Motion Sensing Technology

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Executive Summary

Objective
This report provides a technology assessment of the future of motion sensing technology. In particular, we identify motion sensing's boon in the gaming industry and analyze trends there as well as in potential areas of application outside gaming. Our focus technology will be Microsoft's Xbox360 Kinect peripheral, which is the first demonstrator of touchfree motion sensing, although we also discuss competing technologies.

Approach
To analyze this vast field, we employed the following techniques:

- Interviews with Microsoft Kinect developers, Microsoft researchers, and the CEO of a competitive technology
- Reviewing appropriate research journals detailing the technology behind the Kinect
- Research of potential applications through hacker websites along with official electronics review websites
- Examining the market performance of Kinect by comparing sales figures to other gaming consoles and peripherals

Conclusions
We find many technical difficulties preventing Kinect from making a fully-disruptive, overwhelming impact within the gaming realm. Combined with the importance of the traditional controller in gaming, we conclude that the Kinect will never completely integrate itself as the prime gaming input method by supplanting traditional controller input.

However, we characterize markets for commercial applications of the motion sensing technology represented by Kinect. In particular, we discuss three main areas of potential expansion: consumer and enterprise multimedia, immersive military training, and hospital aid for surgery. We provide predictions for the readiness of the technology in each area over the next decade.
Introduction

Motion-sensing capability has become a boon in the gaming industry, with 90 million Nintendo Wii units sold since its 2006 introduction and over 10 million units of Microsoft’s Xbox360 Kinect peripheral sold since its winter 2010 launch, the latter having surpassed the former as the “world’s fastest-selling consumer electronic device” [4]. Distinguishing Kinect from Wii is its dedication to pure, controller-less motion input -- “you are the controller”, as the marketing slogan goes.

One of the key aspects of Kinect that has generated much excitement is its promotion of the natural user interface (NUI) paradigm, which in many ways aims to succeed the traditional graphical user interface (GUI) and command line interface (CLI) paradigms for human-computer interaction. Indeed, Microsoft’s approach to Kinect clearly focuses on the expansion of NUI and a vision for Kinect that goes far beyond gaming [Tashev]. Craig Mundie, chief research and strategy officer at Microsoft, recently stated that the “computing interface [is evolving] from something we drive to something that’s more like us” [1], but while the world searches for applications that may be primed to accept NUI, Kinect and the activity surrounding it offer clues as to where motion-sensing technology may be headed in the next 5-10 years.

Technology Background

Motion-sensing in gaming has had many premature starts, with a history of products for older generation consoles ranging in reputation from grossly unsuccessful to largely forgotten (SegaPods, Sega Activator, PlayStation EyeToy and Eye) [1]. The first true success in introducing motion input into gaming came with Nintendo’s Wii, whose appeal opened the floodgates for family-oriented and casual gaming, but which still relied heavily on traditional button/joystick controller input. The first pure (controller-less) motion gaming experience would arrive with Microsoft’s Kinect peripheral for the Xbox 360 console. Kinect’s explosive success has led many to posit many paths for the growth of motion gaming, and this is the starting point for our technology investigation. Though Kinect, as the technology demonstrator for our report, is a gaming device, our search has uncovered the potential for motion-sensing to be much more far-reaching in application, as detailed later in the report.

Predecessor

The entrance of non-conventional input mechanisms in gaming began in 2006 with the release of the Nintendo Wii. Breaking away from the usual controller interface, the Wii used a remote + nunchuk (joystick) combination. The primary controller, the remote used built-in accelerometers and infrared detection to gauge its position in space from the light emitted from a sensor bar placed on the television screen. As a secondary peripheral, the nunchuk also featured an accelerometer as well as an analog joystick. Both components offered buttons for traditional input as well. The success of the Wii served to break the ground for alternative input methods in gaming, specifically, motion input [5, Rubin].

Inception

In mid-2009, Microsoft announced the introduction of a new gaming experience. Codenamed Project Natal, it would feature a natural user interface. Whereas the Wii included position tracking capability in the traditional remote, Natal (later known as Kinect) would allow the player to move freely and interact with the game without holding any controller components. This marked the entrance of pure motion sensing into gaming, and to date is the only one of its kind released to market.

