DIVER HEALTH MONITORING SYSTEM

USER MANUAL

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1 OVERVIEW

1.1 PURPOSE AND SCOPE OF THIS MANUAL

This manual describes the features and functionality of the Creare Diver Health Monitoring System (DHMS).

1.2 PURPOSE OF THE SYSTEM

The Creare DHMS is a body-worn sensor system for monitoring a diver's physiologic condition, as well as of his environment. Currently, the DHMS consists of a single body-worn sensor that measures the diver's electrocardiogram (ECG). The DHMS sensor records the ECG and determines the diver's current heart rate. The device logs the data for later retrieval and it also broadcasts the data in real time over a wireless link to a nearby computer. The use of the DHMS system is aimed at researchers performing experiments on divers. The system can be used wet or dry, at the surface or at depth.

1.3 DESCRIPTION OF THE SYSTEM

The DHMS is composed of three components: (1) one or more body-worn sensors, (2) a general purpose PC running a custom-written application to control the sensors and to receive the data, and (3) a dock for recharging the body-worn sensors. The system components are shown in Figure 1.

Figure 1. The Creare Diver Health Monitoring System

Currently, only one type of body-worn sensor is available for the DHMS. The DHMS sensor records the subject's ECG and computes the subject's instantaneous heart rate. The sensor stores both the raw ECG waveform and the heart rate values on nonvolatile memory within the device. The stored data can be downloaded from the device after one's experiment is complete. The sensor also can transmit that data in real time to the PC for immediate monitoring.

The sensor can be worn in dry or wet conditions, and at normal ambient or elevated pressures (up to 300 fsw). The sensor is attached to the body using a consumable adhesive strip, which is supplied by Creare. The built-in battery on the sensor lasts four to eight hours when transmitting in real time, or 18 to 28 hours when not transmitting. The battery is recharged by placing it its dock, which is connected via USB to the PC.

The PC is used to control the sensor, to collect the data from the sensor, and to recharge the sensor. The PC can be any general-purpose PC running Microsoft Windows XP or later. It must have two free USB ports: one for a Bluetooth® wireless adapter (supplied by Creare) and one to connect to the dock to recharge the sensor.

1.4 Creare Point of Contact

For inquiries relating to this system or to the Creare program, please contact the Principal Investigator for this work:

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2 DETAILED SYSTEM DESCRIPTION

2.1 DHMS ECG SENSOR

The DHMS ECG sensor is a body-worn device for measuring the instantaneous heart rate. The device is attached to the chest with an adhesive strip. It uses two integrated ECG electrodes to record the diver's ECG. The sensor detects the R-waves within the ECG and computes the instantaneous heart rate by measuring the difference between successive R-waves. The device logs the raw ECG signal and the heart rate values in nonvolatile memory. It also transmits the data in real time over a wireless data link to a PC. The DHMS ECG sensor is shown in Figure 2.

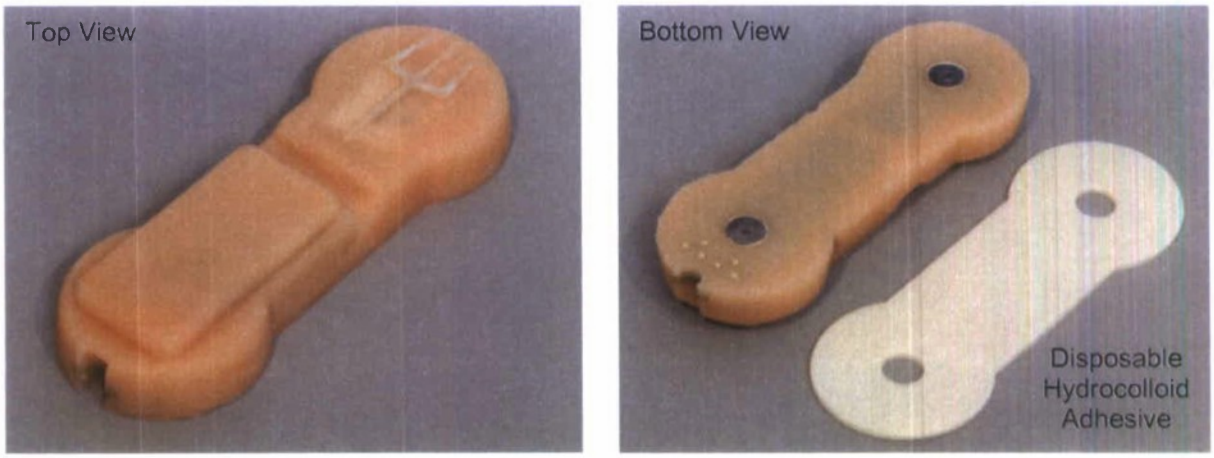


Figure 2. DHMS Electrocardiogram Sensor

2.1.1 Wearing the Sensor

The DHMS ECG sensor is a highly integrated device intended to be worn by active test subjects. As shown in Figure 3, existing ambulatory ECG systems often require the application of a number of discrete electrodes, which are then wired back to a data recording device. These lead wires are prone to failure, frequently generate noise and signal artifacts and often encumber the test subject. The Creare DHMS sensor avoids these issues with its integrated design.

Furthermore, ECG signal corruption due to contraction of skeletal muscles is a common problem when using a traditional placement of ECG electrodes. The DHMS sensor is designed to be worn directly on the sternum where skeletal muscles are thinner and less likely to corrupt the signal. This nontraditional placement does affect the apparent morphology of the ECG signal complex, but the individual signal elements are still visible and the timing of the signal elements is persevered.

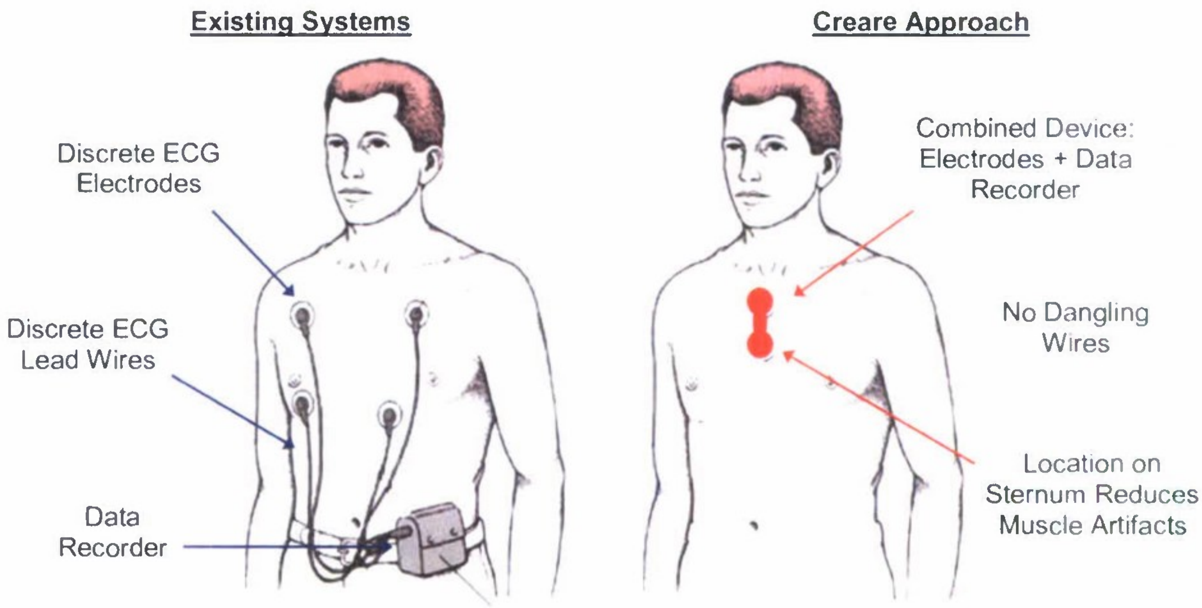


Figure 3. (Left) A Common Approach Used by Existing Ambulatory ECG Systems for Recording a Person's Electrocardiogram. (Right) The Creare approach used by the highly integrated DHMS ECG sensor.

