INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

ME 206

STATICS & DYNAMICS

Professor: Jayaprakash K R

Experiment-2

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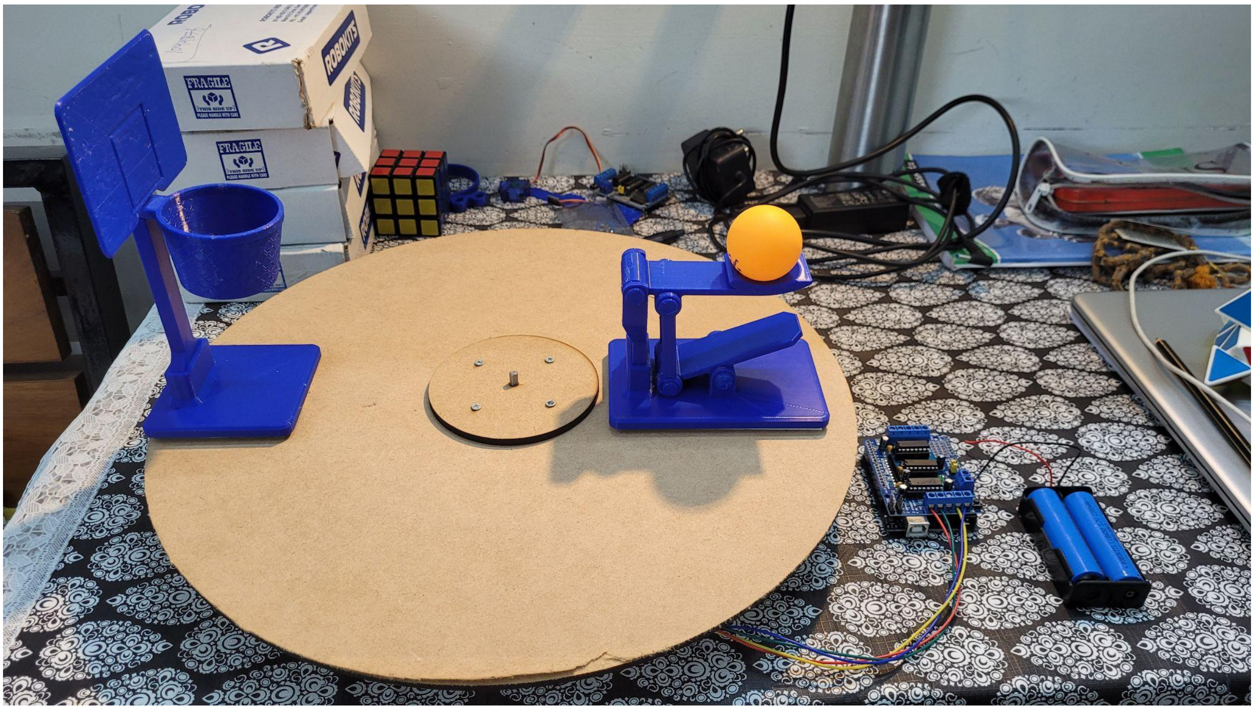
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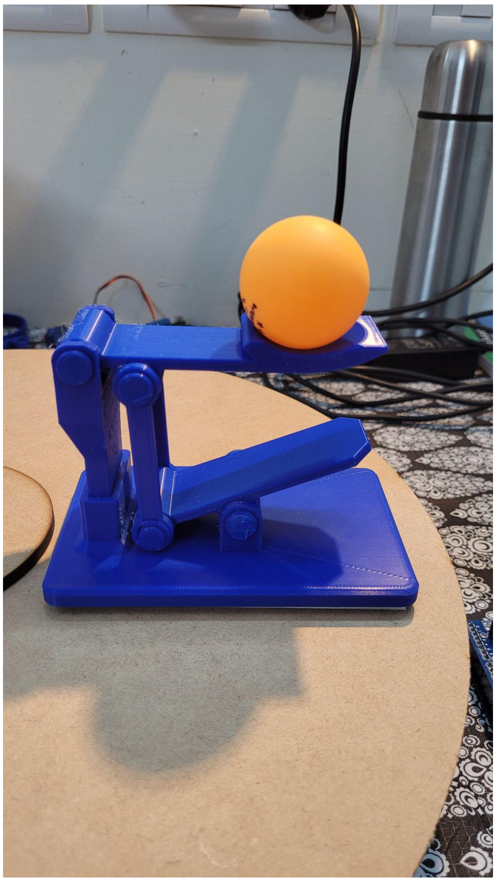
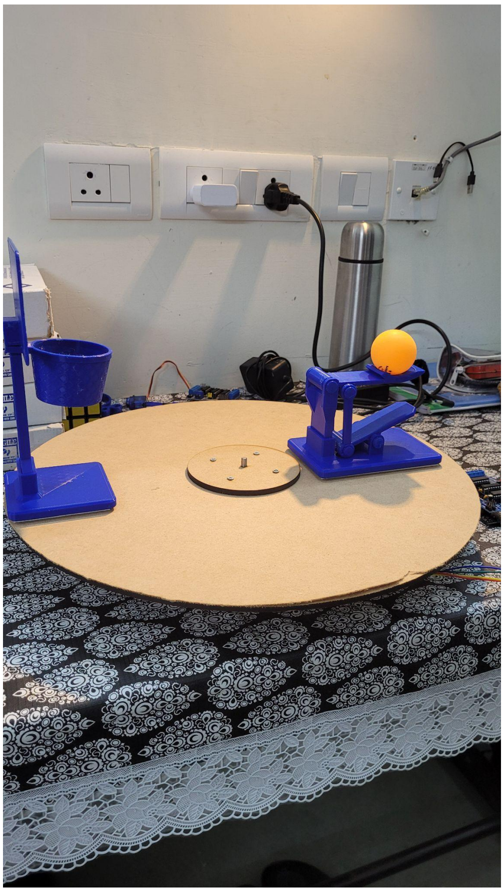
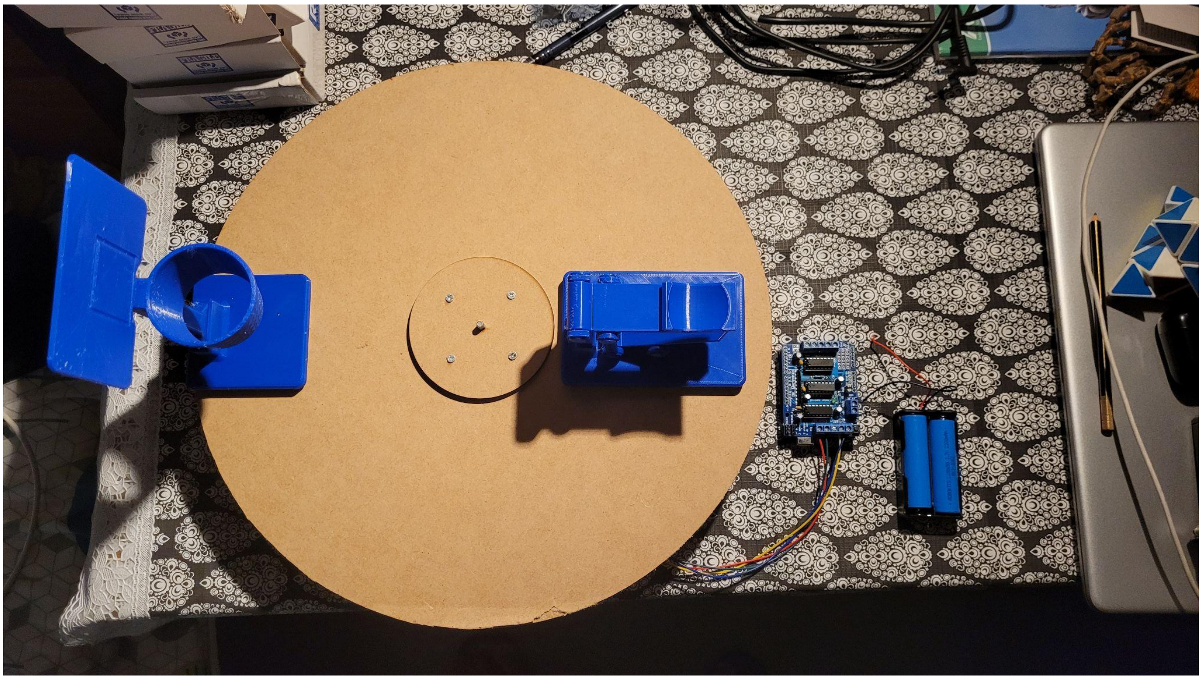






Abstract:

In this experimental study, we designed and implemented a setup to investigate and quantify the velocity and acceleration of a moving particle for a rotating frame and measuring quantitively, $\vec{w},, \vec{r}_{AB}$, $\left(\frac{d\vec{r}_{AB}}{dt}\right)_{Bxyz}$ etc., by taking into account the Coriolis effect.

Objective:

1) We have to establish an experimental setup to exhibit the velocity and acceleration of a moving particle for a rotating frame of reference ($\vec{\Omega}$, $\dot{\vec{\Omega}}$).

