Position Paper: *MoViz*: UWB-IMU Sensors as Input to Body-Movement Visualizations

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ABSTRACT

Generating art through body-movements has widespread utility spanning several fields including physical rehabilitation post-surgery, to entertainment, to health and well-being. This paper introduces a new modality available for researchers via distance measurements using ultra-wideband (UWB) devices, in addition to the traditional IMU based approaches. As a versatile tool, UWB allows rich information to be garnered while consuming minimal data bandwidth and requiring minimal computation that can be easily performed on a microcontroller. We showcase some of the art we have generated using this platform and call upon the research community to explore the topic further.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing systems and tools**; **Visualization systems and tools**.

KEYWORDS

Visualization, UWB, IMU, Digital Art, Generative Art

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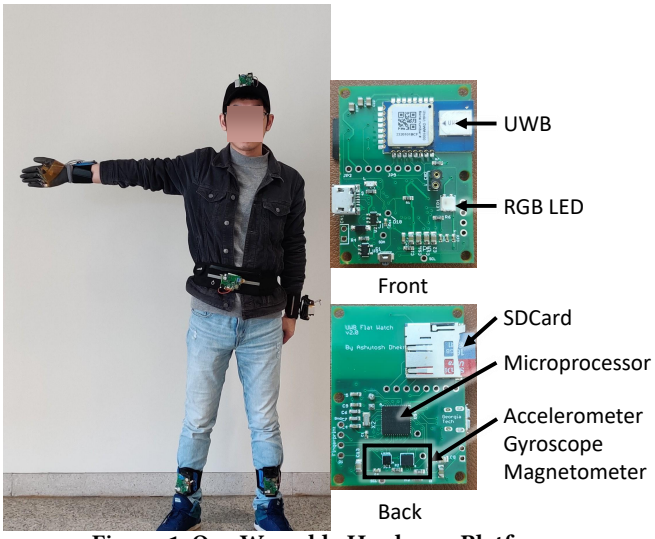

Figure 1: Our Wearable Hardware Platform

1 INTRODUCTION

On-body movement sensing has been long associated with inertial sensors in wearables such as in smartwatch and smartphones. This paper explores supplementing inertial sensing with on-body and near-body distance measurements using ultra-wideband radios. Further, we plan to represent body movements in the form of art or gamify movements as encouragement to users to perform a certain set of actions. We believe such systems can usher in a wave of novel approaches to physical rehabilitation, improve well-being, instill calmness, and improve concentration. These systems can also be used for generating souvenirs or memoirs, transforming dance or sports into a different visual art-form. Our work can lead to new forms of NFT art generated through physical movements, potentially making it easier to associate the artist with the art. We call our platform, *MoViz*.

The overall idea is to capture body movements using a set of wearable devices, such as smartwatches, smart sweatbands, smart shoes etc. embedded with inertial sensors and ultra-wideband (UWB) radios. While inertial sensors detect

