Human factors design for the BMIT biomedical beamlines

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Abstract. Operation of a biomedical beamline poses a unique set of operational and instrumentation challenges for a synchrotron facility. From proper handling and care of live animals and animal tissues, to a user community drawn primarily from the medical and veterinary realms, the work of a biomedical beamline is unique when compared to other beamlines. At the Biomedical Imaging and Therapy (BMIT) beamlines at Canadian Light Source (CLS), operation of the beamlines is geared towards our user community of medical personnel, in addition to basic science researchers. Human factors considerations have been incorporated wherever possible on BMIT, including in the design of software and hardware, as well as ease-of-use features of beamline control stations and experiment hutchs. Feedback from users continues to drive usability improvements to beamline operations.

1. Introduction
The Biomedical Imaging and Therapy (BMIT) facility at Canadian Light Source (CLS) consists of both a bending magnet (05B1-1) and an insertion device beamline (05ID-2), along with laboratory infrastructure [1,2]. BMIT delivers a comprehensive set of synchrotron-specific imaging and therapy techniques, in support of research primarily in human and veterinary medicine, agriculture, and other biomedical areas.

Human factors is an extensive field in which knowledge about human capabilities and human interaction with technology is used as a basis for design of technical systems and equipment [3,4]. A guiding human factors principle is “design for use”: information presented to the user must be accurate, complete, and organized; tasks should be simplified as much as possible; standardization should be used to reduce misinterpretation; memory dependence should be reduced as much as possible [5].

Human factors considerations have been incorporated on BMIT wherever possible, including in the design of software and hardware, as well as ease-of-use features of beamline control stations and experiment hutchs. Feedback from our users continues to drive usability improvements to BMIT.

2. BMIT Software: Human Factors Considerations
BMIT beamline software is designed for ease-of-use. An abstraction layer in the software hides details of component operation, simplifying beamline use for the researchers. Examples of this abstraction include the “Beam On / Beam Off” feature, and software to set beam dimensions at the sample location.

2.1. Beamline Operation Screens
All important beamline information is summarized on the beamline's main screen. This main screen is also used to launch all beamline operations screens. Ease-of-use features include:
- A dashboard of indicators quickly alerts the user to any problems with machine protection components (cooling water flow levels, temperatures, vacuum levels, filters not in position etc.).
- Currently selected beamline settings are summarized on the main screen.
Screens include 3D beamline models, showing staff members the exact location of any problems.

Figure 1. BMIT 05B1-1 beamline main screen.

Figure 2. Water flow status screen for the first optics hutch of BMIT 05ID-2 beamline.

2.2. Beam On / Beam Off
For the BMIT 05B1-1 beamline, bringing the beam into the POE-2 (primary optical enclosure) experiment hutch requires opening a sequence of four safety and photon shutters, in the correct order. Before personnel can re-enter the experiment hutch, shutters have to be closed in the reverse order (figure 3). Using the Beam On / Beam Off pushbuttons opens / closes all required shutters in the correct order, making operation of the beamline analogous to using a light switch.

Figure 3. Beam On / Beam Off simplifies beamline operation.

2.3. Beam Size at Sample Location
The objective of the user is to set the dimensions of the beam that will pass through the sample. To determine the horizontal and vertical slit positions required in order to deliver the desired beam size at the sample, beam dimensions must be calculated based on horizontal and vertical divergence of the beam, and distance of the sample from the slits. BMIT’s “Beam Size at Sample Location” does this automatically, requiring only that the user set the required beam size, and the sample location. Distance markings along the floor of the hutch and the surface of the optics table aid the user in determining the sample location.

2.4. Logit - Experiment Setup Database
BMIT’s Logit application allows staff and users to capture all details of their experiment setup and operating conditions. Information is both recorded to a database and summarized as an “automated logbook” entry for the users. Automatically captured data includes all beamline parameters, as well as information about the detector and detector settings. This information can be supplemented with manually entered data about the sample and the purpose of the experiment. The database is then searchable by staff, enabling them to exactly recreate experiment conditions for the next beamtime of a particular user, to determine settings used for experiments of similar types etc.

Logit is a customized application specifically designed for the BMIT beamlines. In terms of functionality, Logit falls mid-range between simple log files of beamline settings used by a few CLS beamlines, to full beamline automation systems in use at others [6].

3. Experiment Control Station: Human Factors Considerations
The BMIT experiment control stations are designed to provide the beamline user with easy access to
all information and controls needed both to run their experiment and to monitor conditions, all within arm's reach while seated at the control station.