2) With the experiment, we have to exhibit and quantitively measure all the terms on the RHS of the following expressions:

$$\frac{d\vec{r}_{AB}}{dt} = \left(\frac{d\vec{r}_{AB}}{dt}\right)_{Bxyz} + \vec{\Omega} \times \vec{r}_{AB}$$

$$\frac{d}{dt}\left(\frac{d\vec{r}_{AB}}{dt}\right) = \left(\frac{d^2\vec{r}_{AB}}{dt^2}\right)_{Bxyz} + \dot{\Omega} \times \vec{r}_{AB} + 2 \times \left(\frac{d\vec{r}_{AB}}{dt}\right)_{Bxyz} + \vec{\Omega} \times (\vec{\Omega} \times \vec{r}_{AB})$$

Educational Alignment and Practical Engagement:

- **Alignment with Learning Objectives:** The experiment directly aligns with the core learning goals of the statics and dynamics course, facilitating a practical application of theoretical concepts. In this case, it would be to understand and quantitatively measure the velocity and acceleration of a particle in a rotating frame, as described by specific equations derived in class.

- **Bridging Theoretical and Practical:** The experiment effectively bridges the gap between abstract theoretical ideas and their real-world implementations by involving hands-on activities. This includes concepts related to frames of reference, relative motion, velocity, acceleration, and the Coriolis effect.

- **Preparation for Complexities:** The hands-on approach readies us to tackle intricate scenarios in structural dynamics, fostering a more profound comprehension of physics concepts.

Application of Fundamental Principles:

- **Kinematics:** Position, velocity, and acceleration are applied to describe the ball's motion.

- **Relative Motion:** The experiment illustrates how the motion of a particle appears differently when observed from different frames of reference, demonstrating the concept of relative motion.

- **Coriolis Effect:** The experiment also illustrates how the Coriolis Effect affects the motion of objects on the rotating frame of reference. It is responsible for the deflection of the moving objects. It occurs because different points on the Earth's surface are rotating at different speeds.

Materials used in the Experiment:

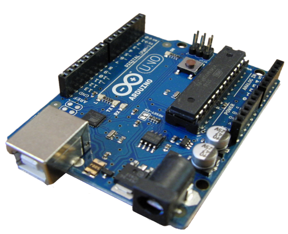
Various materials and components were utilized and carefully chosen to represent the
Coriolis Effect to ensure the project's success.

1. **3D Printing Materials:**

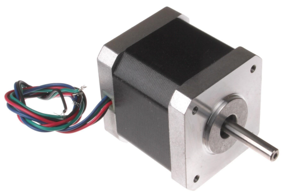
   We used PLA filament as the 3D printing material for printing the model's components because PLA is known for its ease of use, durability, and design suitability.

2. **Arduino UNO & Connecting Wires:**

   We used the Arduino Uno microcontroller as the system's brain, controlling the stepper motor.



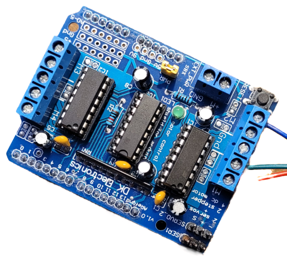
3. **Stepper Motor with D-Shaft:**



We used the stepper motor with a D-shaft because it is responsible for imparting the rotational force to the base for implementing *the Coriolis Effect,* and the D-shaft ensures the secured connection.

4. **Motor Shield Driver:**

We used a Motor Shield Driver to enable motion-based control and tracking of the movements. It is a circuit board with connections that contains a motor chip that drives motors.



5. **MDF Board (Medium Density Fiberboard):**

We used an MDF board for making the rotating frame and as a support structure for the model. We used the MDF board because of its smooth surface, rigidity, etc.

6. **3.7 Volt Battery & Battery Holder:**

We used two 3.7 V batteries to give power to the Arduino Uno stepper motor. Corresponding to the battery, we used a battery holder to support the battery.

7. **Others:**

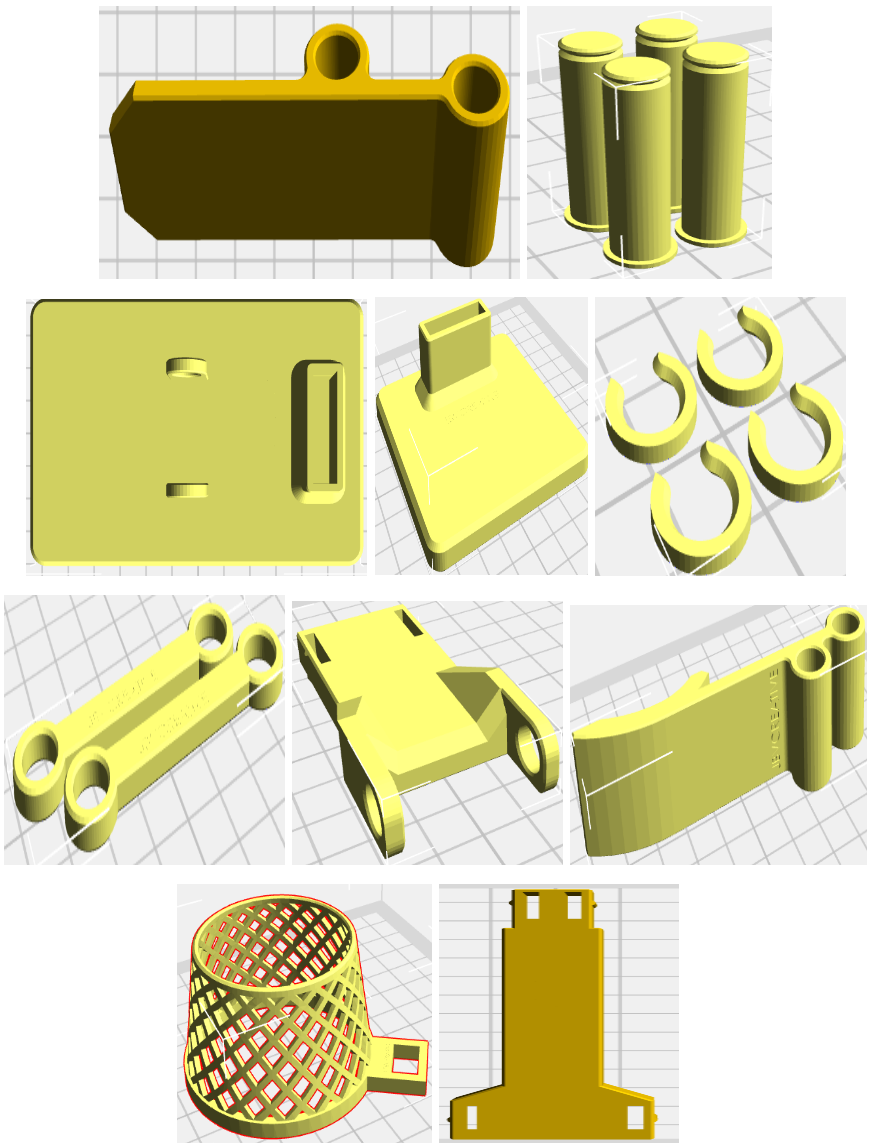
We used a tripod stand to shoot concerning the reference (rotating) frame. Also, we used screws, nuts, connecting wires, double-sided tape, etc.

Fabrication Details:

The experiment employed a combination of various materials components and carefully created a function to create a functional and instructive setup.

1. Design & 3D Printing:

- The design process involved the creation of detailed 3D models for the model, including the support structure.
- The 3D printing process utilized precise parameters to ensure accurate and high-quality printing. This included the *Flash Print app*'s layer height, infill density, raft, and temperature settings.
- Once the individual components were printed, they were carefully assembled to create the model structure.



2. **Electronics Integration:**

- **Arduino Uno:** Arduino Uno was programmed to control the stepper motor and process data from the triple-axis accelerometer and gyro connector.
- **Stepper Motor:** A stepper motor with a D shaft was employed to impart rotational motion to the model, effectively simulating *the Coriolis Effect*.
- **Motor Shield Driver:** A dual full-bridge driver is designed to drive the stepper motor.
- **Battery Components:** A 3.7 Volt battery, placed in the battery holder, served as the portable power source for the Arduino and stepper motor.

