you want to track a user’s body motion (e.g. as input for a game).

**how would you do it?**
list all the different methods (at least 5)

<1 min brainstorming>
optical tracking: structured light
structured light:
- project a **known pattern** onto the scene
- infer depth from the **deformation of that pattern**

Zhang et al, 3DPVT (2002)
• typically IR light and IR cameras are used (invisible)
• the first Kinect used this approach
Kinect only ‘sees’ a pattern of stretched ellipses

here’s what the algorithms compute from this:
so can we use more than 1 Kinect at the same time?

<30s brainstorming>
so can we use more than 1 Kinect at the same time?

no, the different projected patterns overlap and can no longer be clearly recognized

-> very noisy tracking
so can we use more than 1 Kinect at the same time?

no, the different projected patterns overlap and can no longer be clearly recognized

or maybe we can?

can you **invent** sth that fixes the problem?
(while still using the same IR emit/sense approach)

<30s brainstorming>
solution for multiple structured light sensors:

- vibrate each Kinect at a predefined frequency
- since both emitter and sensor vibrate at the same frequency, the IR pattern is still sharp
- however, for other Kinects the pattern will be motion blurred
Shake’n’Sense: Reducing Interference for Overlapping Structured Light Depth Cameras

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Figure 1: We present a novel yet simple mechanical technique for mitigating the interference when two or more Kinect cameras point at the same part of a physical scene. (a) Interference between overlapping structured light patterns from two regular Kinect cameras pointing at a person produces invalid and noisy depth pixels marked red. (b) Our method reduces noise and invalid pixels in the depth map. (c) The resulting point-cloud shows significant artifacts without our technique. (d) Point-cloud with our technique applied. (e) Our technique can be used to create an entire instrumented room with multiple overlapping Kinect cameras. (f) Meshed output accumulated from multiple Kinects shows reduced interference between cameras (color-coding indicates data from different cameras).

ABSTRACT

We present a novel yet simple technique that mitigates the interference caused when multiple structured light depth cameras point at the same part of a scene. The technique is particularly useful for Kinect, where the structured light source is not modulated. Our technique requires only mechanical augmentation of the Kinect, without any need to modify the internal electronics, firmware or associated host software. It is therefore simple to replicate. We show qualitative and quantitative results highlighting the improvements made to interfering Kinect depth signals. The camera frame rate is not compromised, which is a problem in approaches that modulate the structured light pattern. Such modulation degrades depth quality and therefore hinders the machine learning and computer vision research community and computer science research [4,5,7]. Whilst there has been a great deal of research on depth sensing cameras, Kinect has now made such sensors cheap, commodity devices and dramatically broadened accessibility. Kinect’s depth sensing is based on a structured light source positioned at a known baseline from an infrared (IR) camera. IR laser light passes through a diffractive optical element (DOE) to project a pseudo-random pattern of dots into the scene. The disparity between the illumination pattern and the observed dots is used to calculate depth. An on-board ASIC performs this calculation, generating a 640x480 depth map at 30 frames per second.
optical tracking:
time-of-flight
time-of-flight:

• emit light
• **light bounces of nearby objects** and reflects back
• **measure time** until the light hits the sensor

• closer objects = less time until the light reaches them
• far away objects = more time until the light reaches them
• again IR light and camera
• but measures bounce time and not how the pattern looks
Computational Imaging with Multi-Camera Time-of-Flight Systems

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Figure 1: We explore computational imaging with multi-camera time-of-flight systems. Our prototype (left) uses commercially-available sensors, but we design and build external signal generation and control electronics to synchronize the exposures of up to three sensors and drive them with programmable waveforms. One of many applications is multi-device interference cancellation (right). When two time-of-flight cameras are used simultaneously (right), their temporally-modulated illumination codes interfere with one another, which creates periodic artifacts in the estimated depth maps. Operating each light source-camera pair at a different modulation frequency solves this problem. We explore this and other applications of computational multi-camera time-of-flight systems.

