

Potential and Limitations of Prototypes in Developer-User Communication

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Abstract

Prototypes primarily support communication between developers and other stakeholders in the development process. Any artefact that contributes to representing structural and/or behavioural characteristics during development can be considered a prototype. Since stakeholders, primarily users in this case, view prototypes from different perspectives than developers, their interpretations also differ. This leads to misunderstandings. This article examines what this interpretation process looks like and what factors influence it in order to build a better understanding of the communication processes between developers and users. From this, recommendations are derived on how the information content of the prototype can be best adapted to the communication task.

Keywords

Prototype, user communication, information transformation, development process

1. Introduction

Today, prototypes are essential components in development processes. They are both physical and virtual embodiments of critical elements in the development process [1]. In addition to their importance for exploration in the development process, their role in the verification and validation of development results must also be emphasised [2]. They answer the question of whether system properties are fulfilled and to what extent they satisfy the wishes and needs of customers [3, 4]. By discussing this question on the prototype, the prototype supports a learning process [5]: On the one hand, they give stakeholders an idea of what is technologically possible in order to be supported by products in action situations. On the other hand, developers can build up a deeper understanding of usage situations by working with prototypes and discussing their functionality. This makes prototypes an essential element in supporting communication between users and developers [6].

The following considerations and analyses of prototypes (PT) focus on their significance and function as tools to support the communication process. PTs can take many different forms, depending on what information they are intended to support within the communication process, but also depending on the development phase in which the PTs are used. Considering that development processes are iterative and can be divided into the following four phases of planning, conceptualising, designing and integrating from a development methodology perspective [based on 7], virtually every product artefact within the development process can be understood as a PT. A fundamental distinction can also be made between virtual and physical PT. In the early phases of development, only little information is known about the technical system to be developed, which is also subject to a high degree of uncertainty [8]. As development progresses, the information on the product to be developed becomes more complete. Accordingly, PTs can be designed in greater detail or enriched with more information. Ultimately, however, PTs are always models that are subject to reduction, serve a specific task and only depict the properties that are important and relevant for communication [9].

This article focusses on the use of PT as a means of communication between users and developers. The aim is not only to identify factors influencing the user's interpretation process of PT, but also to better understand the process of developing an understanding of PT. From this, in turn, it is important to derive starting points for the design of PT in order to adapt its information content to the communication task in the best possible way.

2. State of research and research question

The baseline for analysing the use of PT is that users and developers have fundamentally different views of a product [10]. Developers work according to the finality principle. This means that they anticipate an effect that users expect in an action situation in order to cope with it. Accordingly, a system behaviour is derived and broken down into sub-functions, for which solutions can then be sought, which in turn lead to an overall system integrated into the product [7]. Users interpret the product in terms of causality. They have only limited knowledge of the intention of product development. Users view the product as an isolated object and interpret it in their individual context of use and based on their experience. The focus here is generally not exclusively on the task to be accomplished. As a rule, users develop routines for completing tasks, into which the product can ideally be integrated. Only when the product supports or extends the ability to act is it accepted [11].

With different perspectives also come different backgrounds of experience. This leads to different evaluation criteria, especially for PT, which can result in difficulties in understanding [10]. In turn, communication about the properties of a product via PT also offers considerable potential: developers can collect information about the intentions of using the product and the usage situation, which in turn supports the search for solutions. Users are given the opportunity

to familiarise themselves with new technologies in order to evaluate them in terms of the support they provide in everyday life. This results in the need to better understand the communication mechanisms between users and developers, to identify differences in interpretation and, as a consequence, to adapt the information content of a PT to the respective information requirements.

A number of approaches can be found in the literature for the theoretical description of communication processes [e.g. 12, 13]. The basis for the development of a communication model to describe the information flows between user and developer is the approach of SHANNON/WEAVER [14], according to which PT serve as a means of transport for information. Encoding and decoding processes, which can be explained by different perspectives and experiences as well as disruptions within the communication process, distort the information content or lead to misinterpretations [12]. In addition, both developers and users act in both roles: as senders and receivers of information. The systems theory approach according to ROPOHL [15] serves as the basis for modelling the information flows as two nested control loops. Figure 1 shows this extended communication model. PT correspond to the controlled system, which is influenced by disturbance variables and thus manipulates the controlled variable, i.e. the information to be transmitted [16].