2.1.2 Sensor Construction

The major internal components of the DHMS ECG sensor are shown in Figure 4. As can be seen, the device is built around a MSP430 processor from Texas Instruments. The MSP430 digitizes the ECG signals, processes the signals to measure the heart rate, stores the data in local nonvolatile memory (SD), and services the digital wireless link (Bluetooth). The ECG signals themselves are received from the body via two integrated ECG electrodes on the bottom of the device. The low-level ECG signals from the body are conditioned by analog circuitry built into a daughter card mounted above the MSP430. The device is powered by an integrated, rechargeable, lithium polymer battery pack (3.7 V, 280 mA-hrs). The battery is recharged via gold pads that are exposed on the bottom of the sensor which mate to power pins on the Creare DHMS sensor dock. The whole device is potted in urethane to make it waterproof and pressure tolerant.

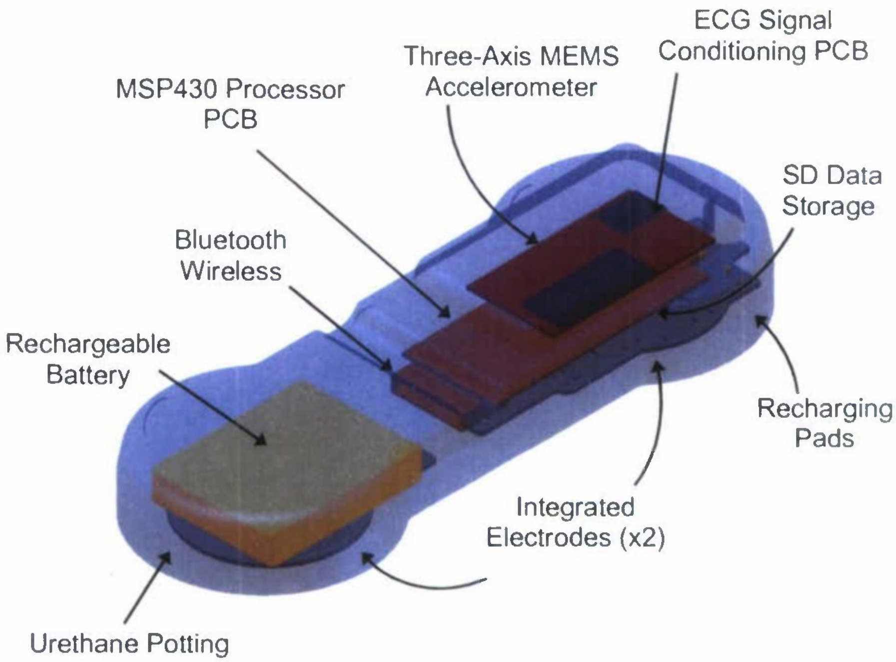


Figure 4. Layout of Components within the DHMS ECG Sensor

2.1.3 Donning the Sensor

Procedure. The procedure for using the adhesive strip and electrode gel to don the sensor is described in detail in Section 3.

Adhesive Strip. The adhesive strips themselves are composed mainly of hydrocolloid film mounted to a foam or plastic substrate. Hydrocolloid is used on both sides of the adhesive strip. One side is for adhering to the sensor and the other side is for adhering to the skin of the person's chest. The two sides of the strip are identical.

ECG Electrode Gel. To make contact between the integrated ECG electrodes and the skin, the user must use ECG electrode gel. We believe that any high-quality clinical ECG gel will work, but all of Creare's testing has been performed using Spectra 360 Electrode Gel as manufactured by Parker Laboratories, Inc. (Fairfield, NJ).

2.1.4 Using the Sensor

Controlling the Sensor. The DHMS ECG sensor is controlled by a software application that runs on any general-purpose PC. Using this software, the user can command the sensor to start or stop a recording session. The user can also download the logged ECG and heart rate data from the sensor using this application. See Sections 2.2 and 3 for more information on how to control the sensor. Note that the sensor cannot be turned off—as long as it has power, it will remain active so that it can respond to user commands from the PC.

LED Indicators. When the sensor is operating correctly (i.e., when the device is recording an ECG and saving data to its nonvolatile memory), small green and yellow LED lights within the sensor will blink. A solid red light indicates that the sensor is not recording data.

Resetting the Sensor. If the sensor becomes nonresponsive, the most likely cause is that it is out of power. Recharging the device will usually return its functionality. In the event that it continues to be nonresponsive, there is a noncontact reset switch embedded within the left side of the device. A small magnet is supplied with each DHMS dock. To activate the reset switch, slide the magnet along the left side of the sensor. If the sensor has power, the embedded LEDs will blink indicating that the device has successfully reset.

2.1.5 Data Storage and Downloading

During each recording session, the raw ECG signal and the instantaneous heart rate measurements are saved to nonvolatile memory on the sensor. The raw ECG data is stored in one file, while the heartbeat and heart rate data are stored in a second file. When a new recording session is started, a new pair of data files is created to hold the new data. The old data are not overwritten. At the conclusion of a test, the data can be downloaded from the sensor to a PC using the software application provided by Creare. Data can be deleted from the nonvolatile memory using the same PC software.

Note that the data can only be downloaded from the sensor wirelessly. For long recording sessions, the data file containing the raw ECG data can become quite long. Since the data rate over the wireless link is relatively slow, downloading these long records can be time consuming. To prevent the device from running out of power during the download, it is recommended that long downloads only be started when the sensor is in its dock being recharged.

During a recording session, data accumulates at approximately 2000 bytes per second. The nonvolatile storage is 2 GB, so there is space for roughly 270 hours of data to be stored on the sensor. The data download speed from the sensor to the PC is only 7000 to 8000 bytes per second. Therefore, if a recording session were four hours long, it would take approximately one hour to download the data.

2.1.6 Battery Life

The battery integrated with the DHMS ECG sensor is a rechargeable Lithium-Polymer battery with built-in protection for over-charge and over-discharge. It has a nominal capacity of 280 mA-hrs and a nominal voltage of 3.7 V. Due to the complexities of the Bluetooth wireless protocol (dynamic power adjustments, dynamic retransmissions to ensure deliver), battery life is highly dependent upon the local RF conditions.

While streaming the raw ECG data in real time, our testing has shown operating lifetimes between four to eight hours. In tests where the real-time Bluetooth transmission was stopped, our tests have shown operating lifetimes between 18 to 28 hours. In mixed testing environments (some real-time streaming followed by a loss of streaming due to being underwater), we have seen lifetimes of eight to nine hours.

2.1.7 Sensor Specifications

Table 1. Specifications for the DHMS ECG Sensor	
ECG Data	Single differential channel Input protection for ESD, RF/EMI filtering, and current limiting Analog gain of 175 (nominal) Analog passband of 0.05 Hz to 159 Hz Digital sampling at 500 Hz with12 bits of resolution
Data Logged	Raw ECG and instantaneous heart rate (~2000 bytes/sec) 2 GB nonvolatile storage (> 100 hrs)
Wireless Telemetry	Standard Bluetooth connection (2.4 GHz, unlicensed) Roving networks RN-46 Class 2 Bluetooth module Real-time raw ECG and heart rate Post-test download of Raw ECG and heart rate
Battery Life	Integrated Li-polymer battery (280 mA-hr, 3.7 V nominal) 4 to 8 hours while streaming the raw ECG data 18 to 29 hours without wireless streaming
Pressure Tolerance	Potted in urethane Proof tested in air to 300 feet of sea water Tested on divers in fresh water to 20 feet of sea water

2.2 DHMS PC SOFTWARE

In the DHMS, the PC is used to control the DHMS ECG sensor, to collect the data from the sensor, and to recharge the sensor. Software provided by Creare allows the PC to perform these functions. The software runs on any PC running Microsoft Windows XP (or later) and which has a Bluetooth interface (a USB Bluetooth interface is provided by Creare).

2.2.1 Graphical User Interface

The graphical user interface of the Creare DHMS software is shown in Figure 5. As can be seen, there is a menu bar at the top, a large area for displaying the ECG data streamed wirelessly from the sensor, and a text display at the bottom for showing the current heart rate transmitted by the sensor.

