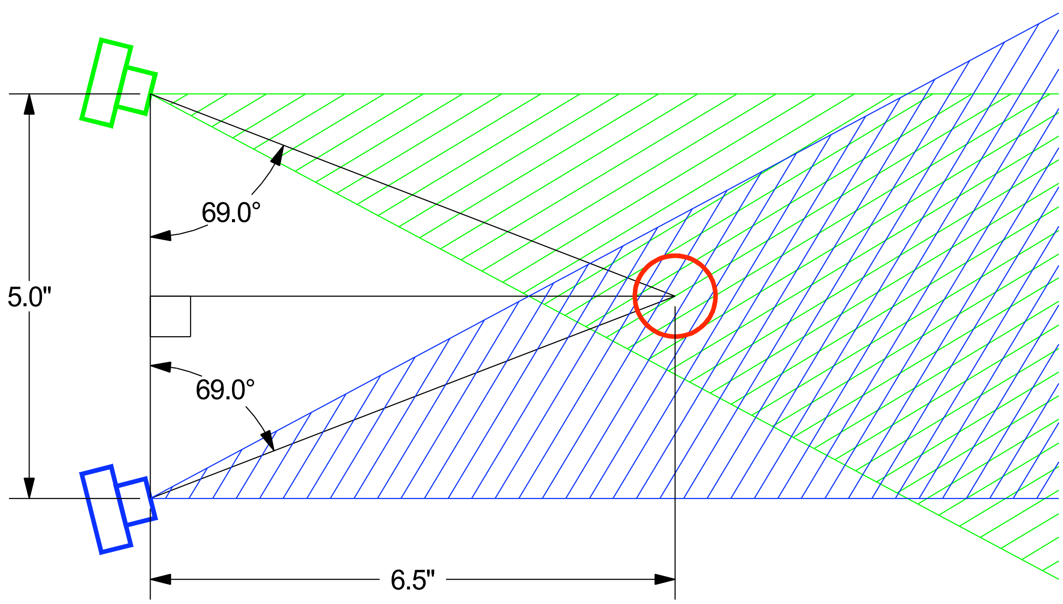

Figure 2: Object placed near and centered in camera view.

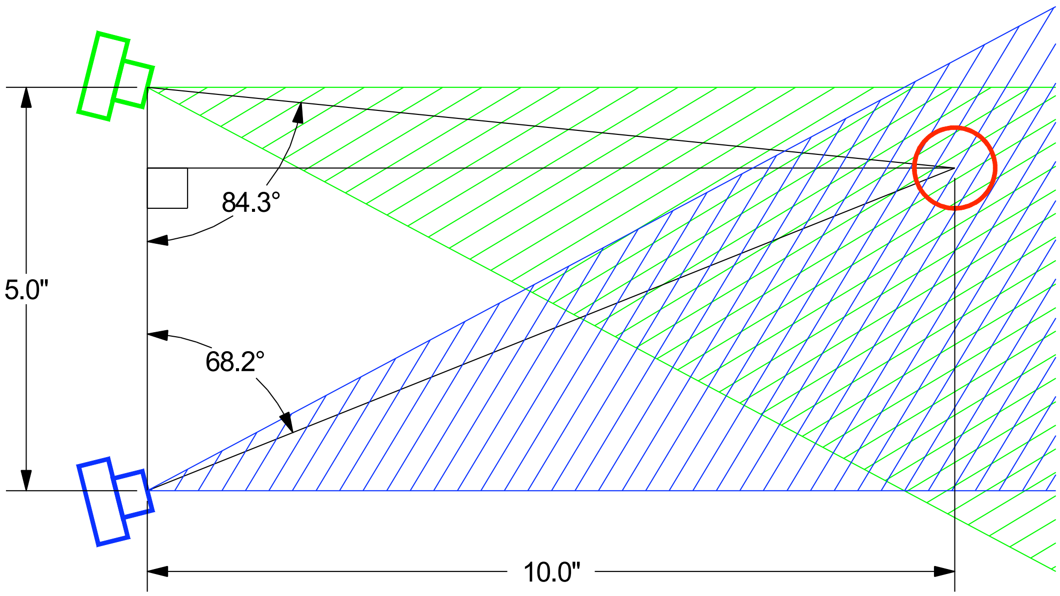

Figure 3: Object placed off-center in camera view.

6 Stereo Vision Coding

The overall program is too large to present here but is straight-forward except the communication aspects. This is an example program that would make one XBC continuously send the number 120 every second through the serial port connection.

xbc_sender.ic

```
#use "xbcserial.ic"
void main()
{
    serial_set_mode(BAUD_9600);
    while(1)
    {
        serial_write_byte(120);
        sleep(1.);
    }
}
```

There is, however, a bug in the library “xbcserial.ic,” requiring some editing. Several lines need to be commented out.

```
void serial_write_byte(int byte)
{
    while(_serial_write_busy);          Comment out this line.
    _serial_write_busy=1;
    callml(181, byte);                       Comment out this line.
    _serial_write_busy=0;                    Comment out this line.
}

//Returns 0 if there is nothing to be read
int serial_read_byte()
{
    while(_serial_read_busy);           Comment out this line.
    _serial_read_busy=1;
    return callml(180, 0);
    _serial_read_busy=0;                Comment out this line.
}
```

Having a robot “listen” requires a slightly different code.

xbc_listen.ic

```
#use "xbcserial.ic"
int info;
void main()
{
    serial_set_mode(BAUD_9600);
    while(1)
{
    info=serial_read_byte();
    if(info>0)
{
    printf("%d",info);
}
    sleep(.5);
}

}
```

In this program, an integer called “info” tells us if new information is coming into the buffer. When running these two programs on two XBCs simultaneously while they were connected with a male-male serial cable, one would show no sign of running while the other printed off “120” every .5 seconds.

7 Conclusion

In conclusion, the techniques required to complete a project similar to this one vary greatly from mechanical design of robots to trigonometric functions. I did not create a look up table. Using my experience from Botball and math courses, it only took several nights of studying to figure out how to make it all work together.

Although we do not use stereo vision in Botball, its applications are broad in the field of robotics and navigation. Computer stereo vision can help handicapped people, unmanned vehicles, and reconnaissance and surveillance.

References

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