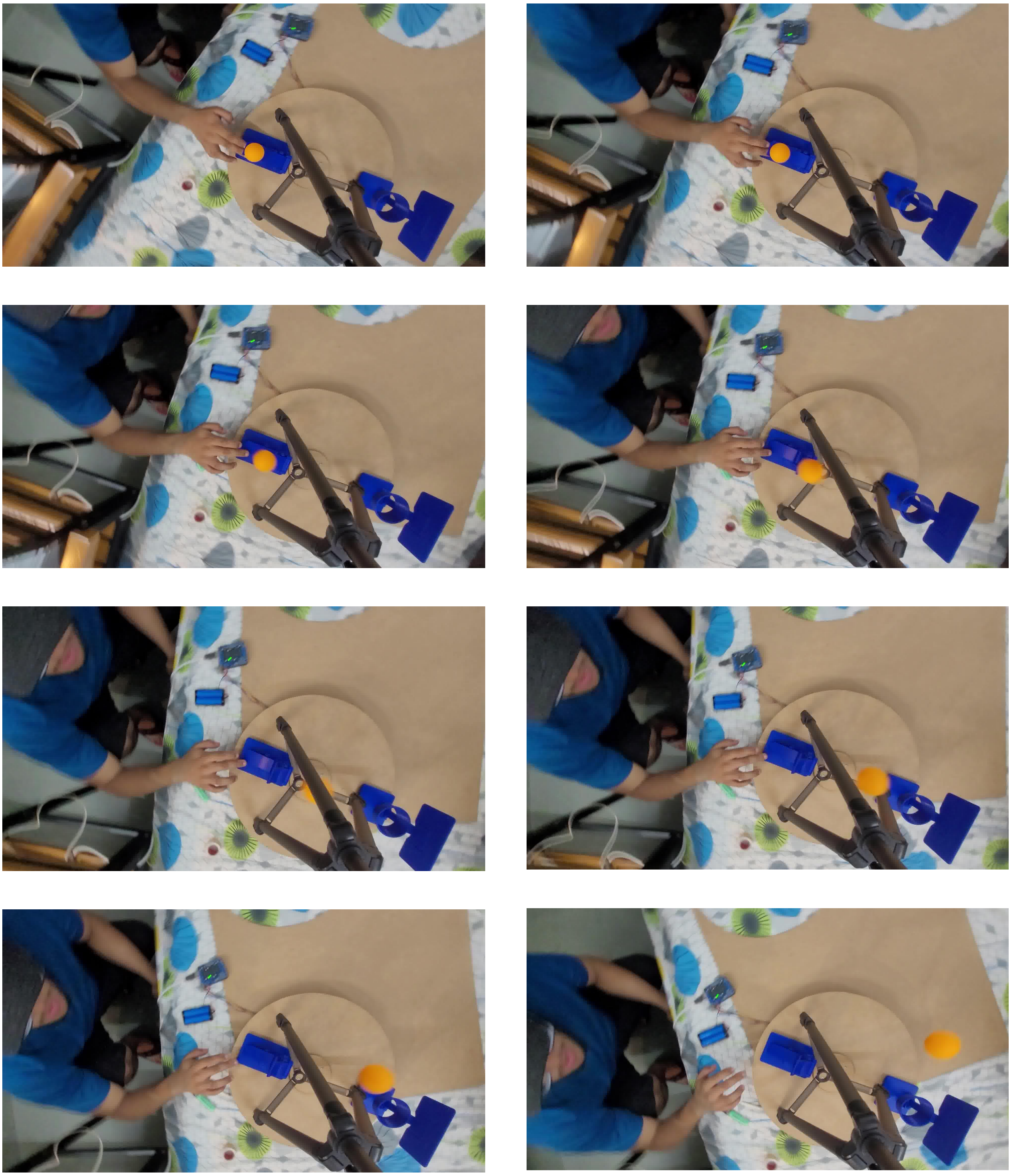
Video Showing Motion from Rotating Frame

Video Showing Motion from Stationary Frame

Procedure:

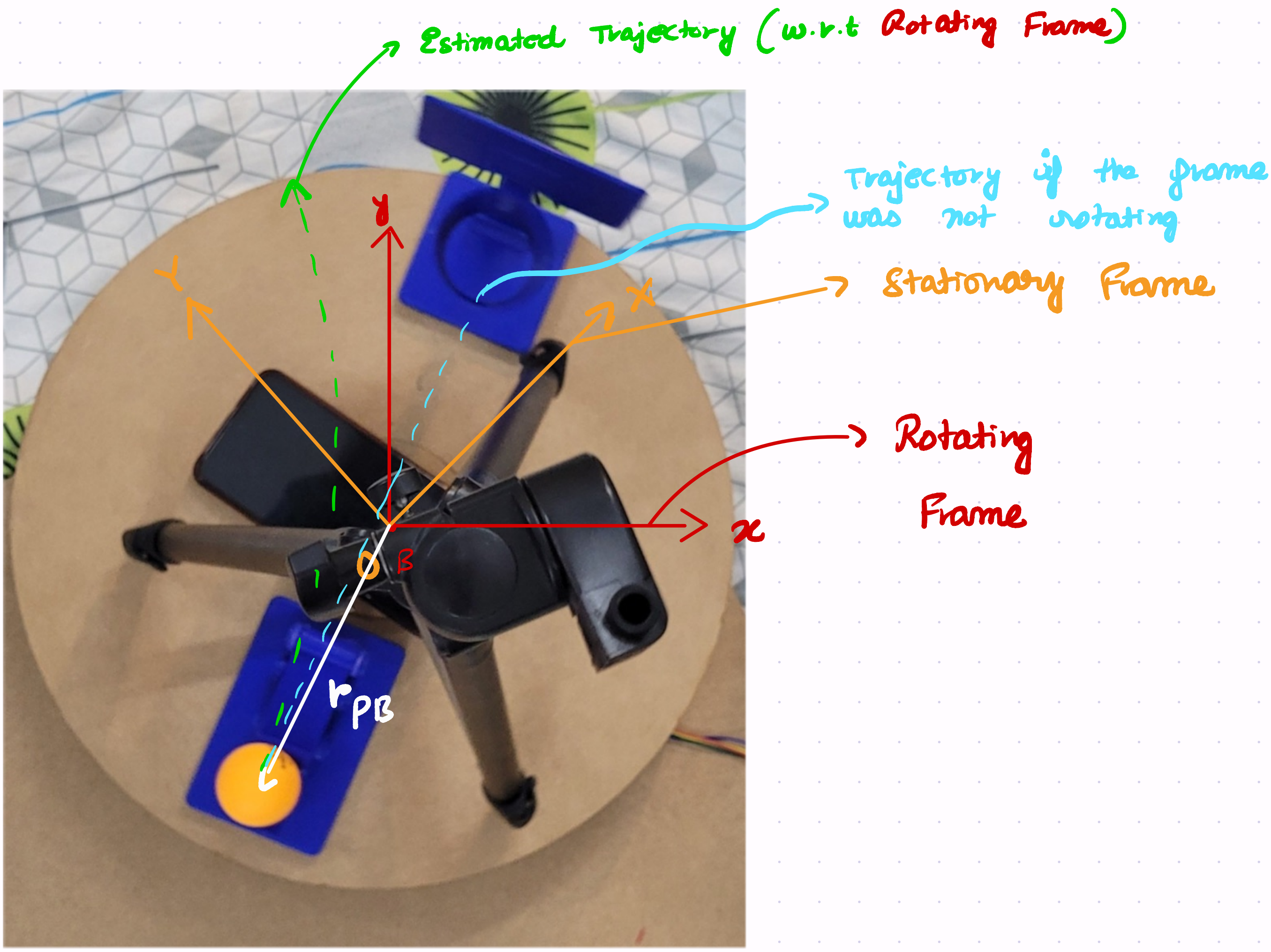
1. First, different components of the model were connected, and the code to rotate the frame was flushed on the Arduino.
2. Now we fixed the tripod with the camera on the rotating frame to shoot the in perspective from the rotating frame.
3. Now, the video was broken down into different photos. The video was recorded in 30 Frames per Second. So each second of video recording outputs 30 pictures.
4. Now the important pictures that capture the motion were extracted and their position vectors and angular position were calculated using *Matlab image processing extension*.
5. These were further used to analyze the different components of the motion of the moving particle in a rotating frame with rest to a stationary frame.
6. All the information was then used to perform the required calculation. The calculations are discussed in the next section.

