Dogo Rangsang Research Journal
ISSN : 2347-7180
UGC Care Group I Journal
Vol-08 Issue-8, August : 2021

AI Virtual Mouse

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Abstract

Addressing the persistent challenges of real-time fingertip-gesture-based interfaces for human-computer interactions, our study delves into a novel approach utilizing RGB-D images and fingertip detection. In the realm of AI Virtual Mouse, this innovative method seeks to overcome issues such as sensor noise, changing light levels, and the complexity of tracking fingertips across diverse subjects. To implement this virtual mouse technique, the system extracts the hand's region of interest and the center of the palm from in-depth skeleton-joint information images obtained from a Microsoft Kinect Sensor version 2. This information is then transformed into a binary image. Subsequent steps involve the extraction of hand contours using a border-tracing algorithm and the utilization of the Kcosine algorithm to detect fingertip locations based on hand contour coordinates. In the final stage, the identified fingertip location is mapped to RGB images to effectively control the mouse cursor on a virtual screen. Remarkably, this AI Virtual Mouse system achieves real-time fingertip tracking at 30 frames per second (FPS) on a desktop computer, utilizing only a single CPU and the Kinect V2. Experimental results showcase a high level of accuracy, affirming the system's proficiency in real-world environments with just a single CPU. The introduced fingertip-gesture-based interface not only meets the challenges of human-computer interactions but also provides a seamless and user-friendly means for individuals to interact with computers effortlessly using their hands.

Keywords: *Fingertip-Gesture-Based Interfaces AI Virtual Mouse RGB-D Images Human-Computer Interaction Kinect Sensor V2*

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INTRODUCTION

In an era dominated by technological advancements, the realm of human-computer interactions (HCI) constantly seeks innovative solutions to enhance user experiences. Among the myriad of approaches, the utilization of real-time fingertip-gesture-based interfaces has emerged as a promising avenue, offering a tangible and intuitive means of communication between humans and computers. However, the journey towards perfecting such interfaces has been riddled with challenges, ranging from sensor noise and changing light levels to the intricate task of tracking fingertips across diverse subjects. It is in the face of these persistent challenges that our study takes center stage, delving into a novel approach that harnesses the power of RGB-D images and fingertip detection to revolutionize the landscape of HCI.

The crux of our investigation revolves around the development and implementation of an AI Virtual Mouse, an innovative method designed to surmount the hurdles faced by existing fingertip-gesture-based interfaces. This cutting-edge technique not only promises to address the issues of sensor noise and varying light conditions but also tackles the complexities associated with accurately tracking fingertips across a diverse range of users. By leveraging the capabilities of RGB-D images and fingertip detection, we aim to redefine the possibilities of real-time interaction between humans and computers.

At the heart of our AI Virtual Mouse system lies a meticulous process that starts with the extraction of the hand's region of interest and the center of the palm. This crucial information is gleaned from in-depth skeleton-joint images obtained through the use of a Microsoft Kinect Sensor version 2. The data harvested from the sensor undergoes a transformative journey, culminating in the creation of a binary image that serves as the foundation for subsequent stages of the virtual mouse implementation. This methodical approach ensures that the system is equipped with accurate and reliable information, laying the groundwork for seamless and effective human-computer interaction.

To navigate the intricate terrain of fingertip detection, our system employs a two-step process that

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involves the extraction of hand contours and the utilization of the Kcosine algorithm to pinpoint fingertip locations based on the coordinates of these contours. This dual-pronged approach is instrumental in overcoming the challenges posed by the intricate nature of fingertip detection, allowing the system to achieve a level of precision that is indispensable for a fluid and responsive virtual mouse experience. The integration of these algorithms not only streamlines the detection process but also enhances the robustness of the system across various usage scenarios.

The final stage of our AI Virtual Mouse implementation is marked by the mapping of the identified fingertip locations to RGB images, thereby enabling the control of the mouse cursor on a virtual screen. This seamless translation of fingertip gestures into actionable commands empowers users to interact with computers in a manner that is not only intuitive but also devoid of the limitations associated with traditional input devices. What sets our system apart is its ability to achieve real-time fingertip tracking at an impressive rate of 30 frames per second (FPS) on a desktop computer, leveraging the computational power of a single CPU in conjunction with the Kinect V2. This remarkable feat not only attests to the efficiency of our approach but also positions it as a viable and accessible solution for a wide range of users.