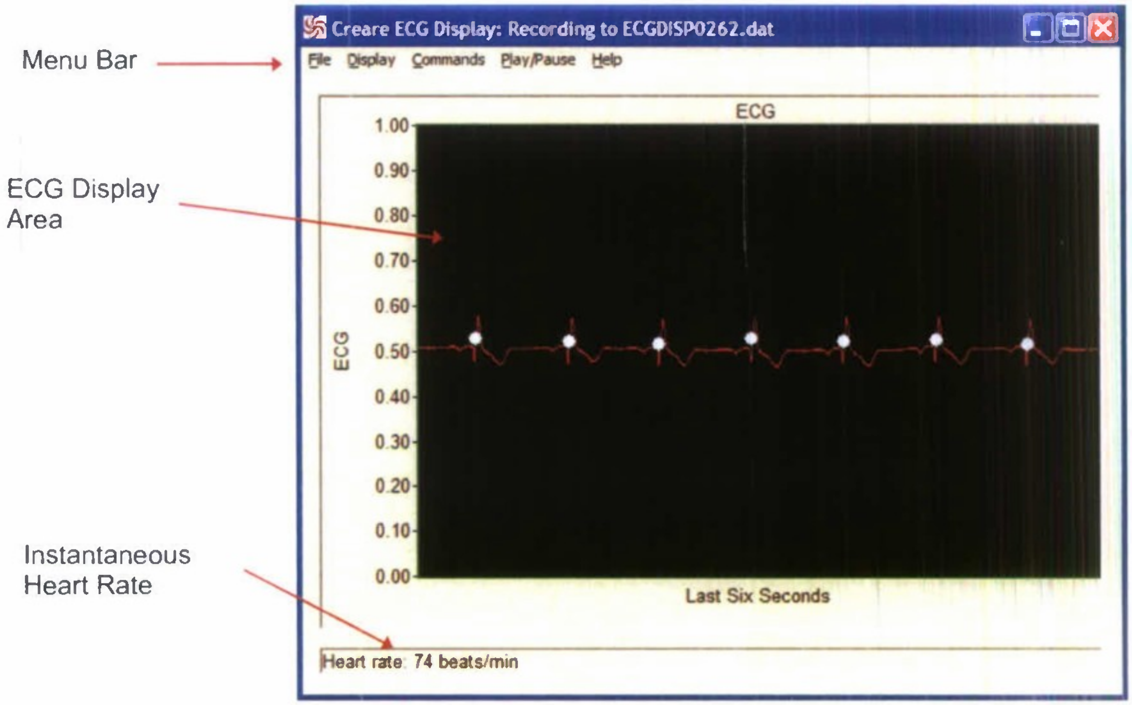


Figure 5. Graphical User Interface for the Creare DHMS PC Software

2.2.2 Controlling the Sensor

Wireless Interface. All interactions between the DHMS PC software and the DHMS ECG sensor are through the wireless (Bluetooth) interface. Therefore, the sensor must have power (i.e., be charged or be sitting on the dock), it must be within Bluetooth communication range (10 to 20 feet), and it must be "connected" over Bluetooth so that Microsoft Windows assigns a COM port. The DHMS PC software connects to the DHMS sensor using this COM port. For details on configuring the Bluetooth connection, see Section 3.1.

Starting an ECG Recording Session. The DHMS PC software can command the DHMS ECG sensor to start a new ECG recording session. Simply press the **Play/Pause** entry in the **Menu** bar. This will command the sensor to stop any existing recording session and to begin a new one. If successful, new ECG data will begin streaming from the sensor and be displayed in the ECG **Display** area. By starting a new recording session, a new pair of data files will be started in nonvolatile memory on the DHMS sensor.

Monitoring During Testing. As long as the sensor is able to maintain its Bluetooth connection during the testing, the PC application will continue to receive ECG data. All received data will be displayed. If the PC application receives no data after ten seconds, it will assume that the Bluetooth link has been lost (such as due to going out of range or underwater) and it will generate a pop-up window stating this fact. Closing this window will stop the real-time display on the PC, but it will not stop the data collection from being performed by the DHMS sensor itself.

Stopping an ECG Recording Session. When the sensor is within Bluetooth range of the PC, the recording session can be stopped by pressing the **Play/Pause** menu item. Under some conditions it will stop the previous recording, but also immediately start a new recording session. Press the **Play/Pause** menu item again to stop the recording.

Downloading Data. After completing a recording session, the PC application can be used to download the data from the sensor. Simply choose the **Commands** menu item and select **File Download...** Figure 6 shows the dialog box the appears to allow the user to select which data files to download from the sensor. Note that similarly-named files appear in pairs. One pair of files is created for each recording session. The file with the .dat extension holds the raw ECG data, while the smaller file with the .hb extension holds the heartbeat and heart rate values. The user can select one or more files to download and then press the **Download** button at the bottom. The user can also delete files from the sensor using this dialog box. Since the downloading process uses the wireless interface, the download can take a lot of time (one hour to download four hours of raw ECG data). It is recommended that longer files be downloaded while the sensor is charging in its dock.

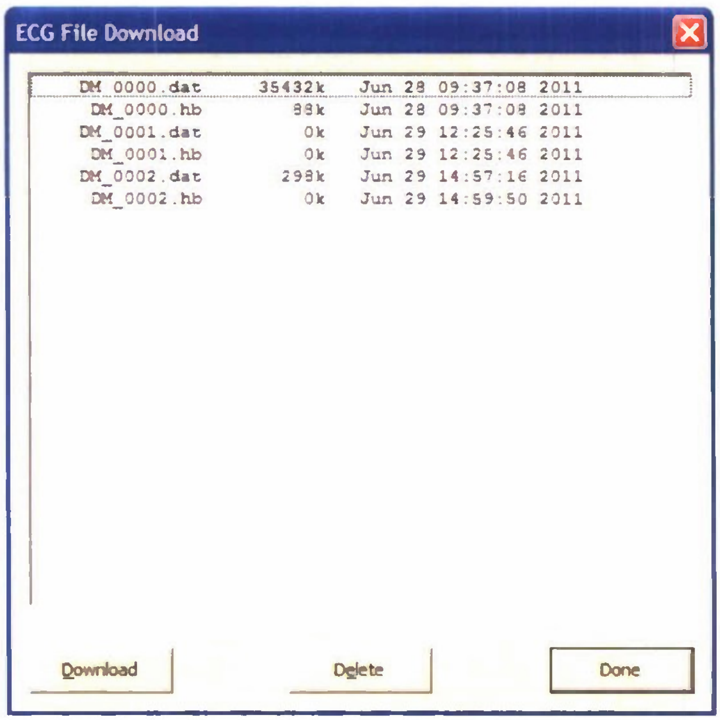


Figure 6. Dialog Box Used for Downloading or Deleting Data from the DHMS Sensor

Activating or Deactivating the Sensor. The DHMS cannot be turned on or off. As long as it has power, it will stay active so that it can respond to commands issued from the PC.

2.2.3 Using the Downloaded Data

The data files downloaded from DHMS ECG sensor are in binary format. The data can be read in any environment that can read binary data (such as MATLAB®). See Appendix A for the data format and for example code to read the data.

2.3 DHMS Sensor Dock

The DHMS dock (Figure 7) is used to recharge the DHMS ECG Sensor. Power is supplied to the sensor via its protruding gold pins which mate to gold pads on the bottom side of the ECG sensor. Power is supplied to the dock itself via a USB connection to the PC.

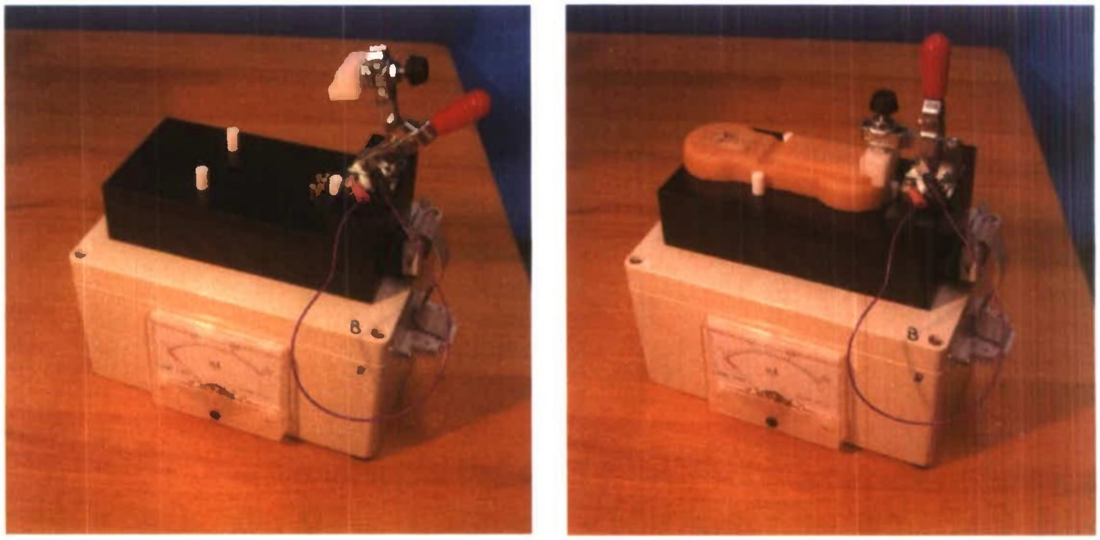


Figure 7. DHMS Sensor Dock. (Left) Dock without the DHMS Sensor. (Right) Dock with the DHMS Sensor.

