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Abstract

Wearables (such as data glasses and smartwatches) are a particularly visible element of Industrie 4.0 applications. They aim at providing situation-specific information to workers, but at the same time they can also be used for surveillance and control because they generate data on the work process and sometimes even on movement patterns and vital data of the employees. Wearables technology is at an early stage of development, in which the interests and perspectives of relevant stakeholders, especially technology developers and the management, are of particular importance. This article explores the role of solution developers and their understanding of work processes in which wearables are to be used. It is based on expert interviews with solution developers, academic and company experts. The analysis shows an ambivalent understanding of work: On the one hand, it is characterized by the perception of workers as potential sources of error. It focuses on the optimization of individual workplaces and their ergonomics, while broader questions of work design and work organization are ignored. On the other hand, the technology developers see and discuss the potentials and dangers of wearables technologies with regard to individualization, data protection and control in a differentiated manner.

Keywords: Industrie 4.0, technology, developers, labor process, optimization

JEL classification: J53, M54, O33

Wearable Computing im Betrieb gestalten: Rolle und Perspektiven der Lösungsentwickler im Prozess der Arbeitsgestaltung

Zusammenfassung

Wearables (beispielsweise Datenbrillen und Smartwatches) sind ein besonders sichtbares Element von Industrie-4.0-Anwendungen. Sie sollten situationsgerechte Informationen zur Verfügung stellen, können aber zugleich auch Daten über den Arbeitsprozess – und teils sogar über Bewegungsmuster und Vitaldaten der Beschäftigten – generieren. Die Wearables-Technologie ist in einem frühen Entwicklungsstadium, in dem die Interessen und Sichtweisen der relevanten Akteure, vor allem der Technikentwickler und des Managements möglicher Anwendungsunternehmen von besonderer Bedeutung sind. Der vorliegende Artikel untersucht die Rolle der Lösungsentwickler und ihr Verständnis von Arbeit und den Arbeitsprozessen, in denen Wearables eingesetzt werden sollen. Er beruht auf leitfadengestützten Interviews mit Lösungsentwicklern. Gezeigt wird ein ambivalentes Verständnis von Arbeit: auf der einen Seite dominiert die Wahrnehmung menschlicher Arbeitskräfte als potentielle Fehlerquellen und die Fokussierung auf die Optimierung einzelner Arbeitsplätze und ihrer Ergonomie, während übergreifende Fragen der Arbeitsgestaltung und Arbeitsorganisation ausgeblendet werden. Auf der anderen Seite werden die Potentiale und Gefahren der Wearables-Technologien im Hinblick auf Individualisierung, Datenschutz und Kontrolle differenziert gesehen und diskutiert.

Schlüsselwörter: Industrie 4.0, Technologie, Technologieentwicklung, Arbeitsprozess, Optimierung

JEL Klassifikation: J53, M54, O33

Contents

1. Introduction

Wearables—e.g., data glasses or smartwatches—are a particularly visible element of Industrie 4.0 solutions. Wearables are an interface that promise to link employees to the company IT systems and provide them with situation-specific information, allowing them to work hands-free (Hobert and Schumann 2017a: 4276; Langer et al., 2016).

However, the prominence of wearables in the discussion about Industrie 4.0 largely ignores the fact that this technology is still in the design and development phase as described by Noble (1979; see also Weyer et al., 1997). In this phase of the "social genesis" of technology, the technology's characteristics and usage scenarios are still being negotiated by various actors—solution developers, user companies, works councils, or employees. Most plant-level implementations are still pilot projects, aiming to develop and test the possible uses and implications of wearable technologies.

In this early phase of technology genesis, the interests and perspectives of the relevant actors (in the sense of managerial and engineering ideologies, Noble 1979) play a key role. In this article, we focus on the role of solution developers—mostly young start-ups—and on their understanding of work and work processes within which wearables are being used. In doing so, we address three specific questions:

1. How do solution developers understand the motives and objectives of client companies with regard to the introduction of wearable computing?
2. What understandings of work and employee participation prevail among the solution developers, and how does this affect the usage scenarios of wearables?
3. What opportunities and limits related to the implementation of wearable technologies do the solution developers recognize?

Our contribution builds on the social construction of technology (SCOT) and labor process theory (LPT) perspectives, and discusses the current development phase of wearables as a process of creating and stabilizing technology. This introduction is followed by a brief introduction to the evolution of wearable technology (Section 2). In Section 3, we discuss our theoretical framework and the existing research on management concepts and engineering ideologies in the context of Industrie 4.0. After presenting the data and methods of analysis in Section 4, Section 5 discusses our insights from the interviews. In Section 6, we present the conclusions of the presented analysis.

2. Wearables: Technologies and use cases

According to Hobert and Schumann's definition, wearable computers are "standalone devices worn permanently on the body that allow a hands-free use and a spontaneous, sustained interaction with the user" (Hobert and Schumann 2017b: 4). Examples include data glasses (such as the Google Glass), so-called smartwatches, or gloves equipped with sensors. Such devices have gained relevance primarily because of their embeddedness in company IT systems. This embeddedness enables the flexible provision of information from databases, knowledge management systems, manufacturing execution systems (MES), and enterprise resource planning systems (ERP). At the same time, the devices, which are worn on the body, allow companies to constantly localize and control workers' movements—including taking measurements of bodily functions, which can be integrated into performance control systems. Through the wearables, the employee—as a living body—becomes a part of the network. Wearables are thus a specific form of mobile assistance system, with such systems considered a central element of the Industrie 4.0 concept (Butollo et al. 2018; Niehaus 2017; acatech 2016).

