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INNOVATIVE PRODUCTS TO CONTROL, POWER AND MONITOR EXTERNALLY POWERED UPPER LIMB PROSTHESES

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ABSTRACT

Animated Prosthetics has combined recent advances in battery chemistry with a microcomputer control system and a unique method of battery charging to provide new products for the externally powered upper extremity patient. The result of this combination is an energy efficient system that offers the prosthetist many power and control options to customize the prosthesis. This technology benefits the patient by providing a prosthesis that has improved cosmetics, added capabilities, longer wear time, and fast recharge cycles. New diagnostic tools allow monitoring and configuration of the system even while the patient is wearing the prosthesis.

OVERVIEW

During the 1940's the typical transradial patient was fit with a body powered prosthesis that consisted of a harness, a triceps cuff, actuation cables, and a hook. During the 1950's many advancements were made in the suspension methods and the externally powered system was created. This system eliminated the cables and harness and used a mechanical hand that has natural looking cosmetics. These systems continued to evolve and were considered experimental until the 1980's when their acceptance increased. Miniaturization of the system components allowed very young children to be fit in the late 1980's. Now, the next step in the evolutionary process is occuring to resolve deficiencies that have limited the acceptance of the externally powered method.

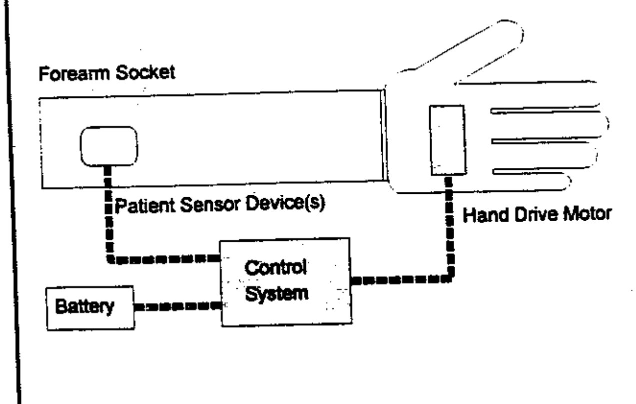

Figure 1

The externally powered transradial system, shown in Figure 1, uses a rechargeable battery as the power source. The battery is the critical component in the system and ultimately decides how well the prosthesis will perform. Consistency is very important in the training and general usage of the prosthesis, especially with children. If the battery does not allow the prosthesis to operate properly, the patient will lose confidence and possibly reject the prosthesis.

While the mechanical components can be customized for a proper fit and near natural cosmetics, the traditional control system cannot be modified to match the specific needs of the patient. A small selection of Patient Sensing Devices (PSD's) and limited functionality of the control system allow only simple hand operations and non-precise speed and grip of the hand. Inefficient operation compounds the battery problem by wasting energy while driving the hand motor.

Diagnostic tools are virtually nonexistent. Since all the operational components are located inside the prosthesis, it is very difficult to determine what is happening inside once the prosthesis is positioned on the patient. Complete arms have been re-fabricated, often at the prosthetists expense, due to the inability to locate and correct a problem in the prosthesis.

Animated Prosthetics, Inc. has researched each of these areas and has created the ACS-1000 Animation Control System to solve these problems and to provide many new capabilities to the patient and the prosthetist.

POWER MANAGEMENT

A goal of this product is to provide the longest life possible from the battery. Analysis of the power consumed by the prosthesis and the methods other systems used to control it, revealed there were many areas needing improvement. The results of this effort were integrated into the ACS-1000 design to provide efficient operation, energy conservation, and battery protection.

An example of power management is shown in Figure 2. A typical system (dark gray area) allows a large turn-on surge when starting the motor and continues to apply power after the hand has reached its maximum grip. The ACS-1000 (light gray area) soft-starts the hand motor and stops applying power when it determines that the maximum programmed grip force is exerted. This method of motor control can reduce the power consumption as much as 50% for each full travel movement of the hand.

Another method of power management allows the system to go to "sleep" when the patient is not operating the hand. This feature reduces the nominal power consumption by 90% compared to a system that is always active. The system is always ready to perform and the patient is unaware of this operation. Also, circuitry not required for the current operation is placed in a low power "standby" mode.

