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The role of rapid prototyping in the product development process: A case study on the ergonomic factors of handheld video games

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Rapid prototyping, Product development, Ergonomic, Fused deposition modeling

Abstract

The impact rapid prototyping (RP) can have on the design process and the product development process as a whole is demonstrated in this paper. The speed and flexibility of RP technologies decreased the overall time to complete the new product. This also ensured that the final mechanical enclosure of the new handheld video game incorporated the ergonomic design features that users desired.

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1. Introduction

There are certain guidelines to follow in the product development process in order to ensure that the product created meets specified criteria. A product definition must be created, user needs must be established, and concepts must be generated and perfected through design and iteration. The entire process can be time-consuming and difficult to manage. The time taken to complete the design portion of the process can be drastically reduced, however, with the use of rapid prototyping machines and CAD tools. The availability of these tools helps a product development team to create computer and physical models that fully encapsulate the ideas of the team in a fraction of the time it takes using conventional methods. The use of rapid prototyping then allows for the quick and efficient production of prototypes of designs, which in turn shortens the overall development time of the product by providing instantaneous feedback on designs. It also allows for rapid iteration of designs due to the speed and accuracy with which rapid prototyping machines can manufacture.

In this project, rapid prototyping greatly influenced the product development process used to create a mechanical enclosure for a handheld video game. Specifically, 3-D Printing and Fused Deposition Modeling (FDM) were applied to broaden the scope at the beginning of the project and narrow it down toward the end. In this product development process (Figure 1), the focus group, preliminary design, personal interviews, and final design were all influenced by rapid prototyping and associated technologies. Rapid prototyping allowed for physical models of a design of any shape and geometry to be created quickly. It also provided an opportunity to test different features and then change and iterate the design to create an even more complete model. In this paper a case study has been presented showing the completion of an ergonomic video game enclosure.

2. Product background

Video games were first available in wide release when Magnavox introduced the "Odyssey" in 1972. The system was so primitive that the user had to physically tape

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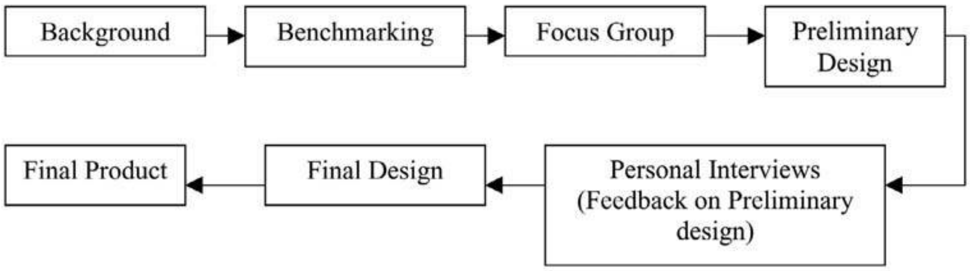
Figure 1 Product development process followed in this project, based on Ulrich and Eppinger (2000)

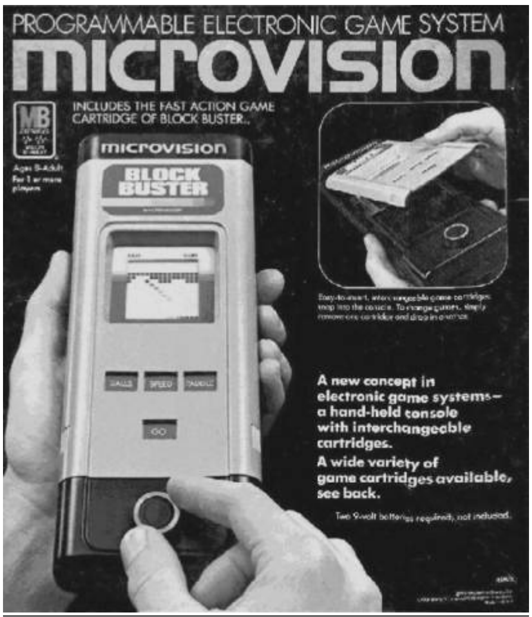


a plastic sheet to the television in order to represent a playing arena or court. The next large introduction came in the form of a simple game called "Pong." Atari introduced "Pong" in the mid 1970s and was followed by vast amount of "Pong" clones that saturated the market and promoted innovation in order to set each system apart from the rest.

