

## Analysis of 3D Shear Transformation Applied to the Control of Robot Arm

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## 1. Introduction

We propose a robot control method based on spatial shear transformation. The purpose of our study is to allow different operators to control the robotic arm according to their own habits, which is essential in general graphics processing and space deformation. Further apply this method to spatial data processing. Our attempt is to realize the unified transformation of the control characteristics of different operators under certain constraints and changes, including different swing amplitudes in other spaces, different individual arm lengths, and different standing directions, to control the mechanical arm to achieve the same movement purpose. We wanted to explore this approach's possibilities and pros and cons.

## 2. Principle

Our approach involves using a 3D camera to capture human body data and accurately recognize the position of the hand. Through the application of a spatial 3D Shear transformation, we correct the data related to the hand and map it to the position of the end of the robotic arm being utilized. This enables control without physical contact [2][3].

In plane geometry, a shear mapping is a linear map that displaces each point in a fixed direction, by an amount proportional to its signed distance from the line that is parallel to that direction and goes through the origin. This type of mapping is also called shear transformation, or just shearing [1].

$$T = \begin{bmatrix} 1 & m_x & n_x \\ m_y & 1 & n_y \\ m_z & n_z & 1 \end{bmatrix}$$

Our fundamental principle revolves around condensing transformation laws into matrix form and applying them to corresponding calibrations and mappings. It is crucial to recognize that the Shear transformation necessitates distinct transformation matrices in each quadrant. This is essential due to the differing requirements of each quadrant.

Considering the limited range of motion of the human arm and the presence of blind spots in the camera's field of view, our data acquisition and control focus is on the front of the human torso. However, even within this

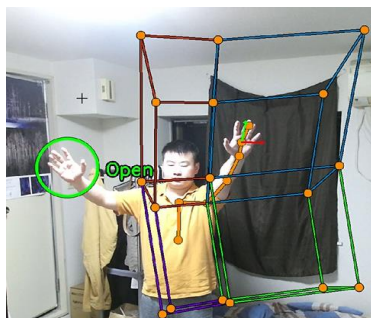


Figure 2 Data Collection Area

region, there are four quadrants, each demanding a specific transformation matrix. Please refer to the attached picture, illustrated in Figure 1.

## 3. Experiment method

Through experiments conducted on individuals, we collect personal data and information from various perspectives, including control range and operational experience. We then comprehensively compare this data with the simple mapping method and discuss the advantages and disadvantages.

Initially, it is essential to swiftly make corrections for each individual participating in the operation. This enables the system to adapt quickly to the operator with minimal time and effort.

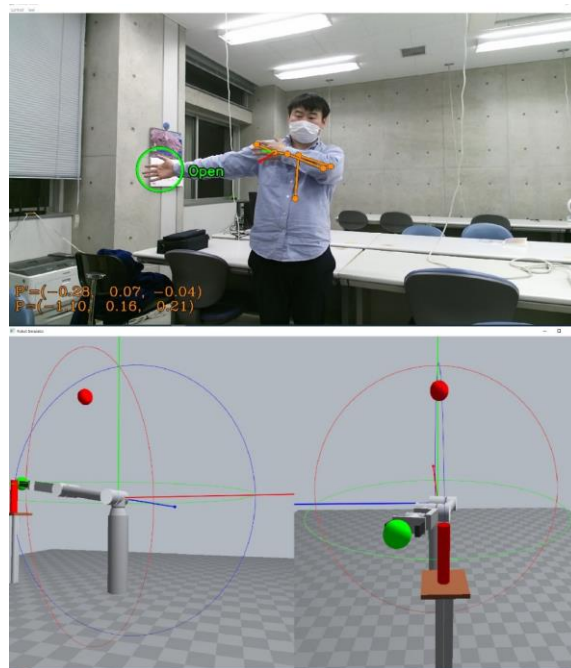


Figure 1 Demonstration of Human Recognition and Robotic Arm Control

During the calibration process, we position the 3D camera to face the individual, allowing it to recognize the human body and initiate body tracking. Next, we guide the subjects to extend their arms and capture five key points in the air. This step facilitates the alignment between the positions of the human arm and the corresponding positions of the robotic arm. The five key positions, based on the human body, include front, top, right, left, and bottom. These positions correspond to the five positions of the robotic arm. As for the orientation of the robotic arm, we have the flexibility to determine it. By adopting this experimental approach, we acquire data from different individuals.

In our study, we explore two different correction relationships. The first one involves using the vertical line drawn from the front of the human body identified during the initial recognition process as a reference direction. This reference direction is then associated with a specific direction of the manipulator. Regardless of how the person turns, the reference direction is always based on

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the individual's orientation.

The second correction relationship entails fixing the frontal direction determined during the initial recognition of the human body in space. The robotic arm is aligned with this fixed orientation. Regardless of the direction the person is facing, this fixed direction remains constant in space, and any rotation of the person does not affect this direction.