The Kinect is composed of three major hardware components: a webcam, an infrared laser projector and camera, and a multi-array microphone. Performance advancements in all three areas,
decreasing production costs, and a push for innovation provided the incentives for Microsoft to develop their new gaming device (see Appendix A). However, the primary innovation of Kinect (and the most secretive) is the software that enables advanced posture, gesture, facial, and voice recognition [4].

Though the Kinect is Microsoft-branded, the depth-sensing hardware capability is provided by Israeli company Primesense [15]. The depth sensor uses infrared laser projection and a CMOS sensor to capture video data, which creates a map of every visual point and its position in space. The resolution of the depth map depends on the capabilities of the projector and sensor system.

Body part recognition uses proprietary algorithms to attach a computer skeleton model onto the user. Machine learning using millions of example images ensured that Kinect works for all body shapes and poses. This means that players can enter at any time and a new skeleton is affixed to their figure.

The microphone array uses acoustic source localization and ambient noise suppression to allow for headset free chatting, honing in on the users speaking. Instead of capturing sounds close to a source, the microphone is wide-field and can pick up ambient speech within the range of play [4].

**Disruptive Technology in Gaming**

We found the most prominent disruptive technology in gaming to be the Razer Hydra, developed by Sixense, to be released in June 2011. It is a wireless motion and orientation detection game controller that uses a magnetic field wearable object to detect the absolute position and orientation of the controllers. The controllers themselves are similar to Wii controllers, but have six degrees of freedom and a precision of 1 mm and 1 degree. The use of magnetic fields eliminates the line of sight problem present in Kinect. Refer to Appendix D for further discussion.
General Challenges

Limited Camera and Sensor Capability

The system is capable of 640×480 pixel resolution and can differentiate and capture objects with a spatial horizontal resolution of 3mm (0.01”). According to one of our interviewees, Matt Haigh, this only affords precision to a few centimeters. Thus the system can differentiate movements of the wrist and elbow but cannot distinguish movements of the fingers and hands.

In addition, the depth resolution of the Kinect can differentiate objects in 1 cm (0.4”) increments. The image output is 60 fps. However, the range of the sensor is the clear limitation: it only works in a range between 0.8m to 3.5m (2.4ft to 10ft) to the user. These parameters are not ideal for use in large family rooms and in games which could include up to 4 players.

Another major, but less used, component of Kinect is its audio sensing capability. As of now, improvements still need to be made to the algorithm of voice recognition. According to Ivan Tashev, Microsoft’s principal software architect for audio control, the challenge is two-fold:

1. Filtering out ambient noises and noises from surround sound speakers.
2. Registering the meaning behind the human speech.

To overcome the first hurdle, they have developed acoustic echo cancellation algorithm, which is the first algorithm of its kind to be able to filter out not just single point source, but a full surround sound system. Now they can pick up the soft speech of a child from 4 meters away. They are working on differentiating multiple voices speaking simultaneously, allowing the implementation of NUI (natural user interface) in multiplayer games. For the second hurdle, the human speech is very imprecise and heavily based on context. In order for the computer be as competent as human beings, more research will have to be done in statistical processing of audio signals. As of now, a certain phrase has to be spoken in order for Kinect to register the command (see Appendix B)

For future implementation, Microsoft is focusing on moving towards NUI. As Amir Rubin said during our interview, “The best game controller is the type that disappears once you start playing.” Being able to use natural speech to command the Xbox is a step in this direction [Rubin].

Limited Body Recognition

Related to camera resolution is the problem of limited body recognition. The human body can produce multitudes of poses, which Kinect cannot completely capture. Instead, Kinect tries to create a database of the variety of poses that humans would achieve in an entertainment scenario. It does not calculate the individual movement possibilities of each joint on the body. Once Kinect overlays a skeletal body on the user, it theoretically can track motion of the user with the depth camera and this database of poses. However, the poses given are for a standing gamer, so Kinect games only work when the gamer is standing, even if he or she simply wants to navigate through menus [7]. When the gamer sits down, Kinect will only work via voice recognition.

Another problem with the use of depth cameras is that body parts not visible by the camera are hidden in the game as well. This limitation of line of sight proves to be a large problem because it requires that the hands stay in front of the body at all times, which is not a completely natural gaming experience. Since the biggest issue is to create that experience, a solution around the limitation of this input device is needed by Kinect [Rubin].