Observations:



Calculations

RATE OF CHANGE OF THE POSITION VECTOR WITH RESPECT TO FIXED REFERENCE



The rate of change of the position vector with respect to the fixed reference is

$$\dot{\vec{r}}_A = \dot{\vec{r}}_B + \dot{\vec{r}}_{AB} = \dot{\vec{r}}_B + (\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath}) + \left(x_{PB}\frac{d\hat{\imath}}{dt} + y_{PB}\frac{d\hat{\jmath}}{dt}\right)$$ (As derived in class)

$$= \dot{\vec{r}}_B + (\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath}) + (x_{PB}\vec{\omega}\times\hat{\imath} + y_{PB}\vec{\omega}\times\hat{\jmath}) =$$

$$= \dot{\vec{r}}_B + (\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath}) + (\vec{\omega}\times x_{PB}\hat{\imath} + \vec{\omega}\times y_{PB}\hat{\jmath})$$

$$= \dot{\vec{r}}_B + (\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath}) + \vec{\omega}\times(x_{PB}\hat{\imath} + y_{PB}\hat{\jmath}) = \dot{\vec{r}}_B + \underbrace{(\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath})}_{\boxed{\vec{v}_{AP} = (\vec{v}_{AB})_{Bxy}}} + \underbrace{\vec{\omega}\times\vec{r}_{PB}}_{\vec{v}_{PB}}$$

Velocity of the particle A as measured by an observer stationed in the rotating Bxy reference

In our experimental setup $\vec{r}_B = 0$ [O and B co-inside]

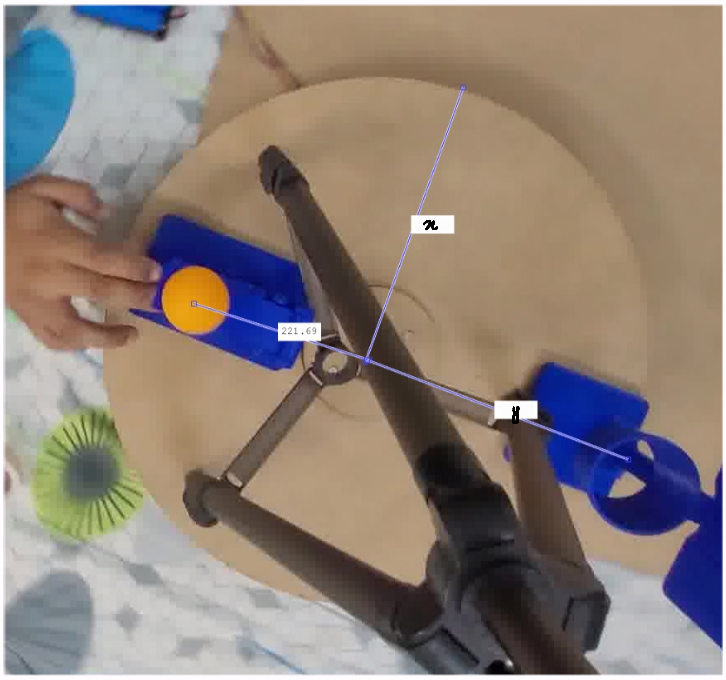
Hence $\dot{\vec{r}}_A = \dot{\vec{r}}_{AB}$

$$\left(\frac{d\vec{r}_{AB}}{dt}\right)_{Bxy}$$

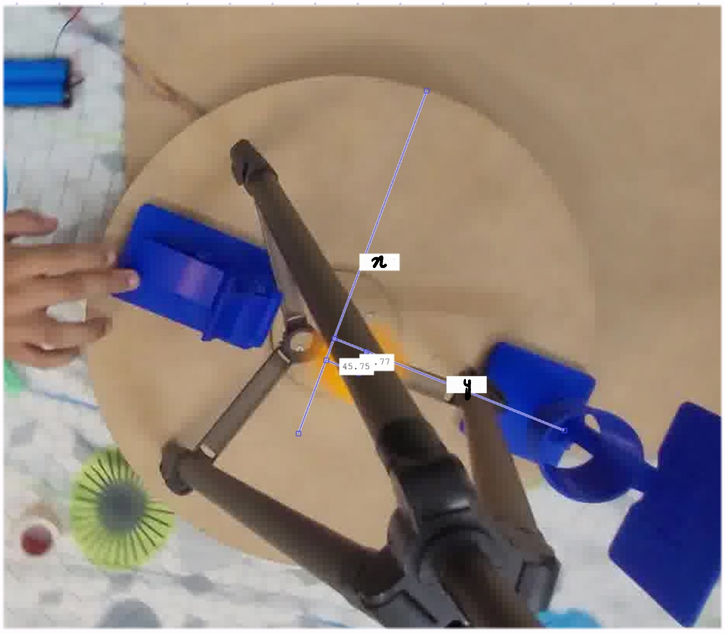
$$= \underbrace{(\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath})}_{} + \vec{\omega}\times\vec{r}_{PB}$$

Velocity as observed from the rotating frame

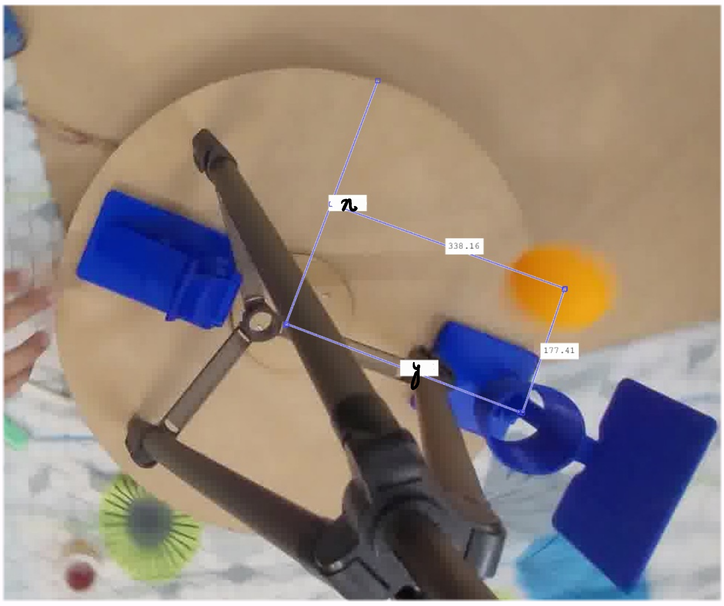
Position Vector w.r.t the rotating frame of reference



96th Frame

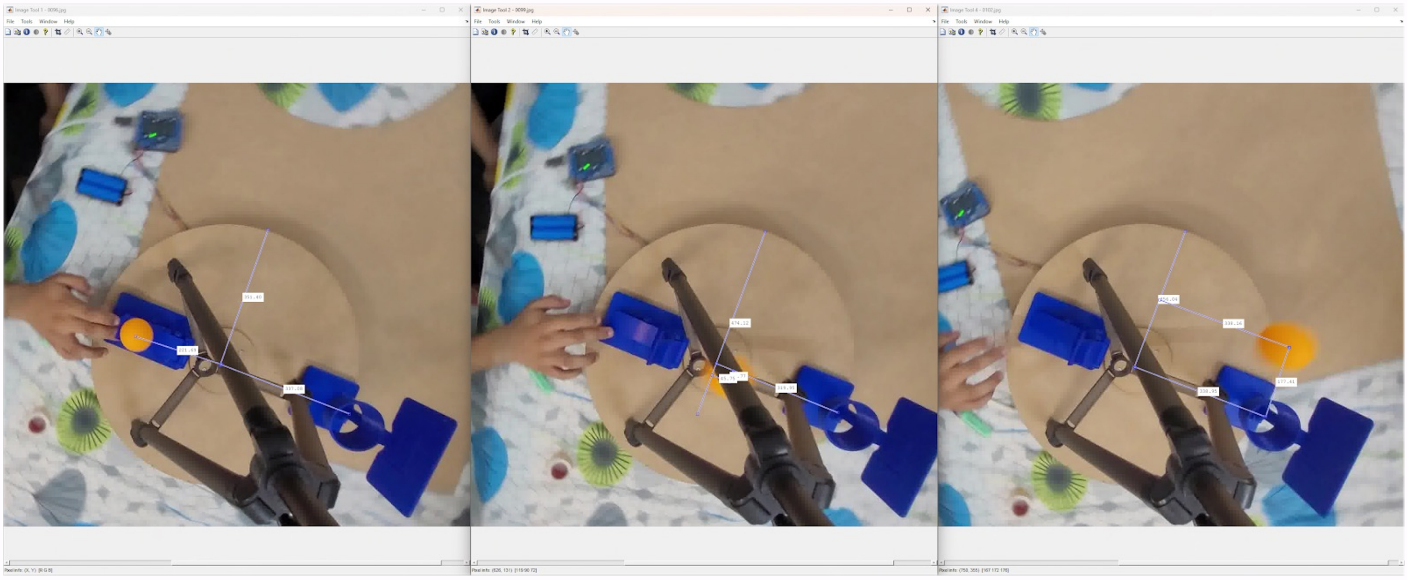


99th Frame



102nd Frame

MEASURING EXPERIMENTALLY $\left(\frac{d\vec{v}_{AB}}{dt}\right)_{Bxyz}$



96th Frame　　　　99th Frame　　　　102nd Frame

The Video was recorded in 30 FPS

Hence the time gap between each frame is $\frac{1}{30}$

Here the image processing is done in matlab where distance calculations are done for pixels they can be converted using a scaling factor

Here the scaling factor is 400 mm : 650 units

For the 96th Frame

$$\vec{r}_{AB_1} = -221.69\,\hat{i} + 0\,\hat{j}$$

For the 99th Frame

$$\vec{r}_{AB_2} = 45.75\,\hat{i} - 29.77\,\hat{j}$$

For 102nd Frame

$$\vec{r}_{AB_3} = 338.16\,\hat{i} + 177.4\,\hat{j}$$

Post using the conversion factor

For the 96th Frame

$$\vec{r}_{AB_1} = \underset{(x')}{-136.4246}\,\hat{i} + \underset{(y')}{0}\,\hat{j}$$

For the 99th Frame

$$\vec{r}_{AB_2} = \underset{(x'')}{28.1538}\,\hat{i} - \underset{(y'')}{18.32}\,\hat{j}$$