Experimental data were collected to examine the effectiveness of these two setups. we acquire data from different individuals, which can be compared to the results obtained through the simplistic mapping approach.

For a visual representation of the human-machine control, please refer to Figure 2, which illustrates the display of the man-machine control.

#### 4. Results

The 3D Shear transformation plays a crucial role in correcting the range of motion for the robot arm. Without correction, there are certain locations that a person's hand cannot reach due to physical obstructions. As a result, the robot arm will also have corresponding unreachable positions. By applying the 3D shear matrix for correction, these previously unreachable areas can also be covered. The illustration below provides a clear demonstration of the range change resulting from the shear correction.

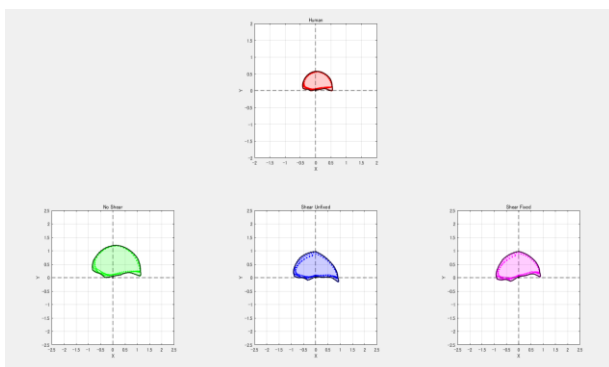


Figure 3 Range Experimental Data

In the first image of the top row in Figure 3, the perspective is from a high altitude looking down towards the ground, which can be referred to as the XOY plane. Since the movement data of the right hand is collected, and the movement range primarily lies in front of the person, it forms an approximate semicircular area with the origin offset to the left. The region near the body exhibits an uneven and bumpy shape, representing the inaccessible area due to spatial obstruction by the human body and shoulders.

Subsequently, the lower row of Figure 3 is a plot of the data that was rectified and mapped to the end of the robotic arm. The first image on the left represents a simple zoom-in transformation. However, the range of motion of the robotic arm is still spatially limited due to the hindrance of the body and shoulder.

The second image in the second row of the figure observed that the range of movement for the robotic arm has been partially supplemented, repairing the areas that were originally inaccessible to the human body. This expansion of the robotic arm's movement space is achieved.

The third image in the second row depicts the fixation

of the initially defined orientation. No matter how the person moves, the initial orientation of the correction remains the same.

In Figure 4, a change in the person's orientation is observed, leading to a noteworthy finding. Although the person's orientation has changed, we have retained the orientation data of the robot arm based on the correction. This adjustment proves to be more suitable for control. Upon closer examination of the second and third images in the second row, some changes in radians can be observed. The application of the skew transformation to the rectangular range appears more reasonable, while the change in the circular range is subtle. This aspect will be the focus of our next experiment and discussion.

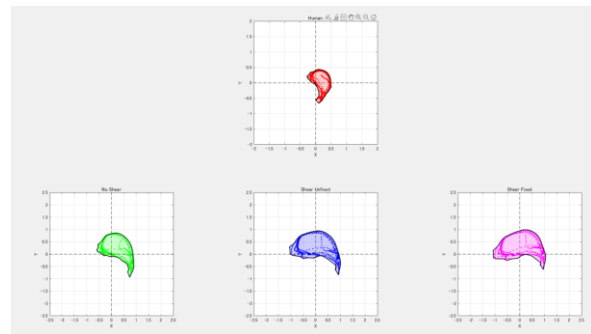


Figure 4 Direction Experimental Data

#### 5. Discussion or Conclusion

Based on the current results, operators can quickly align themselves with the robotic arm control system and achieve control through calibration. To address the sporadic and unstable nature of data collection, we have implemented moving average adjustments. Furthermore, the ability to control the robotic arm's movement and grasp simulated objects has been successful. Previously inaccessible areas have now become reachable through the calibration process. While range adjustment and mapping appear feasible, they may not be suitable for precise control at present.

In summary, our study aims to apply the concept of spatial 3D interleaved graphics processing to effectively control a robotic arm. The results indicate that control is feasible, offering expanded range, convenient calibration, and high versatility. However, non-smoothness is observed in the data within the changing region. To further improve the system, we plan to collect additional data and explore the potential of adapting the transformation properties of the appropriate cube to better suit the human body. This could involve adjusting the shear transformation of the cube to an irregular ellipsoidal hemisphere transformation.

#### References

- [1]. From Wikipedia, "Shear mapping," [https://en.wikipedia.org/wiki/Shear\\_mapping](https://en.wikipedia.org/wiki/Shear_mapping)
- [2]. Lin C S, Chen P C, Pan Y C, et al. The manipulation of real-time Kinect-based robotic arm using double-hand gestures[J]. Journal of Sensors, 2020, 2020: 1-9. Du G, Zhang P, Mai J, et al. Markerless Kinect-based hand tracking for robot teleoperation[J]. International Journal of Advanced Robotic Systems, 2012, 9(2): 36.