Range constraints for gaming

Motion-sensing technology as implemented in Kinect currently requires a sizable area for use (0.8m minimum to 3.5m maximum user distance), which is restrictive for families not having large living
spaces (a common situation in Japan and Europe) [Benko]. This is an issue affecting the prospect of motion-sensing for capturing the new family-oriented and casual gaming demographic. In particular, the average living room size in the United States measures 16 feet x 16 feet. This decreases to about 12 feet x 12 feet for student rooms. A standard couch has a width of about 3 feet and the average television set and fixtures is about 3 feet in thickness as well [13]. Assuming no other materials in the room, the space in front of the Kinect set is now about 10 feet, whereas the maximum user distance specifies 11.5 feet. Thus we see that even in a minimally occupied room, the space requirements are still quite large and difficult to accommodate.

Legacy control and compatibility

As of now Xbox 360 has no other peripherals that work with Kinect. While gesture recognition of Kinect coupled with voice recognition provides a more natural gaming experience, it should be noted that some games (especially action games) require some type of peripheral to feel realistic. First person shooter games such as Bioshock and Call of Duty cannot be easily played with gesture. For example, Kinect’s inability to recognize finger movements will hinder it from registering the act of pulling the trigger or switching between semi-auto to full-auto. This means that Kinect will exclude a large portion of the hardcore gaming population and yet some of the most popular games sold today are these action games (see Appendix C). This is an issue that was consistently brought up during our interviews. Amir Ruben, CEO of Sixense (a potential competitor of Kinect) says that Kinect has explored the limits of the games that work well with gesture recognition alone (such as Dance Central), beyond this small peripherals are probably going to be needed if it wants to compete against existing controllers. The current generation users may be uncomfortable moving away from the traditional controllers.

Lack of excellent games

Nintendo introduced motion control to the masses with a small number of games that worked well with a limited number of gestures. It succeeded magnificently because of that relatively conservative strategy. Kinect, on the other hand, is as ambitious but is not as carefully planned as Wii. Kinect introduces a new way to use voice and gesture to downloaded movies through the Xbox’s Zune channel or to watch sporting events streamed through the regional ESPN3. But the options for control input with gesture and voice are so numerous, and the line-up of launch games so diverse and scattered, that Kinect fails to do any one thing excellently [9]. This can been seen in the comparison of Kinect game ratings and sales to those of Wii games from numerous websites (see Appendix C).
Development Prospects in Selected Fields

Given the nascence of motion-sensing technology and its nature as a tool, a myriad of speculative applications have cropped up since the introduction of Kinect as the technology’s forerunnering product. Kinect’s aforementioned shortcomings have not hampered efforts to capitalize on its immense potential, even in other fields. Amateur “hacks” have explored the capabilities of Kinect’s hardware and software package, but we focus on activity among mainstream innovators such as major technology companies or prominent research groups. Our attention is on only three areas of potential application, but we provide depth in understanding and an evaluation.

Consumer and enterprise multimedia

Prior to motion sensing’s entrance into gaming, the technology has primarily been used for security applications, as with detecting unauthorized entry, lighting control, and triggering cameras to capture images of a moving subject.

The introduction of Kinect technology has gradually moved motion sensing technology towards the creation of an immersive and interactive user interface applicable in multiple situations. One important application is the integration of motion sensing technology with video conferencing technology, such as the Skype software application. Microsoft recently bought Skype for $8.5 billion, and currently there is much speculation on how they plan to integrate Skype with the Kinect system. One possible application of Kinect with Skype is to provide a more immersive video conferencing experience. The MIT Media Lab has done considerable work by using the Kinect system to integrate spatial depth information, audio, and a live video stream to calibrate an immersive conferencing application. One feature of this system built by the MIT Media Lab is called "Spatial Augmented Reality" [8]. This feature allows the size and position of objects in the conference room to be defined in three dimensions. Users can click on the objects (which are in reality located somewhere else, but whose image is projected on a display screen) and zoom into the object and get its dimensions.