In 1979 the first cartridge-based handheld system was introduced to the market in the form of the Milton Bradley "Microvision" (see Figure 2). The idea and concept that this product embodied, a handheld system with interchangeable games, was novel and progressive. Unfortunately for the makers of this system, it was too far ahead of its time and the system did not last for more than 2 years due to lack of customer enthusiasm and sales (Brown, 1998).

Toward the end of the 1980s, handheld systems found their niche in the video game industry. In 1989 three major systems were released in the United States—Atari "Lynx," Sega "Game Gear" and Nintendo "Game Boy." Lynx and Game Gear were color systems that were far superior to others on the market in terms of technology and overall performance. Game Boy was able to get a great share of the market, however, because of vast support from software developers. Since its introduction, Game Boy has been able to outlast competitors, primarily through its vast game selection and marketing strategies.

Figure 2 The first handheld system, the "Microvision" by Milton Bradley released in 1979 (Brown, 1998)



Modern handheld video games are more powerful than computers of fifteen years ago and are small enough to fit in the back pocket of a pair of jeans. With all of the interest surrounding handheld video games, one would expect to find elaborately designed and ergonomic systems. Current hand held systems are little more than plastic boxes in which printed circuit boards sit. In the past, mechanical enclosures for video game systems, both console and handheld, have been designed purely for functional purposes. Industrial design and ergonomics have been virtually non-existent.

3. Benchmarking against other products

Table I shows a comparison of four handheld systems used for benchmarking: System A, System B, System C, and System D. Although it was unavailable in the marketplace at the time of this research, System A was used for benchmarking because it will be the most technologically advanced system to be brought to market and surely a competitive system as well. System B is the current market leader, with over 90 per cent of the world market. It was used for benchmarking because handheld consumers prefer its features and capabilities and thus it is a good model to look to. Systems C and D were chosen because they are two systems technologically comparable to A and B that tried to break into the market. They also provide an excellent insight into what has been done to try to

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Table I Technical specifications for System A, System B, System C, and System D handheld systems. Sources include: (Chamberlain, 1999a, b), (Harris, 2001), (Strietelmeier, 1999)

	System A	System B	System C	System D
CPU	32-bit ARM	8-bit Z80	16-bit	16-bit
Screen	2.9″ TFT reflective, 240 × 160 resolution, 511 colors simultaneously	2.3″ TFT reflective, 160 × 140 res, 56 colors simultaneously	TFT reflective, 160 × 152 res, 146 colors simultaneously	TFT reflective, 224 × 144 res, 241 colors simultaneously
Size (mm)	135 w × 80 h × 25 d	75 w × 133 h × 27 d	130 w × 80 h × 30.5 d	74 w × 120 h × 25 d
Weight (g)	140	138	145	110
# Batteries	2 AA	2 AA	2 AA	1 AA
Bat Life (hours)	20	20	40	20

compete with market leaders. Each system has similarities and differences, providing excellent benchmarks for what systems of the future should have, both technologically and aesthetically.

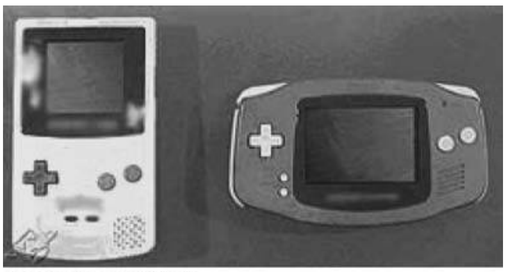
System A will be released in March 2001. It is a simple handheld system with the processing power of a home video game system. It is unique due to its technological superiority and physical features. To complement its two action buttons, it contains two shoulder buttons, not found on any other handheld systems. It also has a large viewing screen unrivaled by current and past systems. In addition, it is played in a horizontal orientation, which is a departure from current successful systems. It will be released to great anticipation and will be a benchmark for future designs.