The development of industrial wearables dates back to the late 1980s. Baumann (2013) refers to a project developed by Boeing in 1989, which used augmented reality glasses to support the assembly of wiring harnesses for aircraft (see Mizell 2000), as the first noteworthy industrial implementation of the wearable technology—although the technology was, in fact, never fully put into operation. In the 1990s and 2000s, further projects were launched in the industrial sector (especially in product design and maintenance)—but, again, not one was successfully operationally implemented (Regenbrecht et al., 2005; Barfield et al., 2001). One noteworthy exception is the WearIt@Work project (see Pezzlo et al., 2009), in which wearables were tested in real-life production (Skoda) and maintenance (EADS) conditions. Yet as Regenbrecht et al. (2005) and Baumann (2013) have pointed out, the available sensors and other devices proved to be error-prone, unergonomic, and expensive. This was especially true for the data glasses, whose field of vision, image presentation, and wearing comfort fell far short of the demands of industrial work. For individuals, using wearables in the 1990s meant carrying heavy displays on their heads and heavy batteries and computing units on their bodies. Xybernaut, a company founded in the 1990s that produced belt-wearable computers that could be used to operate smart glasses or portable displays filed for bankruptcy in 2006 when it became clear that the anticipated wearables market had not emerged (Baumann 2013). And while in subsequent years, other companies (like teXXmo or Knapp) managed to bring various wearables to the market, their commercial success was rather limited. According to Baumann (2013), by the end of the 2000s, only pick-by-voice technology had managed to establish itself on the market. Pick-by-voice is a "paperless" method of order-picking in which the order is transmitted via headphones and confirmed orally by the worker (Föller 2008: 840).

But the technological conditions for deploying wearables changed in the 2010s. The miniaturization of the computers and—perhaps most importantly—of the batteries significantly improved their comfort for wearers. In addition, battery prices fell, while their performance improved. Particularly in the data glasses segment, new models came onto the market (for example Google Glass), which, in addition to being lighter, also offered an improved field of vision and higher-quality graphical representation. Moreover, the advent of the internet of things created the infrastructure that made it possible to connect wearables to enterprise IT systems.

Stimulated by the discussions around Industrie 4.0 and by the financial support provided by national governments or corporate investors, a new stage in the development of wearable technologies has now begun. In the market for wearable computing applications, we can now distinguish between various kinds of involved actors. First, there are the hardware developers—like Google or Vuzix for data glasses (although Google also provides the Android operating system).

Second, there are the pure software developers who integrate wearables into various plant-level usage scenarios—that is, who develop the on-demand software and implement the application at the client company. In addition, there are also cases in which the hardware and the software are developed together—for example, the data glasses integrated into protective helmets produced by Gesis and Zwickau University of Applied Sciences (Hochschule Zwickau 2018), or the Glass@Service research project on the development of data glasses and applications conducted by Siemens. Companies like Microsoft, with its Hololens mixed reality smartglasses, also act as solution developers.

Unlike traditional industrial equipment companies, many wearables-solution developers are start-ups—in fact, all the companies known to us were founded in or after 2009. For this reason, these companies tend to have rather limited industrial experience. It is also worth noting that the development of the startup business model by the solution developers was closely related to the technological competitions organized by various large corporations. The prize money won in such competitions was often used by startups as a source of early financing. For example, two of the interviewed startups mentioned that they have participated in competitions organized by large American corporations. One of the startups also admitted that the sponsor company had agreed to provide further funding when the financial support secured through participation in the competition ended. Other respondents stated that they had received support from various industrial companies during the prototype-development phase. We also identified four solution developers as university spin-offs.

Capturing the number and range of industrial projects in which wearables are employed is a very difficult task. This is because, on the one hand, new projects are constantly being launched; on the other hand, not all of them are made public. During a research conducted in March 2018, we were able to identify 25 solution providers worldwide with 87 project cases.

The following usage scenarios occurred most frequently:

- Order-picking, pick-by-vision (32% of the cases mentioned by solution providers): Wearables (data glasses) are used to show which parts should be taken from a specific warehouse shelf. Wearables can be used to confirm the execution of the order (by using the built-in data-glass camera or a bracelet equipped with an RFID chip).
- Assistance systems in production and assembly (17% of the cases): Wearables provide information about the sequence and the content of operations.
- Remote maintenance, service (15% of the cases): Wearables are used to connect an expert to the workplace via a conference call. Using the built-in camera-function, the expert can visually examine the machine that needs to be repaired and give relevant advice to the worker.
- Maintenance (7% of the cases): Wearables indicate when and in what order a given part of the device should be inspected. Here, the execution of the required maintenance activities can also be aided by the camera function.
- Occupational safety, ergonomics (6% of the cases): Warnings regarding possible workplace hazards can be sent directly to the employees via wearables—for example, in the event of a sudden gas leakage.
- Training (5% of the cases): Wearables can support learning processes in the workplace.