![Hand Manipulative All Object in 3D Space](image1)

Microsoft Research has also been using motion sensing technology to create a more natural user interface. Their project LightSpace seeks to create interactive surface manipulation on any surface and even the spaces in between by combining elements of surface computing with augmented reality research.

LightSpace is innovative because it uses motion sensing technology to allow the user to interact with a display projected onto various surfaces in a small room specially designed for this purpose. It uses 3D real world coordinates to calibrate its depth cameras and projectors, which allows its graphics to correctly project on any visible surface. A standard table or office desk and the air between them can be
transformed into an interactive display using selective depth camera projection. The user can transfer an object from one surface to another by touching both the object and the destination. They can also sweep the object into their hand and walk over to the destination surface [3].

Another field of application for motion sensing technology is consumer multimedia. Wavi Xtion, developed by Asus, is a new approach to PC entertainment that combines the WAVI wireless media streaming device with the Xtion motion sensor. It can stream high definition media wirelessly from a PC located in one room to a TV at another location. The Wavi Xtion uses infrared camera for the motion sensing function; the motion sensing is used to control the gesture-based multimedia playback function, games and other applications. This would be the first motion-sensing PC interface [2].

**Immersive military training**

There are currently two active projects that involve military applications. The first project is sponsored by the Office of Naval Research and the Army Research Office. It involves the military use of Kinect in reconnaissance missions. Developed by students at MIT, a drone equipped with a Kinect system makes a map of a room in real time and is able to navigate through it. The combination of a real-time visual odometry system and the Kinect depth sensor allows for fast and accurate measures of the trajectory of the vehicle. Also, all calculations are performed onboard the unit, which aligns camera frames by matching features across images and uses depth information derived from Kinect to determine the camera’s motion [19].

The second is a Request For Information from DARPA for Biologically Driven Navigation. The goal is to search for a more immersive military training experience. More specifically, they would like to explore “novel approaches to sense and interpret biological signals correlated with human user intent, and to translate these signals into actual waypoints or movement commands in a virtual or physical environment.” There has been speculation that Kinect technology can be used in this [20].

**Surgical aid**

The ability of motion-sensing technology to provide touchfree interaction has many implications for medicine, where both patients and their caretakers would benefit from reduced risk of contamination. Interest centers around two applications for the operating room: the use of gesture control to manipulate and view crucial MRI and CT imagery, and the use of gesture control to aid or perform actual surgical procedures through robots.

With imagery, the benefits are immediate and clear: touchfree control allows surgeons to avoid exposure to non-sterile computer surfaces. Currently, “scrubbing in and out to access the computer safely can add as much as two hours to an operation”, leading to precarious operation delays (during which patients can suffer complications), fatigue in the operating staff, and prolonged patient recovery time [17]. Having an assistant to aid with accessing imagery alleviates the problem, but with additional human resource and coordination costs in navigating through thousands of images. A Toronto hospital pioneering this concept has reported the dramatic effectiveness of using Kinect to access imagery: “That computer that had so much information but was kept separate now becomes integrated right in front of you” [17].

Implications for robotic surgery are much more uncertain, with the effectiveness of robotic surgery itself being questionable and many doctors lamenting its shortfalls [16]. Still, putting the debate aside for the moment, where robotic surgery is needed or desired, gesture control could improve surgeons’ performance in several ways. By using Kinect’s powerful ability to capture spatial information in a scene, some pioneers have attempted to address one of the most commonly offered criticisms about robotic surgery: the need for haptic, or tactile (touch), feedback for surgical robot operators [16]. Making use of Kinect’s depth camera, the doctors have produced proof-of-concept for operators to “feel”
when the robot has contacted a surface, in particular with areas they wish to avoid damaging. The system restricts control stick movement in response to the information from the depth camera, thus providing feedback to the operator.

It’s really good for demonstration because it’s so low-cost, and because it’s really accessible,”[said] Ryden, who designed the system during one weekend[.]. “You already have drivers, and you can just go in there and grab the data. It’s really easy to do fast prototyping because Microsoft’s already built everything.”

