Image Processing in Logistics - Considerations on the Role of Intelligence*

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***Abstract*—In this paper, we examine the role of intelligence of logistics solutions that are built by image processing components. Based on studies of the research field of intelligence and observations on how the term intelligence is used in practice, we derive an understanding of what intelligence encompasses in the context of image processing for logistics. The resulting conceptual framework offers different perspectives to intelligence and integrates sub-concepts, functions, and terms in an organized and interrelated manner. Thus, the presented study leads to a better understanding of what intelligence may mean in the context of designing intelligent logistics solutions by means of technical components such as image processing.**

***Index Terms*—Image Processing, Computer Vision, Logistics, Intelligence, Intelligent Systems**

I. INTRODUCTION

Within Logistics 4.0, technologies and concepts are being developed in order to equip logistics objects with technical components, so that these can either guide themselves as cyber-physical systems through logistics processes in a self-controlled and decentralized manner or provide human operators with technical assistance functions for decision-making [1]. Similar concepts, such as Smart Logistics Zones [2] or IoT in Logistics [3], also indicate the tendency to increasingly equip logistics solutions with technical components, so that they can perceive their environment and both provide and consume information in order to affect the physical logistics processes under certain efficiency goals. In this context, *intelligent* or *smart* are omnipresent terms. These are imprecisely used to indicate operations as being "planned, managed or controlled in a more intelligent way compared to conventional solutions" [4]. The term "more intelligent" often corresponds to the integration of new information and communication technologies, e.g. sensors, data mining or, information fusion into solutions. Especially in the context of IoT, nearly everything that is attached with sensing and communication technology is immediately referred to as intelligent or smart [5]. Within the field of image processing the term intelligent (or smart) is often used to refer to intelligent cameras, which provide processed information [6], or used to underline that intelligent solutions can be designed through the application of image processing [7] [8]. However, the widespread and diverse use of this term also means that it loses its expressiveness. For this reason, we want to sharpen the understanding of the term intelligence in the context of the design of image processing components for intelligent logistic solutions. We will examine how image processing is linked to logistics via the concept of intelligence and show that a clear description of this interface can also have added value for the planning and development of logistics solutions by means of image processing.

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II. TERMS AND DEFINITIONS

A. Image Processing

The term image processing refers to the processing of images by means of a computer [9]. However, the boundaries of what image processing encompasses are described differently in the literature, in demarcation from concepts such as image formation, image enhancement, image analysis, image understanding, machine vision or computer vision. Some researchers define image processing in a narrower sense as a set of computational operations that transform images to enhanced images [10] [11] [12]. In this sense, image processing is a component of computer vision or machine vision methodologies. Other researchers define image processing in a broader sense that comprises a variety of processes whose common goal is to enable the extraction of useful parameters from images or sequences of images [13]. In this sense, image processing encompasses methods such as image formation, image enhancement, image analysis, and image understanding [14]. In this paper, we use the broader definition of image processing. Depending on which thing is associated with image processing capabilities, this term is interchangeable with machine vision, robot vision, computer vision, or terms yet to be established such as car vision.

In image processing, everything is about images. From a practical point of view, images are numerical representations of spatially distributed physical properties such as color, depth, or temperature of the captured environment and its contained objects (see Fig. 1). They are arranged in arrays of discrete points, where every dimension is built by one or more channels. The images are formed by sensing devices that are sensitive to electromagnetic waves, e.g. infrared, visible light, thermal. The sensing devices are not limited to visible light but can capture almost the entire electromagnetic spectrum. However, sensing devices which operate within or near the visible light spectrum are very common, such as sensing devices that generate color images, depth images or thermal images. Images can be generated either by scanning or by direct imaging. A sensor that captures an image sequentially by moving sensor parts or by moving itself is called a scanner. If a sensor is capable of capturing an image without scanning, we call it a camera. A camera can also be used as a building block for a scanner [15].

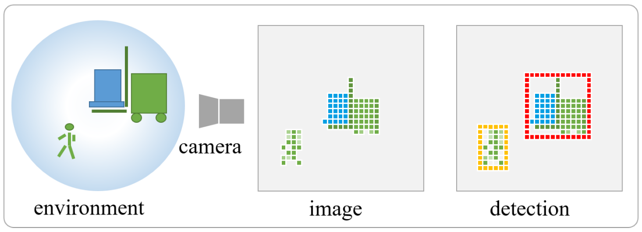

Fig. 1. Image processing in a nutshell: Images (numerical representations of spatially distributed physical properties) are generated by sensing devices and processed in order to extract useful parameters.

