# Wearable Digitization of Life Science Experiments

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## Abstract
Experimental work in Life Sciences is done with protective garment to contain harmful agents and to avoid contaminations. This limits the amount of documentation that can be done during experimentation, since pen'n'paper and other equipment is hardly allowed in those environments. Relying on her memory, the scientist has to reconstruct the important details of her experiment later on. Wearable computers, like Google Glass or wrist-worn Smartwatches, can enhance the scientist's ability to record key information while conducting his experiment. Especially the possibility of hands-free, and implicit interaction with the wearable system creates new possibilities for augmenting the scientist's memory.

## Author Keywords
Life Science, Documentation, Wearable Computing, Google Glass, RFID, Assistance

## ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

## Introduction
Vannervar Bush's vision[3] of a scientist able to record his activities and access information while conducting experiments is becoming a non-prototypical technical

possibility. In Bush's scenario a scientist "with a walnut-sized, forehead-mounted camera... moves about and observes, he photographs and comments. Time is automatically recorded to tie the two records together." Those records can later be reviewed, combined and further analysed on a personal computer. 70 years later, wearable devices like Google Glass are enabling scientists to enjoy the reality of this vision.

In life sciences, especially in laboratory work, wearable devices have the highest potential to augment the scientist's memory. Not only does the scientist wear protective garment (cf. Fig. 1), but she is also continuously manipulating the environment with her hands. Cutting organic material, mixing fluids, calculating dilutions, taking notes, measuring quantities, labelling samples, operating machinery etc. hardly leave time for capturing the ongoing experiment digitally. Especially when considering "traditional" touch input methodologies. Those require the experimenter to take off his garment to avoid contaminations. Devices that can be worn underneath and provide non-touch input/output modalities, or continuous sensor recordings allow to capture an experiment easily while conducting it. The question arises how this im- and explicit interaction can supplement current work-practises.

Reproducibility of experimental research in biology is of major concern. A recent report has found that results of pre-clinical cancer research[2] could be duplicated in only 6 of 54 cases. Reproducing experimental research requires the exact restoration of environmental conditions, which first of all requires them to be documented in a protocol. However these protocols are routinely written "offline", i.e. after the experiment has been conducted and reconstructed from memory. Important information could have already been lost or simply overlooked. Hand-written laboratory notebooks still serve as the main archival mediums for experimenters[11]. These contain not only notes, but also figures and print-outs, providing a very flexible system. Compared to digitized information these notes are hard to organize later, search, copy and share. Documentation capabilities, and therefore reproducibility of experiments, can be enhanced with wearable technology.

**Figure 1:** A scientist working in a laboratory with an L1 security level, taking notes on the current workflow while conducting an experiment.

In this paper we describe possible interaction designs for a combination of wearable devices in wet laboratory environments. After presenting related work on digitizing laboratory work, we describe interactions geared towards extending short-term memory (STM) during an experiment, as well as long-term memory (LTM) for archival purposes. We conclude with an outlook on future challenges.

## Related Work

The necessity of computer-supported electronic notebooks [4] has been observed in several research projects before. Related work aims at providing interactive displays, recording equipment in the environment (such as augmented containers, cameras, or microphones), and introducing extra input methods in the lab (such as keypads, photo capture buttons, barcode scanners) to fulfill this necessity.

The *LabScape*[1] project was an early investigation in an ubiquitous computing platform to help scientists and students to access and capture information in the laboratory. It uses interactive flowchart diagrams to vizualize experiment procedures and annotate ongoing procedures that are accessed via a touch-tablet, barcode scanner, numeric keypad and wireless keyboard.
The *Combechem* project proposed the Semantic Smart Laboratory[6], a system for supporting chemistry experiments focused on providing a flexible ontology for describing experiments and storing them for later retrieval. The *Prism*[11] project reports on a study of biologists' work practices and presents a hybrid system using hand-written notes as well as digital content to capture, visualise and interact with activity streams in the laboratory. The *a-book*[8] combines a tablet and PDA to capture paper notebook writing and merging the physical and electronic information involved in biology laboratory notebooks. A system to support biologists in the field was presented in the *ButterflyNet*[13] project, in which handwritten notes are captured and combined with visual and audio information for later access. The *eLabBench*[12] and *Biotisch*[5] take the integration in the laboratory further by replacing the traditional workbench with a tabletop system that presents information on the bench's surface, also allowing interaction, sensing of augmented objects (e.g, racks of test tubes) and taking pictures of the whole setup with an overhead camera. The gathered information is stored in a wiki-like notebook for retrieval.