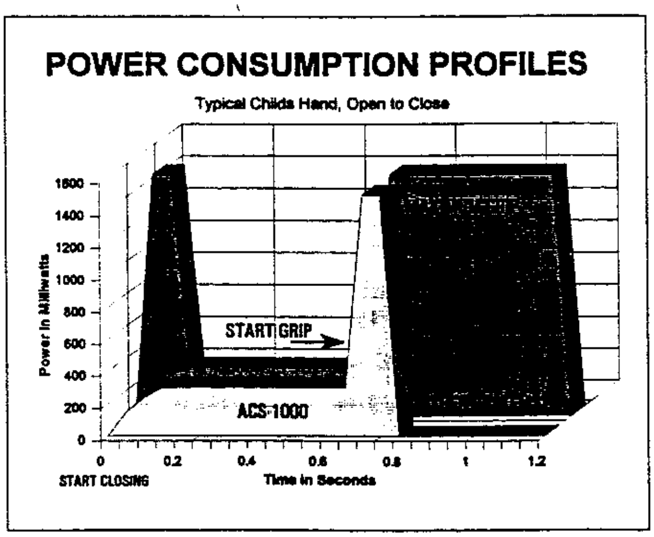

Figure 2

Circuitry in the control system protects the battery from operating in areas that would reduce its life or possibly cause permanent damage. When the battery voltage reaches its minimum point, the system will shutdown to prevent excessive discharging. When recharging the battery, the control system is programmed to select the best method of recharge based on remaining power and will terminate the charge when the optimal point is reached.

The battery also contains circuitry to protect it from external conditions that are beyond the control of the ACS-1000. This circuitry can detect situations that could cause permanent damage, such as a short circuit in the wiring, and will disconnect the battery until the problem is resolved.

BATTERIES

Animated Prosthetics is bringing new battery technologies to the prosthetics field that allow the prosthesis to have a longer operating time, and to be more efficient. These technologies are lithium-ion and lithium-polymer. Figure 3 [1] shows that these batteries have greater power densities than other styles normally used in prosthetics, such as nickel-cadmium and nickel-metal hydride.

These batteries will recharge in one to two hours, depending on the size, and are chargeable any time because they do not suffer the "memory effect" associated with older technology batteries. The charge/recharge cycle life is over 1000 for the lithium batteries [1] compared to around 500 for the others. Lithium-ion and lithium-polymer batteries contain no heavy metals and are therefore environmentally friendly.

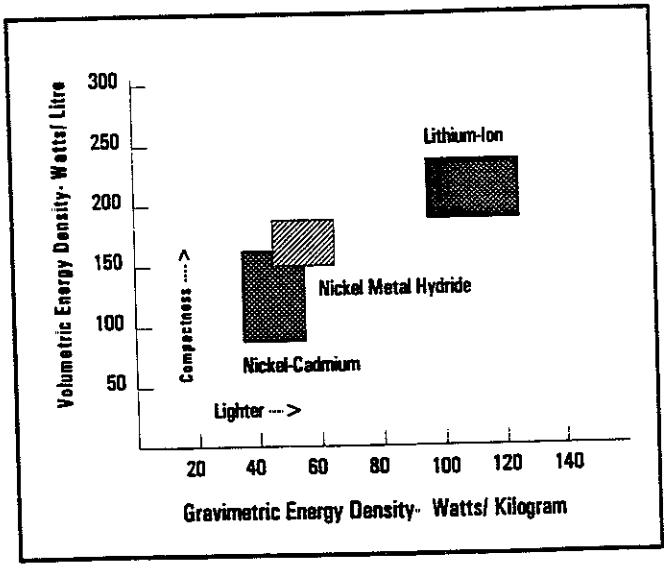

Figure 3

Animated Prosthetics has currently developed four sizes of lithium batteries to fit infants to adults. The infant size battery is the most exciting development because it is flat, flexible, and about the size of a business card. All are designed to mount inside the prosthesis which eliminates external cables, belt clips, "popeye arms," battery boxes, and the need to roll down the glove to change batteries. Normally the battery is installed in the cavity between the distal end of the arm and the wrist. If the residual limb is long and there is no room for the battery, a recess can be formed inside the prosthesis to make room for the battery which would only slightly increase the circumference of the arm.

BATTERY CHARGING

The battery charging scheme is a unique concept of this system. The patient simply positions the prosthesis on the Energy Transfer Device (ETD) and the battery is charged through the prosthesis. There are no wires or cables to connect and the glove does not have to be rolled down. Indicators on the front panel of the ETD display information relating to the status of the battery.

The ETD-800, will operate from 110/220 volts AC and the ETD-812 will operate from 12 volts DC to allow battery charging in automotive or recreational vehicles. The ETD is not a charger, it only supplies the raw power for charging. The actual charging circuitry is integrated in the ACS-1000 control system. The prosthesis can be left on the ETD indefinitely as the control system will not overcharge and damage the battery.

CONTROL SYSTEM

The ACS-1000 is a microcomputer based control system contained in a small module that mounts in the wrist of the prosthesis. Other mounting configurations will be available in the future. The control system is preprogrammed, but it allows the prosthetist to configure the operating method of the PSD's and the hand to match the needs and motor skills of the patient. This system allows the patient to have precise control over the speed, grip and positioning of the hand.

Active filtering of the PSD signals allows the system to differentiate between real signals and those caused by noise or inadvertent motion. This feature will reduce nuisance movements of the hand.

This filtering also allows a smaller PSD signal to activate the prosthesis. Therefore the range of control is increased and patient fatigue is decreased.