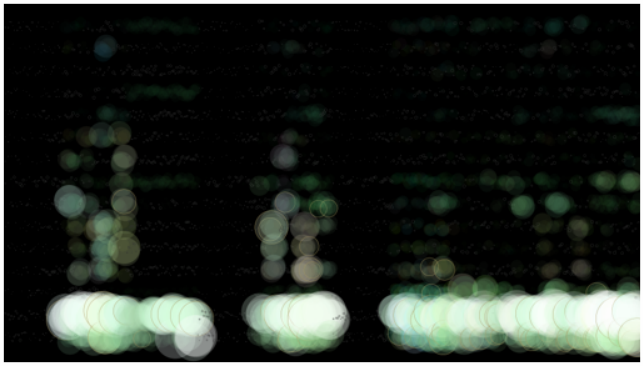

Figure 2: Bubbles: Example art generated from body gestures

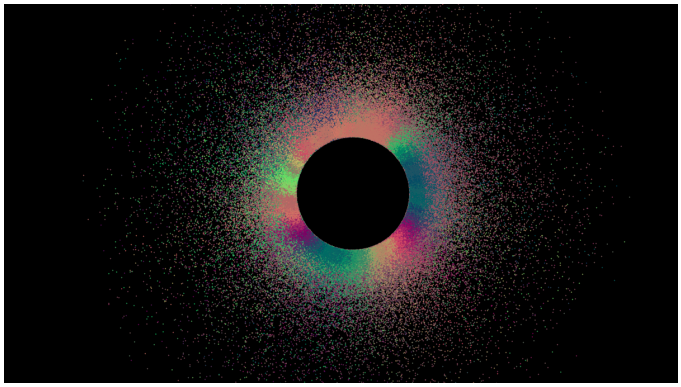

Figure 3: Wrist Movements to Color

individual device orientation, the UWB sensors allow inter-device distance measurements. Together, the inertial sensors and UWB sensors provide a rich set of data which can be intelligently converted to art visualizations. Being on-body devices, data can be collected over the whole day in all the user's contexts without depending on any external infrastructure. With flexibility in choosing any combination of the UWB and IMU sensors, and several possible data-capture rates, the extent of data generated can be controlled. The data can then be represented in the form of appealing visualizations by consolidating all the information collected during the day. In a completely different setting, on-body distance and inertial measurements can be used to assess the quality of physical rehabilitation exercises and to track progress. Specific actions can be tied to game actions, such as throwing a virtual basketball and as the full-range of movements start to return, the exercise visualizations can start to challenge the user to perform more rigorous actions.

As a position paper, our aim is to seed interest in development of body-movement based visualizations, particularly with the unique attributes enabled by our UWB+IMU sensor. We have previously used this sensor combination for identifying human gestures and signals based on different body poses [1]. Figure 1 shows the hardware worn while performing body-pose based gestures. Given the IMU+UWB data recorded during a series of such poses, we have generated an example art called bubbles shown in Figure 2. The hardware, firmware, and software for the visualizations is open-source here: https://github.com/ashudhekne/MoViz

2 RICHNESS OF SENSOR DATA

We will discuss the use of the IMU sensor when using a single sensor and then the utility of the UWB sensor when paired with another similar device.

2.1 IMUs on individual sensors

As a source of input to something as abstract as generative art, the richness of the sensor data is important. Meaning, it should be possible to capture several different aspects of body movements using the data from the sensors. As an individual sensor, *MoViz* allows capturing of inertial data and comprises accelerometer, gyroscope, and magnetometer data. We typically collect IMU data at 100Hz, but have tested stable performance up to 200Hz. When representing the sensor data directly in the form of art, we have found it most natural to map the accelerometer's x, y, and z axis values to the color of artistic entities. These values change as the sensor's orientation is changed, due to the acceleration due to gravity. Figure 3 shows an example where a circular rotation of the wrist is represented as a splash of various colors.

A similar approach is possible using gyroscope data as well. However, since the gyroscope measures angular velocity, it remains zero under slow movements or stationary orientations. However, the speed of turning movement of the sensor can be easily coupled with the orientation measurements to create an amplification effect. For example, if in the previous example the wrist is moved fast the size of the color dots can be made larger, providing emphasis to the action. Gyroscope also captures data in 3D which can be easily mapped to colors if the emphasis is in the form of colors rather than size (in which case the amplitude of the gyroscope is more useful than the individual values). The fleeting nature of the gyroscope can be used to add personalization effects such as brush stroke size, textures, or brightening the colors used. If the same body-actions are performed by two individuals, it is easier to match the accelerometer values (due to gravity being a prominent force) but much harder to match gyroscopic values. As such, if associating the art with a particular artist is important, gyroscope can be a powerful input. A signature twist of the wrist can texturize the whole image in a specific way, making it easier to recognize different arts from the same artist.