Before the idea to use a Kinect, a similar system would have cost around $50,000, Chizeck said. [...] In the meantime, the sensors will need to be scaled down to a size deemed appropriate for surgical use, and the resolution of the video will need to be increased before it is usable. [18]

As the above supports: amongst all the proposed fields of expansion for motion-sensing technology, medicine may have the distinction of bringing immediate benefit to an unmet need and thus looks to be an area of intense activity in the future.
Technology Readiness Level (TRL) Assessments

Using NASA’s TRL chart, we are able to classify the readiness of motion sensing and Kinect in the following areas based on our research and knowledge of the advancements in technology in those areas (see Appendix F for chart).

**Consumer and Enterprise Multimedia**

- **Video conferencing** - TRL 9.

Microsoft has its own Kinect with Windows Messenger video conference. On May 10th, 2011, Microsoft also acquired Skype [21].

*5-10 year projection:* Video conferencing is already a very prevalent trend in both private and business market. Given the fact that words are often spoken faster than typed, video conferencing will become more popular.

- **Security** - TRL 9.

This has been fully implemented in the past and successfully commercialized.

*5-10 year projection:* Usage of motion detection for security purposes has been around for years; there are no major innovation occurring in this field so the technology itself will eventually plateau.

- **Spatial Augmented Reality** - TRL 6.

IT Media Lab has shown that it is possible to show the relative position of objects through the use of Kinect. However, this seems to be useful for highly specialized tasks such as design. Therefore Team Bazinga feels that there is a relatively small market for this type of product and it may not grow to maturity. (See Appendix G for S-Curve)

*5-10 year projection:* While this technology is definitely innovative, the usage of such a technology is more narrowly tailored to professionals. Without the mass market, even a solid technology will not blossom to maturity.

- **LightSpace** - TRL 6
Microsoft Researchers Andrew D. Wilson and Hrvoje Benko recently published a paper describing such prototype and its potential [14].

5-10 year projection: The next decade will see more products in this area. Since it is in sync with Microsoft’s drive to provide Natural User Interface to its customers, more R & D will probably bolster the development of products in this area.

- **Asus Wavi Xtion** - TRL 8

It is slated to be released during the summer of 2011.

5-10 year projection: The introduction of Wavi Xtion means that one can connect the Kinect to a PC. This could be a popular product for Asus users. However to capture the market at large, this product could benefit from being completely adapted to all types of PCs.

**Immersive Military Training**

- **Kinect in recon missions** - TRL 6

The system has been tested by MIT students in simulations.

- **Biological Navigation** - TRL 2.

There has been a call for projects with the full backing of the Department of Defense but no known groups have attempted this yet.

5-10 year projection: Since there have been no developments at all, we predict that the next decade will see no complete release of a product in this area.

**Surgical aid**

- **Surgical imagery manipulation** - TRL 5.

With only one noted demonstration of this in our reporting, it is hard to project impending stunning growth -- however, it is safe to say that the ease of adoption combined with the immediate relief to a medical “market pain” offered make this application a very exciting area to watch.

5-10 year projection: Without additional tests of the technology in this area, we predict no products to arrive in hospitals for the next 5 years. However, research will push this technology to be developed further during this time.

- **Robotic surgery** - TRL 4

The proof-of-concept in our investigated case gives the technology a readiness value of 4 for providing useful solutions in robotic surgery. However, the projected outlook is less optimistic
than that of imagery manipulation, as the field of robotic surgery itself suffers from many critical shortfalls that limit its adoption (such as cost, unverified efficacy, and steep learning curve).

5-10 year projection: Though the concept is desirable, repeated implementation in real surgery depends on the trust in the robotic responses and a general acceptance from the people undergoing surgery. Thus we predict that, though advances may push this to be technologically closer to usability, other issues will influence the growth of this field.
Conclusion

Motion sensing, though important in gaming, will ultimately make its biggest impact in non-gaming applications. Though it has been effective in expanding the gaming demographic to include females and older users, it will never completely replace the controller based gaming of today. This is due to the inability of pure motion sensing to completely supplant legacy controllers with regard to games requiring peripherals, such as driving and shooting games.