The large analog ammeter displays the amount of electrical current flowing to the ECG sensor. When the current flow is down to below 20 mA, the sensor is charged. If an ECG sensor is completely out of power, placing it on the dock does not always immediately induce current flow. It may take a few minutes for the sensor to accept current and for the ammeter to move. Using the magnet to reset the sensor can speed this initialization process.

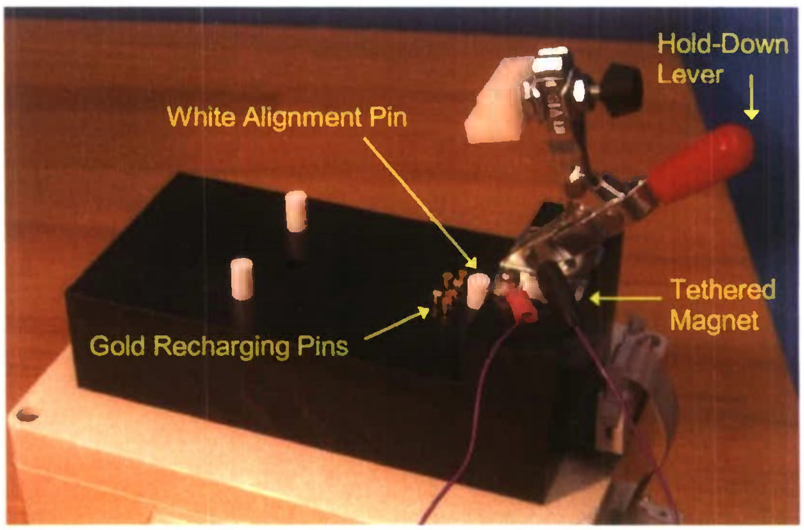


Figure 8. Features of the DHMS Sensor Dock

3 INSTRUCTIONS FOR USE

This section provides detailed instructions for performing common tasks with the DHMS sensor and PC software. The procedures necessary for performing three common tasks are shown in Figure 9. The step-by-step instructions for performing each step in these procedures are described in the subsections that follow.

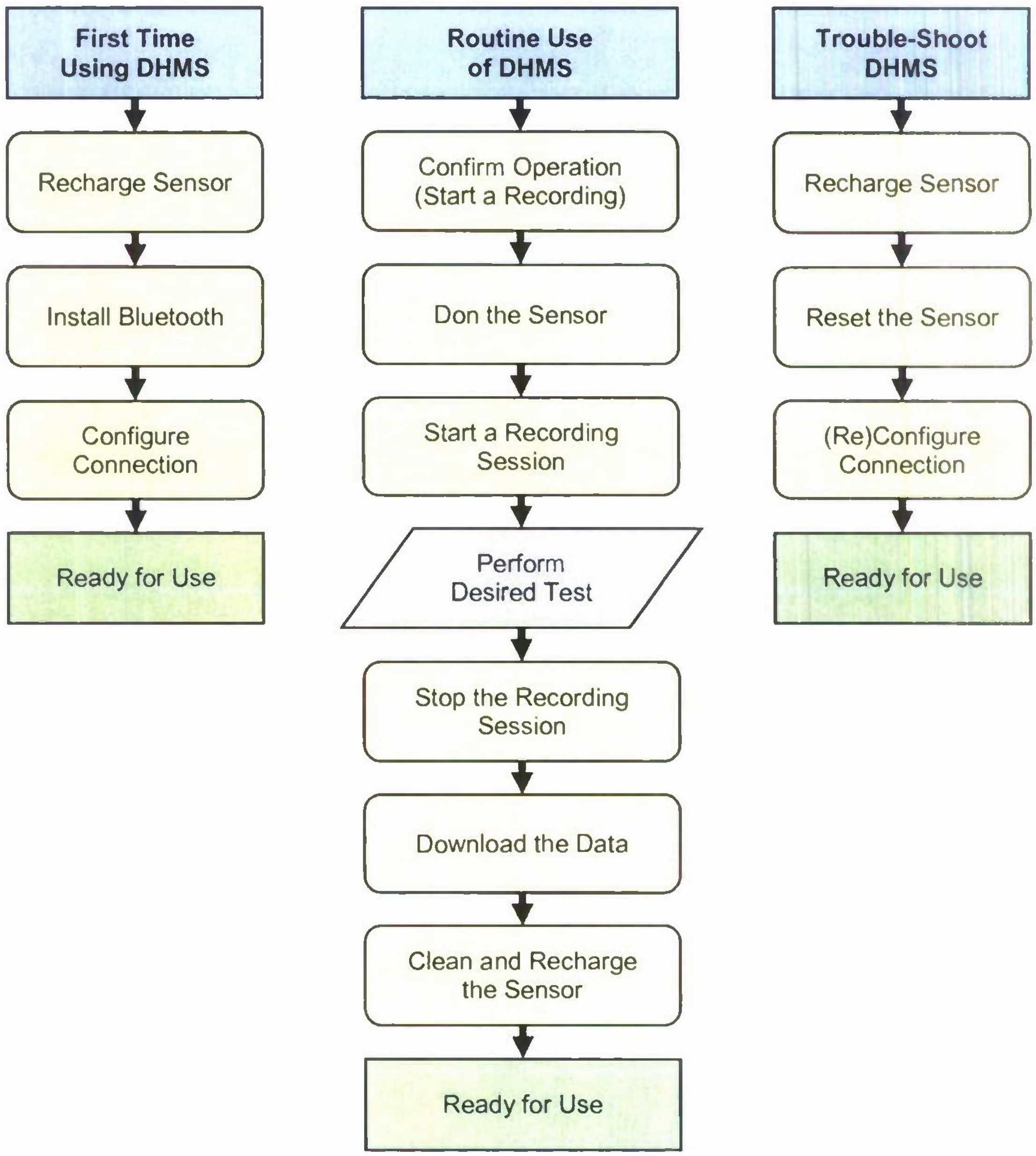


Figure 9. Three Common Procedures for Using the Creare DHMS

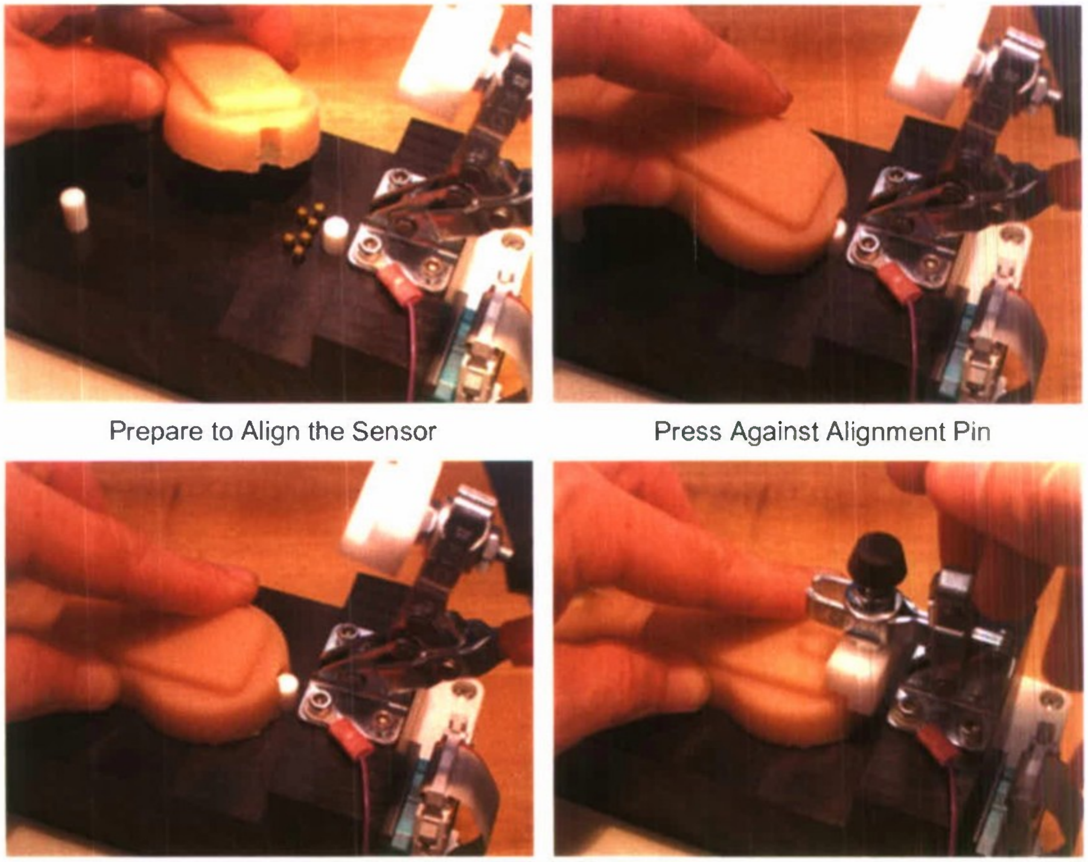
3.1 RECHARGING THE SENSOR

Prior to using the DHMS sensor for a recording session, it is important that the sensor be recharged. The sensor cannot be turned off, so the sensor must be in its recharging dock until it is time to mount it to the human subject for the recording session.