System B is the current leader in the handheld market. With over 90 per cent of the world market (Video Game Exchange Staff, 2001) it seems virtually impossible that any other product could rival its performance. System B has sold over 100 million units with sales still on the rise. This system has only two buttons with little room for movement between buttons and the control pad. It is oriented in a vertical fashion, which tends to cramp the hands of people with larger size hands. System B is very popular, however, because it has a large selection of game titles, is small and compact, and readily available.

It can be seen in Table I that System C is comparable to, if not better than, System B, the industry leader, in a number of ways. The CPU is faster and the screen is larger with slightly better resolution. The shape of the back of the system has small contours making it a little easier for gripping. In addition, the physical size and features of System C greatly rival those of System B. Unfortunately for the developers of the system, game development was stagnant and sales of the system declined and eventually disappeared in the United States. This system is no longer sold in the United States (Figures 3, 4 and 5).

System D is a compact and uniquely designed system, which can be played in both vertical and horizontal orientations. Recently a color version that complements its small size and unique features was released. Its small size is convenient for transportation, but can be a problem for people with larger hands.

Figure 3 Picture of the System B (left) and System A (right). (Harris, 2001)



Source: Harris (2001)

Figure 4 Picture of System C. (Chamberlain, 1999a)

Source: Chamberlain[1] (1999)

Figure 5 Picture of System D. (Chamberlain, 1999b)

Source: Chamberlain[2] (1999)

Table I shows its technical specifications, which also rival System B. The original non-color System D is no longer on the market in the United States due to a lack of software development and poor sales. The recent release of a color version of System D, which is unavailable in the United States, demonstrates a desire of its creator to remain competitive in the field.

These four systems provide insight into design considerations essential to the benchmarking process. System B is the industry leader because it has the software development to back up demand for a large selection of game titles. System B's physical characteristics, however, lack the sweeping curves and innovative user-interface that modern day consumers enjoy in products. Systems C and D are closer to being considered aesthetically and ergonomically pleasing, but failed in the market due to lack of software support. A handheld system that gets the user excited about picking it up and playing it because it is entertaining, attractive, and ergonomic could break into the lucrative handheld market with the help of a company that can stimulate software development.

4. Focus group

A focus group was formed to solicit the wishes and desires of handheld video game users. In this case, the scope of the focus group was greatly broadened due to the use of rapid prototyping. Six different handheld video game systems were purchased in order to expose the focus group members to a variety of features that current handheld systems have. Each player was given five to ten minutes to play each handheld system and experience all of its features. After the allotted time expired they were then given five minutes to fill out a survey for the system they had just played. When each person had played all of the systems and filled out their surveys, they were given one larger survey that allowed them to compare the systems to each other. A total of thirty people participated, filling out a total of over two hundred and ten surveys. This information was then translated into user needs that helped define exactly what users wanted. This focus group was influenced by the suggestions outlined by Ulrich and Eppinger (2000). For a more comprehensive analysis of this management tool the reader is referred to Griffin and Hauser (1993) and Kinnear and Taylor (1995).

4.1 Surveys

The individual survey was created to gain information about the users' thoughts on each system. The survey was used as a way of gauging customer reactions to unique aspects of the systems. For example, one system had a touch screen. The individual survey allowed the user to discuss and share their feelings about the touch screen and or any other aspect of the system. It also contained questions designed to help users think about the aesthetics and ergonomics of the system. In addition, issues such as ease of use and suggestions for possible additional features were discussed to fully maximize user feedback. The individual survey helped to establish what was liked and disliked about each individual video game system.

The general survey was filled out after each person had played the six systems. This survey allowed the users to rank various characteristics of the systems against each other to establish which system they thought was the best. It also gave them the opportunity to discuss what common good or bad themes ran throughout the systems. Other items, such as controller preference, preferred number of buttons, and physical size of the unit were also discussed. The general survey helped bring closure to the individual surveys by allowing the users to compare and contrast the features that they had experienced in the handheld systems.

5. User needs and results of focus group

The user statements and needs showed that a number of features of current video game systems were either missing or needed to be changed. For example, issues such as intuitive layout of controls and horizontal orientation were discussed. In addition, players commented how they wanted more finger room on the device and that the controllers on many of the machines were not comfortable. A number of other issues were also discussed and facilitated in the creation of over thirty different user needs.