B. Logistics

Logistics is a concept of everyday life that was already widespread in Greek antiquity and has been subject to a constant change of meaning ever since. At first, it was influenced by philosophy, later by military affairs and in modern times by economy [16]. Due to the interdisciplinary character of logistics science, logistics is defined differently nowadays [17]. From a scientific perspective, Schenk defines logistics as the science of designing and controlling processes and structures of holistic systems in order to fulfill individual customer demands in a goal-oriented manner with efficient use of resources [18]. From a more practical view, Mallik defines the task of logistics as "having the right item in the right quantity at the right time at the right place for the right price in the right condition to the right customer" [19].

The diversity, the constant change and the influence of new technologies on logistics practice and logistics science pose a great challenge to the development of new and cost-effective solutions. For this reason, Illés et al. proposed a logistics thought model that divides logistics into logistics product, logistics process, and logistics system and acts as a framework for specification and development of reference solutions [16]. In this context, Illés et al. define the following basic elements:

- *Operands* as part of the logistics product, e.g. goods, parts, orders
- *Operators* as part of the logistics system, e.g. conveying technology, storage technology, communication technology
- *Operations* as part of the logistics process, e.g. conveying, storage, identification

In slightly extension to this thought model one can differentiate between system element or infrastructure element regarding the operator. In contrast to the logistics system itself, operators are assigned to the infrastructure if they are generally and not exclusively allocated by a concrete logistics system but can be used by several systems. Infrastructure operators are particularly associated with investment costs for development and are designed for a long operating lifespan. In other words, they are already available and generally usable as a basis for solution development. Infrastructure components can be communication infrastructures such as mobile communications, computer infrastructures such as cloud services, and sensor infrastructures such as global navigation satellite systems or video systems. The distinction between operators is helpful within the planning phase of logistics systems, since infrastructure elements may be integrated into the logistics solution in a different way. Within the operating phase, the characteristics and behavior of both types of operators do not differ and merge within the logistics processes to form a functioning logistics solution.

III. Intelligence by Image Processing

A. Intelligent (Smart) Logistics

As shown in the introduction, the term intelligence is widely used in logistics. Often the term is associated with the equipment of logistics solutions with technical components. In addition, intelligence often refers to the fact that a solution was inspired by processes from nature or by processes in the human brain [20]. Obviously, intelligence is associated with different aspects in research and industry. According to our observations, the following aspects may be considered in the application field of logistics:

- *Intelligence as a keyword* for the postulated property of Logistics 4.0 and IoT solutions
- *Intelligence as symbol* that refers to the mapping of human or natural intelligence to technical entities
- *Intelligence as a requirement* within a solution concept for a technical system
- *Intelligence as a quality indicator* of an existing solution

These considerations show that intelligence is an important and widespread concept in logistics. Definitely, it goes hand in hand with the integration of technical components into logistics systems. Thus, a general relationship between a logistics system and an image processing system as a technical component can be claimed, with intelligence forming the connector. However, for a deeper understanding of the role of technology such as image processing in logistics, this is still insufficient. For this reason, this relationship is further examined in the following sections. First, concepts of intelligence are presented in order to make the term *intelligence* more tangible and a definition of intelligence in the context of the work of this paper is derived. In addition, a conceptual framework reflecting the role of intelligence in logistics solutions with image-based components will be presented.

B. Concepts of Intelligence

Intelligence research encompasses a broad spectrum of research fields with different research perspectives. While psychologists rather focus on how human intelligence is structured functionally or which skills are the basis for intelligent behavior, neuroscientists and computer scientists rather take the perspective of the genesis of intelligence more into consideration and ask about the biological or technical mechanisms on which intelligence is founded. From the different interdisciplinary perspectives, attempts are made to define what intelligence is. Another related interdisciplinary question is how intelligence can be measured (see Fig. 2).