For 102nd Frame

$$\vec{r}_{AB_3} = \underset{(x''')}{208.0985}\,\hat{i} + \underset{(y''')}{109.1754}\,\hat{j}$$

Between 96th and 99th Frame

$$\vec{r}_{AB_1} = \frac{x''-x'}{\Delta t_1}\,\hat{i} + \frac{y''-y'}{\Delta t_1}\,\hat{j}$$

$$\Delta t_1 = (99-96) \times \frac{1}{30} = \frac{3}{30} = \frac{1}{10}\,s = \Delta t$$

Between 99th and 101th Frame

$$\vec{r}_{AB_2} = \frac{x'''-x''}{\Delta t_2}\,\hat{i} + \frac{y'''-x''}{\Delta t_2}$$

$$\Delta t_2 = (102-99) \times \frac{1}{30} = \frac{3}{30} = \frac{1}{10}\,s = \Delta t$$

$\vec{\dot{r}}_{AB_1} = 1645.784\,\hat{i} - 183.2\,\hat{j}$

$|\vec{\dot{r}}_{AB_1}| = 1655.9490$ mm/s

$= 1.6559$ m/s

$\vec{\dot{r}}_{AB_2} = 1799.447\,\hat{i} + 1274.984\,\hat{j}$

$|\vec{\dot{r}}_{AB_2}| = 2205.3383$ mm/s

$= 2.2053$ m/s

$$\boxed{\left(\frac{d\vec{r}_{AB_1}}{dt}\right)_{Bny} = 1645.784\,\hat{i} - 183.2\,\hat{j}}$$
Bny (Between 96th & 99th Frame)

$$\boxed{\left(\frac{d\vec{r}_{AB_2}}{dt}\right)_{Bny} = 1799.447\,\hat{i} + 1274.984\,\hat{j}}$$
Bny (Between 99th & 102th Frame)

MEASURING EXPERIMENTALLY $\left(\frac{d^2\vec{r}_{AB}}{dt^2}\right)_{Bnyz}$

$$\vec{\ddot{r}}_{AB} = \frac{\vec{\dot{r}}_{AB_2} - \vec{\dot{r}}_{AB_1}}{\Delta t} = \frac{1799.447 - 1645.784}{\Delta t}\,\hat{i} + \frac{1274.984 - (-183.2)}{\Delta t}\,\hat{j}$$

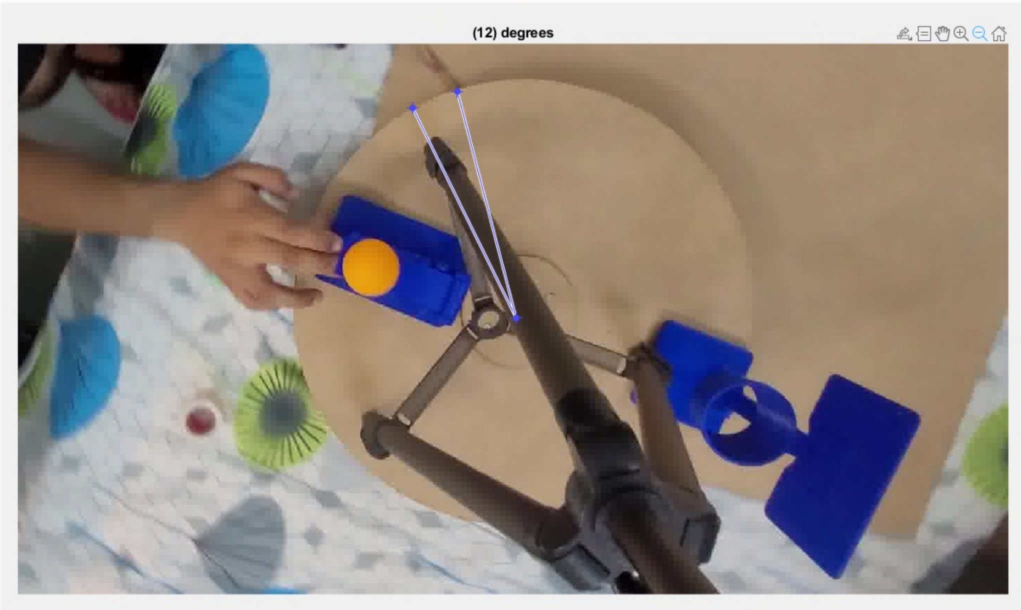
$$= 1536.63\,\hat{i} + 14581.54\,\hat{j}$$

$|\vec{\ddot{r}}_{AB}| = 14662.2829$ mm/s^2

$= 14.66$ m/s^2

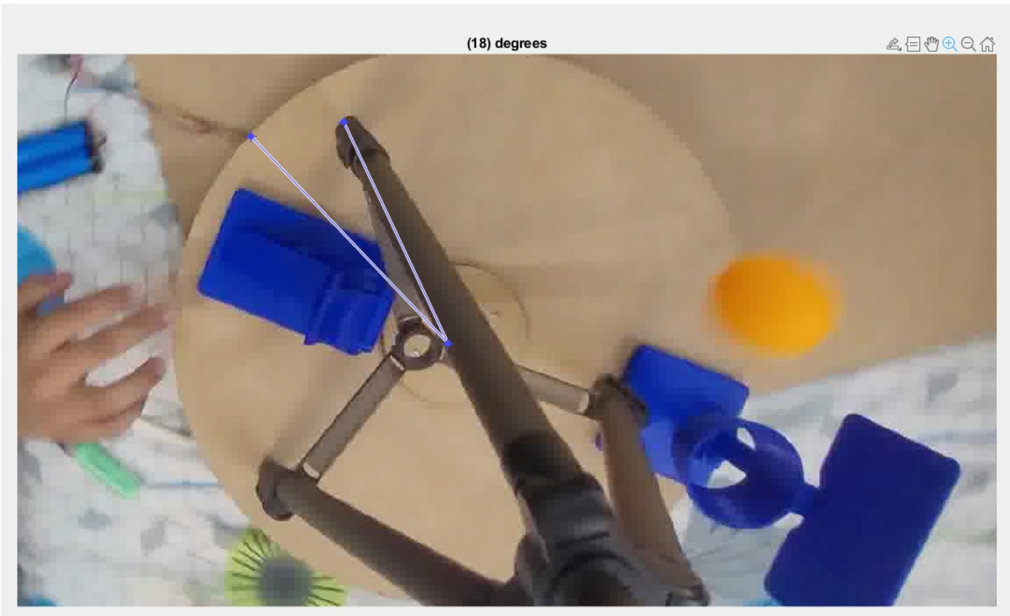
$$\boxed{\left(\frac{d^2\vec{r}_{AB}}{dt^2}\right)_{Bnyz} = 1536.63\,\hat{i} + 14581.54\,\hat{j}}$$

Angle of Rotation of the Rotating Frame



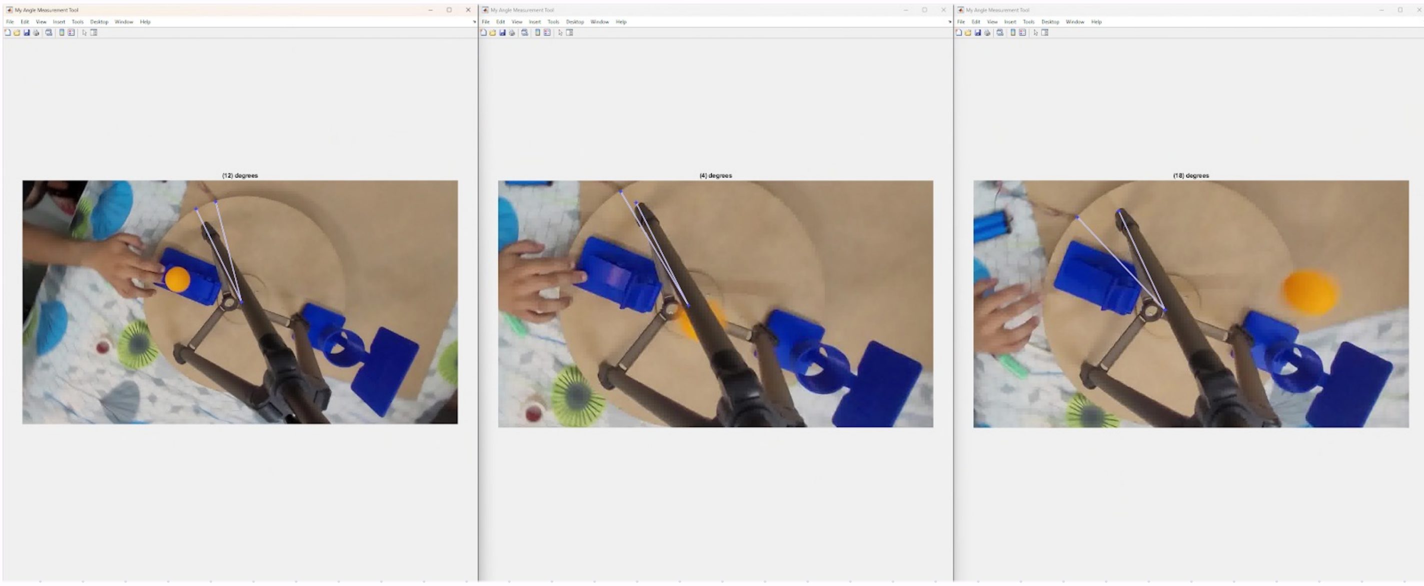
96th Frame

99th Frame



102nd Frame

Measuring ω and $\dot{\omega}$ Experimentally



At 96^{th} Frame $\theta_1 = -12$ degrees $= -0.20944$ rad

At 99^{th} Frame $\theta_2 = 4$ degrees $= 0.0698132$ rad

At 102^{th} Frame $\theta_3 = 18$ degrees $= 0.314159$ rad

$$\boxed{\omega_1 = \frac{\theta_2 - \theta_1}{\Delta t} = 2.792532 \text{ rad/s}}$$