However, the current volume of hackers (904 forum members on www.kinecthacks.net alone) exploiting the technology in Kinect shows the many applications of motion sensing outside of gaming. With the upcoming release of the official Kinect SDK, Microsoft plans to encourage the contributions of hackers in developing additional uses for the Kinect, signifying their acceptance of the movement of Kinect to non-gaming applications. In particular, from our research we feel that the most likely commercial use of motion sensing will be in video conferencing. This is due to Microsoft’s recent acquisition of Skype, which we feel is significant to their plan to formally introduce Kinect as a peripheral for a better conferencing session on Skype. We expect to see formal videoconferencing products within the next 1-3 years.

Group Interaction

In general our team function has been very good over the term. Though we faced an issue early on with accurately defining our hypotheses, we were able to remedy this through collaboration with Professor Pickar. There were a few issues prior to the midterm with being slack with the rules set forth at the beginning of the term, but after setting up more accountability methods we were able to ensure that no members fell behind.

Though in the beginning we had trouble tracking down potential interviewees for primary sources, after the midterm we were able to secure multiple useful interviews for our research. Overall, our group interaction has been good. We were able to resolve all issues that arose as a team.
Interviews and References

List of Interviews Conducted

- Cole Hershkowitz
  - Caltech undergraduate working on Kinect home applications
  - April 26, 2011
- Matt Haigh
  - Microsoft former employee working on Kinect
  - April 29, 2011
- Sam Stokes
  - Microsoft outreach specialist
  - May 4, 2011
- Hrvoje Benko
  - Microsoft NUI researcher for depth sensing cameras
  - May 12, 2011
- Dr. Michael Maire
  - Caltech Computer Vision Lab
  - May 12, 2011
- Dr. Piotr Dollar
  - Caltech Computer Vision Lab
  - May 13, 2011
- Amir Rubin
  - CEO of Sixense
  - May 17, 2011
- Ivan Tashev
  - Microsoft developer of Kinect audio software
  - May 18, 2011

References

20. https://www.fbo.gov/index?s=opportunity&mode=form&id=30b78e15f5784715a0112413b4420215&tab=core&cview=
Since the number of transistors per chip is increasing according to Moore’s law, the cost to produce a webcam with similar specifications over the years will decrease due to the decrease in the number of required chips.
## Appendix B

<table>
<thead>
<tr>
<th>If you want to...</th>
<th>Say this...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go to the Kinect Hub</td>
<td>&quot;Xbox Kinect&quot;</td>
</tr>
<tr>
<td>Play a disc</td>
<td>&quot;Xbox play disc&quot;</td>
</tr>
<tr>
<td>See more options in the Kinect Hub</td>
<td>&quot;Xbox next&quot; or &quot;Xbox previous&quot;</td>
</tr>
<tr>
<td>Sign in to your profile</td>
<td>&quot;Xbox sign in&quot;</td>
</tr>
<tr>
<td>Start the Kinect Tuner</td>
<td>&quot;Xbox Kinect Tuner&quot;</td>
</tr>
<tr>
<td>Start Kinect ID</td>
<td>&quot;Xbox Kinect ID&quot;</td>
</tr>
<tr>
<td>Open or close the disc tray</td>
<td>&quot;Xbox open tray&quot; or &quot;Xbox close tray&quot;</td>
</tr>
<tr>
<td>Go to the Xbox Dashboard</td>
<td>&quot;Xbox Dashboard&quot;</td>
</tr>
</tbody>
</table>

*[11]*
Appendix C

To compare the quality of the games we looked at an authoritative website called IGN, which scores each video game on a basis of 10, based on individual aspects such as presentation, graphics, sound, gameplay and lasting appeal. We understand that Wii and PS3 games have been released much earlier than that of Kinect games and have had more time to cultivate the market. To eliminate this confounding effect, we took only the most recent 6 months worth of reviews of games (as the first Kinect game was released roughly 6 months ago). The result of this exercise is shown in the chart below with Kinect trailing behind the Wii and PS3: Kinect: 5.95; PS3: 6.65; Wii: 7.74.

Looking into the future IGN also rates the anticipation of upcoming games on a 5-point scale: “BOOM”, “Hot”, “Solid”, “What?”, and “ZZZ...”. As of May 28, 2011, there are ten games that are rated as BOOM: 4 PS3, 4 Xbox 360 (not Kinect), 1 DS, and 1 PC (see figure below). There is hardly any keenness on upcoming Kinect games. The most-anticipated Kinect game (Star Wars) is only a solid, two ratings between the best games.