2.2 UWB on sensor pairs

UWB measures distance from another UWB device using wireless signals. We currently support 20Hz update rate, which means for every 5 IMU readings one UWB reading is available. Since measuring distance is the key functionality

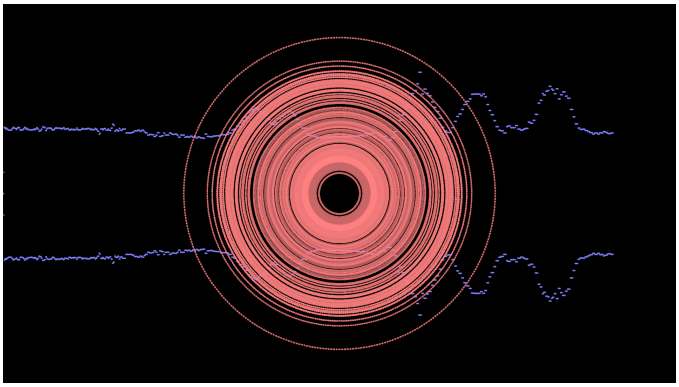

Figure 4: Distance changes mapped to circle size and timeline

provided by UWB, it is only used in pairs, or in a one-to-many fan-out. If the user carries a single *MoViz* sensor, the UWB will not be useful[1] (except as a communication tool if real-time data capture of the IMU device is desired). However, just adding one more device to create a pair immediately adds to the richness of the sensor. For example, if two devices are worn on the two wrists, moving the arms close to each other will result in smaller distance being reported while moving the arms farther away will increase the distance measured. In a time-series these changing distances can be used to represent size of an artistic element, or a widening or narrowing gap of some form. Figure 4 shows an example where the inter-arm distance is represented as the diameter of a ring. Art of this form is particularly useful in physical rehabilitation exercises where a certain range of movements is a desired outcome and one can trace their progress over time. For example, on-body distance measurements can be helpful to determine if a leg is being fully extended or not following knee surgery. Upright and ergonomic posture can be tracked and a user alerted when they slouch, affecting various inter-appendage distances.

2.3 Combining UWB and IMU

Combination of UWB distance measurements and IMU can provide an even richer data set allowing several artistic renditions. For example, when IMU is combined with UWB, distance between the two hands and the relative orientation of the two hands can be represented as a combination of size and color of the artistic element. For example, imagine combining Figure 3 and Figure 4, to get a color changing ring whose size determines the distance between the hands and color represents how the two hands are oriented relative to each other. Individual IMU measurements can also be used instead of relative measurements. For example, different sections of the image can be colored differently based on the IMU orientation of each sensor placed on body. Orientation measurements or accelerometer average could also be an input to determine number of edges on a geometric shape, or the depth of a fractal drawing. Rhythmic movements such as in dance or gymnastics could be rendered as rich visualization as well with rapidly changing graphics.

When using UWB, it is also possible to statically place a UWB sensor in the environment allowing us to measure the body to infrastructure distances. This could allow a better spatial representation of a user in a home or other indoor spaces. In dance, it can capture the on-stage movements better, while the on-body sensors capture most of the on-body movements. Further multiple users wearing UWB devices can also collaborate and provide inter-people spacing information as input to the visualization.

[1]Our current design does not use a UWB radar as used in [2]

3 *MOVIZ* APPLICATION USE-CASES

In the previous section we focused on the foundational capabilities providing a rich set of sensor data for visualizations to be developed on top. In this section, we will discuss specific applications and how a minimal setup can still enable interesting use-cases.

3.1 Physical Rehabilitation Tool

We consider the arm movement as an example to demonstrate how *MoViz* can be used as an in-home exercise tracking tool. Figure 5 shows an example gamfication where a user wears two *MoViz* sensors one on the forearm and another at the biceps. As the user bends the arm at the elbow, a Pac-Man like figure "eats" colored candy on its path. While such a game works best for younger patients, for older patients, a different level of gamification is possible which is more graph-like. As an example, Figure 6 shows a visualization where the target extent of movement is expressed as two concentric white circles and the orientation of the wrist is expressed as different colored targets. The blue filled circle shows the current extension of the arm and the yellow circle on the left shows the wrist's orientation.

Figure 5: Arm bending at the elbow being used as input to play a computer game where a Pac-Man figure eats candy on the screen by moving back and forth.