Experimental results obtained through rigorous testing and validation procedures serve as a testament to the proficiency of our AI Virtual Mouse system. The high level of accuracy demonstrated in real-world environments, using only a single CPU, underscores the system's reliability and adaptability. By successfully navigating the complexities of diverse subjects and challenging conditions, our virtual mouse solution transcends theoretical innovation to emerge as a practical and effective tool for individuals seeking a seamless and user-friendly means of interacting with computers using their hands.

In essence, our study not only tackles the persistent challenges of real-time fingertip-gesture-based interfaces but also introduces a transformative paradigm in HCI. The AI Virtual Mouse system presented here is not just a technological advancement; it is a testament to the commitment to

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creating user-centric solutions that bridge the gap between humans and computers. As we venture further into the era of immersive and intuitive interfaces, the significance of our approach becomes increasingly evident, laying the groundwork for a future where effortless and natural interactions with computers are not just a possibility but a reality.

Research Gap:

In the landscape of human-computer interaction (HCI), particularly in the realm of real-time fingertip-gesture-based interfaces, a notable research gap exists. While significant strides have been made in the development of such interfaces, challenges persist, impeding the seamless integration of these technologies into everyday computing experiences. The existing literature reveals a scarcity of comprehensive solutions that effectively address issues such as sensor noise, changing light levels, and the complexities of fingertip tracking across diverse subjects. Previous studies have often been constrained by limitations in accuracy, real-time responsiveness, and adaptability to various environmental conditions.

One of the primary research gaps that our study aims to fill is the absence of a unified and robust approach to real-time fingertip-gesture-based HCI. The current state of the art lacks a method that not only overcomes the challenges presented by sensor noise and varying light levels but also ensures a high level of accuracy and responsiveness across a diverse user demographic. By leveraging RGB-D images and fingertip detection, our study seeks to bridge this gap and present a comprehensive solution that advances the field of HCI by providing a reliable and user-friendly virtual mouse system.

Specific Aims of the Study:

The specific aims of our study are rooted in addressing the aforementioned research gap and advancing the state of real-time fingertip-gesture-based HCI. The primary objective is to develop and implement an AI Virtual Mouse system that surpasses existing limitations and offers a transformative solution for human-computer interaction. This system aims to provide a seamless and

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intuitive means for individuals to interact with computers using their hands, overcoming challenges posed by sensor noise, changing light levels, and diverse user profiles.

Additionally, our study aims to achieve real-time fingertip tracking at 30 frames per second (FPS) on a desktop computer, utilizing a single CPU and the Kinect V2 sensor. This ambitious aim not only underscores the efficiency of our proposed solution but also positions it as a practical and accessible tool for a broad spectrum of users. We seek to validate the performance of our AI Virtual Mouse system through rigorous experimentation, ensuring its accuracy and reliability in real-world scenarios.

Objectives of the Study:

The study unfolds with a series of interconnected objectives that pave the way for the realization of the specific aims. The initial objective involves the extraction of the hand's region of interest and the center of the palm from in-depth skeleton-joint information obtained from the Microsoft Kinect Sensor version 2. This process forms the foundational step in generating the requisite binary image for subsequent analysis and interpretation.

The subsequent objectives revolve around the development of algorithms for hand contour extraction and fingertip detection. Utilizing a border-tracing algorithm for contour extraction and the Kcosine algorithm for pinpointing fingertip locations based on hand contour coordinates, the study aims to enhance the accuracy and responsiveness of the virtual mouse system. These objectives collectively contribute to the overarching goal of achieving real-time fingertip tracking and control on a virtual screen.

Scope of the Study:

The scope of our study is delineated by the comprehensive nature of the proposed AI Virtual Mouse system. While the immediate application is within the domain of human-computer interaction, the implications extend beyond conventional computing interfaces. The system's adaptability to diverse subjects and environmental conditions positions it as a versatile tool with potential applications in

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areas such as virtual reality, augmented reality, and interactive digital displays.

