Opportunities and Challenges of Video Content and Video Technology in Smart Factories

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Abstract. Production companies typically have not utilized video content and video technology in factory environments to a significant extent in the past. However, the current Industry 4.0 movement inspires companies to reconsider production processes and job qualifications for their shop floor workforce. Infrastructure and machines get connected to central manufacturing execution systems in digitization and datafication efforts. In the realm of this fourth industrial revolution, companies are encouraged to revisit their strategy regarding video-based applications as well. This paper discusses the current situation and selected aspects of opportunities and challenges of video technology that might enable added value in such environments.

1. Introduction

Video technology is largely present in our everyday lives, in both private and professional contexts. In our private lives it is primarily used for news and entertainment purposes, while for professional purposes, it functions as enabling and assisting technology in many different forms and application contexts. Not every sector, however, does already exploit and benefit yet from video technology to full extent, especially when it comes to advanced, intelligent features. Some companies simply haven't yet investigated what potential there is for their specific environment, while others opt not to deploy due to careful consideration of the technology's downsides. The following discusses opportunities and challenges for the adoption of video technology in the specific context of the manufacturing sector, i.e. factory environments of the producing industries.

There, we can observe a diverse range of technological state-of-the-art: on the one hand, to exemplify, one can still find production lines that were built with technology of the 1990s or even earlier, and never fundamentally upgraded. For these kind of factories, it appears to be a valid strategy to exploit long-established business models of routine production as long as possible, and major change is simply not reasonable economically, based on return-on-investment (ROI) assessments. For the most part, video and more advanced audio-visual content technology hasn't found its way yet into such companies.

On the other hand, we can find high-tech factories at the forefront of innovation with respect to automation, use of robots, digitization and datafication throughout their business processes. Examples of such businesses can be found in the pharmaceutical and semiconductor industries among many others. These businesses require to constantly innovate and hence business processes are more rapidly changing in continuous cycles, in what these days is often coined 'Industry 4.0' advancements – factories become *smart* in a fourth industrial revolution. Clean room production is particularly demanding with respect to information technology (IT) infrastructure – hence in such *fabs*, video storage and transmission per se is

not a challenge in terms of feasibility and cost. While video technology may be used for a diverse set of purposes, there are further opportunities not yet realized, and especially recent innovations stemming from research efforts that are only slowly adopted.

We learned in an interview study conducted within a research and innovation project focusing on the semiconductor industry that, in general, companies make informed decisions regarding the use of video technology. In case they opt not to exploit video for a certain case, there is in principle a good understanding of the limitations and downsides of the technology. Since any underlying factor for these deliberate decisions may change at any time, especially in the realm of Industry 4.0 market competition, there is reason to be optimistic about video being increasingly utilized in factory environments in the near future.

Recently, (Waschnek et al. 2017) described what may explain why currently any novel multimedia technology is only slowly taken up in this sector:

> *"In a fast moving field, with standardization still ongoing, companies are reluctant to make investments in new technologies. High-level strategies offer little orientation as they do not get specific enough to derive concrete recommendations. The fear of investing into the wrong technology slows down innovation tremendously. Strategies need to be broken down into smaller parts to provide tangible steps towards the implementation of an Industrie 4.0 vision."*

Due to the complexity of production processes and manifold implications and side-effects, in the realm of Industry 4.0 innovation the assessment of the impact of these advancements, both technical and social, is currently a topic of discussion in the community among researchers and practitioners. Beyond the difficulty of quantifying the ROI of existing systems, predicting user acceptance and the success of information systems in general is very challenging (cf. Larsen 2003).

This paper aims to contribute to innovation in this regard and breaks down selected application opportunities and technologies both for live and recorded content scenarios. It discusses both what can be enabled as well as potential issues such as for example issues when monitoring employees on a permanent basis. The insights we present are based on our current and previous research streams, on-site observations, a set of semi-structured interviews, and discussions and reflections conducted during a scientific workshop[1].

2. Towards adopting state-of-the-art technology in factory environments

This section discusses both reasons why companies have decided to not adopt video technology in the past, and current research advances which may be applied in the manufacturing sector in the foreseeable future. To complete this step, however, researchers need to acquire an even deeper understanding of this specific context and adapt solutions to it.

