A system for work efficiency improvement by user activity analysis and feedback

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Abstract. The efficiency of work processes is an important factor in company success and economic growth. Many companies are still using inefficient processes due to a lack of knowledge or defective implementation. The processes that rely upon intellectual labor, such as software development or management activities, are often undocumented, which makes them difficult for optimization. We present a method of tracking of the psychophysical state and activities of employees and providing them feedback intended to optimize the work process for work efficiency and user well-being. We use recorded traces of the user actions, including the created artifacts, and detect the psychophysical states on the base of data acquired from portable devices, including fitness wrist bands and EEG sensors. The method has been implemented in a hardware and software system whose architecture we describe in this paper. The system has been developed for the software engineering industry, but the method itself applies to other domains as well. We show how to adapt the proposed approach to different types of working environments and business processes. As the efficiency of the work process is a major factor contributing to the industrial and economic modernization, we discuss the ways to apply the method to business processes that are important for the Arctic region of Russia.

1. Introduction
Competitiveness requires companies to implement effective business processes. At the same time, many existing business processes lack the desired efficiency. There are several possible causes of organizations performing inefficiently.

1. The organization has no efficient process for a specific activity. It is the case when the company does not optimize its business processes at all, e.g., it implements an established practice without any analysis nor improvement. Other causes include the missing knowledge about the equipment capabilities, insufficient level of automation, and the lack of resources required to complete a task effectively.
2. Knowledge management procedures are missing or fail. Individual workers may know how to perform their job efficiently, but there is no systematic way to transfer this knowledge to other employees. In the best case, the knowledge is transferred informally from masters to apprentices, while in the worst case, people may never share the know-how. This situation may lead to a complete loss of technologies when no one knows how to make a previously mass-produced item.

3. There are efficient and documented business processes, but employees fail to comply with them properly. Incorrect implementation or skipping of process steps leads to defective end products or require workers to spend extra time for correction.

The first two causes are associated with the first organizational issue identified by Sanders and Hild [1]: “Business functions are neither defined nor managed as processes.” The main property that unifies these issues is the lack of objective knowledge about the business processes and their performance.

Closely related to the business process optimization is the problem of efficient use of employees' skills and capabilities. There are two main tasks a company may want to solve.

1. Expertise identification: is there somebody in the company who has a specific skill or is knowledgeable in a specific area? If the organization is searching for new markets, it may formulate the question in another way: in what areas does the company have expertise? It is hard to answer these questions even for organizations of moderate size, but the ability to identify the available expertise is crucial to the company’s success: “The essential thing is no longer the product, with a very short life cycle, or even the service, but the company’s capability of adapting to faster and faster changes, and therefore of mobilizing its expertise and skills as quickly as possible.” [2]

2. Choosing a career path: what is the most effective way to use the skills of a specific employee? How to keep and promote talented employees in the company, i.e., to match employees’ roles with their preferences?

Last but not least, a very important aspect of the work organization is working conditions. They are especially important in arduous work environments, i.e., the Arctic region that has been gaining importance due to its strategic role and new possibilities related to climate change. Even the companies who don’t have to deal with harsh climate or dangerous materials may be interested in working conditions improvement as they directly influence the efficiency of business process implementation. Our hypothesis is that, alongside the obvious security requirements, the management of working conditions should consider individual physiological and psychological characteristics of every employee to use their capabilities better and provide a comfortable working environment. It is especially important in domains where skilled employees are hard to find. For example, a company may set the following goals regarding the individual treatment of its employees.

- Reduce the malevolent factors that lead to undesirable psychophysiological states, such as accumulated fatigue and stress.
- Provide optimized and personalized work and rest schedules for employees.
- Assign to each employee a position that suits best their capabilities.

Implementing these goals requires managers to know about the current psychophysiological state of employees, their actual expertise and performance, as well as the dynamics of these characteristics.

Considering the above, we suppose that an efficient organization has the following properties.