In addition to extracting vital user needs information, the general survey also helped to establish data about the users' feelings toward the various systems. Table II shows how the focus group members felt about each of the systems and how they compared to each other.

Apart from the statistical data and user needs extraction, the focus group provided an environment of video game playing in which people played the games how they naturally would. Around thirty people with different size hands and different game playing characteristics helped give a clear impression that an extremely versatile enclosure should be created. It could be seen through observation that people held the systems, pressed the buttons, and engaged the games differently. Some common occurrences observed were that people attempted to wrap their index finger around the top of the system to stabilize it. Also, people had a hard time holding the systems because there were no contours for gripping. Some people abused the buttons and some pushed the joystick/touchpad fast and furiously. These observations gave a good impression that an ergonomic and versatile system needed to be designed for a large audience.

Table II Focus Group Results comparing all 6 systems tested (Based on a score between 1–10, with 1 being least desirable and 10 most desirable)

System	Aesthetics	Comfortable	Screen Clarity	Overall
1	8.55	8.03	9.00	8.60
2	7.41	5.55	7.09	6.34
3	7.25	7.03	8.07	7.57
4	4.76	5.45	5.24	4.96
5	4.79	5.63	5.19	5.30
6	3.50	5.61	3.75	4.04

6. Preliminary design

The feedback received from the focus group was the starting point for the design of the mechanical enclosure for the handheld system. The user needs indicated in the surveys, along with the observations and personal discussions, helped to suggest a number of new design concepts. Based on this information, sketches of initial ideas were created. These sketches then led to three computer-generated solid models via the CAD software package SolidWorks®. Finally, the availability of a Z-Corporation (Z-corporation, 2001) 3-D Printer rapid prototyping machine allowed for the production of prototypes, which helped make the abstract and convoluted suggestions and ideas of the users come to fruition.

6.1 Turning feedback into ideas and sketches

The compiled feedback from the focus group did not lead to one single overwhelming consensus of what the perfect handheld video game system would have. On the contrary, it sparked a number of ideas for mechanical enclosures that fit a number of the needs expressed by the users. Most people preferred the joystick, yet a great number also enjoyed using the touchpad. Some people liked only having two buttons, while some preferred up to four. Since there was such a wide variety of needs and desires indicated by the focus group, a number of different designs were created to try to encompass as many of these ideas as possible.

The fact that this was the preliminary design stage of the process was conducive to helping facilitate the encapsulation of the different ideas. Sketches allowed for many different and related ideas to be portrayed quickly and efficiently. The point of these sketches was to take what the users had said they desired and to put them in a design that represented their words.

In the preliminary design of this mechanical enclosure, over 20 different ideas for designs were put onto paper. When two sketches were compared to each other, in some instances it could be seen that various features of the two designs should be combined with each other. In addition, the sketches also allowed for quick iterations to be done.

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6.2 Solid modeling and rapid prototyping

In the creation of the mechanical enclosure for the handheld video game, solid modeling and rapid prototyping were completed using SolidWorks® and the Z-Corporation 3-D printer, respectively. These technologies allowed for the translation from sketch to physical model in only a fraction of the time that it takes using traditional methods.

Three sketches were selected based on the variety of user needs and features they satisfied and incorporated. These sketches were made into solid models via SolidWorks®. Each of the models took five to seven hours to create on the computer. After the work was finished on the computer, the files were saved in a format that was readable by the Z-Corporation (Z-Corp) software. Once the files were transferred to the computer, six to eight hours were required to produce all three of the real life parts. From start to finish, the average time it took to create one prototype was approximately eight hours, about a quarter of which was machine time. This means that besides overhead there were only about five man-hours spent creating each prototype as opposed to the several days it might take using traditional methods.

The Z-Corp 3-D Printer created parts from geometries input via.stl or VRML file formats. The software that controlled the Z-Corp machine took the input geometry from the CAD file and sliced it into layers of specified thickness (default is .004 inches). The machine then printed a layer of glue, corresponding to the geometry of the part on the layer, directly onto a powder surface. When the layer was completed, the bed in which the layer of glue was just printed was lowered by the layer thickness (specified above) and the machine then printed a new layer of powder on top of the previous layer. This process was repeated until each one of the layers was complete.