Certain myo-electric PSD's are voltage sensitive and their signal output (gain) is affected by the applied voltage. Most systems connect the PSD directly to the battery, therefore as the battery discharges, the patient must make stronger myo-electric signals to place the same grip on the hand. This situation increases muscle fatigue. The ACS-1000 provides a separate regulated power supply for the PSD's which generates a constant voltage independent of the battery voltage.

Permanent memory in the system stores information relating to the operation of the prosthesis. Data such as the number of open and close cycles, battery recharge cycles, etc., can be tracked by the prosthetist to determine the actual usage of the prosthesis.

A radio communications link inside the module allows the system to talk to other Animated Prosthetic devices for configuration and diagnostic purposes.

TASC'S

The ACS-1000 is preprogrammed with various techniques of interfacing with the patient and the terminal device. These are called Techniques And Strategies of Control (TASC's). There are TASC's that emulate all currently available methods like proportional control, "cookie cruncher," single site dual function, plus many new methods. The TASC's can be changed from time to time as the patients condition and motor skills change. They can even be changed while the patient is wearing the arm. The table below lists the currently available TASC's.

TASC	DESCRIPTION	FEATURES AND FUNCTIONS
VOAC	Voluntary Open Automatic Close	A single PSD is activated to open the hand. The hand will close automatically when the PSD is deactivated. This operation is sometimes called the "cookie cruncher" mode. The speed and maximum grip of the hand can be fixed or variable.
VOAC-DS	Voluntary Open Automatic Close Dual Site	Similar to VOAC except two PSD's are used and either one can open the hand.
VCAO	Voluntary Close Automatic Open	A single PSD is activated to close the hand. The hand will open automatically when the PSD is deactivated. The speed and maximum grip of the hand can be fixed or variable.
VCAO-DS	Voluntary Close Automatic Open Dual Site	Similar to VCAO except two PSD's are used and either one can close the hand.
SSDF-A	Single Site,Dual Function, Ver A	A single analog PSD is used to open and close the hand. This operation is called "fast muscle-slow muscle" operation. The maximum grip and speed are fixed.
SSDF-B	Single Site,Dual Function Ver B	Similar to above except that the speed and grip are variable.
DSSF	Dual Site Single Function	Two PSD's are used, one to open and one to close. This is the standard dual PSD operation. The speed and grip can be fixed or variable.
DSDF	Dual Site Dual Function	Two PSD's are used, one to open and close the hand, and the other to control an auxiliary device such as an elbow or a wrist rotator.

The TASC is selected to fit the normal operational requirements of the patient. For example, if it is assumed the patient is capable of operating dual PSD's to perform the Dual Site Single Function (DSSF) actions, and it is discovered after fabrication that the patient can only operate one PSD reliably, the prosthetist can simply select another TASC such as Voluntary Open Automatic Close (VOAC) or Single Site Dual Function (SSDF).

Each TASC has several supporting variables such as maximum speed, maximum grip, fixed or variable speed, fixed or variable grip, etc. These variables are preset at the factory for normal conditions, but they can be modified by the prosthetist to fine tune the prosthesis to the patient. Some TASC's have unique secondary operations such as; a) variable speed and grip based on time of activation; b) maximum speed closing until resistance is detected, then provide a slowly increasing grip; and c) the ability to disable the PSD after X seconds of activation.

DIAGNOSTIC TOOLS

A configuration unit is available that allows configuring, controlling and monitoring all functions of the prosthesis. This device, called a Prosthesis Configuration Unit (PCU), provides a visual display of the actions of the prosthesis while the patient is wearing the arm. A radio link communicates data from the hand to the PCU to allow the prosthetist to "see" inside the prosthesis.

The PCU-700 has menu driven screens and allows simple select-the-variable configuration. No programming knowledge is required. Various screens on the display allow the PCU to read and write the data from the prosthesis such as the TASC's, number of battery charge cycles, the number of hand operations and various diagnostics. Real-time data from the PSD's can be displayed while the patient is wearing the prosthesis. This is a useful tool to verify PSD placement and operation and to confirm the patient's actions.

For example, if the patient complains that in certain positions the prosthesis does not operate properly, the prosthetist can enable the PCU, have the patient don the arm, and watch the actions of the PSD's. This could determine whether there is a problem with the fit or simply a gain adjustment error. Also, when dealing with infants it is impossible to get feedback, so the prosthetist can monitor the arm to confirm that the PSD's are fitting and acting properly. The prosthetist can even override the PSD's and command the hand to open and close remotely for training purposes.

PRELIMINARY TESTING

Field testing is just beginning so actual usage data is not available. However, lab testing shows that with these new control methods and battery technology the patient should receive two to four times the operating time per charge compared to other systems.

REFERENCES

[1] Ultralife Batteries, Inc. press release, "Statistics for rechargeable battery systems," March 10, 1995