Abstract

Depth cameras are a ubiquitous technology used in a wide range of applications, including robotic and machine vision, human-computer interaction, autonomous vehicles as well as augmented and virtual reality. In this paper, we explore the design and applications of phased multi-camera time-of-flight (ToF) systems. We develop a reproducible hardware system that allows for the exposure times and waveforms of up to three cameras to be synchronized. Using this system, we analyze waveform interference between multiple light sources in ToF applications and propose simple solutions to this problem. Building on the concept of orthogonal frequency division, we demonstrate state-of-the-art results for instantaneous radial and angular tracking of individuals. With this technique, we can fuse computer vision with computer graphics researchers, with applications such as scene reconstruction and understanding, pose estimation, action recognition, localization and mapping, navigation, tracking, segmentation, recognition, feature extraction, and reconstruction of geometry, material properties, or lighting conditions (see [Gall et al. 2014] for an overview). Beyond computer vision applications, range imaging is useful for human-computer interaction [Shotton et al. 2011], biometrics, autonomous vehicle and drone navigation, and also for positional tracking of immersive visual computing platforms (augmented and virtual reality, AR/VR). Today, range imaging technology is largely dominated by time-of-flight (ToF) cameras due to their small device form factors, good resolution, robustness in the presence of ambient light, low power, and fast on-chip processing (Wetzstein et al. 2013).
imaginary reality basketball
how would you have to **mount a set of Kinect cameras** to track all players while minimizing occlusion?

<30s brainstorming>
how would you have to **mount a set of Kinect cameras** to track all players while minimizing occlusion?

- let players wear the kinects on their chest
- let them track each other (hard)
Imaginary Reality Gaming: Ball Games Without a Ball

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Figure 1: (a) Six players in a game of Imaginary Reality Basketball. Player 15 on the Black team has thrown the imaginary ball at the basket and scored. There is no visible ball; players get all information from watching each other act and a small amount of auditory feedback. (b) Under the hood & invisible to the players, the system represents the imaginary ball as a large number of ball particles, each of which represents one plausible ball trajectory. Players are tracked using accelerometers and an overhead camera.

ABSTRACT
We present imaginary reality games, i.e., games that mimic the respective real world sport, such as basketball or soccer, except that there is no visible ball. The ball is virtual and players learn about its position only from watching each other act and a small amount of occasional auditory feedback, e.g., when a person is receiving the ball.

Imaginary reality games maintain many of the properties of physical sports, such as unencumbered play, physical exertion, and immediate social interaction between players. At the same time, they allow introducing game elements from video games, such as power-ups, non-realistic physics, and player balancing. Most importantly, they create a new game dynamic around the notion of the invisible ball.

Researchers have tried to merge physical and virtual play in display-based augmented reality games such as Human Pacman [5] or AR Quake [16]. These games overlay a virtual world onto the physical world using hand-held or head-mounted see-through displays. This allows these games to introduce virtual game elements, such as power-ups (e.g. [22]) or creating virtual game elements that are not limited by the rules of physics (e.g. [20]).

Unfortunately, the use of displays takes away many of the qualities of physical sports, as players now perceive the
optical tracking:
passive markers
infra-red cameras

retro-reflective markers
IR light + retro-reflective markers:

- cameras emit infrared light
- bounces of the retroreflective marker
- camera sees the marker as a **bright dot** in the IR image
extracting marker position:

- track marker from **two or more cameras** at the same time
- cameras are **calibrated** to each other
- **triangulate** the marker position to get the 3D coordinate
calibration wand
mh, but this is only a point, so it only gives me location. how do I get the rotation?

<30s brainstorming>
predefine multiple marker positions on the model
rigid bodies offer already registered multi-marker arrangements
passive markers are great:
they require no power / battery.

what are some of the drawbacks
of using passive markers?

<30s brainstorming>
markers cannot be identified. they all look the same to the camera.
optical tracking: active markers
infra-red cameras

LED markers
(emit their own light:
blink LEDs quickly one after another
to know which one is which)
we use this a lot for research projects
Continuous Interactive Fabrication

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ABSTRACT
Several systems have illustrated the concept of interactive fabrication, i.e. rather than working through a digital editor, users make edits directly on the physical workpiece. However, so far the interaction has been limited to turn-taking, i.e., users first perform a command and then the system responds with physical feedback. In this paper, we explore how to extend interactive fabrication to make the workpiece change while the user is manipulating it.