The dimensions of the prototypes created by the Z-Corp machine were accurate to within less than .1 inches, almost an exact replica of the design created on the computer. In addition, all three of the designs that were created had some aspect of freeform geometry. Even for a skilled prototype maker it would be difficult to maintain this kind of accuracy by hand. Additionally the prototypes that were created were small and had many intricate features that would be difficult for a person to replicate. The layer-by-layer building process of the Z-Corp machine allowed for construction of all parts of the model with little difficulty.

7. Prototype evaluation

The Z-Corp rapid prototyping machine created three look/feel prototypes. Although the Z-Corp machine has the capability to produce parts in colors, experience has shown that the binding of the powder particles is more effective in the plain white version. In order to get a feel for what the system may look like, colors and a display screen were added to each of the prototypes to give them an authentic look. Figures 6, 7, and 8 named "*Space Ship*," "*Bubble Vertical*," and "*Amoebae*," are pictures of the three prototypes after they were after they were finished.

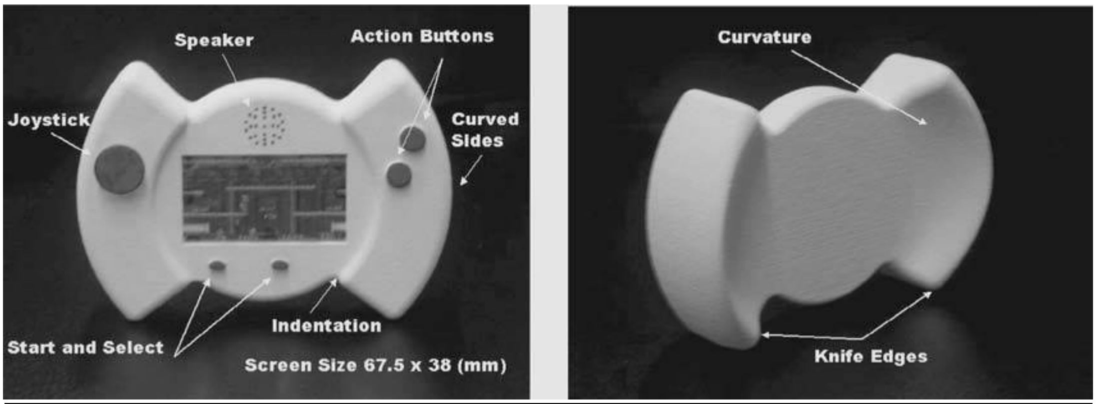
7.1 Personal interviews

The rapid prototyping machine produced three different models that contained a number of the characteristics and features that the users had mentioned were desirable. This made it possible to go back to the users with models containing exactly what they had said they wanted. Holding physical models containing the user-defined features helped users further refine what they wanted in the final design of the casing. In other words, the prototypes from the Z-Corp machine enabled the users to evaluate their own ideas and decide which ones they liked the best. Twelve people were interviewed and their comments and suggestions on each of the three systems narrowed down the large amount of feedback obtained from the focus group and helped establish clear objectives for the final design.

7.1.1 Space ship

In general, users thought that the button placement of the first prototype, *Space Ship* (Figure 6), worked well with the rounded sides. In general people thought that the button placement worked very well with the rounded sides. In addition, the rounded sides made it possible for people with different sized hands to get a comfortable grip on the system by moving their hands along the rounded edges. Also, people thought that the indentation on the face (going from joystick to screen level) was aesthetically pleasing, but thought that it should be a little less drastic.

Figure 6 Picture of *Space Ship* prototype from front and back views



Users reported that the ridge on the backside was a very undesirable characteristic. It was called a "knife-edge" on a number of separate occasions. The curvature of the back made it difficult for people to hold the system. Also, people mentioned that the start and select buttons were not well placed because they took away from the symmetry of the system.

7.1.2 "Bubble vertical"

As for the *Bubble Vertical* (Figure 7), users found the contours on the back to be a desirable feature. Users mentioned how it sat very snug in their hands and that it felt natural. The location of the start and select buttons were also popular. The appearance of stereo sound intrigued some people as well.