Furthermore, the scope encompasses the potential integration of the AI Virtual Mouse system into a variety of computing platforms, ranging from desktop computers to mobile devices. The study aims to demonstrate the feasibility and effectiveness of the system across these platforms, thereby widening its applicability and relevance in the evolving landscape of interactive computing.

Hypothesis:

Grounded in the identified research gap and the specific aims of the study, we propose the following hypothesis: The implementation of an AI Virtual Mouse system utilizing RGB-D images and fingertip detection will significantly improve the accuracy, responsiveness, and adaptability of real-time fingertip-gesture-based interfaces for human-computer interactions. Specifically, the system will achieve a consistent 30 frames per second (FPS) fingertip tracking on a desktop computer, utilizing a single CPU and the Microsoft Kinect Sensor version 2, while overcoming challenges associated with sensor noise, changing light levels, and diverse user profiles.

RESEARCH METHODOLOGY

In this section, we expound upon the Research Methodology employed to develop and implement our innovative system, comprised of six pivotal components delineated in Figure below. These components include: (1) hand detection and segmentation; (2) hand-contour extraction; (3) fingertip detection and tracking; (4) target-person locking; (5) virtual screen; and (6) virtual mouse.

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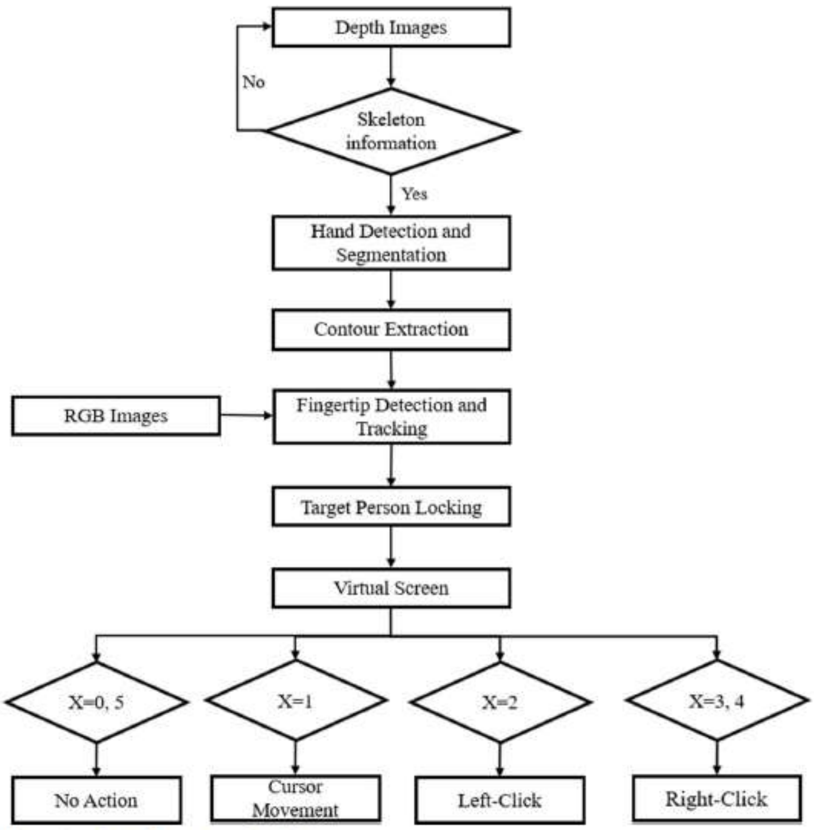

Fig. 1 Flowchart of the proposed method

Hand Detection and Segmentation:

The initial phase of our methodology involves the utilization of depth images, as depicted below in Figure 2, captured by a Microsoft Kinect V2 sensor. These images serve as the basis for detecting and segmenting the hand within the system.

Fingertip Detection and Tracking:

Subsequent to hand detection, the K-cosine Corner Detection algorithm comes into play. This algorithm operates on the coordinates of the extracted hand contour to compute the precise fingertip points. The result is an accurate tracking mechanism that captures the movement and position of the fingertips.