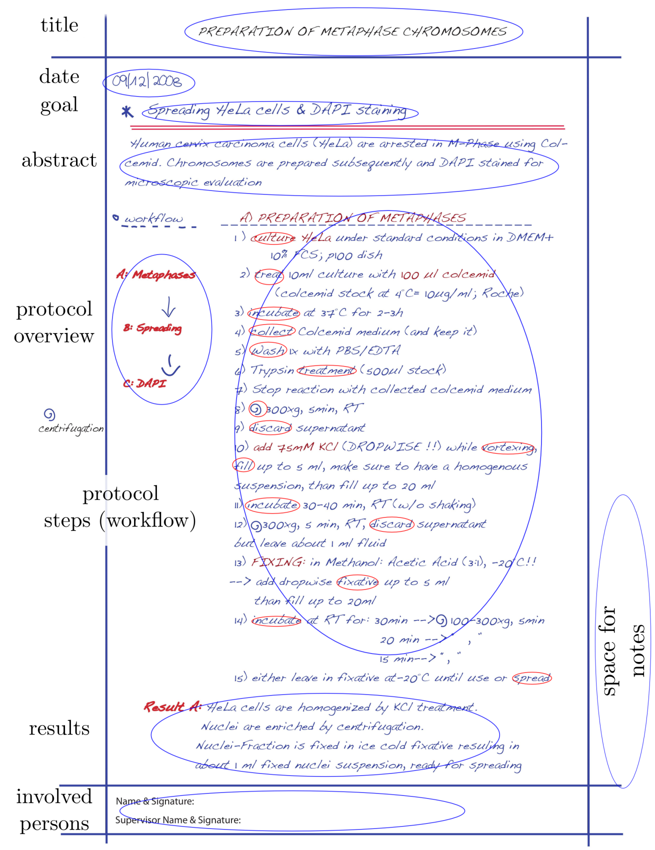


**Figure 2:** An example laboratory protocol page.

These systems form the basis of augmenting the memory of a scientist in the laboratory. By providing the means to design an experimental workflow beforehand, make recordings, taking notes and storing information about augmented objects they support the scientist remembrance capabilities. In contrast, our proposed system focuses on the largely unexplored area of supporting and augmenting such laboratory tasks by means of a lightweight wearable system that requires little to no interference with the laboratory environment and its inventory, and support hands-free operation. We argue that this approach of augmenting the *researchers* instead of the laboratory, has many advantages, not in the least the fact that the users in existing laboratories can opt to keep on documenting experiments with traditional methods. The concepts of wearable workflow monitoring, documentation access, and assistance have been thoroughly explored by research in other domains[7, 9, 10] though. Key components of the envisioned system in this paper were also inspired by the Remembrance Agent (Remem) project at the MIT more than a decade ago. We are however focused on the specific scenario of documenting and assisting wet laboratory tasks, where contextual knowledge is well-defined, and tasks and information have additional constraints that the lab environment poses.

## Wearable Digitization of Life Science

Life science experiments can be categorized into two major themes: *establishing* a new protocol and *reproducing* an already existing protocol. When establishing a new protocol, interaction with the system will be more explicit since an important aspect is the documentation of the experimental steps. The scientist will be more content to invest an additional burden to digitize the taken steps. This is different when reproducing an already established protocol. Depending on the familiarity of the scientist with the protocol, the less information will be queried and recorded *explicitly*.

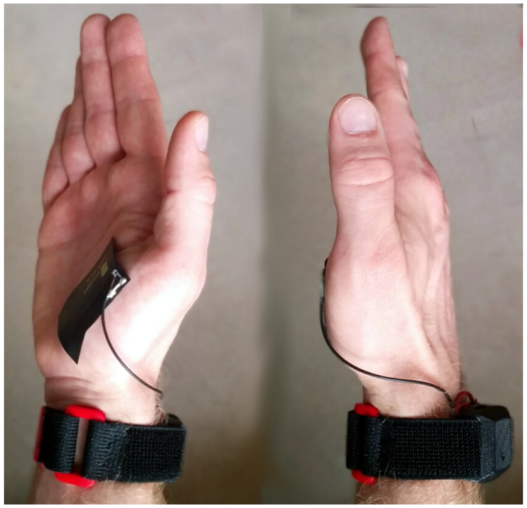

**Figure 3:** The prototpyical RFID bracelet used for implicit identification of labelled materials/containers. A wrist-worn accelerometer logging device (called HedgeHog) is also visible.

There are also combinations of both cases, where the scientist re-establishes only a fraction of the original protocol. An experiment is therefore most probably commemorated as a fixed procedure of steps performed from a set of organic/chemical material using machinery/tools to quantify some physical property, exposing the material to varying physical conditions. Memory augmentation techniques therefore should revolve around those specific steps. During the Labscape[1] project these steps were categorized as:

**Combination** forming a single compound from several other compounds.

**Dispensing** non-selectively extracting a sub-volume of a compound.

**Separation** selectively extracting a sub-volume based on a range of some physical property, e.g. by molecular mass during centrifugation.

**Incubation** exposing a compound to specific, possibly varying, environmental conditions. This includes varying salinity, temperature, humidity, acidity etc.