To recharge the DHMS sensor:

1. Disconnect the Dock from the PC. Disconnect the dock from the PC to remove power from the dock.
2. Clean Off the Sensor's Gold Pads. Looking at the bottom of the DHMS sensor, make sure that the gold pads are clear of water, residual adhesive, ECG gel, or other fouling materials. The device can be cleaned with soap and water or with alcohol pads.
3. Align the Sensor with the Alignment Pin. Place the sensor over the dock and align the concave notch in the end of the sensor with the plastic alignment pin protruding from the top of the dock (see Figure 10).
4. Press the Sensor Down into Place. Once aligned, press the sensor down into place on the dock so that the pins are compressed (see Figure 10).
5. Lower the Lever. Secure the sensor into place using the lever on the dock. Align the plastic block on the lever with the stepped surface on the end of the sensor. The fit should be snug (see Figure 10).
6. Connect the Dock to the PC. Connect the dock to the PC using a USB cable. This will bring power to the dock and to the sensor.
7. Confirm Current Flow. By looking at the large analog meter on the base of the dock, confirm that power is flowing. In some cases, it may take 10 to 20 seconds for current to flow. Current flow should be 200 mA or less. The current flow might be smooth or it might pulse. If no current flows at all, try resetting the sensor using the magnet. If still no current flows, the pads on the bottom of the sensor might not be properly aligned with the pins in the dock. Remove the sensor and repeat this placement process.

The recharging process can take several hours. The sensor is fully charged when the current meter indicates a flow of 10 to 20 mA or less.



Prepare to Align the Sensor | Press Against Alignment Pin

Press Down onto Gold Pins | Secure with Lever

Figure 10. Steps for Placing the DHMS Sensor in the Dock

The sensor can be removed from the dock by unplugging the dock from the computer, raising the dock's lever, and removing the sensor.

3.2 Installing the Bluetooth Hardware and Software

The Creare DHMS software should be able to work with any Bluetooth-compliant hardware. However, all of the testing performed by Creare has been performed using a Bluetooth USB Micro Adapter from Kensington (model K33902US). This USB Bluetooth adapter comes with software for the PC called the "Bluetooth Stack for Windows" and is produced by Toshiba. We were using v6.00.05, which is compliant with Bluetooth specification V2.1. If you are going to use the Kensington USB Bluetooth adapter with a computer running Windows XP, Creare strongly recommends that you install these Toshiba drivers instead of using the default Windows XP Bluetooth drivers. To install the drivers, follow the instructions provided with the Kensington adapter.

3.3 Configuring the Bluetooth Connection

The first time that one uses a DHMS sensor with a particular computer, it is necessary to manually create a Bluetooth connection. The process is highly automated, but it does have to be manually initiated by the user. After a sensor has been connected to the computer the first time, the Toshiba Bluetooth software will save all of the relevant connection information and the Bluetooth connection will be made automatically in the future. This only applies to a specific sensor-computer pairing, so the process will have to be repeated for each sensor and for each computer that you would like to use.

To manually initiate the Bluetooth connection:

1. Ready the PC. Make sure that the Kensington Bluetooth adapter has been inserted into the computer and that the Toshiba drivers are successfully installed.
2. Ready the DHMS Sensor. Make sure that the DHMS sensor has been recharged, that it has been reset using the magnet, and that it is within range of the computer (e.g., within six feet).
3. Open the Bluetooth Control Panel. Start the Toshiba Bluetooth control panel (by selecting **Bluetooth->Bluetooth Settings** under the Windows **Start** menu, or by double-clicking on the **Bluetooth** icon in the Windows system tray). The control panel should look similar to Figure 11, though the central display could be blank.

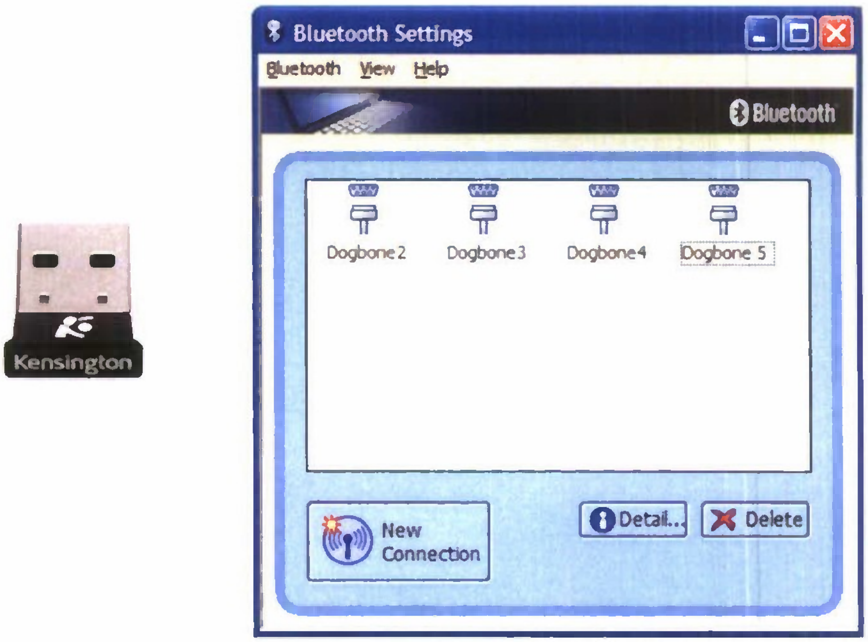


Figure 11. (Left) Bluetooth USB Micro Adapter (Model K33902US) from Kensington. (Right) PC software interface for the Bluetooth Stack for Windows by Toshiba.

4. Create the New Connection. Press the **New Connection** button. For each question, accept the default value. If the software asks for a PIN code, type **1234**.
5. Note the Icon. If successful, a new icon will appear in the display area. The alpha-numeric value shown for its name is its Bluetooth identification number. This icon, therefore, is specific to the particular DHMS sensor that you have just connected to. If desired, you can rename the connection by right-clicking on the icon.

6. Confirm the Link. To confirm that the link is functioning, double-click on the new icon that represents your Bluetooth connection. After a brief pause, the icon will change to be like Figure 12, which indicates an active Bluetooth connection.

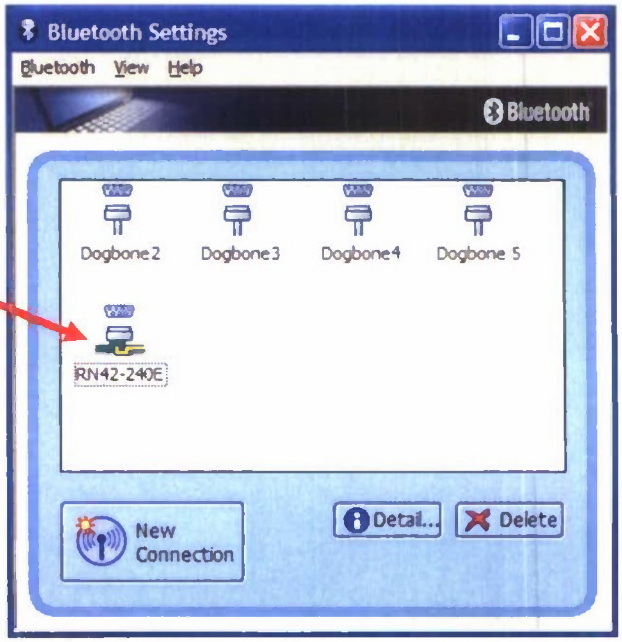


Figure 12. Bluetooth Control Panel Showing That it is Connected to the DHMS Sensor

7. Repeat. You will need to repeat this process for each DHMS sensor and for each computer with which you will use the sensor.