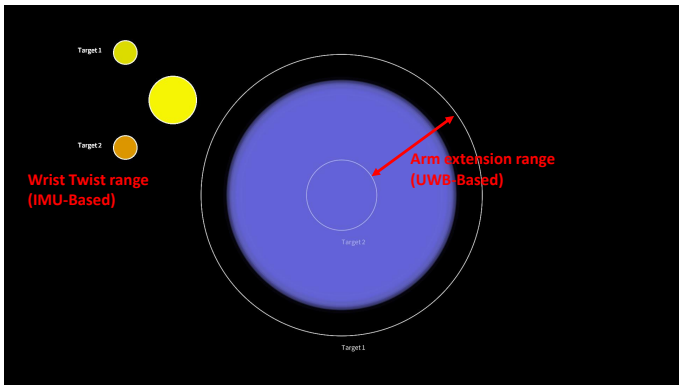

Figure 6: A tool for evaluating a user's ability to stretch the arm from wrist-near-shoulder to fully extended (measured by UWB), and wrist twisting (measured by IMU).

Figure 7: Keeping the toy stationary leads to a clear enjoyable cartoon image on the screen. Movements of the toy starts to wash-out the image.

3.2 Concentration Tool

Longevity and depth of concentration is an important skill for children. We have developed a simple task where a child can hold a toy in front of a TV screen. So long as the child holds the toy still, a cartoon image on the screen will appear clear. However, if the toy is moved beyond a certain acceptable threshold, the cartoon fades away or becomes blurry. Figure 7 shows the transitions between this clear-blur continuum.

3.3 Artist's Tool

Generating computer graphics typically involves strokes of the mouse (rather than strokes of a brush in physical art). With our *MoViz* platform, we are able to return an element of physical movements to the creative process for computer graphics. Embedded inside a hand-held wand, the *MoViz* platform measures distances from two vantage points in the room, (or on two sides of the computer) to allow the artist to create their own computer graphics. Left-right movements, near-far movements, and the orientation of the wand enables a rich creative experience (see Figure 8).

3.4 Visual Effects for Performing Arts

The IMU and UWB sensors on-body can also produce an on-body visual effect without any need for offloading data to a computer and then showing graphics on the computer. Instead, using the RGB LED on the device, it is possible to design stunning visual effects based on inter-device distances and orientation. Figure 9 shows a person wearing a *MoViz* device which illuminates the inside of a sleeve based on the orientation of the hand.

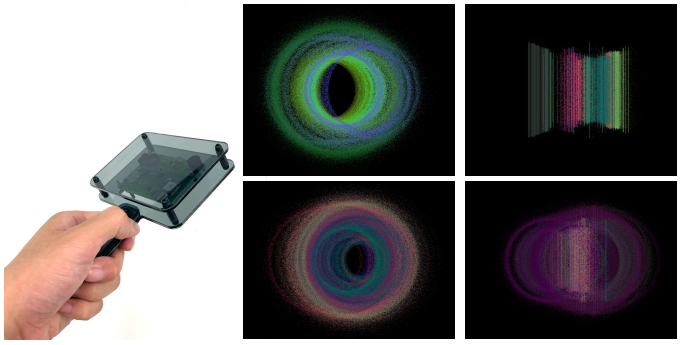

Figure 8: Using the wand movements an artist can generate different computer graphics elements. Here the left-right and near-far movements determine the center and size of the shape. The wand's orientation determines color.

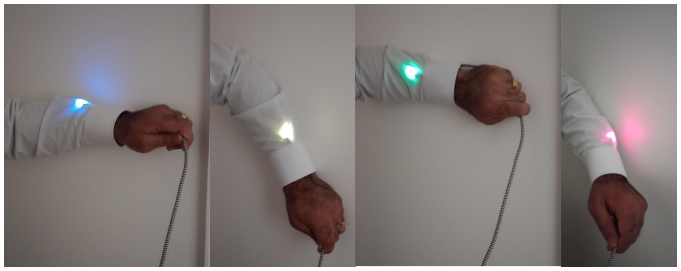

Figure 9: IMU orientation automatically controls the RGB LED creating a light-up shirt-sleeve that changes colors based on the hand's orientation.

4 CONCLUDING REMARKS

We take the position that the rich set of data produced through the UWB and IMU sensors in *MoViz* can indeed lead to innovative work in visualizations and artistic renditions. We have open sourced the code and hardware used in this paper: https://github.com/ashudhekne/MoViz. We are excited to see how the research community takes the ideas presented in *MoViz* forward.

Acknowledgments

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