A STANDALONE EXERCISE DEVICE FOR INTERACTIVE GAMING

Aldo Aguirre, M.S.
University of Illinois at Chicago

BACKGROUND

The goal of this project was to produce a standalone exercise device to support access, participation, and sustainability to exercise, with the ultimate goal of providing better opportunities for wheelchair users to achieve health and function. The development of this standalone gaming device, or SGD, is part of a coordinated effort to provide an engaging exercise system for wheelchair users. This paper describes the mechanical design process of the SGD itself; the completed SGD will be integrated with other project components in future work to provide a comprehensive system.

RESEARCH OBJECTIVES

The achievement of a device to promote access, participation, and adherence encompasses several development objectives:

1. The SGD should be usable by an individual in a wheelchair, and provide access to beneficial exercise.
2. The SGD should support a minimum of three different *topographies*, or exercise motions. This objective is intended to promote both participation and adherence, by allowing for a variety of motions that can be incorporated in a scenario to provide a more engaging exercise experience.
3. It should be possible to control the resistance level of the SGD through a communication channel that can be connected to a *game server.* The SGD should also be capable of reporting the current levels of both energy expenditure and resistance through the same communication channel.
4. The SGD is to be instantiated in a demonstration prototype. This demo should be a platform that is capable of supporting many different topographies/activities, rather than a new gaming device. The SGD is intended as a proof of concept for an interactive system with multiple exercise topographies, with the first three topographies included in the prototype.

TECHNICAL APPROACH

This project is an engineering design and development project. The technical approach is therefore to employ a structured design process [Pahl & Beitz 1996, Dym & Little 2009] with the following steps:

1. Consumer needs assessment
2. Elaboration, organization, and evaluation of functional requirements
3. Conceptual design: selection of overall concept and architecture
4. Embodiment design: development and drawings of required subsystems
5. Detail design and prototype construction

The process is iterative, with testing and evaluation at different stages providing feedback to the designers and sometimes occasioning revisions in an earlier design stage.

CONSUMER NEEDS ASSESSMENT

The first step in the design process was to identify and prioritize consumer needs. The developers interviewed RERC director William J. Schiller, who served as the project client, to identify device requirements, and interviewed experts in exercise physiology to select appropriate exercise motions or topographies for use in a wheelchair exercise device.

The following is an abbreviated list of device requirements elaborated in consultation with the project client:

1. The SGD should be simple.
2. The SGD should be easily stowable.
3. The SGD should be a standalone device.

4. The SGD should allow 2-way communication with a game server.
5. The SGD should be appropriate for the home market.
6. The SGD should provide three different exercise topographies, each requiring a different interface (handle) or pulling motion. These should be chosen with the input of people knowledgeable about the physiology.
7. The SGD should be securable to a wheelchair or other chair.
8. The SGD should allow for line of sight to a TV screen or something similar as output to the user.
9. It is acceptable for the demonstration prototype to utilize an external power source.
10. The overall exercise system, of which the SGD is one component, should allow for the eventual addition of other exercise topographies. These may be added as modules.
11. Transitions between exercise topographies may eventually be automated, but this is not a requirement for the initial prototype.
12. There are no particular customer requirements on the materials to be utilized.

Two professors of Kinesiology at UIC, Dr. Karen Troy and Dr. Thayne Munce, were consulted on the particular exercise topographies for the device. The result of this meeting was a list of three recommended exercise modalities:

1. A kayaking or canoeing motion in which both arms are used to pull a handle past the body on one side at a time.
2. Rowing with both arms together using a two-handed attachment. This modality provides extra cardiovascular benefit if the user is capable of engaging the trunk in the exercise.
3. A seated curling motion was proposed which does not provide significant cardiovascular exercise, but could be incorporated within the exercise system as a strength training step or simply to provide variety.

FUNCTIONAL REQUIREMENTS

The consumer needs are then organized and analyzed to provide functional requirements. The first step is to rewrite the consumer needs in a more precise mathematical fashion, so that their fulfillment can be measured and determined objectively. In the interests of space, this list is not included in this paper, but is available in the reports. The functional requirements list is then used to generate a description of the device as a set of *functions* to be provided. This step in an engineering design process is used to ensure that the device is designed to deliver a desired functionality.