- It implements measurable and efficient business processes.
- It knows and efficiently uses the expertise and skills of its employees.
We also suppose that better and personalized working conditions contribute to better implementation of business processes, as they reduce human errors, and the company itself becomes attractive for more qualified employees.

To attain these goals, the company needs explicit knowledge of two kinds: knowledge about the business processes that occur in the company, and knowledge about the people and the dynamics of their states and activities.

It is possible to obtain knowledge about business processes from several sources, such as:

- Experts: the knowledge that people have about the processes they perform or manage.
- Documents: descriptions of processes in written form such as regulations or documentation.
- Logs of the interaction of people with the work environment.

Interaction logs are one of the most important sources of knowledge. As Matta et al. [3] notes, “In a company, actors produce knowledge because they interact continuously with these dimensions [sign, reference, and sense] that are present in their work environment (interaction with a problem, interaction with other actors, interaction with a situation, etc.). So managing knowledge in a company leads us to support these interactions.” We see interaction in a broad context, including the following interaction types.

- The interaction between users and information systems, which we can record using the information system logs. Each information system implements a set of business processes in a company, but these processes may have no explicit documentation except the information system source code. In this case, we may apply well-known process mining methods [4] to extract the business process model from interaction logs.
- The interaction between users and equipment, or between users and software systems. In this case, business processes are implicit: although we can observe the interaction, we generally don’t know why the user proceeds in a specific way. The process mining techniques work here as well, but the interaction log is much less structured than the log of an information system. A common case here is an unstructured video recording that one has to preprocess before any process model can be extracted. The same techniques may be used to track processes that involve interaction between users.
- The communication between users. When we are dealing with decision-making processes, communication of participants becomes the main source of knowledge about the roles and expertise of actors. In a corporate environment, one may track communication by storing and processing e-mail and instant messenger logs, and by recording meetings. The main obstacle in the task of knowledge extraction is the external nature of these logs concerning a specific process: a single letter may contain information about several processes or no process-related information at all. Usually, there is no explicit process description, and the temporal sequence of messages does not follow the process timeline.

The information about the individual state of a person is also present in the interaction logs. For example, the speed of operations and the number of corrective actions can provide data about the level of fatigue or stress. Other data, especially of physiological nature, should be acquired using the specialized equipment.

In this paper, we limit ourselves to the observable interaction between users and software systems, and to the individual psychophysiological states of users. We discuss the data acquisition and feedback generation in the context of software development teams, although the same method may apply to other domains with the prevalence of the intellectual activities (e.g., to engineering, design, or management). We also discuss the possibility of adapting our approach to other domains, including the activity types common to the Arctic region.
A common framework is necessary to represent and handle the information about the processes the people perform and the individual state of each person. It is necessary to align the individual actions to a common timeline and provide the context for each event observed. We describe a hardware and software system based on the presented approach whose goal is to improve the efficiency of teams and individual users performing intellectual activities.

2. Methods

The development of a system for modeling and improvement of processes based on the behavior of its users requires to specify the set of collected data and the algorithms that should be used to process the data. In this section, we describe our approach to the modeling of user behavior.

To be able to improve the way users work, we need to track two types of data: their actions and their psychophysiological state. There is a potentially infinite number of actions that a person may perform. Thus simple observable actions combine into complex actions that are impossible to interpret without context. To handle this action space, we utilize an activity hierarchy model.

The model accounts for the sequence of events belonging to different levels aligned to the common time scale. Lower levels represent the directly observable events: a user presses a key on a keyboard, starts an application, or changes the pose. These elementary events correspond to higher-level activities. For example, a sequence of key presses results in a new sentence in a document that the user composes, or in an address of a website that the user opens. We can directly observe some of these results as atomic events, provided that we have the necessary software and hardware (e.g., a Microsoft Office plugin that tracks the changes the user makes in Word documents). Other types of events may be added later by an event-processing software that analyses the entire event log using a personalized user activity model corresponding to the set of business processes that the user implements at the workplace (in particular, a hidden Markov model [5], a hierarchical hidden Markov model [6], or a hidden semi-Markov model [7] that detect a specific set of complex activities consisting of several simpler actions). For example, for software developers, the set of inferred activities includes operations on the source code, like the creation of classes and methods, or even more higher-level activities like introducing new functionality or fixing bugs [8]. Thus, we consider these activities as having two roles: they are both states corresponding to lower-level business processes and actions in higher-level business processes.