After this initial setup, you are not required to perform this manual connection process again for this particular combination of computer and sensor. Sometimes, however, it is helpful to use this Bluetooth control panel to trouble-shoot the operation of the DHMS sensor. After the initial setup, the Creare DHMS PC software will attempt to reconnect to the sensor automatically whenever the user commands an action. If there is no response from the sensor, this control panel can be used to confirm that the link is active. If not, ensure that the sensor has power, that it is within range, and that it does not need to be reset. You can also try to manually make the Bluetooth connection by right-clicking on its icon and selecting **Connect**.

3.4 CONFIRM SYSTEM OPERATION

Prior to mounting the sensor onto the diver, it is recommended that the user start a recording session on the sensor to confirm that data is being properly transmitted and received. The sensor does not have to be worn on the body for this test to be completed.

To start a recording session, follow the instructions in Section 3.6. If the sensor is working correctly, and if the communication to the PC is working correctly, a signal will start scrolling across the computer screen. Touching the ECG electrodes on the bottom surface of the DHMS ECG sensor will result in changes in the signal.

If the device appears to be working, stop the recording session using the instructions in Section 3.7. If the device was not working correctly, try the trouble-shooting procedure outlined in Figure 9.

3.5 DONNING THE SENSOR

This section describes a method for mounting the DHMS ECG sensor to the diver's chest. The goal is to create a secure attachment to the body while maximizing the quality of the ECG signal. These instructions assume that the DHMS ECG sensor has been fully charged.

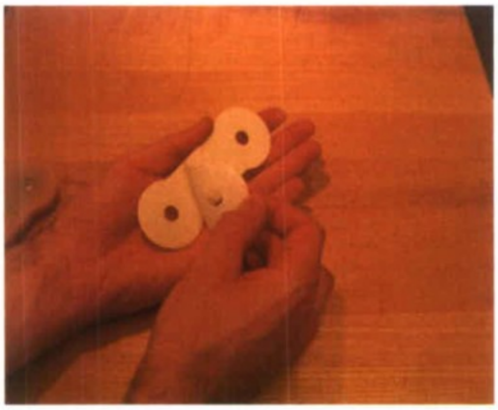
Because it is time-consuming to remove and remount the sensor (and may involve some discomfort), Creare recommends that you confirm the system operation (Section 3.4) before donning the sensor.

1. Clean the Skin. The diver's skin should be thoroughly prepared using similar procedures that are common in ambulatory ECG monitoring of active subjects (diving, sports medicine, military physical training, etc.). We recommend shaving away the hair from the sternum of the chest and rubbing vigorously with a gauze pad and alcohol (isopropyl or ethanol). Allow the site to dry.
2. Clean the Sensor. Confirm that the sensor body has been cleaned of residual adhesive, dirt, or other fouling. The unit can be cleaned with soap and water or with an alcohol pad. Visually examine the two ECG electrodes on the bottom surface of the sensor. If they appear discolored or dirty, rub the electrodes with a pencil eraser to remove any corrosion. Prior to applying the adhesive strip, make sure that the bottom surface of the sensor body is clean and dry (and free of any bits of eraser).
3. Warm the Adhesive Strip. The hydrocolloid adhesive strip will not bond properly with the sensor or with the skin if it is too cold. It is designed to best adhere when at body temperature. Therefore, to warm the adhesive, remove a DHMS adhesive strip from its packaging and hold it between your hands for 60 seconds (see Figure 13).

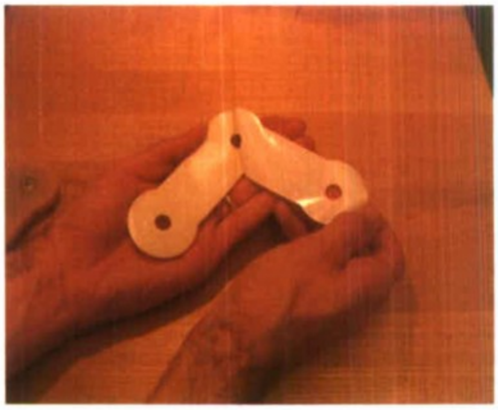
Figure 13. Warming the Adhesive Strip for 60 Seconds

The next three steps should not be performed too slowly or else the adhesive strip will cool off too much, which will increase the chances of poor adhesion.

4. Apply the Adhesive Strip to the Sensor. Remove the thin (nonsticky) plastic protective layer from the adhesive strip. Properly align the strip with the sensor body and press the sticky side against the sensor. (See Figure 14.)



Start to Peel Protective Strip



Remove Protective Strip

Align with DHMS Sensor

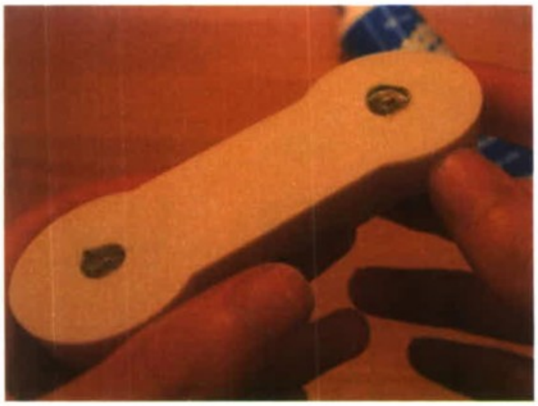
Press onto the Sensor

Figure 14. Attaching Adhesive Strip to Sensor

5. Apply the ECG Electrode Gel. Squirt some ECG gel onto the ECG electrodes. Make sure that there is sufficient gel to fill the well formed by the hole in the adhesive strip (see Figure 15.)

Fill the First Well

Fill the Second Well



Ensure the Wells are Filled

Gel Should Bulge Slightly

Figure 15. Applying the ECG Electrode Gel

6. Mount the Sensor to the Sternum. Remove the (nonsticky) plastic protective layer from the adhesive strip. Align the sensor with the desired location on the sternum (see the discussion of locating the sensor in the paragraph that follows these instructions). Once aligned, press the sensor against the sternum at the desired location. Hold it against the sternum firmly for 60 seconds. This will allow the adhesive strip to warm back up to body temperature and seat properly. See the left picture in Figure 16 for an example of the sensor mounted on the sternum.

7. Secure with Bioclusive. To further secure the sensor to the chest, it is recommended that another flexible adhesive layer be applied over the top of the sensor. One such product is Bioclusive Transparent Dressing by Johnson & Johnson. By using either two pieces of the 4″ × 5″ or 5″ × 7″ or one piece of the 8″ × 10″ dressing to cover the sensor, the DHMS sensor will be less likely to be knocked off the chest by other test equipment during the human subject experiment. An example of a DHMS sensor used with the Bioclusive dressing is shown in the right picture of Figure 16.