The buttons were far too low for most people. The users did not feel as though they could hold the system and play it at the same time without feeling like they were going to lose control of the system. The length of the handles was also an issue. Most people desired longer handles so that their entire hand could fit on the system.

7.1.3 "Amoebae"

The users thought that the placement of the buttons on *Amoebae*, the third design (Figure 8), was good, but that the buttons were a little too close to the screen. Contrary to the norm, the buttons were above the screen, which was considered novel and most found it desirable. In addition, people really liked the shape on the backside of the system. They said it was very comfortable and also beneficial in terms of making the system comfortable for a variety of different hand sizes. The overall structure was considered to be very stable and it was also mentioned that it could be used for a long time without fatigue.

Similar to the *Space Ship* design, the start and select buttons were not conducive to the symmetry. They made the system look unbalanced. People were also not pleased with the divots on the sides where the hands sit. No one put their hands in the divots so they did not understand why they were there.

7.2 The role of Z-Corporation prototypes

The Z-Corporation 3-D printer created realistic prototypes that allowed users to experience the ideas they had portrayed in the

Figure 7 The *Bubble Vertical* design prototypes from front and back views

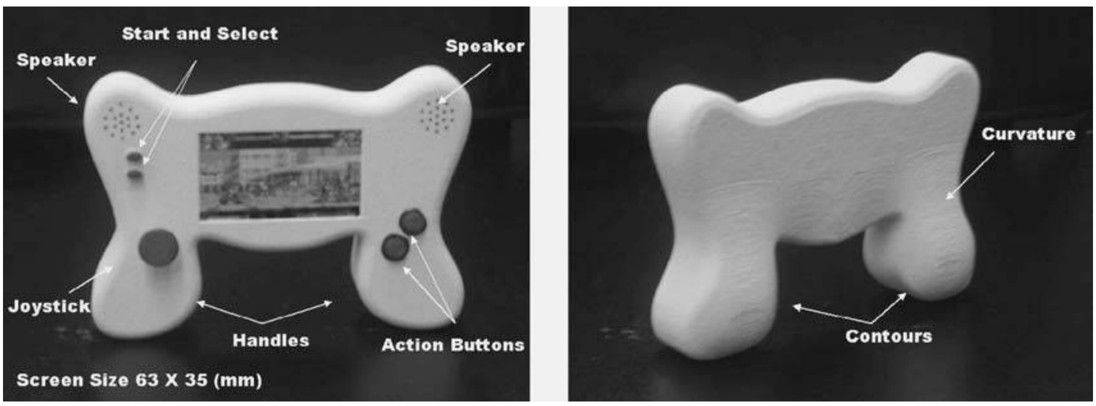
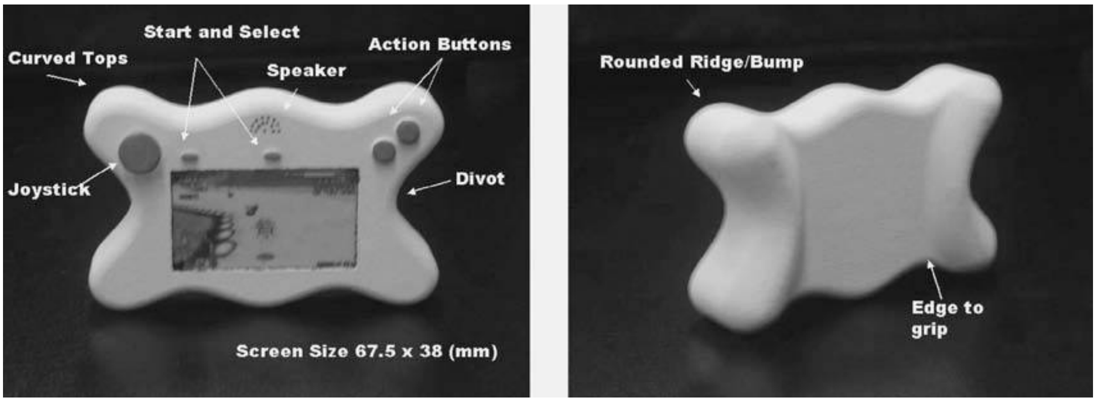


Figure 8 *Amoebae* design from front and back views



focus group. In addition, the rapid prototyping technology decreased the time from the creation of the computer-generated solid model to the creation of the actual physical model. Since the design process is so dynamic in nature, the fact that physical models of ideas could be created in such a short amount of time, drastically influenced the preliminary design of this product development process. It provided the means for testing different combinations of features to see what end-users would like or dislike. The prototypes were far better than anything that could have been done using conventional methods and in addition proved to be a key factor in the rapid development and passage through the preliminary design stage of the product development process.