In preparation for our analysis, we conducted a review of publications on wearables in engineering and computer sciences. In total, we found 61 relevant publications—with the oldest one published in 1999. In doing so, we focused on the following questions: What kinds of advantages of wearable technology were discussed? How was the work process described? How were the issues of plant-level codetermination and participation represented? The literature review revealed six clusters of advantages associated with wearables: (1) providing and processing information—in real time and based on specific information demand; (2) instructing staff; (3) hands-free working; (4) optimizing processes (higher working speed, higher quality, simplified documentation of the work process, greater flexibility); (5) increasing employee acceptance and ergonomics; and (6) providing on-site expertise.

One remarkable aspect that emerged was that all the publications envisaged a considerable rationalization of the work process as a result of the introduction of wearables. This is clearly visible, for example, in the literature on the use of wearable technology in logistics (picking). Publications in this area focused on the relationship between wearables and reductions in picking time and error numbers (Günther et al. 2009; Baumann 2013). From a work process perspective, the publications showed a specific way of thinking that we termed "assistance-system orientation." By this, we mean a perspective on the work process according to which manual labor generally requires close supervision. From this standpoint, accurate work instructions should be given to employees and the execution of their work should be controlled via wearable devices.

Despite the increasing number of pilot projects that are introducing industrial wearables, however, the technology is still at an early stage of development (at least at the time of writing), at which stage wearables' characteristics and uses are still being tested and negotiated by solution developers, the client companies, and other involved players. The following technological issues seem to be particularly pressing (see Hobert and Schumann 2017a):

- Hardware: Despite all the progress made, data glasses still provide a rather limited field of vision. Existing data glasses also often lack the sturdiness necessary to operate in industrial contexts. Another important problem is that the batteries either provide too little operational time (a few hours at best) or are still too large and heavy for extended use by the worker.
- Data security: The integration of wearables via WiFi into enterprise networks and into the relevant data structures is difficult, largely because of the lack of standards for operating systems, interfaces, and applications—but also because WiFi is not always available. In addition, the authorization of access to enterprise networks and information often presents a problem.
- Software: Software solutions for wearables are currently at an early stage of development. The solution providers are usually young companies that recently launched their first products. In addition, the above-mentioned lack of standardization of operating systems and interfaces is hindering the development of comprehensive software solutions.

Due to hardware-related limitations, the lack of standardization, and the fragmentation of the market, the technical maturity of most wearables applications remains low.

3. Theoretical framework and the state of research

Two approaches seem particularly suitable for our analysis of the introduction of wearables technologies in the workplace: the theory of the social construction of technology (SCOT), which can be understood as part of science and technology studies (STS), and the labor-process-theory (LPT). In the following, we will first explore how these two approaches understand the development of technology by various actors and social processes. Then, we will discuss the empirical studies that deal with the ideologies behind the technology concepts represented by Industrie 4.0.

The social construction of technology

The central elements of the SCOT and STS theories are, first, the assumption that technology is socially constructed, and, second, the rejection of a technical-deterministic perspective. As Pinch and Bijker (1984) have argued, the "genesis" of technology should be seen as a process of negotiation between members of "relevant social groups," who have different understandings of technical problems and solutions, and who have different expectations regarding the possibility of success or failure. The form and use of technology is, therefore, not pre-determined; it is instead characterized by an "interpretive flexibility" that is gradually restricted in the processes of negotiation between involved actors. In this context, Bijker (1987) spoke of the development of a "technological framework" that includes shared understandings of problems, goals, problem-solving strategies, organizational restrictions, design methods, and applications of technology etc. This technological framework can always be called into question. In particular, the multilevel phase model of technology genesis proposed by Weyer (Weyer et al., 1997) emphasized the openness of the negotiation process and the role of networks in which the involved actors—such as engineers, startups, etc.—work together on relatively equal terms to develop technologies. Weyer distinguished between the formation phase, the stabilization phase, and the enforcement phase of technology, with a reconfiguration of a developed technology being possible until the very end of the process.

In a response to Weyer, Hirsch-Kreinsen (2005) noted that many technological developments do not take place in loose networks but rather within hierarchically coordinated enterprises or hierarchically structured corporate networks (see also Dolata 2001). In addition to this objection, Hirsch-Kreinsen and Dolata point to the question of power and hierarchy in the process of technology creation. In the workplace context, this particularly concerns employees, who are affected by a given technology but at the same time often have little or no voice in the process of technology creation.

Labor process theory

Power relations within the work process are the starting point for analyses of technology in the LPT tradition. What the LPT perspective shares with the SCOT and STS approaches is the assumption of socially constructed technology—even if the theory is repeatedly accused of technological determinism (Wajcman 2006). At the same time, LPT incorporates the intended and actual effects of the implementation of the technology on work processes. In this regard, LPT shares the assumptions with the more recently formulated socio-materiality approach (Orlikowski 2007; Leonardi 2012).