However, it should be noted that these game titles are usually action, role-playing, or first person shooter games. The graders at IGN are usually more seasoned, intense gamers, whereas Kinect is geared toward family friendly gaming experience. So we looked at a family friendly blog, which rated Kinect games 88% and Wii games 87.5% (4 games each, see figure below). Here, there is practically no difference between how people perceive the quality of the games. This supports what our interviewee Ivan Tashev (Microsoft researcher) said, that Kinect is expanding the demographics of the gaming population beyond the 15-30yr old males.

While the trend is changing, this does not mean a revolutionary change to the market consumption, neither does it translate into phenomenal profits for the Kinect game developers. According to vgchartz.com, none of the top 10 best selling games of the week of 5/21/2011 is Kinect based, neither is any of the top 10 best selling games of the year 2011. Again looking into the future, none of the top preorders is a Kinect game (see figure below). Family-friendly games such as Wii Sports and Wii Fit Plus topped two of the charts. This means as novel as the technology of Kinect is, Wii and other platforms remain serious competitors in terms of gaming software.

Figures: Selected Games and Ratings of Several Console Systems

<table>
<thead>
<tr>
<th>Console</th>
<th>Game ID</th>
<th>IGN Rating</th>
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<tbody>
<tr>
<td>Kinect</td>
<td>Kinect Sports</td>
<td>8</td>
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<tr>
<td></td>
<td>Kinect Adventure</td>
<td>6.5</td>
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<tr>
<td></td>
<td>Kinect Joy Ride</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Dance Central</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Michael Jackson: The Experience</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Virtua Tennis</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Sonic Free Riders</td>
<td>7.5</td>
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<tr>
<td></td>
<td>Your Shape: Fitness Evolved</td>
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</tr>
<tr>
<td>Game</td>
<td>Rating</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
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<td></td>
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<td>YooStar 2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Fantastic Pets</td>
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<td></td>
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<tr>
<td>Carnival Games: Monkey See, Monkey Do</td>
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<td>Zumba Fitness</td>
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<td>Mortal Kombat</td>
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<td>DS</td>
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**Americas Pre-Order Chart**

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**Top Selling Software in 2011**

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<td>Wii</td>
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<td>Wii</td>
<td>Wii Sports Resort</td>
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<td>Call of Duty: Black Ops</td>
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<td>Wii Fit Plus</td>
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<td>LittleBigPlanet 2</td>
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Appendix D

Razer Hydra in depth

One of the major limitations of the Wii that is remedied in the Hydra is the inability to track position. Motion sensing primarily has two functions: tracking of movement and tracking of position. Accelerometers and gyroscopes aid in tracking motion, that is, they are incapable of knowing the start and end points in space but can track the movement between the two. Also, another problem with axis gyroscopes is that an initial calibration of the unit quickly results in drift, after which a recalibration is necessary. Inertial technology has a noise floor in that very slow and small movements are not detected due to their similarity with noise. This makes playing high accuracy games such as golf very difficult.

In terms of position tracking, there are three current methods. The first is ultrasonic, which uses three transmitters and triangulation; however, it cannot give the orientation of the controller. The second uses infrared light and a laser pointer, much like the wiimote camera. The Sony Move uses position tracking with a 2D camera and depends on the light bulb to give spatial coordinates. All of the orientation is done with a gyroscope. Kinect uses the same approach but takes the body as the best controller. Again, we run into the limitation of line of sight as well as an ambient light requirement. Since the cameras require a lot of light, games cannot be played in the dark. Also, the latency in the response poses another problem, since the processors on the Xbox require about 15% to provide positional tracking information. This decreases the amount of processor capability available to game developers.