The decomposition of the device into functions often commences with a *black box* description. These sketches provide the most basic description of what a device is required to *do*. There are only three inputs to the device (mechanical energy from the user, a signal from the game server, and optionally some source of external power for electronics and automatic adjustment), and two outputs (the energy that is dissipated through resistance to provide exercise, and the information signal back to the game server). The device is then designed around the functions to be performed for those inputs and outputs.

The individual boxes within the black box identify subsystems that require further functional elaboration. At this more detailed level, this elaboration may take the form of *function-means trees* that combine a functional description with candidates for providing these functions.

The last step in creating a useful functional description of the device is to identify the most important functions and to organize them in a *morphological chart* to compare the candidate technologies to provide the required functions.

CONCEPTUAL DESIGN

With a complete functional description of the desired device in hand, the process moves to conceptual design, the first step of which is to select basic enabling technologies. The morphological chart provides significant guidance in the selection of basic enabling technologies.

One particularly central function is the provision of resistance; it can be argued that the most basic job of any exercise device is to provide resistance to a given motion so that the user needs to work, and thus exercise, to execute the motion. The four top candidates (variable fluid resistance, electromagnetic resistance, friction resistance, and magnetic resistance) were carried forward in the design process, with a final choice to be made after preliminary sketches were completed. A number of conceptual sketches were made, and an evaluation chart was created to aid in the final decision.

The best candidate from the evaluation chart was the magnetic resistance concept including a rotating flywheel and a strap or rope. The user pulls on the rope and the device spins directly, without an intermediate transmission. The handles are changed manually by the user or a helper. Research into existing devices uncovered several on the market that used such a mechanism to provide resistance. A flywheel device incorporating the magnetic resistance concept was cannibalized from a device on this list of available equipment in order to construct a demonstration prototype. The magnets that slow down the flywheel do not come in direct contact with the flywheel so there is virtually no wear. Pulling on the strap spins the device directly without a need for a transmission, providing a quiet operation. The resistance mechanism is small enough in both size and weight that the portability and stowability requirements may be realistically met. Finally, securing the wheelchair directly to the device is easily accomplished by the user with little or no assistance without presenting undue difficulties in satisfying the portability requirement.

The summary description of the chosen conceptual design is thus a free-standing device incorporating the flywheel and magnetic resistance mechanism of a LifeSpan Fitness RW1000 [LifeSpan Fitness 2010], a commercially available rowing device unsuited for use with a wheelchair. The wheelchair is secured directly to the device using a Manfrotto Magic Arm [Manfrotto 2010]. Different handles are provided for the existing strap, and the height at which the strap exits the device and is grasped by the user is adjustable. When this exit height is set to chest height the rowing and canoeing motions can be effected; the arm curl requires the mechanism to be lowered. The adjustment mechanism for the magnetic resistance was redesigned to allow for automatic setting and to achieve greater resolution as well as permitting setting the resistance to the lowest setting available in the mechanical device. A separate mechanism to measure energy expenditure must also be incorporated, as well as the hardware that permits communication with the server.

EMBODIMENT DESIGN

Once the conceptual design was completed, the components that make up the system were further specified in the *embodiment design* stage. The embodiment design of the SGD encompasses the frame, the height adjustment mechanism for the exit pulley and the attachment mechanism for securing the SGD to the wheelchair.

The frame was designed for both strength and stability. This requires an understanding of the forces that will be applied to the device. Some simple tests were conducted using an experimental setup in which the RW1000 was connected directly to the wheelchair. These tests showed a maximum force of 55 pounds applied to the pulling handle at maximum resistance and a pulling cadence of 60 strokes per minute. Applying a safety factor, the frame is designed to support an applied intermittent load of at least 200 pounds.