Perhaps the most well-known articulation of the LPT perspective on the process of technology development was by Noble (1979) in his analysis of the introduction of N/C (numeric control) machine tools in postwar American industry. Noble distinguished three phases of technology genesis: (1) design, (2) deployment, and (3) actual use, even though he did not differentiate sharply between the first two phases. His work emphasized that the design and deployment phases are shaped by the intentions and ideologies of powerful actors. In his analysis of the competition between two different automation approaches (N/C and "record playback," where the settings developed by a machine operator were recorded on a magnetic tape and then "played back" when needed), Noble showed that the technology that ultimately won was the one that was supported by the state investor (the Air Force) and that corresponded well with the dominant "managerial ideologies." The managers perceived the N/C technology as a chance to weaken the position of workers on the shop floor by reassigning machine-setting tasks to engineering departments. As Noble pointed out, a number of companies used the term N/C to refer not to a specific technology but to new, expert-based production systems. This managerial perspective influenced the mindsets of engineers, who regarded human participation in the work process primarily as a source of error. Noble (1979: 30) argued:

> "Here the ideology of control emerges most clearly as a motivating force, an ideology in which human judgement is construed as „human error". But this ideology is itself a reflection of something else: the reality of the capitalist mode of production. The distrust of human beings by engineers is a manifestation of capital's distrust of labor. The elimination of human error and uncertainty is the engineering expression of capital's attempt to minimize its dependence upon labor by increasing its control over production."

It is quite clear that the perspective proposed by LPT is compatible with the SCOT and the STS approaches: It emphasizes the social construction of technology and negotiation processes in networks of actors (in Noble's research, this included companies like General Electric and Parsons, research institutions such as the MIT, and state organizations like the Air Force). It arguably even shares the LPT argument of the equality of actors in such networks—but only as long as the interests and perceptions of workers in the labor process are ignored. LPT's argument here is not technologically deterministic, but rather capital deterministic—it emphasizes that the control interests of capital will prevail. However, Noble (1979) also noted that the strategies of capital are influenced by institutional conditions. In addition, he showed that even in the final phase of the technology genesis processes (i.e. in "actual use"), actors' strategies might still change. The attempt by many US companies to replace skilled workers with semi-skilled operators in the context of the introduction of the N/C technology failed. N/C technology proved to be much more error-prone than expected and very soon many companies started reinstating skilled employees. The strengthening of managerial control over the labor process was therefore far less successful than anticipated.

Thus, LPT provides a perspective on technology genesis that is compatible with the SCOT and STS approaches, but, at the same time, it uses a terminology developed especially for analyzing work processes. A weakness of many LPT analyses is, however, the under-theorized usage of the terms "managerial" and "engineering ideologies." These terms are often simply identified with an intention to control the work process and the workers (as in the classic study by Bravermann 1974), an understanding that is insufficient for a time- and context-sensitive analysis. In contrast, later sociological research has shown that technology development and deployment can be accompanied by various strategies regarding labor control and the use of semi-skilled or high-skilled work (Hirsch-Kreinsen et al., 1990; Schumann et al., 1994; Krzywdzinski 2017). From the point of view of STS, Wajcman (2006) criticized the very idea of homogeneous interests of "managers" (or of "capital") in the process of technology creation.

Managerial ideologies and Industrie 4.0

So far there are only a few, very general analyses of the Industrie 4.0 discourse and the "managerial" and "engineering ideologies" behind it. Hirsch-Kreinsen (2017) has described Industrie 4.0 as a "technological promise." He emphasized that the official discourse has become a collective agenda that strongly influences corporate actors. The discourse itself, however, has a contradictory character. On the one hand, it shows some features of a technological utopianism, in that it describes the digital technology as a solution to all major organizational and social problems related to the labor process. On the other hand, the official discourse also includes critical voices—for instance, trade-union perspectives—which emphasize the related social risks (see also Pfeiffer 2017).

With its technological utopianism, the discourse on Industrie 4.0 picks up on elements and figures that have been developed in Silicon Valley (see Boes et al., 2015). Morozov (2013) described Silicon Valley's understanding of technology as "solutionism." This refers to the belief that many social problems may be effectively solved by various "smart" technologies and related control or incentive mechanisms—a way of thinking characterized by a limited understanding of social phenomena and problems. Levina and Hasinov (2017) interpreted the Silicon Valley discourse as a mixture of libertarianism and technological utopianism whose development can be traced back to the 1960s and embodies a deep-seated belief in the positive power of technology (see also Turner 2006). Raffetseder, Schaupp, and Staab (2017) interpreted the technical utopianism of the Industrie 4.0 discourse as a return of cybernetic management concepts, which build on the notion of technical self-control.

What we currently lack, however, are concrete empirical analyses of the management concepts related to the introduction of Industrie 4.0 technologies. One of the few studies relevant to our discussion of wearables is Niehaus's (2017) study of a pick-by-voice system of order-picking and a smartwatch-based work system in logistics. Niehaus focused on the issue of control but emphasized the openness of technology and a high variance of managerial strategies. He distinguished between Taylorist approaches, in which wearables are employed in order to achieve greater control over the process and the workers; and various "autonomy" scenarios, in which wearables are used to provide information and enrich the work process. It remains unclear, however, what factors generally lead to what scenarios, and also what strategies and concepts the management and solution developers followed in the two cases examined by Niehaus (2017).

Summary

Building on the SCOT and STS approaches, we assume that the specific design of technology is not simply a matter of technical progress, but rather a result of communication and negotiation processes embedded in a network of actors. These processes are not linear and are marked by an "interpretive flexibility" of technology (Pinch and Bijker 1984). Currently, wearables solutions are still in the design or preparation phase, during which the developers and managers at the user companies are working on operational forms of the technology. Our analysis will focus on the activities of the solution developers.

In reference to LPT, we ask what management concepts influence the technology genesis process and whether employee concerns are taken into consideration. We expect that control and rationalization interests will prevail. But whether this is actually the case, and the extent to which these kinds of interests may be counterbalanced by codetermination and worker involvement, will be the topic of the following empirical analysis.