**Detection** recording physical properties of the resulting compound, either by images, natural language description, spectral images, optical density etc.

**Labelling and Identification** naming samples or compounds in containers and identifying them.

A system consisting of a head mounted display (HMD, Google Glass), a Smartwatch that records the wearers motion and includes an RFID-reader can support the scientist during those steps. STM can be supported through interaction with Glass by providing details on the protocol at hand, and by accessing previously recorded information. The scientist's LTM can be supported by providing different recording capabilities, indexed by various memory cues. Those cues are described in the following subsections.

*Wrist Motion Sequences*

Laboratory work usually involves a lot of repetitive manual work. Compounds are formed by pipetting, test tubes are collected and put into different machinery for incubation and many more actions are performed while conducting an experiment. This process can take hours to days to complete. Smartwatch like devices (cf. Fig. 3) can record the wearer's motion with high fidelity and accuracy for long periods of time. From this motion certain actions can be identified automatically (for example pipetting) and stored as memory cues.

This would allow the scientist to query the whole process he was involved in while conducting an experiment. For example checking all recordings that have been done just before or after pipetting. Or jumping to the spot in a video log where containers have been openend/closed. Alternatively, the scientist could access recordings from previously done protocol repetitions by this automatic recognition. With an HMD even while he is involved in the experiment, with current information displayed based on the recognition results from wrist motion.

*Labelling and Identification*

One important aspect of laboratory work is the management of different compounds used to conduct the experiment, including samples, chemicals and other materials. With a wrist-worn RFID-reader and tagged containers, information on handled materials can be recorded almost automatically. Alternatively, fiducial markers and a wireless label printer can be used to achieve identification. This in turn can be used to provide cues to navigate recordings ("when have I last worked with sample X?"). It can also provide additional information for detecting actions for an increased activity recognition accuracy, e.g. when holding a pipette the wearer is probably not pouring material from a large container.

Currently containers are labelled with hand-written mnemonics. These labels are sometimes only readable by the originating person, or, after having spent time in the freezer, are not readable at all. Also, for lack of space on those containers, they are sometimes only color-coded and a table with additional information is created on the fly. This kind of manual LTM augmentation, can also be achieved with wearables.

*Notes/Video/Photo Recordings*

Biologist work in environments where protective garment is required. Both for protecting themselves from possibly harmful agents and also protecting the experiment from outside contaminations. However, recording details about the work at hand like taking notes, video or photo recordings requires them to use their hands. In circumstances where the used agents are not harmful or contaminations can be ruled out, they only need to grab a pencil or a digital camera to create this documentation. In laboratories with a security level above L1, where this behaviour is not allowed, more effort needs to be put into documenting experiments. Here, notes and the protocol workflow need to be remembered. Looking up documentation or writing notes is too much of an effort, since all protective garment would need to be put down.

Having a system like Google Glass, which not only allows to view information, but also provides a camera like the one in Bush's vision allows scientist to record and review their experiments in a hands-free manner. The scientist is able to take pictures of the organisms and compounds he creates, recording and commenting key observations while they happen. More radically she could video record the whole experiment and highlight key observations. This could augment her short- and long-term photographic memory. Cues could be provided by spoken text, recognized actions of the wrist, or simply time-based - allowing the scientist to review work a few minutes, hours, days ago or finding executions of similar actions. This could not only be done when reviewing their work later on a PC, but also during the experiment while interacting with Glass.

## Future Challenges

A wearable system, consisting of an HMD and a sensor-enabled Smartwatch, allows scientist to digitally record their experiments without any modification to the laboratory environment. Some of those recordings can happen implicitly, for example by video-recording the whole experiment. The scientist is then able to review those recordings on a PC, after she has conducted the experiment. This is either done for archiving purposes or to elicit important information for repeating the experiment. The major challenges for such a system of wearables include:

**User Interface** of the wearable system, especially regarding that the scientist to be supported is engaged in an experiment. The system should therefore keep interaction times short, and adapt to the current workflow as good as possible.

**Information processing** may allow to provide the recorded data in a way that automates parts of writing a laboratory protocol. Especially for reviewing purposes the question arises, which memory cues are essential for the scientist. Will she/he query for taken *actions*, used *samples/material*, *time of day*, *symbolic locations* in the lab or other memory cues? Can these memory cues be used to compare repetitions of experiments, maybe highlighting differences in their execution?

**Legal problems** can arise for certain laboratory environments. Especially laboratories financed through industry are usually obliged to secrecy by their partners. This includes video and audio recordings of lab benches and workflow materials of experiments. The *scientist* is held responsible if such data is shared. This should be reflected in the technical architecture.

These challenges are not only present for a memory augmentation system in the life sciences, but in other scenarios as well. The solutions used in the context of biology laboratories might prove useful elsewhere.

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