8. Final design

The final design (Figure 9) was drastically influenced by the capabilities of solid modeling and rapid prototyping. It encompassed the user needs established through the focus group and incorporated the refined feedback received from the first round of prototypes. A pencil and paper sketch was made, which incorporated the most desirable characteristics. The sketch was then turned into a solid model using SolidWorks®. The fast and efficient production capabilities of the Z-Corp machine were again employed to make sure that the new design had the right look and feel. The design was then honed and the final mechanical enclosure was created on a FDM machine.

8.1 Final design discussion

The evolution of the final design (a.k.a. *Snoop*) aligned perfectly with the product development process followed. The background and benchmarking provided a starting point as to what competition there was and what had already been done. The focus group then added information by helping provide feedback on what users wanted. The hand sketches helped to sort, combine, and prioritize the user feedback. The solid modeling and rapid prototyping enabled the creation of physical models incorporating all of the features and characteristics previously encountered.

The final design, *Snoop*, incorporated two key features from the *Space Ship* design. The *Snoop* design incorporated curved sides to ensure that the handheld system could be used by a variety of people. In addition, the location of the *Space Ship* buttons and controller were also used in the *Snoop* design.

The stereo sound on the *Bubble Vertical* was another feature found on the final design. Even if stereo sound is not feasible in production, the appearance that the system may have it could be a beneficial selling point. The ridge on the back of the final design becomes increasingly larger going from the top to the bottom. This feature was taken from the *Bubble Vertical* design because the users desired the form-fitting feature on the handle.

The rounded ridge on the back of the *Amoebae* was also included in the final design. This bump allowed for people to easily grip the machine and hold it for a long time comfortably. In addition, the rounded curves on the top of the *Amoebae* were also incorporated in order to make the system easier to hold and play.

The final *Snoop* enclosure was created using the Stratasys Inc. (Stratasys, 2001) FDM machine. Quickslice® (the software used to control the FDM machine) took the.*stl* file and sliced it in layers of a specified thickness

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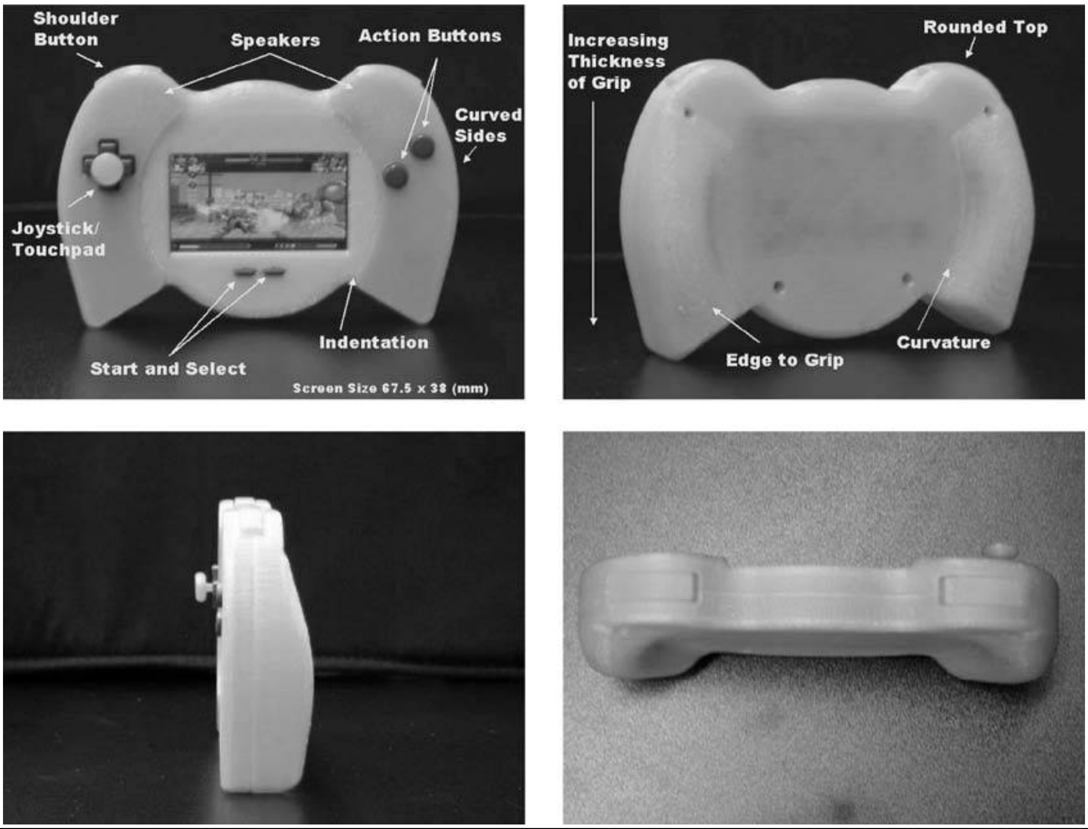
Figure 9 Pictures of the final prototype of the *Snoop* mechanical enclosure