We present FormFab, the first interactive fabrication system that provides such continuous physical feedback. To accomplish this, FormFab does not add or subtract material but instead reshapens it (formative fabrication). A heat gun attached to a robotic arm warms up a thermoplastic sheet until it becomes compliant; users then control a pneumatic system that applies either pressure or vacuum thereby pushing the material outwards or pulling it inwards. As users interact, they see the workpiece change continuously.

By providing continuous interaction, FormFab enables users to explore an entire shape parameter with a single interaction. This improves over existing turn-taking systems that only allow exploring a single option per turn.

We explain FormFab’s hardware and software, provide a walkthrough that illustrates the system’s interactive capabilities, and discuss the design and interaction space.

Author Keywords: personal fabrication; interactive fabrication; direct manipulation; 3D modeling tools.

H.5.2 [Information interfaces and presentation]: User Interfaces.

INTRODUCTION
Recently, Willis et al. [29] proposed the concept of Interactive Fabrication. The key idea is to bring the principles of construction tools into the digital fabrication domain. Interactive fabrication systems, such as Shaper [29], CopyCAD [3], and constructable [11], allow for hands-on interaction during fabrication. This enables intuitive design exploration and permits users to directly manipulate physical workpieces, making them more accessible than digital editors. In this paper, we present FormFab, the first interactive fabrication system that provides continuous physical feedback. The system allows users to explore an entire shape parameter with a single interaction, improving upon existing turn-taking systems that only allow exploring a single option per turn.

FormFab is an interactive fabrication system that combines the principles of construction tools with digital fabrication. The system includes a heat gun attached to a robotic arm, which warms up a thermoplastic sheet until it becomes compliant. Users can then control a pneumatic system that applies either pressure or vacuum, pushing the material outwards or pulling it inwards. As users interact, they see the workpiece change continuously.

By providing continuous interaction, FormFab enables users to explore an entire shape parameter with a single interaction. This improves upon existing turn-taking systems that only allow exploring a single option per turn. The system’s hardware and software are explained, along with a walkthrough that illustrates the system’s interactive capabilities. The design and interaction space are also discussed.
we use this a lot for research projects
A Prototyping Tool for Integrating Energy Supplying Components into Deformable Devices

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ABSTRACT
With recent advances in fabricating flexible electronics, deformable user interfaces are becoming more common in HCI. For deformable devices, traditional methods of supplying energy can be problematic: rigid plug-and-socket connectors create undesirable stresses inside the soft material, energy harvesting mechanisms based on free oscillations and rigid gears are constrained, and embedded inductive power transfer coils become detuned during bending.

In this paper, we demonstrate how to adapt these energy supply methods for deformable devices. The key idea is to incorporate knowledge of how the user interacts with the device, i.e. how the device deforms. To facilitate the process, we contribute an end-to-end prototyping system for deformable devices: designers model the device and export it for physical prototyping. Interaction data collected with a motion capture system is then used to calculate a stress distribution across the device. The system then recommends locations for placement of the energy-supplying components.

INTRODUCTION
Since the early 2000s, HCI researchers envision a future in which devices will no longer be rigid but deformable (Organic User Interfaces [7]). Moving away from rigid objects and being able to squeeze, stretch, and twist devices, including an increased input space (Gummi [23]), output space (Surflex [4]), and better ergonomics [7].

With recent advances in flexible electronics [16], researchers are increasingly able to achieve this vision. In this work, we contribute a new system for designing and prototyping deformable devices. Figure 1 demonstrates the system in action, using an OptiTrack system to capture interaction data.
electro-magnetic tracking
magnetic field generator (transmitter) with two coils

electro-magnetic finger markers (with one coil)
• emits **electro-magnetic field**
• calculate relative **intensity of current of the coils**
• **size of field** varies depending on power of tracker
• **larger field** = larger tracking range
Polhemus Fastrak:

- $12k+ for the tracker and $200 for each marker
benefits & drawbacks:

- **no occlusion** of markers
  - you can hide the tracking hardware
  - you can track through walls and people
- single source, **no cameras to align**
- **doesn’t scale well** with higher number of markers (difficult to decode the magnetic field)
- sensitive to **magnetic and electrical interference**
The working environment