1 http://kti.tugraz.at/conferences/2017/sami40/

2.1 Understanding downsides of video technology adoption

What is possible with today's state-of-the-art theoretically is very impressive. Yet, towards increased adoption of video technology in smart factories, there are also downsides to consider and address. We discuss selected aspects in the following.

Obviously, investing in technology entails cost for procurement, integration and maintenance of infrastructure and devices. Once such applications are critical for production processes beyond providing additional support on a nice-to-have basis, the IT departments need to even more safeguard against failure or provide alternative means to achieve the same task in case of breakdowns.

Not only are there expenses for creating content, but skilled employees are necessary to do so, for planning, deciding what to capture, to conduct the recording and finally the post-processing and distribution of content. Further, it might be necessary to maintain the content, as it might require updates once any detail within the content becomes outdated.

Transmitting and recording significant amounts of video data requires bandwidth, storage capabilities as well as dedicated interfaces to retrieve, analyse and engage with content. In the spirit of Industry 4.0, video-based applications likely would not be added as standalone tools but intertwined with other systems, usually central steering and information systems such as manufacturing execution systems (MES). A MES usually acts as a central knowledgebase and steers complex decision making processes.

Apart from infrastructural and monetary investment aspects, another concern when introducing new technology is the acceptance of the dedicated users who might have some freedom to decide to which degree to make use of video tools. First of all, any camera that doesn't capture only machines but monitors employees conducting their work on a permanent basis can become a serious issue with respect to labour law, employee rights and privacy. Further, even for video communication where an employee takes the conscious decision to join a conversation and be captured by a camera, several participants in our interviews reported that they feel rather uncomfortable and insecure in such situations. Specifically, some who had experience using telepresence tools in meeting rooms felt disturbed seeing themselves when the interface included a self-view. We have yet to evaluate if the same concerns apply for remote video communication within the factory floor, if there are strategies to mitigate these concerns, and if long-term use, practical experience and familiarity increase acceptance on its own. Are there any strategies to lower the mental burden of feeling watched?

From the perspective of the companies themselves, apart from caring about their employees for good reasons, they also need to protect their strategic knowledge (Thalmann and Ilvonen 2018). In that regard, any networked process capturing data is a security risk, and especially remote live video connections bear risks for the protection of sensitive, confidential knowledge which others may acquire and exploit. Controlling that risk for a video connection within the factory is certainly much more complex and difficult compared to communicating from a meeting room. As a consequence of facing this challenge, many companies decide not to allow remote streams from their factory at all, minimizing risk even if that rules

out any benefits based on remote collaboration and fast response times with suppliers and external maintenance staff. From the perspective of an opportunity, however, a reduction of response and repair times in case of infrastructure failures and breakdown can be a major positive cost factor.

Another potentially negative aspect companies consider in their technology strategy are usability barriers, either due to the complexity of a technical tool and process that employees struggle to deal with, or due to a lack of maturity of a candidate technology itself.

As one bold and simple example, we learned in the aforementioned interview study that unfavourable experiences with multipoint videoconferencing are decreasing some companies' motivation to engage with video technology. Participants reported experiencing continuous issues with fluctuating audio and video quality as well as broken connections. Larger remote group meetings were often delayed due to at least one participant having difficulties configuring the microphone and camera setup and corresponding software drivers and settings. One participant described his expectations towards practicable solutions as a *"1-click communication tool"* which just isn't available yet. One conclusion we derived based on these interviews was that such experiences of perceiving applications as unstable and inefficient are contributing to scepticism towards technology based on video streams in general. We assume that this also affects companies' strategic technology investment strategies.

Positive effects of technology use in social regards (e.g. work satisfaction) may only show long-term. This makes ROI valuation very challenging, and especially socio-technical impacts (cf. Denger et al. 2012) are very difficult to capture and assess.

2.2 Research advancements

In terms of video-based applications, research in multimedia and related communities such as human computer interaction (HCI) has made great advances both in terms of technical approaches as well as understanding and assessing user needs, behaviour and experiences. Algorithms are able to automate many tasks based on audiovisual media content which could only be achieved by humans a few decades ago. Examples for that are specific features based on real-time or offline content analysis that allow users to handle large amounts of information, intelligent telepresence systems that support remote communication, or adaptive hypermedia systems that realize personalizable content consumption.

