Imaginary Devices: Gesture-Based Interaction Mimicking Traditional Input Devices

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ABSTRACT
We propose *Imaginary Devices*, a set of freehand gestures that mimic the use of physical input devices. Imaginary Devices allow users to choose the input modality best suited for the task at hand, such as a steering wheel for a driving game or a joystick for a flight simulator. Exploiting the skills that users have acquired using physical input devices, they can instantly begin interacting with an Imaginary Device. Since no physical device is involved, users can switch quickly and effortlessly among a number of devices.

We demonstrate the potential of Imaginary Devices with Grand Theft Auto, a game that requires players to change between roles often and quickly, and we examine the viability of the concept in two user studies. In the first study, we found that participants produced a wide range of postures to represent each device but all were able to reproduce the correct posture after a short demonstration. In the second study, we found that Imaginary Devices afford precise input control and approach the baseline performance set by physical devices.

Author Keywords
Imaginary interfaces; gaming; gesture input; input device

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces. Input devices and strategies.

INTRODUCTION
Gamers benefit from using input devices that are tailored to their current task. For example, while a joystick provides appropriate input functionality to fly an airplane, a steering wheel is best suited for driving a vehicle. Some games require players to assume multiple roles. In particular, open-world video games, such as Grand Theft Auto, expect players to run, drive, shoot and perform other activities.

In such games, however, players are not able to use the device most appropriate for the current task because this would require having a multitude of devices at hand. Since switching between such physical devices is impractical and time-consuming, gamers tend to play all of these roles with the same generic input controller, such as the keyboard.

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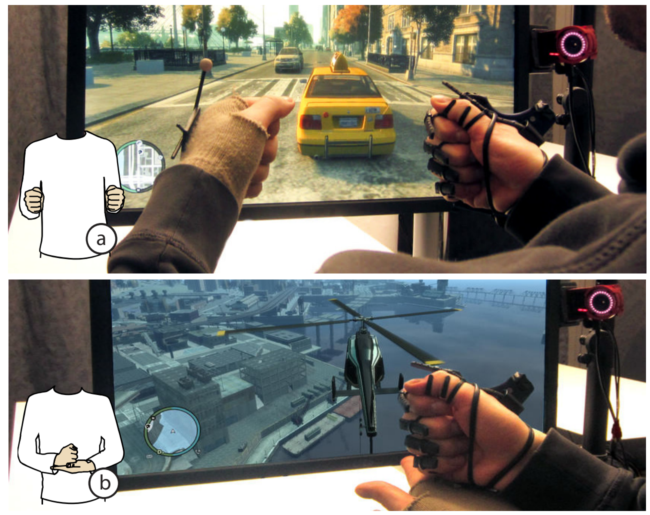

Figure 1: With Imaginary Devices, users mimic the use of physical input devices. Using gestures instead of physical devices allows them to quickly switch among devices to select one best tailored to the current game situation, such as (a) a steering wheel for driving or (b) a joystick for flying.

In this paper, we propose using *Imaginary Devices*: gesture-based input devices modeled after physical devices that enable gamers to quickly switch in-place to the best-suited input device as the game scenario changes (as shown in Figure 1).

The potential of Imaginary Devices comes from having a large set of input devices readily available. While researchers have presented individual Imaginary Devices, such as computer mice (Mouseless [9]), touchscreens (Imaginary Phone [4]) and steering wheels (e.g., in recent Kinect games), the power of Imaginary Devices unfolds once users are able to switch between them.

IMAGINARY DEVICES
Imaginary Devices are non-visual, gestural *input* devices that derive directly from the corresponding physical input devices. Users' knowledge of the physical devices instantly transfers to Imaginary Devices, allowing for gestural input with limited training.

Figure 2 shows the seven Imaginary Devices implemented in our prototype. All devices are inspired by the shape and usage of their physical counterparts.