Stability is a function of frame geometry as well as pulling force. In force testing, the rear of the RW1000 displayed a tendency to lift off the ground when the handle was pulled sharply; as the wheelchair was fixed directly to the test device, there was no lateral motion of the RW1000 relative to the wheelchair. Taking into account the desired exercise motions and the range of wheelchair seat heights, it was determined that the height at which the strap handle leaves the exercise device should be variable between 14″ and 32″. At the max height of 32″ a significant tipping moment is generated by the force generated by the user pulling on the strap. The frame is designed to offset this tipping motion with a rigid attachment between the wheelchair and the SGD.

As noted, the wheelchair is attached directly to the SGD using a Manfrotto Magic Arm

[Manfrotto 2010]. This is a jointed arm that pivots at the elbow and has a full swivel at each end. A lever at the elbow joint is used to lock the elbow and both end joints simultaneously. For the SGD attachment mechanism, a Manfrotto Super Clamp is used to attach one end of the Magic Arm to the wheelchair while the other end is bolted directly to the main frame.

Height adjustability was determined to be an important requirement, to accommodate variability in user height and wheelchair seat height as well as to provide the different exercise topographies. Each topography requires a particular pulling angle between the point where the strap exits the SGD and user's trunk or knee height. This adjustability was implemented using a threaded rod assembly driven by an electric motor. Height selection for this prototype version requires manual intervention by the user, but future versions will be able to have the height set by the game server. This has advantages both for auto-configuration for different users and chairs, and for a creating a more seamless exercise scenario.

The flywheel's resistance is set by pulling on a cable which moves the magnets closer to or further from the flywheel itself. The manual knob which pulls this cable was replaced with another threaded rod assembly driven by a stepper motor. This adjustment assembly is referred to as the Electronic Control of Resistance, or ECR. This implementation provides for a greater range and precision and also allows for the resistance to be set automatically by the game server in future implementations. The resistance of the current prototype must set by the user or technician.

Several of the aforementioned subsystems require some information processing. In addition, the SGD must be able to communicate with the game server, both sending and receiving information. An RJ45 ethernet jack can accomplish the physical connection; the more challenging problem is to process the data received. The current prototype uses a simple open-source programmable micro-processor from Arduino [Arduino 2010] to activate the motors for both height adjustment and resistance setting, and will be used in future versions for energy calculations and game server communication as well.

CONCLUSIONS AND NEXT STEPS

A first-generation prototype of a Standalone Gaming Device (SGD) was developed to support an engaging interactive exercise experience for wheelchair users. The SGD supports multiple exercise topographies so that an exercise scenario may be provided by a game server to which the SGD will be connected. These topographies are a rowing motion engaging the arms and trunk, a canoeing-like motion where the user pulls to the sides, and a curling motion in which the user lifts in an upward direction.

Apart from improvements to the device itself, the main tasks going forward are to incorporate the SGD with a game server to allow a more automated and interactive exercise experience. The SGD will communicate with the game server to set device resistance based on energy expenditure and exercise scenario. The height adjustment for different topographies will be fully automated. The possibility of auto-configuration of device height based on a user profile (user height together with wheelchair seat height) will be explored. Future work is thus focused on integrative tasks to enhance the exercise experience, with relatively small changes in mechanical device design.

REFERENCES

Pahl G and Beitz W. Engineering Design: A Systematic Approach. 2nd ed., transl. Wallace K and Blessing L. Springer-Verlag, 1996.

Dym CL and Little P. Engineering Design: A Project-based Introduction. John Wiley & Sons, 2009.

Arduino. "Arduino – Home Page". http://www.arduino.cc, accessed Sep. 24, 2010.

LifeSpan Fitness. "Rowing Machine | RW1000 Indoor Rower - LifeSpan Fitness". http://www.lifespanfitness.com/rowing_machine.asp, accessed Sep. 24, 2010.

Manfrotto. "Photo Arms, Brackets & Bars, Photo Arms, Manfrotto Photo Accessories". http://manfrotto.us/product_list/8374.77460.76891.0.0/Arms, accessed Sep. 24, 2010. 1998.