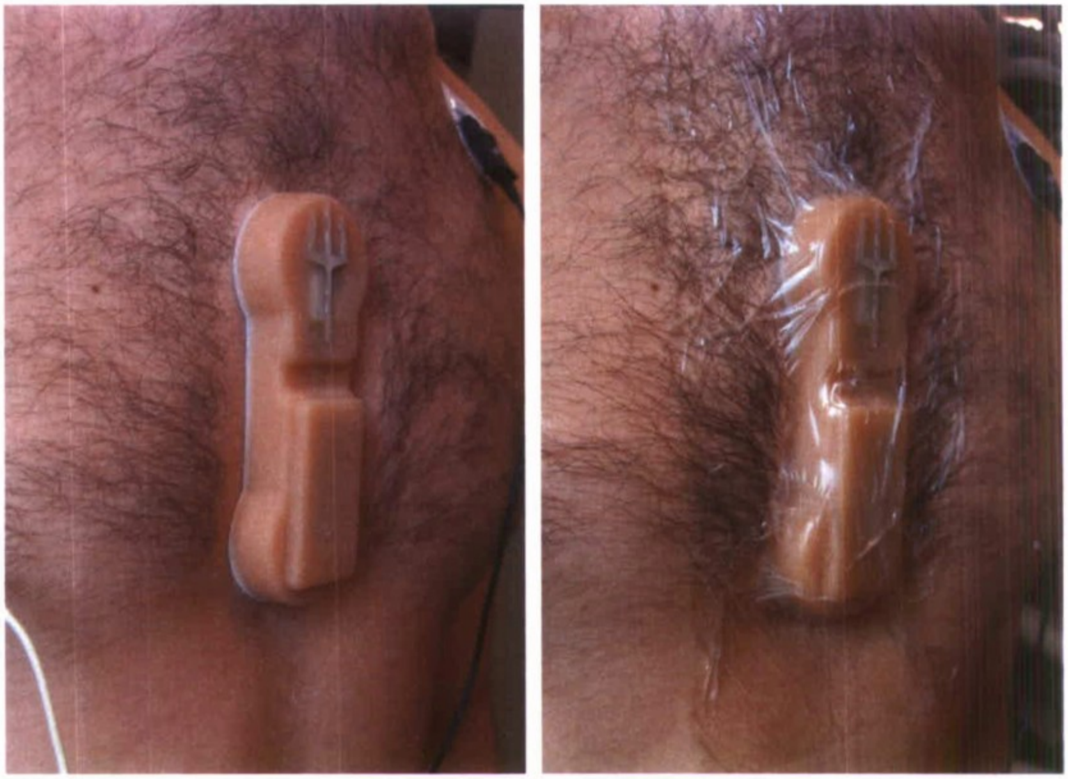


Figure 16. (Left) DHMS ECG Sensor Mounted on the Sternum Using the Custom Hydrocolloid Adhesive Strip. (Right) Sensor secured using Bioclusive transparent dressing.

Notes on Locating the DHMS Sensor on the Sternum. When aligning the sensor with the sternum, the goal is to have the ECG electrodes avoid the large muscles on the chest. Therefore, examine the particular contours of the diver's chest and adjust as necessary. Also, make sure that the sensor body does not extend too far towards the abdominal muscles. For experiments where the test subject is in a seated position (such as on a recumbent cycle ergometer), the skin and abdominal muscles can be pressed into the area near the bottom of the sternum. If the DHMS sensor is mounted too low, this bunched-up skin and muscle can press against the sensor and may lift it out of position, which can negatively impact the quality of the ECG sensors. If this occurs, placing the sensor 1 to 2 cm higher on the sternum can often avoid this problem.

3.6 Starting a Recording Session

The DHMS ECG sensor is active (on) whenever it has power. It is not, however, always recording ECG data. You will need to tell the DHMS sensor to start recording. This command is given wirelessly using the DHMS software on the PC. To start an ECG recording session:

1. Check the Sensor's COM Port. To wirelessly connect to the DHMS sensor from the PC, you will need to know the COM port assigned to the sensor's Bluetooth connection. To find the correct COM port, go to the **Toshiba Bluetooth control panel** (see Figure 12) and right-click on the icon corresponding to the sensor that you are using. In the pop-up menu, select **Details**. The COM port is displayed in the middle of the resulting window.

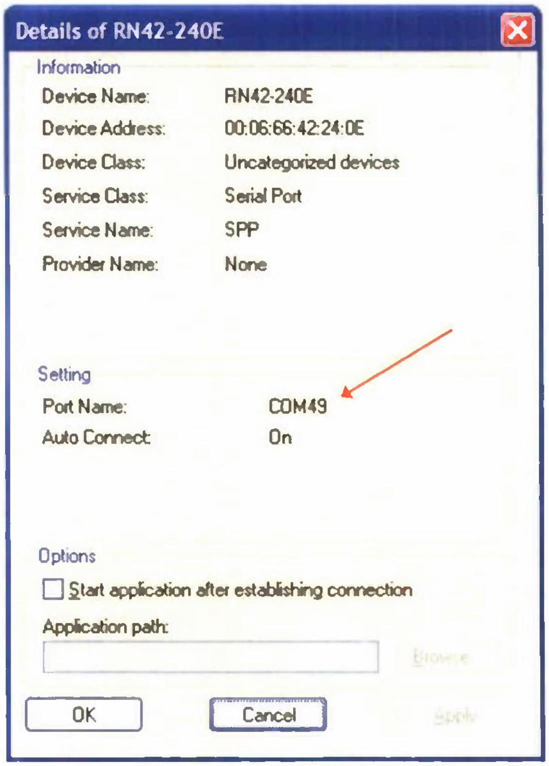


Figure 17. Finding the COM Port for the Sensor via the Toshiba Bluetooth Control Panel

2. Start the DHMS Software on the PC. On the PC, start the DHMS software application. The program is titled EcgDisp.exe.
3. Set the Serial Port. In DHMS software on the PC, go to the **File** menu and choose **Serial Port...** as shown in Figure 18. In the resulting dialog box, use the drop-down menu to choose the COM port for the DHMS sensor that you are going to use.

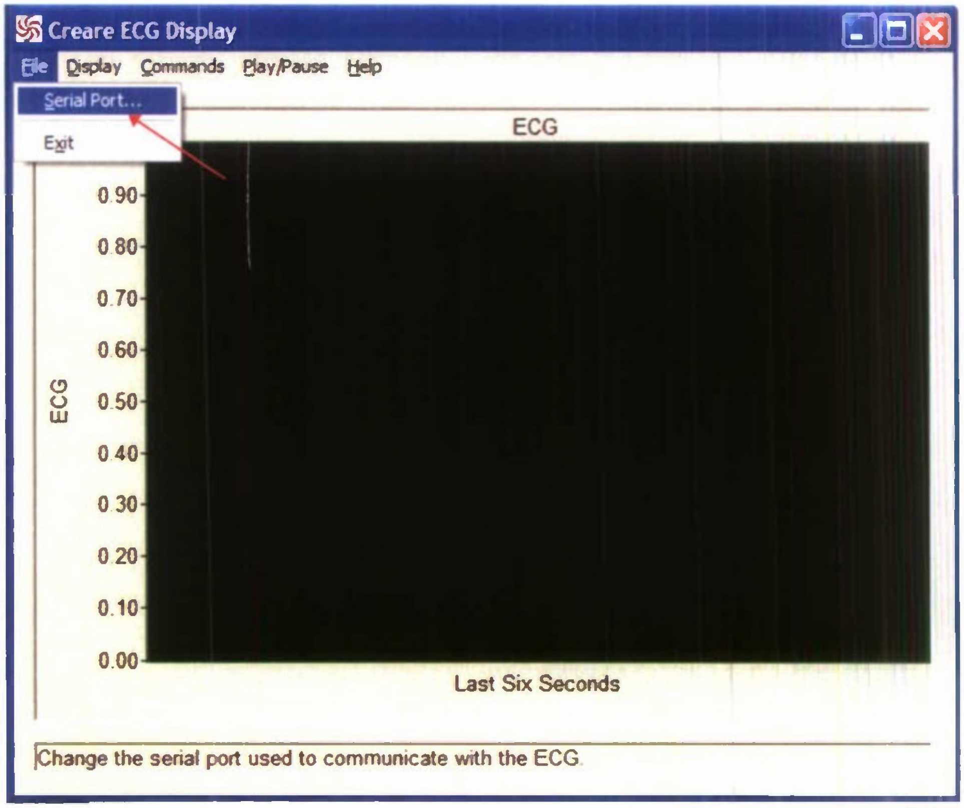


Figure 18. Setting the Serial Port for Communication to the DHMS Sensor

4. Press Play/Pause. In the menu bar, press the **Play/Pause** menu item to start a recording. The DHMS sensor will begin collecting ECG data and transmitting that data to the PC. The DHMS sensor also starts a new pair of data files on its own nonvolatile memory.
5. Confirm Scrolling Data on Screen. When the PC wirelessly receives data from the DHMS sensor, it will display the data within the large ECG display area in the application's window (as shown earlier in Figure 5). At the bottom of the window, the heart rate will be printed.
6. Confirm Blinking LEDs. Embedded within the DHMS sensor itself are small LED lights. When a recording session is proceeding normally, the green and yellow lights will blink. Because the LEDs are embedded within the urethane potting material, the lights can be difficult to see. If the red LED is solidly lit, the device is not working correctly and will need to be reset.

Once a recording session on the DHMS sensor has been started, the sensor will keep recording data to its own nonvolatile memory until it is either explicitly stopped via the DHMS PC application or until it runs out of power. It will keep recording to its own nonvolatile memory whether or not a wireless link to the PC is maintained.

The PC application, on the other hand, will only keep displaying the ECG data as long as the DHMS sensor is functioning and within range. If the diver wearing the sensor goes out of range, the PC application will generate a warning.