$$\boxed{\omega_2 = \frac{\theta_3 - \theta_2}{\Delta t} = 2.443458 \text{ rad/s}}$$

$$\boxed{\dot{\omega} = \frac{\omega_2 - \omega_1}{\Delta t} = -3.4907 \text{ rad/s}^2}$$

Now $\dfrac{\dot{\vec{r}}_{AB}}{dt} = \dfrac{d\vec{r}_{AB}}{dt} = (\vec{V}_{AB})_{Bny} + \vec{\omega} \times \vec{r}_{AB}$

$$= \left(\frac{d\vec{r}}{dt}\right)_{Bny} + \vec{\omega} \times \vec{r}_{AB}$$

Now at the 99^{th} Frame

$$\dot{\vec{r}}_{AB} = \frac{d\vec{r}_{AB}}{dt} = 1645.784\,\hat{i} - 183.2\,\hat{j} + (-\omega\hat{k}) \times (28.1538\,\hat{i} - 18.32\,\hat{j})$$

$$= 1645.784\,\hat{i} - 183.2\,\hat{j} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -2.792532 \\ 28.1538 & -18.32 & 0 \end{vmatrix}$$

$$= 1645.784\,\hat{i} - 183.2\,\hat{j} + (-51.1592)\hat{i} + 78.6204\,\hat{j}$$

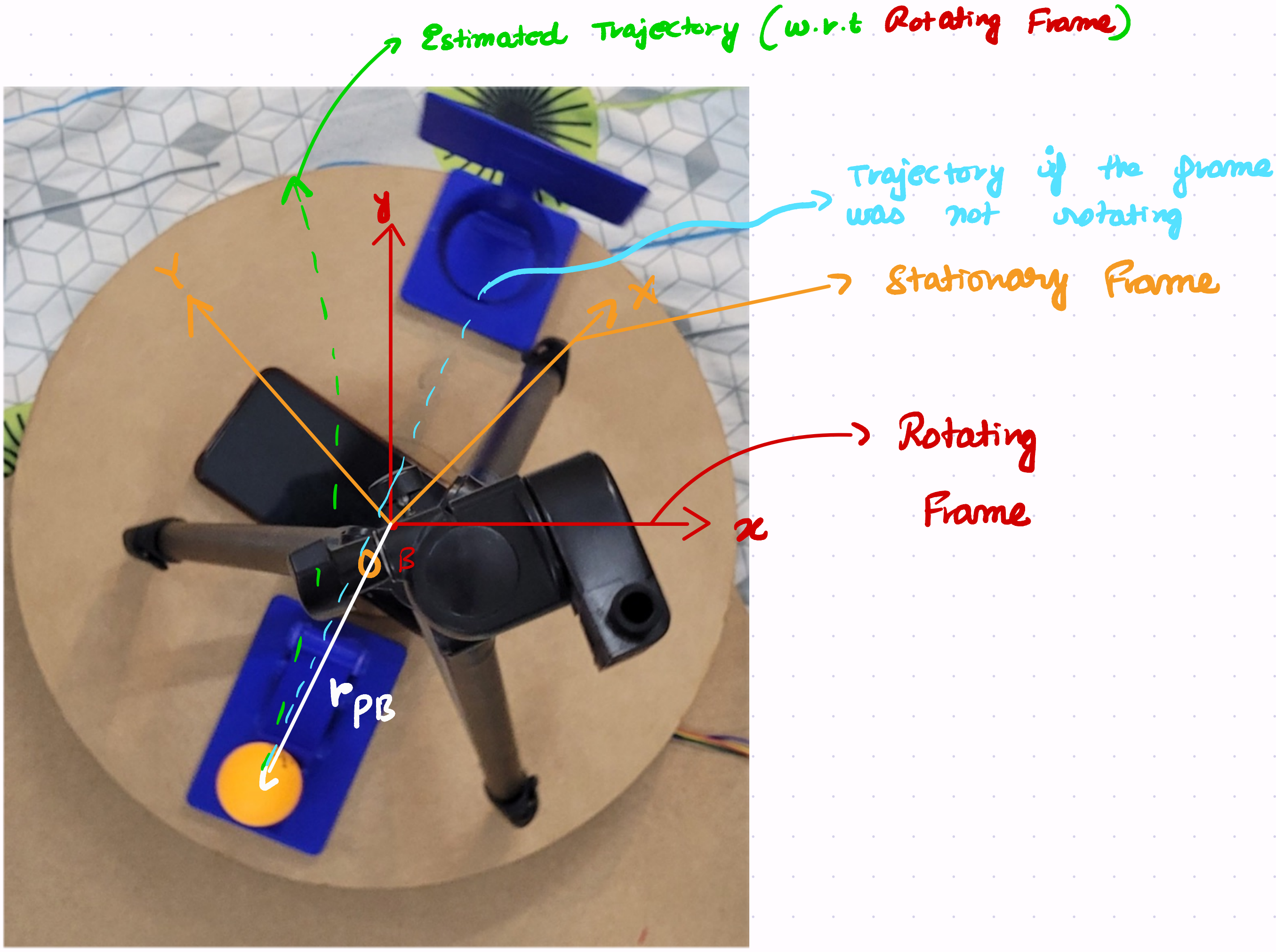
$$= 1594.6248\,\hat{i} - 104.5796\,\hat{j}$$

$$\boxed{\therefore\ \dot{\vec{r}}_{AB} = \frac{d\vec{r}_{AB}}{dt} = 1594.6248\,\hat{i} - 104.5796\,\hat{j}}$$

$$|\dot{\vec{r}}_{AB}| = 1598.0504 \text{ mm/s}$$

$$= 1.5980 \text{ m/s}$$

Rate of Change of the Velocity Vector with Respect to Fixed Reference



The rate of change of the velocity vector with respect to the fixed reference is

$$\ddot{\vec{r}}_A = \ddot{\vec{r}}_B + \ddot{\vec{r}}_{AB} = \ddot{\vec{r}}_B + (\ddot{x}_{AB}\hat{\imath} + \ddot{y}_{AB}\hat{\jmath}) + \left(\dot{x}_{AB}\frac{d\hat{\imath}}{dt} + \dot{y}_{AB}\frac{d\hat{\jmath}}{dt}\right) + \frac{d\vec{\omega}}{dt}\times\vec{r}_{AB} + \vec{\omega}\times\dot{\vec{r}}_{AB}$$

$$= \ddot{\vec{r}}_B + (\ddot{x}_{AB}\hat{\imath} + \ddot{y}_{AB}\hat{\jmath}) + (\dot{x}_{AB}\vec{\omega}\times\hat{\imath} + \dot{y}_{AB}\vec{\omega}\times\hat{\jmath}) + \dot{\vec{\omega}}\times\vec{r}_{AB} + \vec{\omega}\times\{(\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath}) + (\vec{\omega}\times\vec{r}_{AB})\}$$

$$= \ddot{\vec{r}}_B + (\ddot{x}_{AB}\hat{\imath} + \ddot{y}_{AB}\hat{\jmath}) + (\vec{\omega}\times\dot{x}_{AB}\hat{\imath} + \vec{\omega}\times\dot{y}_{AB}\hat{\jmath}) + \dot{\vec{\omega}}\times\vec{r}_{AB} + \vec{\omega}\times\{(\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath}) + (\vec{\omega}\times\vec{r}_{AB})\}$$

$$= \ddot{\vec{r}}_B + \underbrace{\underbrace{(\ddot{x}_{AB}\hat{\imath} + \ddot{y}_{AB}\hat{\jmath})}_{(\vec{a}_{AB})_{Bxy}} + \underbrace{2\vec{\omega}\times(\dot{x}_{AB}\hat{\imath} + \dot{y}_{AB}\hat{\jmath})}_{\substack{\text{Coriolis component} \\ 2\vec{\omega}\times\vec{v}_{AP} = 2\vec{\omega}\times(\vec{v}_{AB})_{Bxy}}}}_{\vec{a}_{AP}} + \underbrace{\dot{\vec{\omega}}\times\vec{r}_{AB}}_{\vec{a}_{\theta}} + \underbrace{\vec{\omega}\times(\vec{\omega}\times\vec{r}_{AB})}_{\vec{a}_{r}}$$