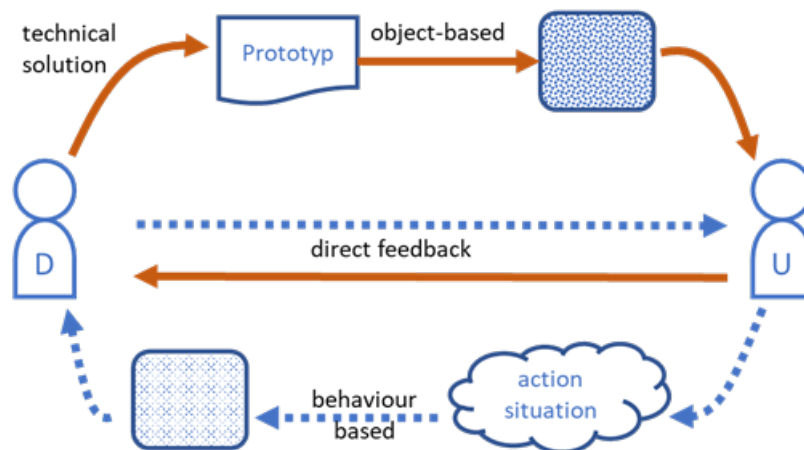


Figure 1: Extended communication model for understanding the effect of PT [16]

The investigations into the interpretation of PT initially focus on the object-based control loop. For the PT as an information carrier, it is important to analyse which properties significantly support the transport of information. The behaviour-based control loop describes how reliably the user accesses the information content in his context and evaluates it for his application. He communicates the result to the developer, who in turn interprets it from his point of view. This article focuses on identifying feature categories that users use to interpret functionalities for themselves.

Virtual PTs are the subject of this study. The advantage of using these is that there is no need for time-consuming and costly implementation in real components and, above all, development results from the concept and early design phases can be used for communication, for which there is still too little information available for realisation in terms of materialisation. The challenge of using virtual PT (vPT) is that primarily structural information can be used as the basis for communication. Information on functionalities or system behaviour must either be provided via animations and simulations or anticipated from the structure.

The research questions for the following investigations can be derived from these considerations:

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- How can characteristics for vPTs be substantiated in order to clarify their properties and support the interpretation of the functionalities of the resulting product?
 - How do vPTs help the developer to understand the context of use?

Two questions were asked in each of the phases, with the first question focussing on the subjects' interpretation of the vPT, i.e. addressing the quality of information in the object-based control loop (from the developer to the user). It therefore served to answer the first research question. The second question addresses the flow of information from the user to the developer in the behaviour-based control loop and serves to answer the second research question, i.e. the extent to which the context of use can be derived from the answers.

The extent to which these aspects influence the interpretation of the vPT and how this affects the information content of the communication will be analysed in the following study.

3. Research method and procedure

A multi-stage qualitative study was conducted to answer the research questions. The subject of the study is the development of a quadcopter for inspecting internal chemical plants. Five mechanical engineering students in their second semester supported the investigations as test subjects. The background to the choice of test subjects was that although they have a certain affinity with the development task, they do not yet have the experience of trained developers and therefore have a rather low bias with regard to finding solutions. In addition, all test subjects had the same experience in using CAD systems, so that a 3D CAD model could be used as a vPT for the analysis and interpretation. This ensures a high degree of homogeneity in the group of test subjects.

Firstly, the utilisation situation was described to the test subjects in a preparatory phase. The aim is to inspect internal chemical plants using a drone. In a joint workshop with the test subjects, they worked out the requirements for such a quadcopter. In this phase, the test manager merely acted as a moderator, collecting the requirements, scrutinising them in the event of imprecise or vague statements and recording the results.