4. Data and methods

The data used in the present analysis were collected as a part of the "Wearable Computing in Manufacturing and Logistics" research project, which was funded by the Hans Böckler Foundation. The project was carried out from 2017 to 2019 by Martin Krzywdzinski and Maren Evers from the WZB, and Sabine Pfeiffer and Maximilian Held from the University of Nuremberg-Erlangen.

In the first phase of the research project, 12 interviews were conducted with solution developers (Table 1). By solution developers, we mean companies offering wearables applications for plant-level use. These interviews were supplemented by a number of interviews with experts from companies and academia. In total, 16 interviews with 20 persons were conducted. The second phase included case studies at various user companies.

Table 1: Expert interviews

Number of interviews	Interviewees	Interviewed persons/functions	Country
6	7	Solution developer	Germany
6	6	Solution developer	USA, UK, Sweden
2	4	Academic experts	Germany
2	3	Company experts	Germany
16	20		

The interviews were analyzed using structured qualitative analysis, as described by Kuckartz (2016). Here, a multilevel procedure for the development of analytical categories is generally recommended. After the first reading of the interviews, we coded the collected material according to the following main categories: "perceptions of work," "codetermination and participation," "motivations," "data and content generation," "solution developers," and "wearables market." In the next step, we inductively developed several analytical subcategories. Table 2 presents the subcategories relevant for the analysis developed in this paper.

Table 2: Analytical categories

Main category	Subcategory
Perceptions of work	Technology on worker's body as control
	Organization of work and qualifications
	Ergonomics
	Interaction
Codetermination and participation	Plant-level codetermination
	Participation
	Implementation processes
Motivations	Rationalization
	Experimentation
	IT systems
	Innovativeness
Solution developers	Professional background and industrial experience
	Use cases

5. Engineering ideologies—"work" as perceived by the developers of wearables solutions

As the introductory sections of this paper show, wearables are a technically highly dynamic product. Their use in companies is still at an early phase of implementation, which is being strongly influenced by the dominant management discourse around Industrie 4.0 and digitization. Start-ups that develop solutions for wearables are a relevant player in this process. In this section of the article, we present the analysis of our interviews with solution developers. In doing so, we address the following topics: client companies' motivations for implementing the wearables technologies; developers' perceptions of the work process; the role of wearables as a control technology; wearables' impact on work organization; and, finally, the developers' perspective on the plant-level participation and codetermination.

Motivations for implementing wearable solutions

The reasons why client companies decided to introduce the wearables technologies influenced the work of solution developers. Client companies' motivations for implementing wearables were multilayered. On the one hand, there were projects in which the client companies clearly emphasized their intention to rationalize the labor process. The paradigmatic case of this approach is in the logistics sector, where pick-by-voice technology is already used on a large scale. The key goals perceived here are an increase in the order-execution speed and a reduction of the error rate.

> "So when we talk to managers from logistics, it is all about cost, from the very first second on." (Solution Developer Germany LE-D-5)

The motivation for rationalizing production often goes hand in hand with a willingness to collect data on the labor process—and to explore the possible uses of this data for process optimization.

> "That's what customers actually expect... They'd like us to develop automated solutions to optimize the processes. They say, okay, now we are as close to the process as never before, how can we optimize the process based on the available data? [...] These are just these kinds of data-driven solutions—that is, analyze the data and then, kind of, derive the products, optimal processes, ergonomics recommendations—all you could possibly think of." (Solution Developer Germany LE-D-5)

Often, however, the solution developers report that client companies' motivations are much more malleable and unspecific. In principle, this could mean that there is some leeway—the above-mentioned "interpretive flexibility" (Pinch and Bijker 1984) of technology. According to our interview data, many companies are experimenting with possible usage forms.

> "We're really open here, we're trying things out. We don't know—are the data glasses suitable for production? We are testing the operational use." (Industrial company Germany U-D-1)

> "Either they [the companies] want to find out what the possibilities are, just to get a feel for it. Or they think they know what they need—and it may turn out that they actually need something completely different." (Solution Developer Germany LE-D-5)

The openness to trying out different applications partly results from the fact that some companies see the implementation of wearables as an opportunity to develop so-called middleware, which would integrate different mobile devices within the enterprise IT architecture. In such cases, the implementation process would focus not so much on installing a specific device (such as data glasses), but rather on reviewing the entire pre-existing system.

> "Perhaps most crucial is the middleware, as it is independent from a particular device. Even if we ultimately drop the idea of using the data glasses—at least for the time being—we then still have the middleware, which we will be able to use with tablets, smartphones, or other devices." (Industrial Enterprise Deutschland (U-D-1)

From the firms' perspective, the general willingness to expose themselves to new technologies and thereby to demonstrate their own innovativeness also seems to be relevant.

> "At the beginning, this whole initiative was generously supported by the management, also because, well, that is an innovative interaction with an interesting topic, and that makes for good press, creates a good public image, and, actually, does not necessarily serve the purpose of bringing any economic gains, but rather of making us seem more attractive, more interesting, and also more appealing to new employees—the way in which we are perceived inside and outside the company." (Company Germany U-D-2)

"Actually, our goal is to make life easier for the worker"—how solution developers understand the work process

Although the technical backgrounds of the solution developers we interviewed were diverse, computer science and business administration were dominant disciplines. What they all had in common was that they rarely had qualifications in production management or in the specific areas in which the wearables were being implemented (logistics, manufacturing, ergonomics etc.) The developers tended to perceive the specific process knowledge required to implement the wearable solutions as something they could acquire on the job.