Polhemus FASTRAK motion tracking system

6D Sensor

Magnetic field source

System electronics unit
CAD/CAM fastforward
Modeling a cup in Rhino3D
The FreeD parts
Human-computer Interaction for Hybrid Carving

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ABSTRACT
In this paper we explore human-computer interaction for carving, building upon our previous work with the FreeD digital sculpting device. We contribute a new tool design (FreeD V2), with a novel set of interaction techniques for the fabrication of static models: personalized toolpaths, manual overriding, and physical merging of virtual models. We also present techniques for fabricating dynamic models, which may be altered directly or parametrically during fabrication. We demonstrate a semi-autonomous operation and evaluate the performance of the tool. We end by discussing synergistic cooperation between human and machine to ensure accuracy while preserving the expressiveness of manual practice.

Author Keywords
Computer-Aided Design (CAD); Craft; Digital Fabrication; Carving; Milling.

ACM Classification Keywords
H.5.2 Information interfaces and presentation: User Interfaces; I.3.8 Computer Graphics: Applications

INTRODUCTION
This paper contributes an application of a digital sculpting device for hybrid carving, using a revised version of the FreeD tool (FreeD V2), previously discussed in [21]. FreeD enabled users to make physical artifacts with virtual control, and FreeD V2 adds manual and computational design modes of interaction such as switching between virtual models through the work; overriding the computer; deforming a virtual model while making it; or searching interactively for an optimal parametric model. In addition, the new tool can operate independently for tasks such as semi-automatic texture rendering.

In the next section, we discuss our previous efforts and related work, and in the subsequent section titled The FreeD V2 Design, we present the new version of the FreeD, focusing on revisions from the early version. In Modes of collaboration and interaction, we present three operational modes: static (rigid)
mechanical motion
(exoskeleton tracking)
but picking up objects and feel their shape and sizes
Dexmo: An Inexpensive and Lightweight Mechanical Exoskeleton for Motion Capture and Force Feedback in VR

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Figure 1. A person using Dexmo to control a virtual exoskeleton model in virtual reality.

ABSTRACT

We present Dexmo: an inexpensive and lightweight mechanical exoskeleton system for motion capturing and force feedback in virtual reality applications. Dexmo combines multiple types of sensors, actuation units and link rod structures to provide users with a pleasant virtual reality experience. The device tracks the user’s motion and uniquely provides passive force feedback. In combination with a 3D graphics rendered environment, Dexmo provides the user with a realistic sensation of interaction when a user is for example grasping an object. An initial evaluation with 20 participants demonstrate that the device is working reliably and that the addition of force feedback resulted in a significant reduction in error rate. Informal comments by the participants were overwhelmingly positive.

INTRODUCTION

There are many ways for people to bring their motion into the virtual world, however, there is little feedback back to the real world. Current force feedback devices are bulky, non-portable, expensive and difficult to manufacture. There is still a lack of a light, easy-to-use and affordable force feedback approach for people to touch or sense in the digital world.

In this paper we present Dexmo, a mechanical exoskeleton that is a lightweight, inexpensive, compact, reliable and safe solution for providing force feedback and motion capture in augmented and virtual reality environments. Figure 1 illustrates a user wearing Dexmo and using it to interact with a virtual world. Rather than applying torque control at each individual joint of the exoskeleton directly, Dexmo uses a micro servos unit to shift stepping blocks linearly to stop the rotation...
benefits & drawbacks:

- tracking and haptic feedback combined
- no occlusion
- infinite tracking volume
- low-cost
inertial systems
(IMUs)
IMU sensor data mapped onto a bio-mechanical model
Inertial Measurement Unit (IMU):

- **linear acceleration**: accelerometer
- **rotational rate**: gyroscope
- **heading reference** (optional): magnetometer
- 3-axis sensors for: pitch, roll, yaw
benefits & drawbacks:

- no occlusion and no noise from electro/magnetic
- infinite tracking volume
- low cost ($1,000+)
- no absolute position of the user
- lower accuracy
electro-muscle
• Myo tracking band on the forearm
• based on **EMG** (tiny voltage from muscle activation)
• includes accelerometer and gyro for overall motion
benefits & drawbacks:

- no occlusion
- infinite tracking volume
- low-cost
- mapping from muscle activation to actual movement
summary
how to select a system?

- depends on your use case
- and how much money you have