There were approximately two weeks between the first and second phase of the experiment, which corresponds to a development phase in practice. In the second phase, the test subjects were first asked to describe their ideas about the operational environment and to formulate challenges for a drone flight in the operational environment as part of an interview. The test subjects were then provided with a CAD model of a drone as an initial concept for realising the requirements on the PC using the CAD software Solid Works in order to evaluate the drone's usefulness in the deployment scenario. Figure 2 shows screenshots of the drone, which was made available to the test subjects as a 3D CAD model. The CAD model could be moved freely and it was also possible to take a look inside, allowing a holistic exploration of the vPT. Data was collected using the think-aloud method. The test subjects' statements were recorded and later transcribed for analysis. The test subjects were asked to answer two questions: a) What do you see in the CAD model? and b) Is the vPT depicted able to act in the outlined deployment scenario?

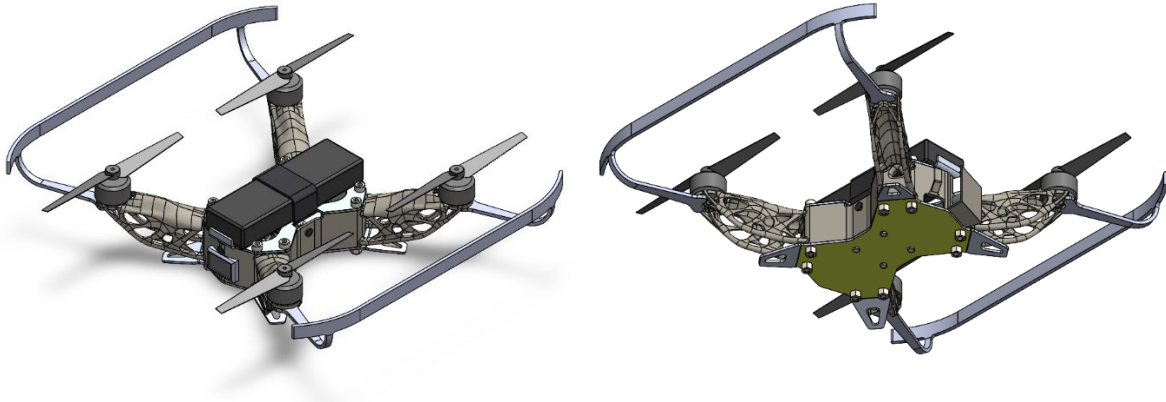


Figure 2: Screenshots of the drone used as a virtual prototype. Image from diagonally above and diagonally below.

The requirements collected in the workshop of the first phase were then used for the following. The test subjects were then asked to assess the extent to which they felt the requirements had been addressed or fulfilled. This was again based on the CAD model of the drone. In the interview, the two questions were asked again, but now with more specificity with regard to the requirements. The data was collected using the think-aloud method, recorded and transcribed for analysis.

A final third phase had more of a synthesis character and was directly connected to the second phase. In an interview, the test subjects were asked what further information they would give the developers. The background to this was to check whether the context of use would be taken up again and explained in more detail. The test subjects were also asked to comment on what additional information would have been desirable for evaluating the solution in order to better assess the characteristics of the drone or what would have helped to interpret the prototype.

4. Presentation of the results

Table 1 summarises the requirements developed by the participants in the preparatory workshop. They were subsequently categorised on the basis of the moderator's assessment of the vPT. These requirements were often also equated with characteristics of the drone as part of the assessment of the vPT.

Table 1: Developed requirements for the drone to inspect internal chemical plants

Requirements / expected characteristics	
Geometrically determined properties <ul style="list-style-type: none"> • Compact size • Payload capacity • Manoeuvrable and agile in flight • Good (stable) behaviour in flight • Propeller guard • Quick-change batteries • Recognisability (position light, signal colour) • Flight safety (stop/collision) • Large memory capacity • Accessibility for battery change 	Properties to be realised by software or information and communication technologies <ul style="list-style-type: none"> • Simple and clear operation • Screen for live image and information • Good camera quality (detection in all direction) • Obstacle detection (orientation) • Low battery downtime • Battery status display • Homing function • Mapping of images in 3D environment • Automated image generation • Flying routes

A typical feature of CAD models is that they are used almost exclusively to represent the geometry. Functional characteristics or statements on behaviour can only be anticipated. So-called signifier functions [17] can be used for this purpose. For example, symmetrical structures can indicate stability or large cross-sections can indicate strength.