The psychophysiological state of a person directly contributes to the efficiency and quality of the performed work. We estimate the state using data measurements obtained from the wearable hardware: wrist bands and neuro interfaces. A wrist band provides integral characteristics such as pulse wave, body temperature, and electrodermal activity, and also the movement data using an accelerometer. A neuro interface allows us to obtain and process the EEG data that reflects the activity of the brain. By contrast with the activity logging where each primitive action corresponds to a point on the time scale, wearable devices make measurements periodically. A neuro interface measures the EEG activity with a predefined sample rate, filters and preprocesses the samples, and sends it to subscribers in batches. A wrist band generally uses the same approach, but due to the nature of the measured value, the measurement process takes significant time (e.g., it requires several seconds to minute to accumulate enough data to estimate the pulse). As a result, the psychophysiological state measurements are not directly linked to the actions but have their own schedule. Nevertheless, using the same time scale for both the actions and psychophysiological state metrics allows us to align all these types of data together.

Although signals like temperature and pulse may be directly interpreted, the EEG samples are too low-level to use in the context of the overall user activity. To provide the necessary feedback to the user, we need to compute interpretable aggregate states based on the EEG data, such as levels of concentration, cognitive load, stress, or fatigue [9, 10, 11, 12]. These aggregate values, together with
the directly interpretable metrics of the person’s psychophysiological state, are used as an input to the activity analysis routines and the feedback generation algorithm [13].

The feedback is the signal presented to a person or to another system to affect their actions. For example, if the system detects that the concentration level of a person significantly decreased after a long streak of continuous work, it may propose the user to take a break. A use case of indirect feedback based on the person’s state and actions but provided to another system is flow detection. When a user is in the high-productive flow state [14], it is useful to minimize the distraction factors, as it takes a long time to reenter the flow state after its disruption. Indirect feedback after the detection of the flow state may be used, for example, to disable notifications from the software (like the e-mail client or the instant messenger) or the smartphone, and then turn them on again after the flow terminates.

An example of a sequence of events and states observed at different levels and aligned to the common time scale is presented in Fig. 1.

3. Results
The presented approach has been implemented in a software and hardware system. In this section, we describe its architecture and main design decisions. The main components and connections that form the system are shown in Fig. 2. A more detailed description of the architecture may be found in [15].
Our goal of the system is to improve the efficiency of work processes by providing feedback based on the psychophysiological state and activity of a user. The system is a platform that provides a unified representation of the data, an open protocol for accessing it, and a set of predefined modules to process the data and provide the feedback to the users.

The system stores states and actions in the form of events. An event is a continuous interval of time that may correspond to a specific activity or just to a working session. For each event, we store a sequence of data items produced by generators. A generator is a specialized software routine that gathers data about the user state or activity. This software may run on a personal computer, a laptop, or on a mobile device, and interact with wearable hardware like a fitness band. Multiple generators can work simultaneously to produce a digital trace of the user. The system includes a predefined set of generators that support gathering the following types of data.

- The physiological data measurements obtained from a wrist band, including the pulse wave, body temperature, and electrodermal activity. A custom sensor has been developed to provide these measurements.
- The EEG data from several supported portable neuro interfaces.
- Computer interaction profile, including data about the keyboard and mouse activity, and application usage.
- Application-specific activity, e.g., actions that a software developer performs in an integrated development environment.

The architecture allows the addition of new event sources. The system by itself does not provide facilities to extract events from raw application-specific data such as video streams, but the software that captures and processes the data may submit events to the system using an open protocol or subscribe to specific events.