In this research domain, it is quite common to address research topics with an interdisciplinary approach. For example, a collaboration among researchers with technical, social science, interaction design or user experience assessment backgrounds is a frequent case. This interdisciplinary nature is also reflected in several research communities. For companies, we suggest to take the same approach when defining project teams for innovation projects in this area.

However, rather little of human-centric multimedia research so far has been concerned with application scenarios within factories or the very specific needs of people working in such environments. Even more general, user experience (UX) research in such contexts has been scarce (Obrist et al. 2011).

One particular evolving technology for applications involving several live video streams in parallel is the 'Virtual Director' approach (Kaiser and Weiss 2014; Falelakis et al. 2016), which may automate the tasks of human camera operators and directors in live event broadcast. Automating the process of viewpoint or camera switching enables new kinds of media formats, video consumption experiences and sophisticated features, for example many forms of (hyper-)personalization (cf. NEM 2017). This technology, however, is currently subject to research and no advanced commercial frameworks are available.

A Virtual Director is capable of fully automatically selecting from a set of available video streams, or of determining a viewpoint as a cropping from a high-resolution video stream, and even of animating such a virtual camera over time. Based on that, such software can not only enable *lean backward* consumption experiences, but also incorporate the preferences of the user, on whatever abstraction level, possibly supporting any working mode in the dimension between fully automatic behaviour on one side and fully interactive on the other. Supporting both lean forward and lean backward consumption and the ability to switch at any time is one of the intriguing aspects of this technology.

Real-time content adaptation and personalization may bring added value for users, both in entertainment and in professional application settings. While researchers have investigated personalization aspects in several domains, we know rather little about generalizable use cases supporting specific tasks within smart factory floors.

Regarding the implementation of Virtual Director software, naturally a piece of software can only take meaningful decisions when it *knows* about what is happening in the captured scene(s), hence it requires interfaces to sensors. In live setups, most apparently, real-time audio and video content analysis can act as such a sensor. Processing fused sensor inputs, a subcomponent of the Virtual Director aims to detect higher-level concepts that describe current actions and situations. This subcomponent is called 'Semantic Lifting'. A second subcomponent, in our approach referred to as the 'Director', in turn triggers cinematographic behaviour that decides what is shown, how it is framed, how virtual cameras are smoothly animated as croppings moving across the full image, and how and when to cut between viewpoints.

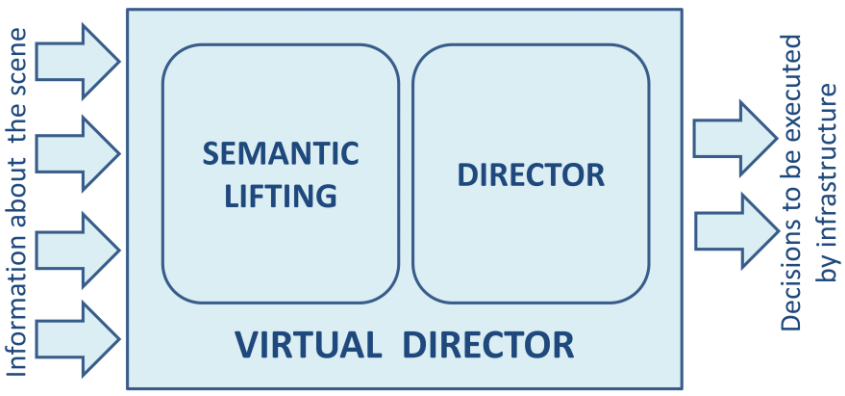

Figure 1. The workflow of a Virtual Director component taking decisions.

A Virtual Director instance might serve more than one user in parallel, and due to the characteristics of its technical approach based on event processing and rule engines, it scales quite well to a larger number of users, and most importantly manages to execute intended behaviour with very low delay. See in the figure above the workflow within a Virtual Director component.

In the case of production factories, an added value due to the use of many different video-based applications is conceivable. In the subsequent section, we discuss only some of them, selected application examples that are rather general. They should be relevant for most environments. Besides, there are also many very specific use cases that differ from company to company.

3. Opportunities and Challenges for Live Video

The two most evident use cases for live video in factories we propose to consider are

- remote monitoring for steering machines and infrastructure and
- remote communication and collaboration with colleagues or external partners.

The following sections will discuss these in more detail.

