IMU Tracking of Kinematic Chains in the Absence of Gravitational and Magnetic fields.

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Body Tracking with IMUs

Body tracking has many applications, from special effects to VR. Optical methods suffer from occlusion and are limited by base stations, whereas solutions using inertial measurement units (IMUs) can overcome this. An IMU measures its orientation in space. With one of these on each limb, an entire body can be tracked over time. However, gyroscope-based dead-reckoning drifts. Current drift correction solutions all rely on gravity and/or Earth's magnetic field [1].

Increasing Presence in Space

Humanity once again has its eyes set on the development of space. There will be an increasing need over the coming years for technologies to be adapted to the challenging environments that space presents. We need IMU body tracking technology that can work in microgravity and without reliance on magnetometers. If future habitats are rotated to generate artificial gravity [2], people will be subject to variable acceleration fields from microgravity at the centre to full centrifugal force at the circumference. Therefore, the presence of a constant gravitational field is longer a good assumption.

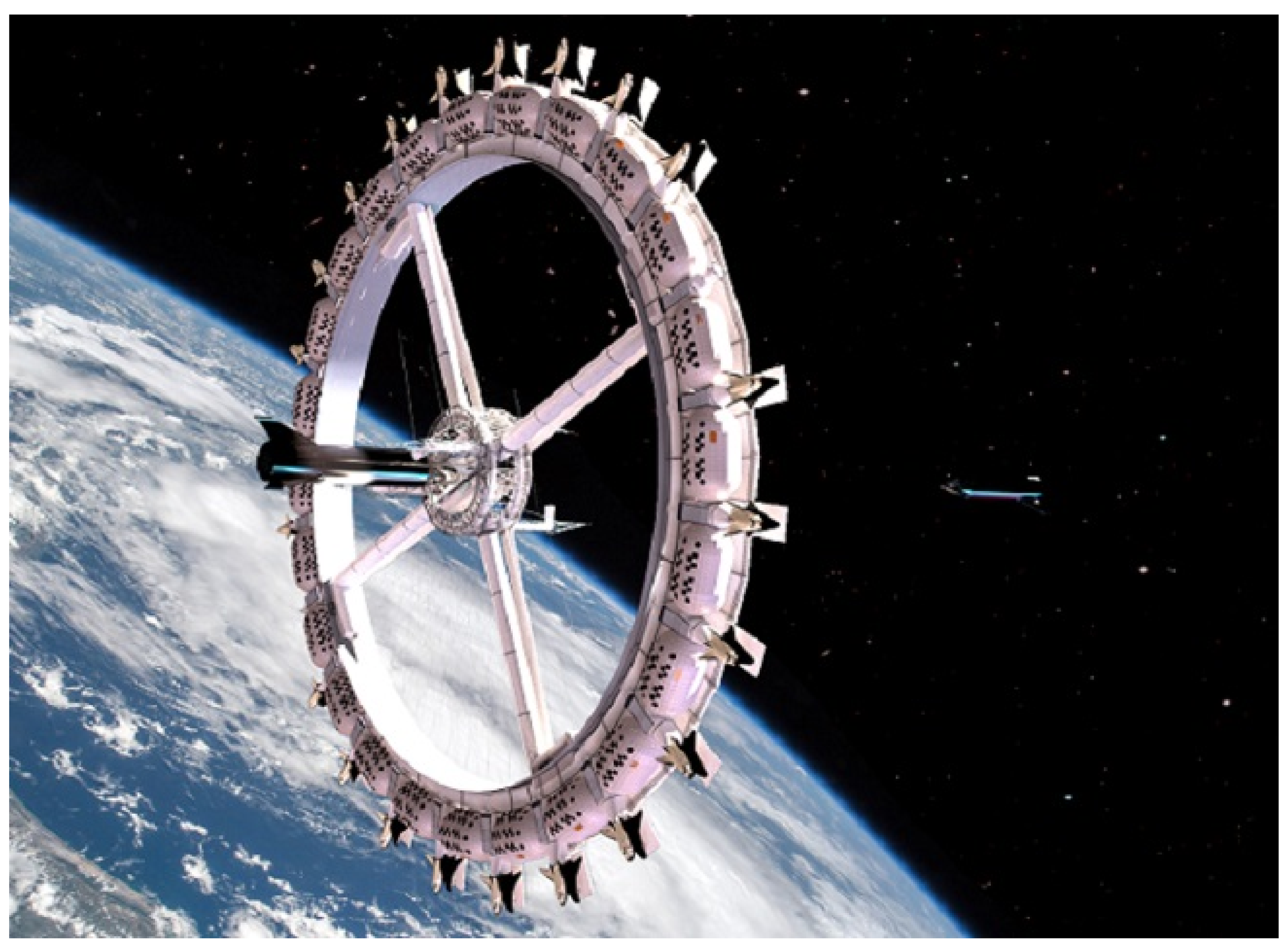

Fig. 1: Rotating space habitats would have variable "perceived gravity" depending on the distance from the centre.