To use an Imaginary Device, users form the hand pose necessary to grasp the desired input device and begin interacting by *mimicking* how they would operate the physical

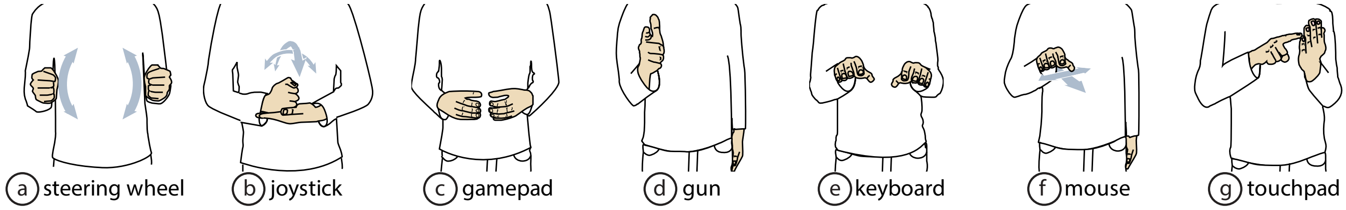

Figure 2: Postures for the seven Imaginary Devices supported by our prototype. Annotations show how hand and finger motions translate to device actions.

device. Similar to Imaginary Phone [4], this allows users to transfer their knowledge of operation of the physical device to the imaginary version. In contrast to physical devices, Imaginary Devices allow for quick switching without interrupting game flow, enabling players to perform each activity with the best-suited input device for the situation.

Example scenario: open world gaming

Figure 1 shows a user playing Grand Theft Auto with Imaginary Devices. When driving a car in the virtual environment, the player assumes the posture of the *imaginary steering wheel* (Figure 2a) and interacts by mimicking the operation of a physical steering wheel. To fly a plane, they form the shape of an *imaginary joystick* (Figure 2b) and mimic how a physical joystick works. When walking around in pedestrian mode, the player chooses the *imaginary gamepad* (Figure 2c). For added precision when shooting, the player forms an *imaginary gun* (Figure 2d) and the angle of the player's hand controls the character's aim. To shoot the gun, players bend their index finger like they would do with a real gun.

Benefits and contributions

Our main contribution is the concept of Imaginary Devices, a set of several gestural input devices, each of which mimics the use of the physical counterpart. The main benefit of Imaginary Devices is quick in-place switching between devices to optimally support the current task.

RELATED WORK

Although gesture-based interfaces offer the promise of more natural input, they often operate on symbolic gesture input vocabularies, which tend to be abstract and therefore not self-revealing [1].

In contrast, some research projects make it easier for users to transfer their knowledge by employing gestures that mimic interaction with a real world object. Such systems, for example, derive continuous mouse input (e.g., DTMouse [2], Mouseless [9]) and joystick input from the user's gestures (e.g., [7, 16]), keyboard input on a projected image [12], touch input to a mobile phone (e.g., Imaginary Phone [4]), remote activation of physical buttons and dials (e.g., UbiFinger [14]), or object selection from the shape of users' descriptions (e.g., Data Miming [5]).

Similarly, Imaginary Devices exploit the knowledge users have built up using physical devices. This makes interaction with Imaginary Devices self-revealing, because users only need to transfer the knowledge from how they have previously used the corresponding physical devices [4].

PROTOTYPE IMPLEMENTATION

Our prototype implements all seven Imaginary Devices by tracking the location, posture and bending of the user's hands and fingers. A ten-camera OptiTrack system (shown partially in Figure 1) captures the position and orientation of the user's hands, which are equipped with reflective markers. We additionally obtain finger bending of the user's right hand from a wired glove (Essential Reality P5). For recognizing the set of devices from Figure 2, we found it to be sufficient to wear a glove only on the right hand.

We implemented our prototype with this combination of tracking systems because both systems provide high sensing accuracy, which allows us to validate the concept of Imaginary Devices. For mobile scenarios, we envision prototypes based on wrist-mounted devices (e.g., Digits [8]) or chest-mounted cameras (e.g., Imaginary Phone [4]).

Posture detection: Our prototype determines the currently used Imaginary Device from the posture of the user's hands and bend of the fingers. Dwelling for 500ms within a specific posture triggers the switch to a new device. Using dwell as the delimiter prevents interference between posture detection and interaction with a device, during which users may temporarily assume ambiguous postures (e.g., interacting with the steering wheel should not trigger the similar posture of the gamepad). If the user lowers both hands below their waist, all input is ignored.

We implemented our posture detector using a set of handwritten rules. Each rule sets the valid range of 17 distinct and 4 compound features: the position of the hands, their orientation and the amount of bend in each finger of the right hand. The compound features were the distance between the hands, absolute difference between both hands' roll angles, sum of all fingers' bend values and the product of this sum and the distance between the hands.