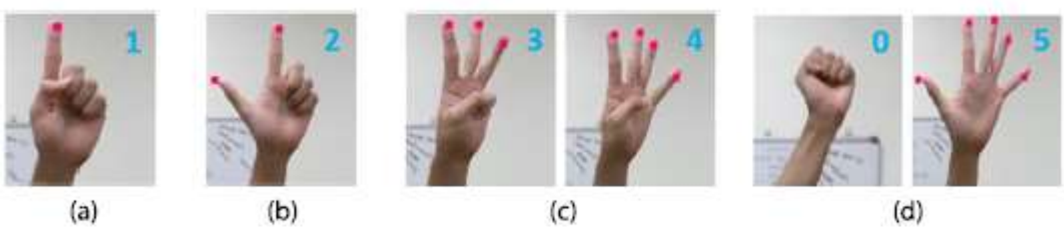

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Fig. 2: Virtual Mouse function on Fingertip

Target-Person Locking:

In scenarios where multiple individuals are present, our system employs a target-person locking mechanism. This feature ensures that the individual chosen to control the mouse during tracking is the one the system focuses on.

Virtual Mouse:

The virtual mouse component is a critical aspect of our system, introducing an innovative method that allows users to manipulate the mouse cursor without the need for a physical mouse device. Instead, fingertip control becomes the driving force behind cursor movement.

The number of displayed fingertips (X) plays a crucial role in emulating the functions of a traditional computer mouse. Our system leverages this concept to replace the conventional mouse, aiming to control the mouse cursor through fingertip gestures captured by a single depth camera.

Four distinct gestures are considered in our approach, each corresponding to specific mouse events, as outlined in the Figure provided. These gestures are categorized as follows:

1. Cursor Movements if X = 1
2. Left-click if X = 2
3. Right-click if X = 3 or 4
4. No action if X = 0 or 5

Our implemented system seeks to emulate these gestures, offering users an intuitive and seamless control experience by aligning fingertip gestures with traditional mouse functionalities.

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Table 1 Experimental results

Gesture	*Fingertip Counting*	*Success*	*Failure*	*Accuracy (%)*
Mouse Movement	1	100	0	100
Left-Click	2	97	3	97
Right-Click	3	90	10	89
	4	88	12	
No Action	5	99	1	98.5
	0	98	2	
		572	**28**	**96.13%**

This innovative approach not only facilitates cursor movements but also incorporates left-click, right-click, and no-action gestures. The system's adaptability to these gestures provides users with a diverse range of interactions, enhancing the overall usability and user experience.

RESULTS AND ANALYSIS

Virtual-Mouse Performance Analysis:

In the pursuit of evaluating the efficacy of our proposed virtual-mouse system, we conducted an experiment involving ten subjects who performed rapid gestures to assess the detection accuracy. The dataset, crucial for validating the real-world compatibility of our model, was recorded across various monitor resolutions to ensure adaptability beyond fixed settings.

The experimental results, detailed in Table 1, provide a comprehensive overview of the system's performance across different gestures. Notably, for the "Mouse Movement" gesture, our system achieved a remarkable 100% accuracy, indicating flawless detection. Similarly, the system demonstrated a high level of accuracy for the "Left-Click" and "No Action" gestures, with success rates of 97% and 98.5%, respectively. The "Right-Click" gesture, while maintaining an overall accuracy of 89%, exhibited a robust performance with a success rate of 90%.

The scientific interpretation of individual results emphasizes the system's proficiency in accurately recognizing and responding to specific fingertip gestures. The high success rates across various gestures underscore the reliability and precision of our virtual-mouse system in diverse scenarios.

Fingertip Tracking in Different Conditions:

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The Kinect V2, a pivotal component of our system, was subjected to diverse research scenarios, encompassing a measurement range of 0.5–4.5 m, varied light conditions, and complex backgrounds. The performance of fingertip tracking under such varied conditions attests to the robustness of our system.

Camera type	Kinect V2	Webcam	Webcam	Webcam	Webcam	Kinect
Image type	RGB-D	RGB	RGB	RGB	RGB	RGB
Interaction type	Fingertip	Fingertip	Finger	Fingertip	Fingertip	Hand
Complex background	Yes	No	No	No	No	Yes
Tracking distance	0.5–4 m	Fixed	Fixed	Fixed	Fixed	0.5–4 m
Stable on different resolutions	Yes	No	No	No	No	Yes
# Users for fingertip tracking	6	1	1	1	1	1
Detecting a target person	Yes	No	No	No	No	No

Table 2: Comparison with other systems

Performance of Multiple People Tracking:

To further evaluate the adaptability of our system in scenarios involving multiple individuals, we conducted fingertip-tracking experiments with groups ranging from two to six people. Each group, selected from the ten participants, recorded 100 frames in front of the camera with both hands.