3.7 Stopping a Recording Session

When testing is complete, or when you would like to close the data files on the DHMS sensor, it is necessary to stop the current recording session using the DHMS application on the PC. Since this is communicated wirelessly, the DHMS sensor must be within Bluetooth range of the PC and the DHMS must still have power. To stop the recording session, simply press the **Play/Pause** menu item in the menu bar of the software. If the system appears to restart ECG recording, simply press **Play/Pause** again.

At this point, the LED lights embedded within the DHMS sensor will stop blinking.

3.8 Downloading Recorded Data

Data recorded on the DHMS sensor is downloaded to the PC wirelessly. Therefore, to download the data, the sensor must still have power and be within Bluetooth range of the PC. The sensor can still be on the diver's body, it can be off his body, or in can be in the dock.

For short data files (such as the heartbeat files), it is very useful to be able to download the data while the device is still on the subject's body. This allows you to check the quality of the data before removing the device from the subject's body in the event any test needs to be repeated.

For longer data files (such as the raw ECG data files), the downloading process can take a long time. A four-hour recording of the raw ECG data can take one hour to download. To make sure that the sensor does not run out of power during the download, we recommend only starting these long downloads when the sensor is in its dock being recharged.

The procedure for downloading data is:

1. Start the File Download Tool. In the DHMS software on the PC, start the file download tool under the **Commands** menu as shown in Figure 19.

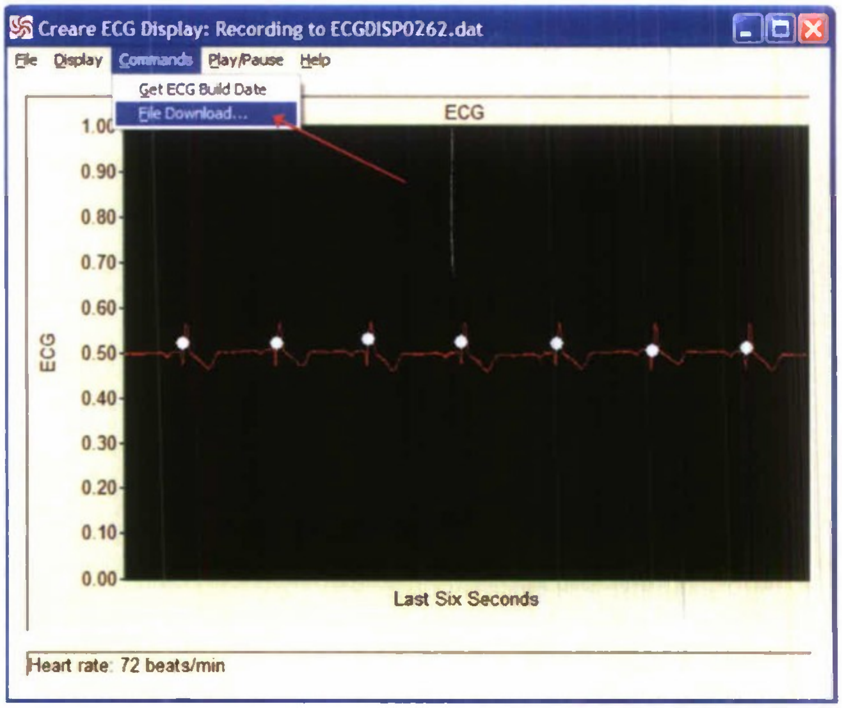


Figure 19. Starting the File Download Tool in the DHMS Software

2. Select Files to Download. As shown earlier in Figure 6, the DHMS software presents a listing of all of the data files stored in nonvolatile memory on the DHMS sensor. Each recording session has a pair of files. The raw ECG data is stored in the .dat file and the heartbeat (and heart rate) data is stored in the .hb file. Select the file that you would like to download. Multiple files can be selected holding down the **Shift** key while clicking.
3. Download the Files. Pressing the **Download** button will bring up a dialog box asking you where to save the downloaded data. After choosing a location, the files will start to download. Since the download rate is only 7 to 8 kB per second, large files can take a very long time to download.
4. Delete the Files. If you choose to, you can elect to delete files from the sensor. The nonvolatile memory is large (2 GB), but it can become confusing if there are many data files remaining from previous tests. Therefore, once you have confirmed the validity of the downloaded data, it is recommended that the data files be deleted from the sensor's nonvolatile storage. Simply select the file(s) and press the **Delete** button.

To read the data in the files downloaded from the sensor, see Appendix A which discusses the file format and shows example code.

3.9 Cleaning and Storing the Sensor

After a test, the sensor should be cleaned to remove any adhesive, dirt, sweat, or other fouling material. The sensor can be cleaned with soap and water and with alcohol pads, paying particular attention to the ECG electrodes and the small gold pads used to recharge the device.

Once dry, the sensors should be stored like any electronics—in a relatively dry environment at moderate temperatures.

Note that you cannot turn the sensor off. It continues to operate until its batteries are drained. Therefore, prior to the next recording session, the sensors will have to be placed in their dock and recharged.

3.10 Resetting the Sensor

If the DHMS sensor becomes nonresponsive or if it's embedded red LED is solidly lit (i.e., not blinking), then the sensor may need to be reset. Built into the sensor is a noncontact hardware reset switch. The switch is activated by a small magnet which has been provided with each dock, attached via a short tether. To reset the device, slide the magnet along the left side of the sensor as shown in Figure 20. When the magnet activates the switch, its LED lights blink to confirm the reset.

Figure 20. Using the Tethered Magnet to Reset the DHMS Sensor. The sensor does not have to be on the dock to be reset. The magnet is tethered to the dock for convenience.

Note that resetting the device reboots the sensor's embedded software. If the device is actively recording, it will stop its recording session without losing any of the data that was previously written in that session. Any other data stored in nonvolatile memory (such as data from previous recording sessions) will be similarly unaffected by the reset. There should be no data lost by resetting the device.

APPENDIX A: DATA FORMATS

For each recording session, the DHMS ECG sensor creates two data files—one holding the raw ECG data and one holding information regarding the heartbeats.

RAW ECG DATA FILES

The data file with the raw ECG data has the .dat extension. Once downloaded to the PC, it is a binary file with two 16-bit unsigned integer (unit16) values for each ECG sample. The first value is the actual digitized ECG value. The second value is a monotonically increasing sample counter. The sample rate for the ECG data is 500 Hz.

The binary data file can be read by any analysis program capable of reading general binary data files. To read this data into MATLAB, for example, one can use the following commands:

```
%% for DAT files (ie, raw ECG traces)
fid=fopen('DM_0001.dat','r');
foo = fread(fid,inf,'uint16'); %unsigned 16-bit integer
rawECG = foo(1:2:end);          %this is the raw ECG
sample_counter = foo(2:2:end); %monotonically increasing counter
fs_Hz = 500; %the sample rate for this data is 500 Hz
```

After reading in the data, one can confirm the integrity of the ECG recording by looking for gaps or discontinuities in the sample counter. If there are no gaps in the counter (except for normal wrap-around to zero once it counts to 2^{16}), then the ECG data was recorded correctly without any drop-outs.

HEARTBEAT DATA FILES

The data file containing the heartbeat and heart rate data has the .hb extension. Once downloaded too the PC, it is a binary file with two 16-bit unsigned integer (unit16) values for each detected heartbeat. The first value is the instantaneous heart rate in beats-per-minute (bpm). This heart rate is computed simply from the difference in time between the current heartbeat and the previously-detected heartbeat. The second value recorded for each heartbeat is the sample index of the detected beat. The value is on the same counting base as the sample counter stored in the raw ECG data file.

The binary data file can be read by any analysis program capable of reading general binary data files. To read this data into MATLAB, for example, one can use the following commands:

```
%% for HB files (ie, heartbeat information)
fid=fopen('DM_0001.hb','r');
foo = fread(fid,inf,'uint16');  %unsigned 16-bit integer
heartRate_bpm = foo(1:2:end);  %heart rate in beats per minute
heartBeat_ind = foo(2:2:end);  %sample index of the heartbeat
```

If you choose to plot the heartbeat detections on top of the raw ECG data, you might notice that the detections do not align exactly with the R-waves in the raw data. The heartbeat detections fall behind each R-waves. This lag is due to the latency of the filters used in the sensor's heartbeat detection algorithms. The lag is frequency dependent, so there is no exact simple correction for this lag. An approximate correction to make detections appear on top of their corresponding R-waves is to move the detections earlier by 31 samples (~62 milliseconds).