Table 2: Compilation of the elements of visual perception (parts list)

Component	Quantity	TN1	TN2	TN3	TN4	TN5	
Base plate	1	X	X		X	X	compact size, stable behaviour in flight
Housing left/right	1/1	X	X	X	X	X	stable behaviour in flight, propeller guard
Control board	1	X	X	X		x	to realise software-based functions
Cover plate	1	X	X				compact size, payload transport
Housing screw	8		X		X		
Motor	4	X	X			X	manoeuvrability and payload capacity
Propeller	4	X	X	X	X	X	manoeuvrability
Electronic Speed Controller (ESC)	4	(X)	X				to realise software-based functions
Velcro strap	1	X	X	X			accessibility to battery
Voltage tester	1	(X)	(X)	(X)	X	X	good stable flight, software-based functions
Board screw	4		X				
Battery	1	X	X	X	X	X	to realise flight and payload transport
Propeller Guard	2	X	X	X	X	X	for safety reasons
Camera Module	1	X	X	X	X	X	automated image generation
Ultrasound sensor	3	X	X	(X)		X	obstacle detection

Table 2 shows a summary of the effects of visual perception. It is clear that in answering the first question of this second phase, the focus was on recognised components. In answering the second question (see Chapter 3), necessary and expected properties and functions were also increasingly addressed. The evaluation of the respondents' answers led us to structure them according to whether properties are recognisable or not. The structural representation of the drone serves as a reference. If properties were not recognisable, a further distinction was made between:

- Properties that are not recognisable but can be interpreted. This allows signifiers to be identified and concretised.
- Properties that are not recognisable and cannot be interpreted. In this case, either signifiers are missing or the expectations were different.
- Properties that are not recognisable and not present indicate elements that cannot be objectively mapped in the vPT, such as software or additional operating devices such as a console.

Table 3 shows the characteristics and their categorisation by the test subjects, and refers to the characteristics initially recorded in the recap and previously also in the requirements description.

Table 3: Elements and their classification into the above-mentioned property categories (number symbolises the respective subject)

Property in question:	Ist he property ...?			
	recognisable	Nicht erkennbar		
		Interpretable	Not interpretable	Not present
Compact Size	1,3,4,5		2	
<i>Flight</i> : manoeuvrable / agile	1,2	3,4,5		
<i>Flight</i> : good (stable) behaviour		1,2,3	5	
Payload capacity		1,5	2,3	
Propeller guard	1,2,3,4,5			
Quick-change batteries (low downtime)	4,5	1		
<i>Flight safety</i> : stop/collision	1,3,4	2,5		
<i>Visibility</i> : position light			3	1,2,4,5
<i>Visibility</i> : Signal colour	2,4,5		3	
<i>Operation</i> : Screen (for live image + information)			2	1,3,4,5
<i>Operation</i> : simple, clear			2	1,3,4,5

The third phase of the study functions as an initial synthesis step. The test subjects were to be given the opportunity to describe from their experience (i.e. from the user's perspective) what information they expected based on their ideas about the product and the usage scenario. While the first question tended to address change requests, the second question specifically asked what expectations they had in order to be able to assess non-visualised features. Interestingly, hardly any aspects were mentioned in response to the first question that indicate misinterpretations of requirements. Although ideas such as '*... charging the battery during flight...*' were expressed, there was agreement that this is an extension of the requirements and therefore not the subject of the development project.

On the other hand, a more precise definition of the requirements was observed. As the camera is stationary mounted on the drone (which was also perceived by the test subjects), some asked how images of the chemical plant should be realised from below or above. This shows that the user is definitely concerned once again with the context of use via the vPT and specifies it more precisely, which leads to valuable information for the developer that must be taken into account when detailing the design.

The answers to the second question, which information would be necessary or desirable in order to be able to interpret and evaluate properties that are not directly recognisable, make it clear that vPT are very strongly focused on geometry, which makes statements on function and behaviour very difficult in practice and can easily lead to misinterpretations and misunderstandings. The following were named as such missing elements:

- Elements that are essential for use but are not part of the core product (here e.g. the control console) or were not presented in sufficient detail (GUI, controls)
- Intangible components such as software or services that are necessary for use or the evaluation of user behaviour
- Elements that represent the haptics of the product
- Elements that represent the performance of the product.