The psychologist John B. Carroll introduced his three-stratum theory, which explains intelligence hierarchically with the general g-factor at the highest level, eight specific intelligence complexes at the middle level and about 70 specific intelligence abilities at the lowest level [21]. Three stratum theory is a structural model of cognitive abilities and excludes aspects of motion intelligence in the original approach. However, in an extension of this model, kinesthetic abilities are also included [22]. The theory of multiple intelligences explains intelligence as "the capacity to solve problems or to fashion products that are valued in one or more cultural setting" [23]. In contrast to three-stratum theory, multiple intelligence theory claims that people have different abilities to process information intelligently and that they are relatively independent of each other. The theory of multiple intelligences includes a capability to "use the body or individual body parts (for example, hands or mouth) to solve problems or create products" [23] as thus aspects of motion intelligence. The idea of incorporating motion intelligence as an essential ability of intelligent behavior and is particularly relevant in the field of logistics, which deals with handling and transportation of objects. The physicists Wissner-Gross and Freer defined intelligence by means of entropy maximization [24]. Later, Wissner-Gross argued that intelligence is a physical process that tries to maximize future freedom of action and avoid restrictions in one's own future [25]. In the field of artificial intelligence research, Legg and Hutter [26] conducted extensive research and defined intelligence as a measure of an agent's ability to achieve goals in a variety of environments.

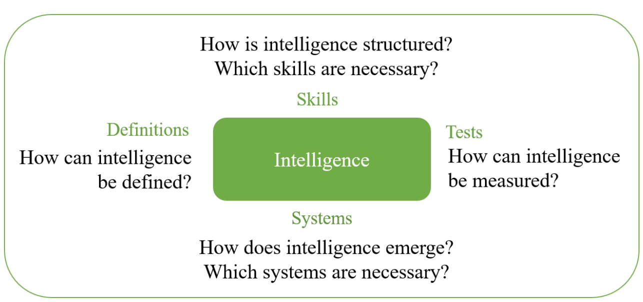

Fig. 2. Different perspectives and research questions on intelligence.

C. Initial Definition of Intelligence

We approach the term intelligence inspired by definitions of Wissner-Gross [25] and Legg and Hutter [26]. These definitions are very general and do not yet give any indication of the inner structure of intelligence, but connect precisely objects of intelligence (agents, processes) with goals of intelligence and certain environments in which intelligence is present (spatial and temporal dimension). Based on these definitions, we derive our initial definition of intelligence:

Intelligence is a complex capacity of logistics solutions that emerges from technological, biological or organizational components and is used by logistics operators (people, machines, hybrids) in a variety of environments to increase their future freedom of action so that they can act in respect to deviations or unknown situations in the logistics processes with the most efficient option according to a variety of goals.

This definition reflects a producer-consumer-relationship, intelligence is produced by technological, biological, or organizational components and is consumed by logistics operators in order to achieve a variety of goals within a variety of environments. The following insight can be derived directly from this relationship: From a logistics point of view, intelligence maximization is not to be aimed at. Rather, the amount of necessary intelligence of the solution, which will be consumed by the logistics operators should be determined by means of logistics process analysis. Then, this amount of intelligence could be produced by adding technological components to the solution. Moreover, our definition of intelligence above is closely related to the agent model, such as described by Rudowsky [27]. In such a model, the sensory input, the agent itself and the effector form the components from which intelligence emerges. Based on this agent model we developed an enhanced model as shown in Fig. 3. In this model, the logistics operator is roughly equivalent to the agent. Furthermore, we define an *intelligence cycle* inspired by the PCA model from Harbor [28]. The intelligence cycle is composed of four components arranged in a cycle, and acts as a connector between operator and environment:

- *Perceptions* encompass detection, organization, and interpreting of sensory information that is further processed by cognitive functions.
- *Cognitions* encompass thinking processes such as knowing, remembering, reasoning and communication.
- *Actions* encompass the physical actions of the operator in the environment which are controlled by cognitive functions.
- *Operations* encompass the logistics processes in the environment resulting from the actions of all participating operators.

This way, the intelligence cycle explains the structure and the function of intelligence in more detail, with its producing part (perceptions, cognitions, actions), its consuming part (operations), and its relational properties such that the integration of technical components (perception, cognition, actuators) have to be balanced and lead to an increase of operational efficiency.