Features of the 05B1-1 beamline control station include:

- Video cameras within the hutch provide multi-angle viewing of the animal or sample and positioning stages. Views from up to eight cameras can be displayed.
- Control Station monitors provide sufficient area for clear display and control of equipment.
- Wireless remote light switches allow researchers to turn hutch lights and positioning lasers on and off while remaining seated at the control station.
- Software provides BMIT staff with the ability to monitor and adjust hutch temperatures, differential pressures, and air flow rates.

4. Extensions to Access Security and Interlock System (ACIS)

4.1. Zone By-pass Button
During live animal experiments, the ability to enter the experiment hutch for a brief time and then to leave quickly is required. This access may be necessary, for example, to adjust anaesthesia settings or to aid an animal in distress. To facilitate this quick access and fast exit, a Zone Bypass Button (ZBB) feature has been implemented as an extension to the typical Access Security and Interlock System (ACIS) at CLS [7]. While ZBB is pressed and held by one researcher who monitors hutch access, a second researcher can enter the hutch without breaking lockup. This permits the researcher to tend to an animal without extending the time the animal remains in the hutch or requiring that the animal be subjected again to the loud warning alarm and flashing strobe light of a typical lockup.

The safety shutter must be closed in order for ZBB to be enabled, and shutters are then disabled while ZBB is held. When the researcher leaves the hutch, the hutch door is closed, ZBB is released, and shutters are immediately enabled without requiring that a lockup sequence be performed.

4.2. Ability to close hutch door from inside the hutch
For BMIT, an extension to the typical ACIS system was implemented to enable hutch doors to be closed from inside the hutch. There are a number of scenarios in which this functionality is required. For example, this enables a researcher to enter the hutch to tend to an animal, closing the hutch door behind him/herself to prevent any possibility of animal escape.

Closing hutch doors from inside the hutch immediately breaks lockup, ensuring that there is no possibility that shutters can be opened when a user has closed him/herself in the hutch.

5. Ease-of-Use Features – Hutches
Ease-of-use features in hutch design and layout on BMIT include:

- **Viewing window in hutchess**: Typical hutch design was modified to add a viewing window to each BMIT experiment hutch. Windows have lead oxide content of 65 per cent by weight.
- **Laser positioning system in hutch**: Two laser systems within the experiment hutchs provide an easy way for researchers to confirm positioning of the animal or sample.
- **Touch screen panels**: A touch screen panel located directly outside the hutch exit door provides an easy way to open shutters immediately after leaving the hutch.
- **Flexible beamline design**: From the beginning planning phases, the BMIT beamlines were designed to accommodate as many modes of imaging and therapy as possible, and to include enough space within hutchs for users to set up their own experiment equipment [8].

6. Time Saving Features for Sample Positioning

6.1. Radiological markers
Radiological markers and x-ray rulers are used to indicate the region of interest within an imaged area. Use of these markers can save valuable time in selecting and adjusting the area to be imaged.
6.2. Laser-based fiducial system
Alignment of the region of interest of the animal or sample with the beam is usually done inside the experiment hutch, consuming valuable beamtime. A laser-based fiducial system has been designed to enable researchers to position the subject and define the exact region of interest outside the hutch. The system defines the target location relative to the centre of the “C” of the C-arm of the positioning system, and the corresponding required movements of the six positioning stages of the MRT Lift to precisely translate this position to be in the centre of the x-ray beam inside the hutch [9].

![Figure 4. Design of fiducial pre-alignment system.](image)

![Figure 5. Example of resulting required MRT Lift stage positions to place region in beam.](image)

7. Planned Future Enhancements
Planned enhancements to BMIT include:

- **Integrated region-of-interest (ROI) system**: Defining the ROI using the in-hutch laser positioning system will automatically set required positions of stages, slits, shutters etc.
- **Automatic beamline configuration for K-edge imaging energy**: Imaging energy will automatically be set based on specified contrast agent. System will then automatically position all downstream beamline equipment to be in the path of the resulting deflected beam.
- **Dose minimization system**: Software will predict delivered dose based on selected beamline settings and experimental parameters, allowing researchers to test settings adjustments to find optimal conditions. Beamline settings are then automatically applied.
- **Implementation of a PACS (picture archiving and communication) system for data storage and retrieval**
- **Virtual beamline**: Spectrum, flux and power hitting each component will be displayed on a model of the beamline. System will allow users to define required imaging parameters (filters, slit positions, exposure times etc.) in advance of the experiment.

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