The Solution: Algorithm + Hardware

This solution comprises a dead-reckoning core, with the following novel drift correction method on top. In a kinematic chain made up of limbs L with sensors S placed at their tips, we can correct drift in all but the root limb, even without gravity. This is done by comparing the world frame acceleration at the joint of each limb as shown in figure 2. Any drift is reflected as a misalignment of these vectors. Predicting acceleration at the base of a limb requires extracting accelerations due to circular motion [3] (figure 3).

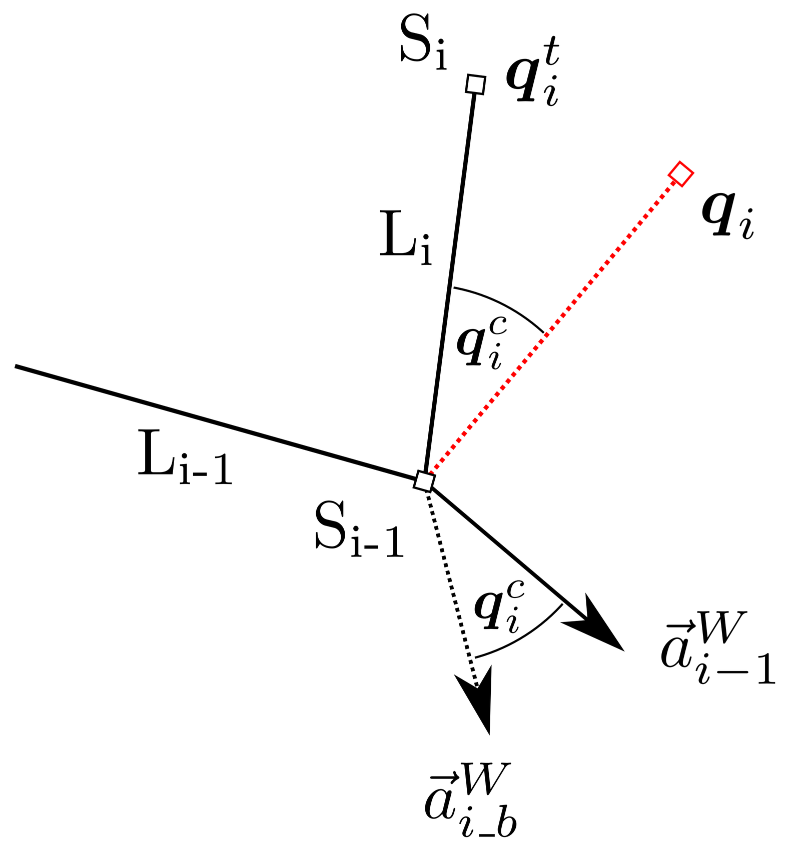

Fig. 2: Drift correction at some parent-child joint.