5. Discussion of the results

The first research question for this article focussed on analysing the object-based control loop (Figure 1), and thus the transfer of information from the developer to the user and the associated interpretation. The study confirmed that vPTs in particular emphasise the structure of the product. Aspects that describe the functionality or behaviour of the virtual product must

be anticipated and interpreted by the user. In comparison to physical PT, depending on the degree of maturity, this is accompanied by a loss of information, which must be compensated for if information on functionalities is required. This requires additional information to be integrated into the visualisations to help overcome these display deficits. This can be visualisation metaphors, for example. Labelling of elements helps to clarify the functionalities. Various links, e.g. to data sheets, can help to illustrate the performance of the resulting product. It is known that simulations or animations associated with vPT make the behaviour of the product easier to understand. It is also worth considering the extent to which haptic impressions can be reproduced in order to create a link to the materialisation.

The second research question focuses on the behaviour-based control loop, i.e. the transfer of information from the user to the developer. In conjunction with the findings from the first research question, it becomes clear that vPT is often provided independently of the context of use. In our example, the drone was modelled specifically, but not the usage environment. In addition, control elements essential for the use of the drone were neglected, which obviously makes it more difficult to categorise the product in the context of use, which in turn can lead to misunderstandings. As a rule, the user's view of the product alone is not necessarily sufficient. A holistic assessment can only be made in the situation of use. However, the studies show that the user's intensive involvement with the PT certainly provokes them to visualise the context of use and reflect on the PT in this context. It also shows that misunderstandings and misinterpretations result primarily with regard to immaterial components such as the software or sensor technology.

However, it is also clear that certain structural elements or structural characteristics have an indicative function that is used to implicitly infer the system properties or system behaviour. An example of this is the statement made by a test subject: *'...four arms ... regular structure ... suggests a stable position in flight.'* Which signifiers can be recognised from the structural design is certainly also dependent on the user's background experience and knowledge. Nevertheless, this aspect appears interesting for further research in order to better understand and utilise implicit interpretations of structural features.

Last but not least, the categorisation of vPT in the data and information flows during development should be discussed once again. In the investigations described above, a vPT was used that can be assigned to the early design phase. Therefore, a lot of information and data that would allow a clear and unambiguous assessment is simply not yet available. There are always uncertainties that can be explained by uncertain and incomplete information. Although these are honoured as the product matures, they are latent, especially when using vPT. This aspect becomes even more important in the development of large, complex mechatronic systems. Here, it is often not complete systems that are used as PT for the evaluation of requirements and properties, but rather systems with partial functions, so that the user must then also anticipate the overall system. This makes interpretation and categorisation in the context of use even more difficult.

In communication between users and developers, it therefore seems essential to make it clear that vPT is only a representation of the product focussing on predefined properties. This limits the verification of requirements in particular. There needs to be clear communication and coordination between users and developers about which properties and aspects the design of the PT in general and the vPT in particular were based on and which properties are ultimately to be evaluated. The challenge here seems to lie more in the fact that a one-sided definition by the developer is not expedient, if only because there is a great risk that the developer will bias the description of the objectives. Rather, it requires negotiation and equal co-operation between developer and user in order to agree on evaluation criteria in the sense of the design and definition of further development tasks, which then also form the basis for the PT design.

Contrary to what is postulated in the sense of an agile development methodology, it does not seem very expedient to equate increments as the result of a development task with the prototype, as this may only address parts of the properties of the resulting product or only parts

of functions or behavioural aspects. Further research is also required in this regard in order to better understand the mechanisms and make them usable for PT design.

6. Summary

The article presented a study that analysed how PT can support communication between users and developers in product development. The basis for this was the assumption that, on the one hand, the developer wants to pass on information about the product to the user and, on the other hand, the user can provide the developer with information about the context of use. Challenges in the transfer of information were identified and initial approaches to overcoming them were identified. Future research will need to further differentiate the challenges and specify possible solutions.

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