A general concern to all of them, from a scientific point of view, is how to evaluate them from the perspective of the user. While in other application domains researchers have evaluated the user experience (UX) and developed means to characterize and assess the quality of experience (QoE) (Le Callet et al. 2012; Zhu et al. 2015), one open challenge is to redefine and adapt these concepts for the specific contexts discussed in this paper.

3.1 Remote monitoring

A key aspect of Industry 4.0 advancements is that via the automation of machines and infrastructure, human work essentially becomes more efficient. Human operators move to monitoring and steering tasks rather than operating specific machines manually. At the same time, they become able to cater for more and more machines in parallel.

Consequently, we need dedicated support for users to manage monitoring tasks. While many states of machines are observed by sensors, some procedures still require the human eye to see what is going on, to spot issues or understand in detail and with confidence what is happening or just happened. To be able to handle many areas in parallel, operators use remote video streams.

While this scales well in principle, dealing with the complexity of concurrently available video feeds implies a set of challenges.

One such challenge is that operators *passively* conducting monitoring tasks for a long time are facing mental stress and/or fatigue due to the repetitive nature of their task and the high level of permanent concentration required. In case something critical happens, though, the need to very quickly act and take the right decision. For such situations, researchers have developed interfaces that support the operators' needs (Kaiser and Fuhrmann 2014) as a first

step. This research could be extended to investigate how immersive technologies could help operators concentrate without or with lesser side-effects.

To tackle the aforementioned and further challenges, researchers need to develop even more advanced, intelligent technical features to support the operators. Dynamic viewpoint control via the aforementioned Virtual Director concept is one promising option to be explored. In this context, the feature of *personalization* needs to be interpreted in different means, however, since an operator should be presented with what is currently most relevant for him or her, and there is less of a personal choice involved. In other words, what a Virtual Director can support in this context is managing the operator's attention such that the work is both effective and sustainable in terms of the working conditions. We hypothesize that nevertheless, we shall study means how to best present the content and how to switch among viewpoints, re-using cinematic principles that proved to work in other contexts.

3.2 Remote communication and collaboration

Most companies are using video communication (or videoconferencing) solutions, some even equip dedicated communication rooms with advanced telepresence systems to be able to conduct efficient remote meetings. Yet, most production companies in our experience use such technology to a much lesser degree or not at all inside the core factory environment, certainly for good reasons, as this is a challenging application context with specific requirements and constraints.

We suggest that previous technology assessments could have become outdated and recent research advancements could be further developed and adapted to even better support processes of remote maintenance and remote collaboration. Potential advantages are rather obvious, especially but not only for clean room production sites where a very limited number of employees is available on site and sending more staff to a specific place from outside the clean room area takes a certain time.

Besides traditional 2D video capture and playout, new content formats and dedicated devices are emerging, e.g. smart glasses that allow hands-free interaction, information overlays in augmented reality (AR), and panoramic/360° video allowing for a more comprehensive representation of and hence insight into a production space. Concretely, as an example, smart glasses supporting remote video assistance[2] (Gödl and Brandl 2017) have been developed.

A very different approach to human-worn video interfaces (both camera and display) is to deploy the same features on self-moving or remotely steerable devices. Telepresence robots are one example for that (Stoll et al. 2017). Since factories are controlled environments and mobile, autonomous robots are used there already, the utilization of such devices seems not far-fetched. In contrast, the indoor use of video drones appears to be more challenging but at the same time also appealing.

2 https://evocall.evolaris.net/

In any complex communication setup involving a larger group of persons or a larger set of live camera feeds, the Virtual Director concept introduced above could be adapted to specific scenarios in order to support specific needs of users. We have previously worked on supporting specific communication needs in remote group video communication, but in social settings rather than professional ones (Falelakis et al. 2016).

As a side-effect of more advanced communication solutions, smoothly working remote video communication can be an enabling factor for companies who intend to change their business strategy to work in a more collaborative fashion. In increasingly global markets, ad-hoc collaborative and co-opetitive endeavours might be a viable strategy towards sustaining innovative product portfolios. Towards the idea behind Open Innovation (cf. Baka 2014), there are many degrees of openness a company can choose to work with. Especially in ad-hoc situations, we believe telepresence technology can be an enabler for effective collaboration.