In contrast, the Hydra is a plug and play unit designed for efficiency. It requires no recalibration past the initial one as it does not lose track of position. It is based off a base station that generates the AC base of approximately 12 feet in all three directions. Two controllers are provided that can detect both position and orientation to 1 mm and 1 degree every 6 milliseconds. The magnetic field generated is 1/50th of the earth’s magnetic field and thus does not magnetize anything. Because magnetics are used, there is no line of sight requirement and it is quick to respond. Currently it is packaged with Portal 2 as a peripheral, though it works with 125 games to date.
Appendix E

Price effect of Kinect

Initially, we thought that the unit price of Kinect could deter would-be users who already own other gaming consoles. We used a price tracker called “Camelizer” to track the Amazon price history of both Kinect and its strongest competitor, Wii, in three different countries. It appears that Kinect unit is cheaper than Wii. However, the additional cost of an Xbox360 will make the package much more expensive than Wii. We also normalized the cost with respect to the country’s income per capita and showed that buying Kinect in general much more expensive outside of US. [Figure 1 (*note that everything is in international dollars)].

To see if the introduction of Kinect has kick-started an increased sale in XBox 360s, we looked at the sales history of the three products: Kinect, Wii, and PS3. Traditionally, Wii has outperformed XBox 360, but it would appear that a month or two after in the introduction of Kinect, XBox 360 is consistently outselling Wii. On average, they lead by a margin of 29% of sales. [Figure 2]

Looking at it worldwide, PS3 is actually leading the sales chart followed by XBox and Wii. In this case our initial assessment will likely to be proven wrong, as it seems unlikely that the higher start-up cost is going to affect the sales of Kinect. Quite on the contrary, (at least in the United States), the introduction of Kinect has spurred on an increase in sales in XBox 360, showing promise that more and more people will purchase it.

Figure 1:

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<th>Japan</th>
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*[10]

Figure 2:

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* The highlighted row is where the overtake happened
* [10]

Figure 3 (Americas only):
Kinect vs. Wii Sales

Wii (launch November 19 2006)

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## Appendix F

### Technology Readiness Levels in the National Aeronautics and Space Administration (NASA)

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<tr>
<td><strong>1. Basic principles observed and reported</strong></td>
<td>This is the lowest &quot;level&quot; of technology maturation. At this level, scientific research begins to be translated into applied research and development.</td>
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<tr>
<td><strong>2. Technology concept and/or application formulated</strong></td>
<td>Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be 'invented' or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.</td>
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<tr>
<td><strong>3. Analytical and experimental critical function and/or characteristic proof of concept</strong></td>
<td>At this step in the maturation process, active research and development (R&amp;D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute &quot;proof-of-concept&quot; validation of the applications/concepts formulated at TRL 2.</td>
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<tr>
<td><strong>4. Component and/or breadboard validation in laboratory environment</strong></td>
<td>Following successful &quot;proof-of-concept&quot; work, basic technological elements must be integrated to establish that the &quot;pieces&quot; will work together to achieve concept-enabling levels of performance for a component and/or breadboard. This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is &quot;low-fidelity&quot; compared to the eventual system: it could be composed of ad hoc discrete components in a laboratory.</td>
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<tr>
<td><strong>5. Component and/or breadboard validation in relevant environment</strong></td>
<td>At this level, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a 'simulated' or somewhat realistic environment.</td>
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<tr>
<td><strong>6. System/subsystem model or prototype demonstration in a relevant environment (ground or space)</strong></td>
<td>A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or system - which would go well beyond ad hoc, 'patch-cord' or discrete component level breadboarding - would be tested in a relevant environment. At this level, if the only 'relevant environment' is the environment of space, then the model/prototype must be demonstrated in space.</td>
</tr>
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</table>
7. System prototype demonstration in a space environment

TRL 7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in a space environment. The prototype should be near or at the scale of the planned operational system and the demonstration must take place in space.

8. Actual system completed and 'flight qualified' through test and demonstration (ground or space)

In almost all cases, this level is the end of true 'system development' for most technology elements. This might include integration of new technology into an existing system.

9. Actual system 'flight proven' through successful mission operations

In almost all cases, the end of last 'bug fixing' aspects of true 'system development'. This might include integration of new technology into an existing system. This TRL does not include planned product improvement of ongoing or reusable systems.

Appendix G

S-Curves for Various Products

![Technology S-curve](image)

Fig. G1. Spatial Augmented Reality
Fig G2. S Curve for Light Space

Fig G3 S Curve for Asus Waxi Xtion
Fig G4. S Curve for Kinect Recon Mission

Fig G5. S Curve for Biological Navigation
Fig G6. S Curve for Surgical Imagery Manipulation

Fig G7. S Curve for Robotic Surgery