The system consists of the following parts:

1. **The event database** that keeps track of the observed activity.
2. **The event processing server** that provides access to the event data and computes aggregate data over periods according to a set of models.
3. **Agent software** that aggregates the event data provided by generators and initiates the feedback.
4. **Individual generators** that gather data about user state and activity.

An event is represented using a data structure with a common header and an event-specific content. The common event attributes include:

- Start and end timestamps of the event.
- A timestamp corresponding to the specific measurement.
- The type of the measured value.
- The identifier of the data source.
- The identifier of the user whose data is collected.

Event-specific content depends on the data type. For example, electroencephalographic (EEG) data readings are represented as number arrays corresponding to each of the electrodes, while the events produced during the interaction with a software application contain the symbolic description of specific operations that the user performs.

The data is stored using a relational database. The event processing server makes queries to the data to compute the aggregate metrics that describe the current state and productivity of each user. Agent software interacts with the data recording software and hardware and subscribes to the event processing server to provide event data and get aggregated state description. A set of rules with tuneable thresholds defines the conditions when feedback of a specific type should be provided for a specific user.
Third-party applications interact with the system in two ways: they can produce events that the system stores in the database, or they can consume events and feedback by using the subscription to the event stream. The system administrator should register the application in the database. Each user should grant each application the privilege to access the event stream so that no unwanted application can access the user state and activity data. The authorization component also allows administrators to create groups. A group provides a unified stream of events corresponding to its members. This feature is useful when using the system in teamwork scenarios like meetings or lectures.

4. Discussion

4.1. Adaptation to other activity types

Although the system targets, in the first turn, software development teams, it may be used in other industries as well, as the behavior tracking by itself does not pose restrictions on the observed state and activity types. Here we describe possible ways to adapt the system to jobs other than software development. We identify three aspects of the business processes that pose specific requirements for the behavior tracking method and its implementation.

1. Individual activity, that may be mostly intellectual (e.g., engineers, designers, researchers, managers) or mostly physical (e.g., industry workers, drivers, porters).
2. Group activity: for some business processes (e.g., engineering or driving), the implementation of the process in many cases relies upon a single person. Other specialists, such as construction workers, military servants, or aircraft pilots, need to work together as a team where each participant has a specific role.
3. Communication: there are job functions where communication is the primary tool required to achieve the goal (managers, teachers, physicians), while in other professions, communication is, to a greater extent, a mean to synchronize the knowledge about problems, solutions, and goals.

In the individual activity aspect, the processes with prevailing intellectual activities are harder to observe than the processes that require physical work. In many cases, we can observe physical activity using recorded video streams and video-based activity recognition methods [16], even if the problem of reliable recognition of actions is not yet completely solved. The sequence of actions also provides a relatively complete description of the process. On the other hand, the analysis and optimization of processes that consist mostly of physical activity require us to consider the physical characteristics of the process, such as weights, sizes, distances, and speed, that are difficult to measure using only a video stream. On the other hand, when a process includes an intellectual activity, the primary actions such as questions, decisions, and validation are hidden as they occur inside the person’s mind. We may record only the product of this activity (e.g., notes, drawings, or documents) and the intermediate actions that lead to its creation (e.g., keypresses, or interaction with applications). The current version of the described system contains a set of tools that capture several types of intermediate actions and provides limited insight into hidden states using aggregate psychophysiological metrics. The adaptation of the system to other types of intellectual activity that shows similar intermediate actions is straightforward. Handling of prevailing physical activity requires more complex preprocessing (in particular, implementation of project-specific activity recognition algorithms for video recordings), but is possible. At the same time, when it is possible to describe a business process in terms of explicit actions, as in the case of physical activity, we can apply more sophisticated process analysis algorithms and provide better feedback.