To detect a device from a posture, our prototype checked how many of the 21 features laid within the respective valid range for each of the seven Imaginary Devices. The detected posture was the one with the highest number of matches and, in case multiple matched with the same number, the one with the lowest distance to each of the median values.

We developed an initial range of values for each feature based on observations in pilot testing. We later refined these rules by replacing ranges with the training data we gathered during our first evaluation.

Interaction with a device: Our prototype derives the parameters of the input device, such as joystick tilt or button presses, from the features listed above. The annotations in

Figure 2 illustrate how gestures are translated into device events. Not shown is the interaction with device buttons, which we exclusively infer from the bend of all five fingers. The fingers are used to fire (joystick, gun), click (mouse), type with five predefined keys (keyboard), accelerate and brake (steering wheel) and press buttons (gamepad).

All these interaction events are predefined for each of the devices, working particularly well for our demo application Grand Theft Auto. Other games may need additional configuration, as is common with physical input controllers. To invoke events in a game, our implementation uses a virtual joystick driver (vJoy [15]) that injects events directly into the operating system's event queue, allowing control of any game that supports a joystick.

STUDY 1: SWITCHING BETWEEN DEVICES

To determine if participants are able to form the required postures to seamlessly switch between Imaginary Devices we performed a first user study. After a brief demonstration of the correct Imaginary Device postures, participants completed the experiment by forming the postures corresponding to the given cues. Before the demonstration, we conducted a pre-study to determine how guessable the device gestures were.

Task and apparatus

Before the study, the experimenter briefly demonstrated the correct posture for each device and the participant practiced the gestures. The experimenter corrected the participant's gesture as required. During the study, participants operated the Imaginary Devices prototype as described earlier. They stood to avoid unnecessarily constricting the possible gestures in the guessing pre-study.

Participants repeatedly formed each of the seven Imaginary Devices from Figure 2 as prompted in random order in four complete blocks. Each trial began with the experiment system displaying the title and short textual description of one of the seven Imaginary Devices, such as "Form a joystick". The participant then formed the posture that they believed matched the prompted device and pressed a footswitch to confirm. The system logged the position and orientation of both hands and the bending information for each finger of the right hand. After 500ms of data collection, participants lowered their hands into a waiting posture (hands at their sides) and pressed the footswitch again to conclude the trial.

We conducted the guessability pre-study in the same manner but before the demonstration of the correct postures.

Participants

We recruited twelve participants (all male) from our institution. They were 21 to 29 years old (M=24.5, SD=2.7) and all were right-handed.

Data processing

In total, we gathered data from 336 postures (28 per participant). We split all data into two sets, training (25%) and testing (75%). From the training set, we analyzed the boundaries and valid ranges for each of our 21 features, extracting the median and range of all values to determine the valid spread of values around it for each device.

Results and discussion

Overall, our prototype detected participants' postures with 96.78% accuracy (SD=3.72%) and all postures were classified above 90%. The high detection rate indicates that participants were able to produce consistent enough gestures to trigger the correct posture detection, enabling them to quickly switch between devices in a real world setting, such as a game.

Guessability pre-study

During the guessability pre-study, device postures of the twelve participants were correctly detected in 58.83% of all trials (SD=30.17%), shown in Figure 3. The majority of errors (71%) were a result of failing to find any matching posture, not a placement into the wrong category.

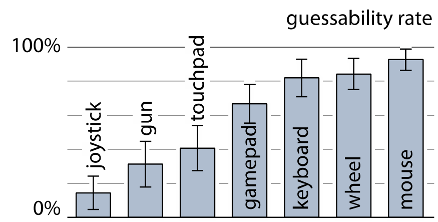

Figure 3: Accuracy when participants guessed the required gesture. (+/- one standard error of the mean)

Participants guessed some device gestures better than others: Mouse had a relatively high detection rate of 92.72% (SD=21.62%), while participants did not consistently guess the gesture required for the joystick (M=14.35%, SD=34.04%).

This high variance between participants suggests that certain postures, such as the joystick, have low *a priori* similarity and are not directly guessable. However, given the high detection rates in the main study after only a short demonstration, it seems that participants had many notions of what the correct posture could be (e.g., some imagined a rifle instead of a pistol for the gun device) and once instructed they were able to easily form the correct posture in a manner that could be easily detected.