Again $\ddot{\vec{r}}_B = 0$. Hence

$$\ddot{r}_A = \underbrace{\ddot{x}_{AB}\hat{i} + \ddot{y}_{AB}\hat{j}}_{\left(\frac{d^2\vec{r}_{AB}}{dt^2}\right)_{Bxy}} \underbrace{+ 2\vec{\omega}\times\dot{x}_{AB}\hat{i} + \dot{y}_{AB}\hat{j}}_{\text{Coriolis Component}} \underbrace{+ \dot{\vec{\omega}}\times\vec{r}_{AB}}_{\vec{a}_{\theta}} \underbrace{+ \vec{\omega}\times(\vec{\omega}\times\vec{r}_{AB})}_{\vec{a}_{r}}$$

$$\ddot{r}_A = \ddot{x}_{AB}\hat{i} + \ddot{y}_{AB}\hat{j} + 2\vec{\omega} \times \dot{x}_{AB}\hat{i} + \dot{y}_{AB}\hat{j} + \dot{\vec{\omega}} \times \vec{r}_{AB} + \vec{\omega} \times (\vec{\omega} \times \vec{r}_{AB})$$

Now for the 99^{th} Frame

$$\ddot{r}_A = 1536.63\hat{i} + 14581.54\hat{j} + 2(-2.792532)\hat{k} \times 1645.784\hat{i} - 183.2\hat{j}$$
$$-3.49074\hat{k} \times (45.75\hat{i} - 29.77\hat{j}) + (-2.792532)\hat{k} \times (-2.792532\hat{k}) \times 45.75\hat{i} - 29.77\hat{j}$$

$$= 1536.63\hat{i} + 14581.54\hat{j} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -5.585064 \\ 1645.784 & -183.2 & 0 \end{vmatrix} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -3.49074 \\ 45.75 & -29.77 & 0 \end{vmatrix} +$$

$$(-2.792532)\hat{k} \times \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -2.792532 \\ 45.75 & -29.77 & 0 \end{vmatrix}$$

$$= 1536.63\hat{i} + 1458.54\hat{j} - 1023.1837\hat{i} + 9161.8090\hat{j} - 103.9193\hat{i} + 159.7014\hat{j} +$$
$$-2.792532\hat{k} \times (-83.1337\hat{i} + 127.7583\hat{j})$$

$$= 1536.63\hat{i} + 1458.54\hat{j} - 1023.1837\hat{i} + 9161.8090\hat{j} - 103.9193\hat{i} + 159.7014\hat{j} +$$
$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -2.792532 \\ -83.1337 & 127.7583 & 0 \end{vmatrix}$$

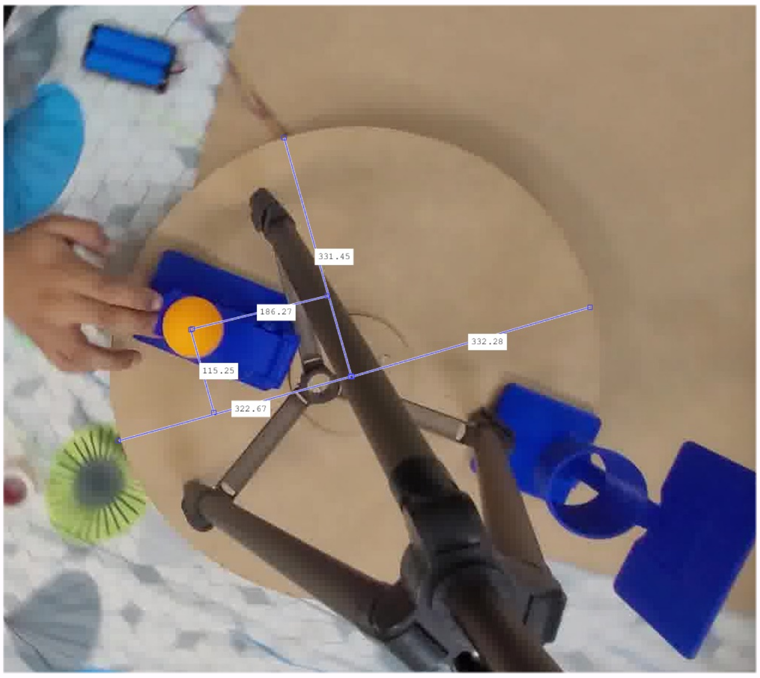
$$= 1536.63\hat{i} + 1458.54\hat{j} - 1023.1837\hat{i} + 9161.8090\hat{j} - 103.9193\hat{i} + 159.7014\hat{j} +$$
$$336.7691\hat{i} - 232.1535\hat{j}$$

$$= 746.2961\hat{i} + 10,547.8969\hat{j}$$

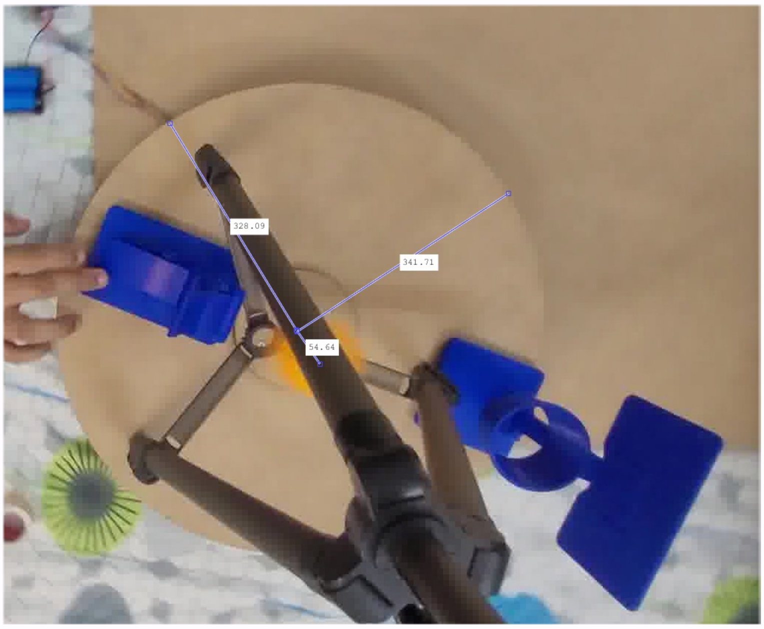
$$\boxed{\ddot{\vec{r}}_{AB} = \frac{d^2\vec{r}_{AB}}{dt^2} = 746.2961\hat{i} + 10,547.8969\hat{j}}$$

$$|\ddot{r}_{AB}| = 10574.2653 \text{ mm/s}^2$$
$$= 10.5743 \text{ m/s}^2$$

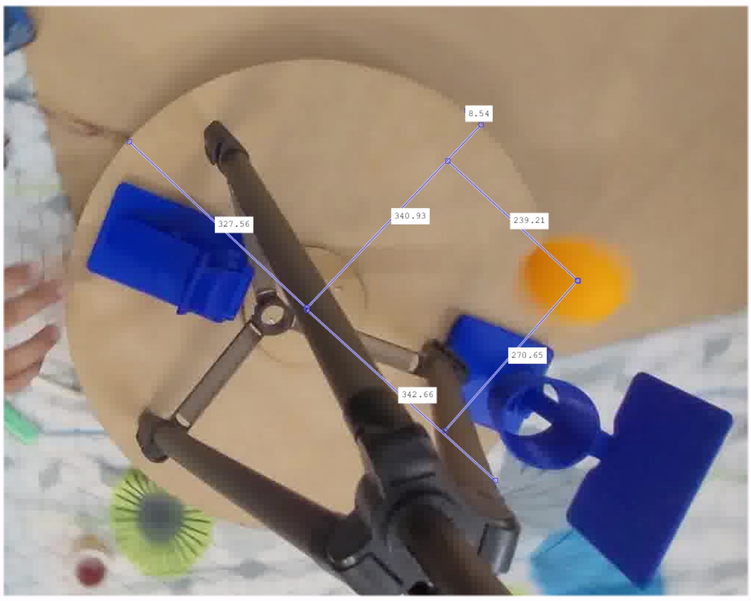
Position Vector wrt to the Ground Frame of reference