The group activity tracking is not technically very different from the tracking of the activity of a single person. The main difference lies in the process modeling: we need to model not only the sequence of activities but also the interaction between actors.
Communication serves two goals. First, it is a particular case of interaction in group activities and allows modeling using the same methods as for the general group activity interaction. Second, communication may be the main type of activity by itself, so the model should be able to describe its structure. In both cases, we need to apply video, speech, and natural language processing techniques to detect and classify communication acts in artifacts (audio and video records, e-mail messages, chats, documents, etc.) Note that the communication is not necessarily verbal. For example, construction workers would often use signs instead of speech due to the high level of noise, and pictures (e.g., charts or graphs) are common media in written communication. Our system does not currently include tools to handle communication, but it is a work in progress.

Based on the above analysis, we can conclude that the initial orientation of the system towards a specific kind of work processes, i.e., software development, does not prevent its application to other domains. The main requirement is to define the set of observable actions and states which are needed to describe processes in a specific domain and to implement, if necessary, the processing algorithms to capture and detect these actions in the observed data.

Another major direction of adaptation is the integration of the explicit business process models into the processing pipeline. With these models, we can detect the cases of deviation of the performed activities from the required process. It also becomes possible to optimize processes not only informally, using heuristical methods [17], but also algorithmically [18]. There are three main sources of business process models: explicit expert knowledge presented in a formal language such as BPMN or UML; logged sequences of actions and interactions from which a model is extracted using process mining techniques; and textual descriptions of processes in forms of regulations, instructions, or informal communications between people. The first two sources are easier to integrate into the behavior modeling framework, as in these cases, we know the set of actions that form the process, and can extract them from the surveyed activity to match with the existing model or to infer a new process model. Extracting process descriptions from texts is a lot harder as it requires not only to process unstructured textual data but also to create an explicit mapping between language constructs and observed actions that the system stores and processes. The support of explicit business process models is currently being integrated into the described system.

4.2. Possible applications in the Arctic region
A particularly interesting question is the possibility to apply the proposed approach to domains where the work efficiency is crucial to the success of the enterprise. A specific example is the development of the Arctic region. The processes that work well in other regions are often difficult to be implemented in the Arctic due to its climate and limited infrastructure. At the same time, the Arctic region is resource-rich and strategically important [19, 20], so it currently faces the necessity of rapid modernization.

There are several opportunities to improve work processes using the behavior modeling approach. The first way is to improve existing processes and working conditions. The prevailing industry in most parts of the Russian Arctic region is the extraction of mineral resources [19] that requires coordinated physical work of many people and interaction with complex equipment. Tracking the psychophysiological state of workers would allow reducing the risks of accidents, although the possibility of using portable neuro interfaces requires careful study. Activity tracking in this setting becomes more limited, as it seems impossible to use video recording hardware that is easy to install in the office space. Nevertheless, some activity tracking is still possible with the use of motion tracking techniques based on the accelerometer data provided by wearable devices such as wrist bands. Reliable recognition of actions requires models created and tuned to the specific process. Another concern is the problem of connectivity, as the transfer of event streams requires a reliable channel and poses constraints on the bandwidth. There are two possible solutions: processing the data directly on the device that produces them, and the introduction of new generation communication channels such as 5G networks. In the first case, the system should detect and handle only the most important aspects
of individual activity and state of its users, while the high-available connection allows more sophisticated data processing algorithms, e.g., for improving the communication between workers. Both of these solutions can be implemented together.

Another option is related to the gathering and transfer of knowledge about efficient working processes. Collection of activity data and extracting business process models from it provides a way to detect both efficient processes and bottlenecks that could otherwise rest unseen and opens the way to more effective innovation in the industrial sector. Finally, active modernization can reduce the migration of educated people from the region, increasing the opportunities to find the job matching their talents, thus making space to apply the proposed process improvement approach to intellectual work directly.

5. Conclusion

In this paper, we described an approach to the improvement of work efficiency based that relies upon tracking the activity and psychophysiological state of the workers and providing them feedback. We also presented a software and hardware system that implements this approach. Although the primary domain of the system is the intellectual work, especially software development, it is possible to adapt it to other types of business processes and working environment. We suppose that the method, with some modifications concerning the collected data and communications, would be useful to improve the efficiency of the work processes in the Arctic and can contribute to the modernization and economic growth of the region.

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