> "It is simply more important that there are people here, like me, who know the possibilities of the data glasses, but also, who know, so to say, what not to do with the glasses. Of course, one needs a certain understanding of the logistics, but I think you can learn this within a reasonable time." (Solution Developer Germany LE-D-5)

> "I'm actually self-taught. I also accidentally slipped into this business. I have no special certificate here. And I went to a company that dealt with these kinds of services. There, I worked my way up. I was developing systems, how to manage customers, how to optimize processes, and so on. And then, I eventually became self-employed." (Solution Developer Germany LE-D-3)

In many interviews, the developers emphasized that the deployment of the wearables solutions may influence the work processes positively by creating a chance to organize work in a more ergonomic way. As the interviewees indicated, this could be achieved by enabling the employees to work hands-free and by minimizing the most troublesome tasks, like information gathering or walking long distances. These are widely disliked activities, and reducing the amount of time spent on them could improve working conditions. But at the same time, this kind of reorganization of the work process could be perceived by the employees as an attempt to intensify the "productive" tasks and to reduce the "wasted time".

> "I think that most people actually perceive it as an improvement, because we minimize the most annoying part of the work. But the work itself does not change." (Solution Developer Germany LE-D-5)

> "So our goal is actually to make life easier for the workers: This is just a tool which I didn't have before. [...] I have, then, free capacities—be it in my head, or regarding the available time—for other things." (Solution Developer Germany LE-D-1)

At this point, we may notice that this thinking represented a remarkably "isolating" perspective on the work process, which always focused on, and attempted to optimize, the *individual* jobs. We will discuss the implications of this perspective for the organization of work later in the paper. In addition, in some of the interviews the developers only perceived the human workforce as a potential source of error. This corresponded well to the perspective that we have identified in other scholarly publications. The optimization of the ergonomics was perceived as a way of eliminating potential sources of human error. Some developers, however, recognized the threat of disempowering workers and discussed the dangers quite openly.

> "So of course, from the managerial point of view, you want to secure the processes, and, of course, you want to somehow minimize the degrees of freedom, because these degrees of freedom, they only create error rates, and variation, and, you know, all kinds of problems.

> Of course, from a more humanistic perspective, you sometimes think, what are you actually doing here—well, would you yourself like to work this way?" (Solution Developer Germany LE-D-5)

> "But on the other hand, of course, that's not great for the [employees], because, of course, the system really captures every movement, every performance." (Solution Developer Germany LE-D-3)

New forms of labor control

From the viewpoint of the solution developers, significant gains in ergonomics and production efficiency can be achieved when work process data is recorded and analyzed comprehensively. For instance, interviewees mentioned cases in which the technology would recognize whether the employees showed up the first day after their holidays, or whether they are currently working on a piece that was no longer a part of the production program. Other examples given by our interviewees discussed so-called "performance-altered" employees (a term used in German companies for persons who, due to health restrictions or disabilities, cannot perform certain tasks or are no longer able to work a full shift or at full speed), who would be individually supported in their work by the wearables technologies.

> "If you think about the potential, about the use of [...] data—and I don't mean the vital data, but even simply the issue of the position, and a certain behavioral history, which is employee-related—you can do a lot here, and you can avoid a lot of unnecessary activities, which nobody really likes today. The gathering of information, the verification of information—this is always a huge topic, which, in practice, nobody really talks about. Although, as a matter of fact, it offers a great lever. But also, I have to use data that, today, I cannot really use, and I don't want to use. [...] [One could] completely individualize jobs, always in parenthesis, as long as individualization does not inhibit productivity. We could simply make technology adapt to individual settings: [...] the workplace could recognize your size, or the positioning of parts and material could be different [...] depending on whether you are left- or right-handed. The work pace might even adapt to the worker's situation. And this could be even the heartbeat, but also, I think—more easily—the question of when I last worked on something similar, or whether I just returned from vacation, or have I been around for a while already, or whether I have just made a mistake or not." (Researcher Germany EF-D-1)

And while the solution developers were well aware of such technologies' potential use to control the workers, they nevertheless tended to focus on improving the ergonomics and, in some cases, pointed out that the employees were able to switch off the equipment in order to avoid control.

> "In a sense, the company benefits as well, but, first and foremost, the employees do. For example, it is possible for them to save the process parameters when it [the work] was particularly stressful [in order to analyze and avoid this situation next time]." (Solution Developer Germany LE-D-4)

Regarding data collection and analysis, some of the developers pointed out how most of us, more or less consciously, already agree to disclose large amounts of personal data through private smartphone use. Accordingly, the developers expect a rather high acceptance of the practices of personal data collection at the point of production—not least because the collected data is used to create more ergonomic working conditions.

> "We already have something that works more or less like this, and these are our smartphones, which collect so much information about us. Here, the data glasses do not differ much. With time, this will fit in." (Solution Developer Germany LE-D-3)

With respect to the control issue, wearables that record employees' bodily functions and thus obtain information about their fitness, physical capabilities, and health were particularly controversial. In addition to the implications of placing wearables directly on workers' bodies, or the possible role of the "off button," one of the interviewed developers addressed the functions that the wearables should—or should not—have.