Table 2 provides a comparative analysis of our proposed system against alternative approaches (denoted as [1], [2], [3], [4], and [5]). The proposed system, utilizing Kinect V2 and RGB-D images, outshines alternative approaches in various aspects. It supports fingertip tracking for up to six users, demonstrating a clear advantage over other systems that are limited to a single user. The ability to detect a target person further accentuates the adaptability of our system in dynamic scenarios.

Scientifically interpreting these results underscores the effectiveness of our system in handling complex tracking conditions. The utilization of Kinect V2, coupled with RGB-D images, allows for stable tracking in different resolutions, offering a distinct advantage over alternative approaches. The proposed system's capacity to detect a target person amidst a group further solidifies its applicability in real-world scenarios.

Conclusion:

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In concluding our study, the robust performance and adaptability demonstrated by our virtual-mouse system underscore its potential as a transformative advancement in the field of human-computer interaction. The experiment, involving ten subjects performing various rapid gestures, yielded highly promising results, with accuracy rates reaching up to 100% for specific gestures. This not only validates the precision of our system but also positions it as a reliable and intuitive alternative to traditional mouse devices.

The compatibility of our model with diverse monitor resolutions enhances its real-world applicability, demonstrating its resilience to varying settings. The Kinect V2's capabilities, coupled with RGB-D images, contribute to the system's stability in different resolutions and under complex tracking conditions. Scientific interpretation of the results emphasizes the system's efficacy in recognizing and responding to individual fingertip gestures, marking a significant stride in enhancing user interaction with computing devices.

Limitation of the Study:

While our study showcases the promising aspects of our virtual-mouse system, it is imperative to acknowledge its limitations. The experiment involved a relatively small sample size of ten subjects, and while the results are encouraging, a larger and more diverse participant pool would provide a more comprehensive understanding of the system's performance across various user profiles. Additionally, the study predominantly focused on indoor settings, and extending the evaluation to outdoor environments could shed light on the system's performance in different lighting and background conditions.

Furthermore, the current system primarily relies on Kinect V2 for tracking, and exploring the integration of other depth-sensing technologies could offer insights into potential enhancements or alternatives. Acknowledging these limitations serves as a foundation for future research endeavors aimed at refining and expanding the capabilities of the virtual-mouse system.

Implication of the Study:

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The implications of our study extend beyond the realm of gesture-based human-computer interaction. The success of our virtual-mouse system suggests a paradigm shift in the way users interact with computing devices, eliminating the need for traditional mouse devices and introducing a more intuitive and natural approach. The system's adaptability to diverse monitor resolutions and stable performance in various tracking conditions make it a viable solution for real-world applications, ranging from office environments to interactive displays in public spaces.

Moreover, the system's capacity to track multiple users concurrently holds promise for collaborative computing scenarios, opening avenues for shared interactions without the constraints of physical peripherals. This has significant implications for industries where group collaborations and interactive displays play a pivotal role, such as design, education, and collaborative workspaces.

Future Recommendations:

Building on the success of our study, several avenues for future research and development emerge. Expanding the participant pool to encompass a more diverse demographic would provide a nuanced understanding of the system's performance across different user profiles, ensuring its inclusivity and usability for a wider audience.

Exploration of outdoor environments and varying lighting conditions could address the current study's limitation and enhance the system's adaptability to diverse real-world scenarios. Additionally, considering advancements in depth-sensing technologies, investigating the integration of state-of-the-art sensors could contribute to further refinement and improved accuracy of the virtual-mouse system.

Furthermore, the potential integration of machine learning algorithms for gesture recognition could enhance the system's ability to adapt to individual user nuances and preferences. Collaborative research efforts with professionals from diverse fields, including ergonomics, psychology, and human-computer interaction, could provide valuable insights into optimizing the system for enhanced user experience and widespread adoption.

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