(default is.02 inch). The FDM machine heated up ABS plastic and fed it through a nozzle. The nozzle was controlled to follow the exact orientation that the CAD file indicated, extruding molten plastic as it traveled. If one layer required no material (an overhang) then the software created easily removable support structures out of a more brittle plastic. This process produced parts that had good structural integrity and tolerances.

8.2 User needs satisfied

The final enclosure incorporated refined features that satisfied the user needs extracted in the focus group. It allowed for ample finger room throughout the system. In addition, it was very easy to hold and to use by people with different size hands. The final design was aesthetically pleasing and was ergonomic. The speakers were not obstructed as they were in most existing handheld systems, and the screen was large compared to any other system on the market.

The *Snoop* mechanical enclosure felt natural to hold. The ridges provided a smooth and comfortable surface to grip. The buttons and controller were clearly laid out. A combination touchpad and joystick were incorporated to satisfy the desires of the users. In addition, two shoulder buttons made a total of four buttons. The shoulder buttons were out of the way and did not obstruct people from playing the system, so users who only wanted two buttons did not have to use them. The orientation of the system was clear and the sweeping curves and lofted contours made the system comfortable to use even over an extended period of time.

8.3 Z-Corporation and FDM machines

Once a preliminary version of the final design was created on SolidWorks®, the Z-Corp machine was used to make a basic prototype simply to check and see if the final design would be comfortable to hold. Since only a reference model was desired, the Z-Corp machine provided an excellent resource in making this prototype because it was fast and created excellent look/feel prototypes.

Once the final design was completed it was then built on the FDM machine. The feedback from the entire product development process had been analyzed, tested, and combined in order to create a final design that was as versatile as it was possible. The final part took about twenty-four hours to make on the FDM machine. The tolerances, look, and feel of the final casing were those that it would have had were it mass-produced.

9. Conclusion

A case study of the ergonomic factors in handheld video games has been described in this paper. This case study supports the observation that prototyping is a way to evaluate the design process and update and change designs based on prototype evaluation (Kamath and Liker, 1994). Rapid prototyping influenced the product development process in many ways:

- Rapid prototyping allowed for the physical realization of desirable features, aesthetic designs, and ergonomic design factors.
- The physical interactions between the sub-components of various designs were evaluated. For example, in this ergonomically oriented study, button positions, screen positions, and grip placements were considered. In other design evaluations (Wang and Wright, 1998), the relationship between the mechanical package, printed circuit board, and other electronic components were considered.
- Prototypes enabled users to see, evaluate, and refine their feedback on the ergonomic aspects of the design.
- Lead times in the creation of typical prototype structures from CAD drawings were three hours in the case of the Z-Corp machine and twenty-four hours in the case of the FDM.

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