96th Frame

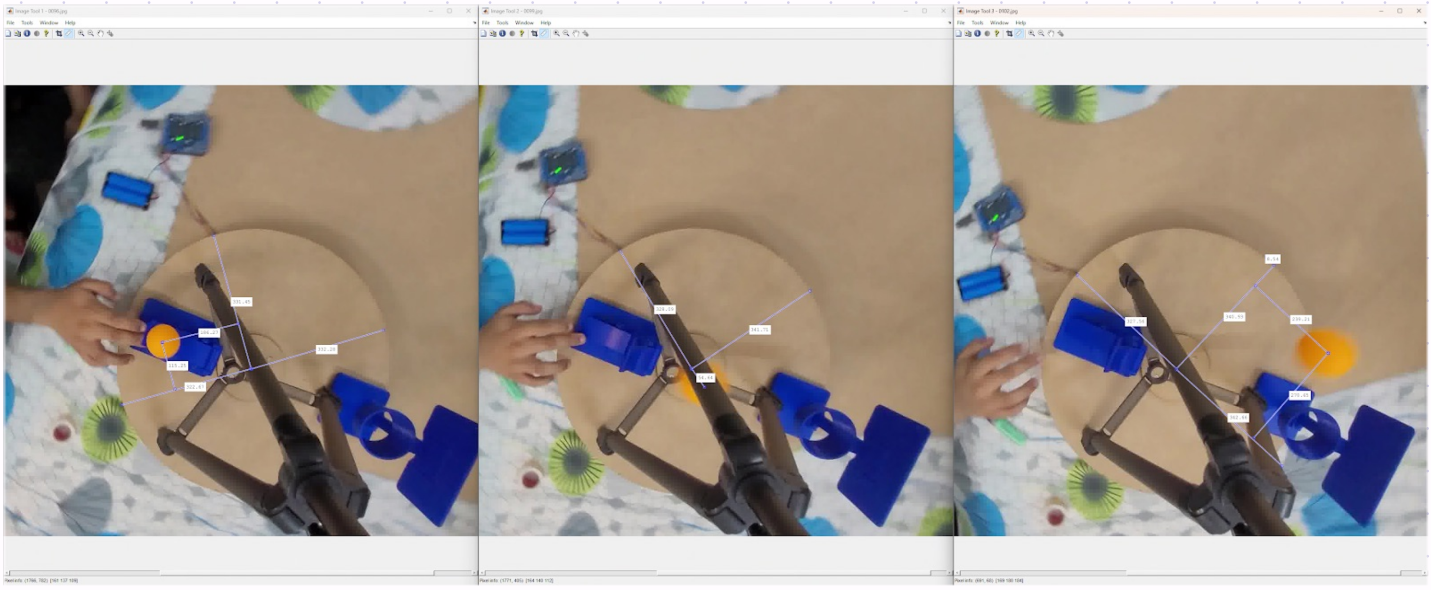


99th Frame



102nd Frame

Measuring $\dot{\vec{r}}_A$ and $\ddot{\vec{r}}_A$ Experimentally



For the 96th Frame

$$\vec{r}_{AB_1} = -186.27\hat{i} + 115.25\hat{j}$$

For the 99th Frame

$$\vec{r}_{AB_2} = 0\hat{i} - 54.64\hat{j}$$

For 102nd Frame

$$\vec{r}_{AB_3} = 270.41\hat{i} - 239.21\hat{j}$$

Post using the conversion factor

For the 96th Frame

$$\vec{r}_{AB_1} = -114.6277\hat{i} + 70.9221\hat{j}$$

For the 99th Frame

$$\vec{r}_{AB_2} = -33.6246\hat{j}$$

For 102nd Frame

$$\vec{r}_{AB_3} = 166.4061\hat{i} - 147.2062\hat{j}$$

Between 96th and 99th Frame

$$\dot{\vec{r}}_{AB_1} = \frac{x''-x'}{\Delta t_1}\hat{i} + \frac{y''-y'}{\Delta t_1}\hat{j}$$

$$= 1146.277\hat{i} - 1045.477\hat{j}$$

$$|\dot{\vec{r}}_{AB_1}| = 1551.4422 \text{ mm/s}$$

$$= 1.5514 \text{ m/s}$$

Between 99th and 101th Frame

$$\dot{\vec{r}}_{AB_2} = \frac{x'''-x''}{\Delta t_2}\hat{i} + \frac{y'''-x''}{\Delta t_2}$$

$$= 1664.061\hat{i} - 1135.816\hat{j}$$

$$\ddot{\vec{r}}_{AB} = \frac{\dot{\vec{r}}_{AB_2} - \dot{\vec{r}}_{AB_1}}{\Delta t} = 5177.84\hat{i} - 908.16\hat{j}$$

$$|\ddot{\vec{r}}_{AB}| = 5258.4417 \text{ mm/s}^2$$

$$= 5.258 \text{ m/s}^2$$

RESULTS

$$\vec{r}_{AB} = \frac{d\vec{r}_{AB}}{dt} = 1594.6248\,\hat{i} - 104.5796\,\hat{j} \qquad |\vec{r}_{AB}| = 1.5980\,m/s$$

$$\vec{r}_{AB} = \frac{d^2\vec{r}_{AB}}{dt^2} = 746.2961\,\hat{i} + 10,547.8969\,\hat{j} \qquad |\vec{r}_{AB}| = 10.5742\,m/s^2$$

computed using RHS Term

THE RHS TERMS

$$\left(\frac{d\vec{r}_{AB}}{dt}\right)_{Bxyz} = 1645.784\,\hat{i} - 183.2\,\hat{j}$$

$$\left(\frac{d^2\vec{r}_{AB}}{dt^2}\right)_{Bxyz} = 1536.63\,\hat{i} + 14581.84\,\hat{j}$$

$$\vec{\omega} \times \vec{r}_{AB} = -51.1592\,\hat{i} + 78.6204\,\hat{j}$$

$$2\vec{\omega} \times \left(\frac{d\vec{r}_{AB}}{dt}\right)_{Bxyz} = -1023.1837\,\hat{i} + 9161.8090\,\hat{j} \quad \text{(Coriolis Component)}$$

$$\vec{\dot{\omega}} \times \vec{r}_{AB} = -103.9193\,\hat{i} + 159.7014\,\hat{j} \quad (\vec{a}_\theta)$$

$$\vec{\omega} \times (\vec{\omega} \times \vec{r}_{AB}) = 336.7691\,\hat{i} - 232.1535\,\hat{j} \quad (\vec{a}_r)$$

THE LHS TERM

$$\vec{r}_{AB} = 1146.277\,\hat{i} - 1045.477\,\hat{j} \qquad |\vec{r}_{AB}| = 1.5514\,m/s$$

$$\vec{r}_{AB} = 5177.84\,\hat{i} - 908.16\,\hat{j} \qquad |\vec{r}_{AB}| = 5.258\,m/s^2$$

Conclusion & Discussion:

Some key points and observations were made during the experiment:

- The ball's motion appeared different when observed from the rotating frame of the disc compared to the stationary observer frame. This difference is a fundamental aspect of relative motion. The experiment also successfully demonstrated the concept of circular motion, with the ball experiencing centripetal acceleration and tangential acceleration.

- Depending on the setup, the Coriolis effect may or may not have been observed. It is essential to consider factors such as the disc's rotational speed and the speed of the launched ball to detect this effect effectively.

- The experiment also allowed us to observe how motion is described differently in inertial (stationary observer) and non-inertial (rotating disc) frames of reference.

- When comparing the LHS and RHS we clearly observe that there is very very small error for velocity but for the acceleration part the error is almost 50%. This could be accounted broadly for two things

    - First the time interval is very very small 1/30 th of a second. Hence when we divide with this value even a small error causes a lot of effect.
    - Morover the terms that have dot and cross products in the RHS compund overall causing large error.

In conclusion, this experiment provided valuable insights into the principles of relative motion, circular motion, and the Coriolis effect. By carefully measuring the position of a ball on a rotating disc and applying kinematic principles, we were able to quantitatively measure the velocity and acceleration of the ball within the rotating frame.

Learnings:

After completing the experiment, we acquired valuable insights and knowledge about real-world implementation and results. Here are the key takeaways:

- Our implementation demonstrated the practical applicability of the Coriolis effect in understanding and predicting physical phenomena in these fields.

- We observed the real-life results deviated from theoretical predictions due to various factors like air resistance, friction, etc.

- We also saw how error could amplify in a an equation depending on operation of the terms.

- We got to know more about various computational tools and software that we used in our experiments.

What could have been done better?

Several aspects of the experiment could have been improved:

- **Camera Alignment:** More efforts could have been made to align the camera as closely as possible with the center of the turntable to reduce parallax errors.

- **Data Synchronization:** Better synchronization between the disc's rotation and the ball's launch could have been achieved, possibly through an automated triggering mechanism.

- **Magnus Effect:** The Magnus effect, which causes spinning objects to experience aerodynamic forces perpendicular to their motion, can introduce complexities in the observed motion of the launched ball. Using a ball with minimal spin or selecting a different object with less aerodynamic influence could have been considered to reduce this effect. Alternatively, controlling and measuring the ball's spin rate could help account for the Magnus effect in the analysis.

- **Considering Ball as a Point Object:** While treating the ball as a point object simplifies calculations, it may not fully represent the complexities of its motion, especially if the ball is significantly large or has a non-negligible size compared to the disc's dimensions. A more accurate representation of the ball's dimensions and shape could have been incorporated into the analysis, accounting for the potential effects of its size on its motion within the rotating frame.

- Further numerical analysis could have been made for better approximation.

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