STUDY 2: INTERACTION PERFORMANCE

Having established that users can successfully switch between Imaginary Devices, we ran a second study to assess how well Imaginary Devices afford interaction. We conducted an ISO 9241-9 Fitts' Law pointing study [6] using two representative devices: the steering wheel as a 1D input device and the mouse as a 2D input device. As a baseline, we included physical versions of the steering wheel and mouse.

Task and apparatus

Participants were seated at a desk in front of a 1680 × 1050 pixel monitor running FittsStudy 4.2.4 [3]. For the baseline conditions, we used a Dell M-UVDEL1 mouse with acceleration disabled and a Microsoft Sidewinder Force Feedback Wheel with force feedback disabled. The Imaginary Devices were implemented as described earlier. We mapped steering wheel movement to on-screen cursor movement and calibrated all input to achieve the equivalent cursor movement.

To start a trial, participants zeroed the input device and pressed a footswitch. They were instructed to move the cursor as fast and accurately as possible to the target. After reaching the target, they confirmed the selection with the footswitch. Before each condition using a new device, participants received a short training session to make them comfortable with the interaction.

Experimental design

The study used a 2 × 2 (imaginary/physical × devices) within-subjects design. Each condition contained 80 trials (4 amplitudes × 5 target widths × 5 repetitions). The order of conditions was counterbalanced and the order of trials within a condition was randomized. The amplitudes (target distances) were 128, 256, 384 and 512 pixels and the target widths were 16, 32, 64 and 96 pixels.

Participants

We recruited a separate set of twelve participants from our institution (one female) aged between 21 and 29 (M=24.92, SD=3.0). All participants were right-handed.

Results and discussion

From the 4320 trials we gathered during the study, we calculated throughput (using the means-of-means approach based on effective target widths [13]) and error rates (percent of trials with missed targets).

Throughput (Figure 3a): The imaginary steering wheel achieved a throughput of 2.5 bits/s and the imaginary mouse had 2.3 bits/s. Although these values are significantly less (t-tests show $p<0.01$) than the physical counterparts (which achieved 3.2 bits/s and 3.6 bits/s respectively) they are comparable to other free hand gesture input devices, such as the Wiimote [10].

Error rate (Figure 3b): The error rate for the Imaginary Devices remained acceptably low with 6.0% for the imaginary steering wheel and 2.0% for the imaginary mouse. The baseline steering wheel was marginally better at 2.9% ($p=0.104$) and the physical mouse was equivalent to the imaginary mouse.

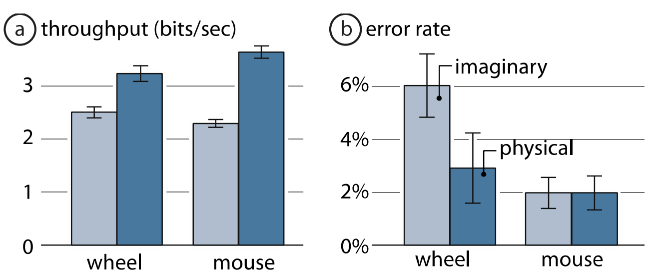

Figure 4: Fitts' Law a) throughput and b) error rate for imaginary and real versions of the steering wheel and mouse. Error bars indicate +/- one standard error.

In addition to supporting fast switching and portability as the main benefits of Imaginary Devices, the results show that Imaginary Devices operate at a level that approaches what is possible with the highly optimized physical devices.

CONCLUSIONS

In this paper, we presented Imaginary Devices, freehand gestures that mimic interaction with physical input devices. We validated the feasibility of our concept by showing that 1) participants could consistently form the required postures after a short demonstration and 2) interaction using Imaginary Devices approaches performance of their physical counterparts. However, more work is required to establish the real world usability of a deployed solution.

We envision future versions of Imaginary Devices to be particularly well suited to mobile gaming contexts. Mobile gamers especially would benefit from Imaginary Devices because it is infeasible to carry around a collection of optimized physical game controllers. Recent advances in computer-vision-based hand tracking (e.g., [11]) could conceivably be integrated into future mobile devices allowing for perfectly tailored, instant-on and high-fidelity control of mobile games.

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