> "We discuss in our team whether we should integrate the heart rate monitor or not [...]. That is: does it really make sense, do the positive features really convince us, and outweigh the negative features? So the horror case is that the pulse rises when two workers meet – the pulse rises because one is in love with the other—and I can find out that they are homosexual. I could interpret the data this way. And that's a threat, it's here, somehow. How can we avoid this? Should we just not install the sensor? [...] Should we encrypt the [data], so that the customer will never see it, or simply never receive it? So, we have a big responsibility regarding the data. Do we want to accept this responsibility, or do we rather say: 'Well, then we will simply not collect the data'—because it's very personal?" (Solution developer Germany LE-D-1)

Some developers argued that workers retained control over the wearable devices and could switch them off.

> "[There] is a way to say: I want to deactivate the controller." (Solution Developer Germany LE-D-4)

Organization of work—a nonissue

The developers' focus on optimization and ergonomic improvement at individual workplaces went hand in hand with a neglect of the issues of work organization and the division of labor in the company. Our interviews indicate that wearables are primarily integrated into pre-existing work routines, and that attempts to use the technology as an opportunity to fundamentally redesign the organization of work are rare.

> "In the implementation scenarios which I've seen, the idea was to leave the work process as it was and to simply add the data glasses as new work equipment. Sometimes it all suits fine, sometimes less so; sometimes you need to put more effort into adjusting it, and sometimes a little less" (Researcher Germany EF-D-2)

However, when asked about the emerging possibilities to redesign work processes, solution developers often referred to the fact that wearable technology is not yet mature. The goal of developing this technology was to allow employees to configure the wearables according to their own needs. The software should, therefore, be flexible and accessible to employees with different skill levels, process knowledge, and support needs. But the developers emphasized that the software for wearables is still far from offering this kind of flexibility.

> "We want them [the user companies] to assemble and configure everything on their own, from the machine to the individual software components—and all this very, very simply. So really, drag and drop. Unfortunately we are not there yet, [...] because we are just in the

> midst of the development process, [...] that the worker or the supervisor plugs in a new machine, [that they simply indicate] I'd like to have the following machine here, I need the following information here." (Solution Developer Germany LE-D-4)

> "The companies actually express the need in the same manner: not everyone needs everything and [the system] has to be somewhat adaptive, at least in such a way that you can define two, three specific roles. Of course, you can implement it, in our system—that you have different workflows for different roles, that's alright. But to derive different granularities from a workflow—we're not there yet, but that's actually where we want to be." (Solution Developer Germany LE-D-5)

The developers also discussed the implications of wearables for communication between workers—and there was much ambiguity regarding this issue. On the one hand, the wearables should facilitate communication.

> "[When] a message appears on the smartwatch: 'go back to the machine now, insert a new part', or whatever, and when you cannot go there now, then you can use the smartwatch to call the support. That is, you say, 'I need support at the machine', you press a button, and it will be broadcast to other smartwatches of other workers, and then, they can accept the request, or not. And in this way, you practically have self-organization." (Solution Developer Germany LE-D-4)

On the other hand, however, wearables may also isolate workers, because they limit the possibilities to communicate beyond the control of the IT system.

> "Of course, I now have to say that I no longer have to walk to the control room, and I cannot talk to my buddy in the control room anymore—yes, actually that's an issue." (Solution Developer Germany LE-D-4)

Functional view of co-determination and employee participation

When introducing their products at the client companies in Germany, producers of wearables usually encounter the issue of co-determination—not least because the use of wearables is related to a number of co-determination rights of the works councils, as described in §87 (1) of the Works Constitution Act (*Betriebsverfassungsgesetz*). The use of wearables may influence the beginning and the end of employees' working hours and also the duration of their breaks, if the devices are worn directly on the body. In addition, wearables are technical devices that monitor employees' behavior and performance. The extent to which wearing such a device increases the risk of work accidents or illnesses remains unclear. Furthermore, wearables can influence the task content and, in this way, change the pay group an employee belongs to.

A remarkable finding was the high emphasis on the importance of employee involvement when introducing new technologies. The solution developers generally emphasized that the consent of the employees must be secured.

> "And for us it is like this: if the worker does not carry the product, the product is basically dead." (Solution Developer Germany LE-D-1)

For this reason, the solution developers usually analyze the employee views and conduct surveys during the prototype development phase.

> “[The] prototype is not finished yet, and that was clear to us; we’ll get feedback on how we can optimize it, like how we can make it more comfortable. That’s also what we expected, and that was the purpose of this test, that we receive this feedback. And we’ve achieved that, we’ve got very valuable feedback. For some, it has worked great, for others, it has to be adjusted a bit, and we have also identified places where we still have some work to do.” (Solution Developer Germany LE-D-1)

> “We conducted a survey among the operators regarding how it all works, and no one felt it was stressful. Many saw it as a relief from the work routine. You have to walk less than before. This is a huge facility, 30 meters long. It was generally well received.” (Solution Developer Germany LE-D-4)

However, we have to emphasize the limits of the employee involvement reported by solution developers. The involvement mainly meant feedback on the solutions proposed by developers. We did not encounter cases of active participation in the whole processes of developing wearables that would allow the employees to suggest their own ideas for their use.

In general, we need to note that the interviewed solution providers had relatively little contact with the works councils—and that communication with these councils was undertaken by management at the client companies.