Fruitful cooperation typically involves a reciprocal process of sharing and receiving. For that to work, *trust* is an important aspect. To establish trust, it makes a difference if you have met somebody or just know their voice from telephone or conference calls. A true telepresence effect where the user gets the sense of being in the same place as remote people can become close to face-to-face meetings, which (Kock, 2004) describes as crucial with respect to the Media Naturalness Scale.

4. Opportunities and Challenges for Recorded Content

A substantially different category of video-based applications are such primarily based on recorded content.

Applications in this realm can be very diverse and multifaceted, including video documentation for quality assurance, support for manual tasks by providing information and instructions in the form of recorded audiovisual content, as well as learning and simulation scenarios on site and hands-on exercises within the factory floor where both instructions and learner assessments are based on video recordings.

A common challenge is to dynamically and automatically provide workers with the information they need (cf. the approach in Stern et al. 2010). Apart of Intelligent features for personalization of video-based information, a key success factor for enabling and supporting video technology certainly is the design of interaction towards the user, considering the restrictions within a factory space. Not only are dedicated interfaces required taking into account the specific constraints in factory environments, but their seamless integration into workflows and processes can be challenging. To appropriately address, at Know-Center[3] we look at potential solutions to be designed as socio-technical interventions that consider both technical aspects and human factors.

3 http://www.know-center.tugraz.at/en/

One concrete application opportunity where video can contribute is learning, an especially important topic for companies going through major changes in the realm of Industry 4.0 advancements that requires them to train new employees as well as their current staff.

Learning involving video content within the factory environment is apparently involving very applied and practical cases of learning content and the ability to see and practice is very important. While learning and knowledge transfer can also be supported in live setups e.g. by means to consult remote experts and teachers, researchers have proposed many intelligent features for learning scenarios, for example video adaptation techniques (cf. e.g. Kravčík et al. 2017). Conducting trainings directly on the shop floor has also been investigated (Fuchsberger et al. 2016).

In our interviews we found that companies have recently showed considerable willingness to experiment with smart glasses and AR devices in innovation efforts, for remote communication and also for learning purposes (Spitzer et al. 2018). Such devices allow to guide workers by displaying instructions or information in textual form or as a video in a more vivid way. Not occupying their hands at the same time allows to seamlessly conduct practical exercises without interruption.

Utilizing advanced forms of content that allows for some interaction per se like 360° video content (cf. Kavanagh et al. 2016) can help create a sense of immersion, and eventually a more practical experience that may lead to more effective learning.

5. Conclusions and Outlook

In this paper, we outline why we think increased usage of video content and video technology could be useful for production companies within their factory environments. We mention the current Industry 4.0 trend as a key reason to be optimistic about more widespread adoption of video in the near future, since it inspires or even forces many companies to reconsider and improve their production processes.

Since the application of video technology entails both opportunities and challenges, companies need to very carefully plan how to use it. Strategically, there is also the danger of an innovation pet project ending without being serious about integrating the resulting components into production processes. And due to increasingly networked applications in the realm of Industry 4.0, moving prototypes to production and clarifying technical interfaces and maintenance responsibilities is no small task. In this context also the tasks and job requirements of the staff are changing, adding to the complexity.

Due to limited exploitation of video opportunities so far, the market is lacking dedicated, stable products that can easily be configured and optimized to the specific situation in a factory. This goes hand in hand with usability concerns which are a key success factor towards user acceptance and as productivity enabler.

In terms of research, the situation is similar, as only a very small share of research efforts into video technology so far have looked at these kinds of environments. Throughout the

paper, unsolved challenges are discussed where research questions can be derived to tackle current shortcomings. Eventually, solutions could be developed that add value in smart factories as an assisting technology.

Acknowledgements

The work has been performed in the project *Power Semiconductor and Electronics Manufacturing 4.0* (SemI40), under grant agreement No 692466. The project is co-funded by grants from Austria, Germany, Italy, France, Portugal and Electronic Component Systems for European Leadership Joint Undertaking (ECSEL JU).

The Know-Center is funded within the Austrian COMET Program – Competence Centers for Excellent Technologies – under the auspices of the Austrian Federal Ministry of Transport, Innovation and Technology, the Austrian Federal Ministry of Economy, Family and Youth and by the State of Styria. COMET is managed by the Austrian Research Promotion Agency FFG.

The author would like to thank Carla Barreiros for her constructive feedback and suggestions.

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