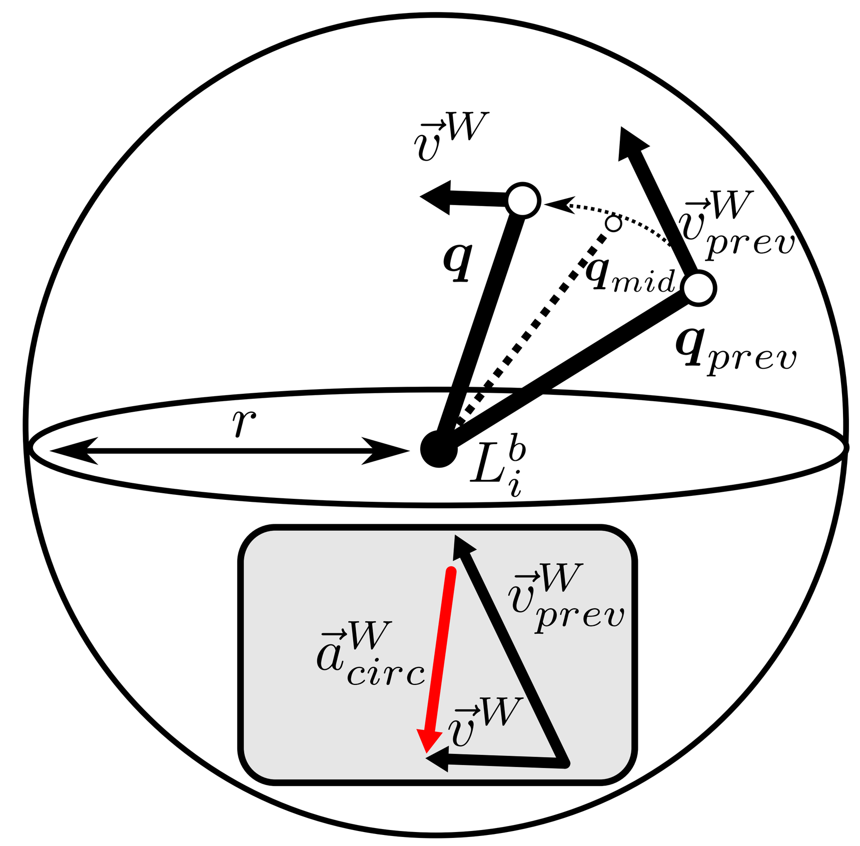

Fig. 3: Acceleration prediction from angular rates.

A custom PCB was designed for the sensor with a high-performance STM32 microprocessor and MPU-6050 IMU. The sensors can communicate with each other via a central hub (ESP-8266 WiFi module) over I^{2}C. Output data is then available via a router - even over the internet. The system outputs pose information in real time (30Hz), so would be suitable for many applications. The system was evaluated using a boom arm with 2 sensors.

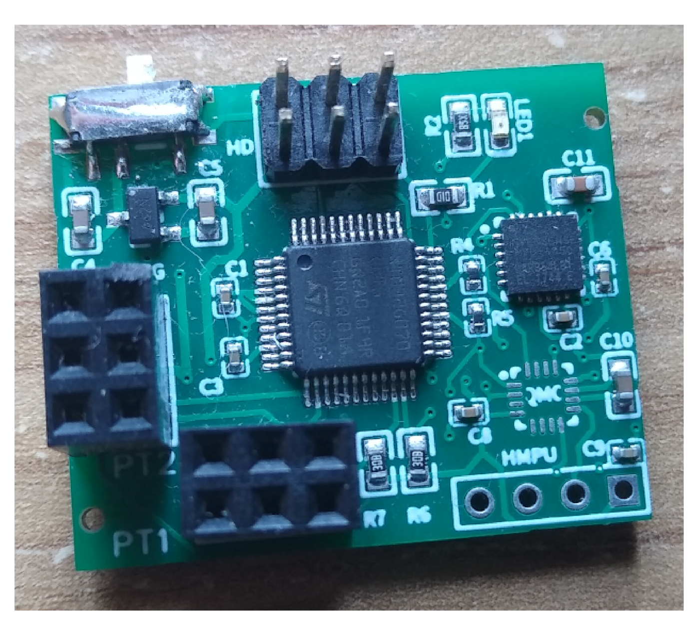

Fig. 4: A single sensor node PCB.

Fig. 5: The test mount.

Results and Evaluation

Dead-reckoning drift was found to not exceed 1° for an average of 30s. Using dead-reckoning with known starting position as a short-term accurate ground-truth, the RMSE of the final correction value was found to be 0.32° when stationary and 1.1° when moving at average 1 rad·s^{-1} (figure 6).

	Stationary		Moving	
Correction angle	**RMSE**	**MAE**	**RMSE**	**MAE**
θ (raw)	3.5	2.8	11.0	6.0
ϕ (filtered)	0.34	0.28	1.1	0.60

Fig. 6: Accuracy of the raw output and complementary filter output (°).

From a 90° starting error in the yaw, the system was able to correct to an accuracy of 3.1° RMSE after 4 seconds of lateral accelerations (20 trials). These good demonstrate the method's viability.

Conclusions

Overall, this was a successful project with significant achievements:

- Developed and evaluated an end-to-end solution for IMU kinematic-chain tracking.
- Furthered the state-of-the-art with a novel algorithm to correct drift in the absence of gravitational and magnetic fields.
- Shown the viability of IMU body tracking in microgravity.

Further work is recommended to evaluate performance when attached to a human body, and adding more components to the algorithm could help filter out more inaccuracies.

References

[1] Alessandro Filippeschi et al. "Survey of Motion Tracking Methods Based on Inertial Sensors: A Focus on Upper Limb Human Motion". In: *Sensors* 17.6 (2017). ISSN: 1424-8220. DOI: 10.3390/s17061257.

[2] Gerard K. O'Neill. "The colonization of space". In: *Physics Today* 27.9 (1974), pp. 32–40. DOI: 10.1063/1.3128863. URL: https://doi.org/10.1063/1.3128863.

[3] A. D. Young. "Use of Body Model Constraints to Improve Accuracy of Inertial Motion Capture". In: *2010 International Conference on Body Sensor Networks*. 2010, pp. 180–186. DOI: 10.1109/BSN.2010.30.