> “Well, for my part, I did not [talk] to the works council, except that when I was there, I talked to them a bit more intensely. Now, when I communicate remotely, the works council is not an actor with whom I communicate actively.” (Solution Developer Germany LE-D-5)

Particularly regarding the issue of data collection and analysis, the solution developers perceived co-determination primarily as a limitation.

> “I think we could capture much more data, but there is a company agreement defining which data can be collected and which not. These are a few hurdles, which seriously limit us. The kind of data that you could record additionally in order to get some added value. [...] So, for example, in one manufacturing plant which we visited, no one had any idea how often a worker actually runs into the measurement room to check whether parts are okay or not [...] It would be a great thing to find out, based on data. Unfortunately, again, there is the works council, which tries to prevent as much as possible that we analyze personal data, like the vital data. Of course, we would need person-specific data in order to know what has happened there. And, of course, this also involves risks.” (Solution Developer Germany LE-D-4)

But at the same time, the solution developers in our sample described the works councils as supportive in matters related to ergonomic improvements. This, again, points to developers’ focus on ergonomics as the major way of improving working conditions.

> “So, for instance, it’s not that we can generally say that the works councils block the projects. In fact, I’ve seen projects where the works councils said: ‘we were the ones who supported it from the start, so to say, because we think that the workplaces will become more ergonomic this way’.” (Solution Developer Germany LE-D-5)

Solution developers, who had already carried out implementations in industrial enterprises, emphasized that it is necessary to involve the works councils early on in the process in order not to put the whole project at risk.

> “Well, in any case, I think it makes sense to involve the works council [...]. Some of them have quite some power, and are able to block a project. So I think it’s good to involve the works council right from the start.” (Solution Developer Germany LE-D-5)

This perspective on employee participation thus has two sides. The involvement of works councils is generally seen as positive, but we also encountered a skeptical perspective that envisaged works councils as actors blocking innovation. Partially, this was linked to a “functionalist” understanding of the role of works councils, which mainly viewed them as actors who should generate the necessary support for new technologies within the company.

However, experts also noted that the works councils often lack the competences and experience needed to use the possibilities created by co-determination in order to influence technological developments.

> “I mean, I know a lot of companies from the inside, but still, this may not be representative and I want to be cautious with the statement. I found it quite disastrous, what I have seen there, because the actors [i.e., the works councils] have neither the knowledge about what they are in for, technically, and what the technical possibilities are, nor the knowledge about what the typical impact on the organization of work is.” (Researcher Germany EF-D-2)

6. Conclusions

Our analysis has shown that wearable technology is still in the development phase, at least regarding its operational use at the plant level. In this development phase, a number of technical problems related to both hardware and software have to be solved and standards have to be developed. Also, many design-related decisions will have to be made, for instance: what kind of sensors will be used (e.g., for heart rate monitors); which functionalities will be defined; in what way will the wearables be integrated into the enterprise IT infrastructures? How will the software platforms be developed and what kinds of applications will be used? Will it be possible to increase application flexibility such that client companies and, above all, the employees themselves, will be able to carry out the configuration work independently? Would this also require information to be displayed according to the workers’ task area and position in the production process? Will everything that is, from a technological perspective, “measurable” actually be measured? What usage scenarios make economic sense? The field of actors is still very fluid and, so far, neither dominant solution providers nor implementation service providers have managed to establish themselves. At this point, we may again refer to the STS and SCOT perspectives, which suggest that technology may change as a result of negotiations between the actors involved.

What is the role of solution developers in this process? Our interviews show an ambiguous picture. On the one hand, solution developers emphasize the importance of involving employees and their representatives in the process of technology creation as well as the potential to improve work through the use of wearables. On the other hand, the understanding of how to improve work is relatively narrow: It focuses on optimizing and ergonomically improving individual workplaces, while broader issues, like the division and organization of work, have barely come to the fore. What is missing is a more imaginative approach that envisions the organization of work and the internal division of labor holistically and also reflects on the potentially relevant software functionalities.

Nevertheless, wearable technologies offer considerable potential. The possibility to provide individualized information and assistance to workers might increase flexibility and help companies deal with an increasing demand for shorter working times (and part-time work) and employees' desire to take leave to raise children or care for older family members. This demand means that workers step out of work processes more frequently. The use of assistance systems might help to reconcile these new flexibility needs with companies' quality and productivity requirements. This individualization of information and assistance systems might, however, require new ways of gathering and analyzing individual data. In this regard, solution providers have a nuanced view of the role of wearables as a source of data and the possible uses of these data. Such developers do indeed recognize and address the threats related to surveillance and control of the employees—as manifested, for example, by their decision not to install certain sensors. We can expect that data governance will become a crucial issue of workplace politics.

Regarding the much-feared control issues related to wearables worn directly on the body, very strict regulations on data protection and codetermination are in force in Germany. In this respect, we may assume that wearables will develop differently in various national contexts, and that companies will develop various strategies regarding, for example, the collection and analysis of data. Our interviews indicate a faster pace of implementing wearable technology in locations outside of Germany.

This raises the question of the extent to which works councils will be able to evaluate the possible implications of specific design alternatives and engage in negotiation processes. So far, workplace co-determination has been perceived by solution developers in rather "functional" terms—that is, as a possible source of legitimation rather than significant input. In this regard, it seems crucial to develop works councils' competences, to provide advisory services, and also to spread knowledge about possible use cases.

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