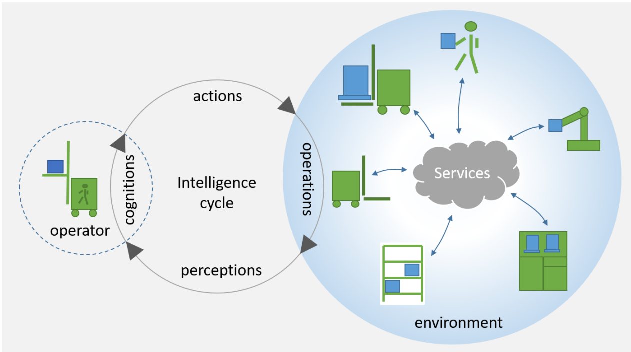

Fig. 3. Intelligence cycle: Model of intelligent operators in logistics environment based on agent model of [27] and inspired by [28].

D. *Synthesis of Intelligence through Image Processing*

Based on the considerations above, the question arises, what role image processing can play within the synthesis of intelligence. In literature, many concepts are described how intelligence emerges from technical or biological systems. Schneider shows how abilities from the CHC-model can be mapped to information processing systems or, in other words, how information processing forms the basis of cognitive abilities [22]. Stancombe defines five senses of artificial intelligence from which intelligent system can be built [29]. Within the research framework of Cognitive Neuroscience Theories, researchers are trying to explain how network topologies and dynamics in the human brain lead to effective information processing and finally to intelligent human behavior [30]. From our point of view, it seems reasonable to follow Stancombe's functional approach [29]. Similarly, we define six aspects that need to be addressed in order to design intelligent systems:

- *Sensing:* The acquisition of data from the environment by means of sensory organs or technical sensors
- *Learning:* The building of knowledge models and information processing pipelines based on the synaptic plasticity of neurons or computer emulations.
- *Inferring:* The generation of inferences from data using the learned models and information processing pipelines based on the synaptic activity of neurons or computer emulations
- *Communicating:* The transformation and exchange of data or information on different levels of abstraction, and between or within technological or biological entities.
- *Acting:* The physical interaction with human or technical actuators based on motoneurons, muscles, limbs, or technical drives.
- *Effecting:* Both the specification and evaluation of the resulting operations in the environment from the point of view of overall objectives to be achieved

Within image processing, the six aspects are addressed as follows:

- *Sensing:* The acquisition of image data from the environment by means of cameras or scanners
- *Learning:* The building of knowledge models and information processing pipelines by means of image processing algorithms
- *Inferring:* The generation of inferences from images using the learned models and image processing pipelines
- *Communicating:* The transformation and transfer of information to other entities
- *Acting:* No direct connection (It uses results from image processing)
- *Effecting:* No direct connection (It defines a quality index and provides a specification)

E. *Conceptual Consolidation*

As shown in the previous sections intelligence is a popular concept and keyword in logistics. However, there are different paths from different perspectives on which to approach. From our point of view, the goal-oriented character of intelligence is the essential core that needs to be taken into account when talking about the intelligence of technical systems. This is evident, on the one hand, from our initial definition and, on the other, from the consumer-producer relationship that characterizes intelligence in systems. On a more process-oriented level, we think it is advantageous to distinguish between perception, cognition, action, and operation. On a functional level, we distinguish between technical functions such as sensing, learning, inferring, communicating, acting and effecting. On this level, concrete procedures, sensors, hardware, and tools can be assigned, such as in the case of image processing for example:

- *Sensing:* Intel RealSense Depth Camera D435 [31]
- *Learning:* Tensorflow machine learning library [32]
- *Inferring:* OpenVINO [33]
- *Communicating:* OLAC Adaptive video streaming [34]

In Fig. 4 a conceptual framework is shown as a pictorial. Here, all perspectives are brought together and thus relates the technology domain of image processing with the application domain of logistics via the concept of intelligence. An important finding from these considerations is the identification of intelligence both as a quality indicator and as a requirement for the system solution, including its image processing components, from a logistics point of view. If this role of intelligence is ignored, there is a risk that the logistics solution will become over-engineered, which in our understanding does not correspond to the main objective of using intelligent components in logistics systems, namely to make the solution more efficient. Moreover, the conceptual framework can support the exchange in interdisciplinary projects by linking the perspectives of different experts, engineers or scientists with regard to intelligence and/or defining their roles in the design of intelligent systems.

F. *Assessing Intelligence*

Being aware that intelligence is an attribute of logistics solutions and components, the question arises how intelligence can be assessed. Possible indicators of intelligence could be

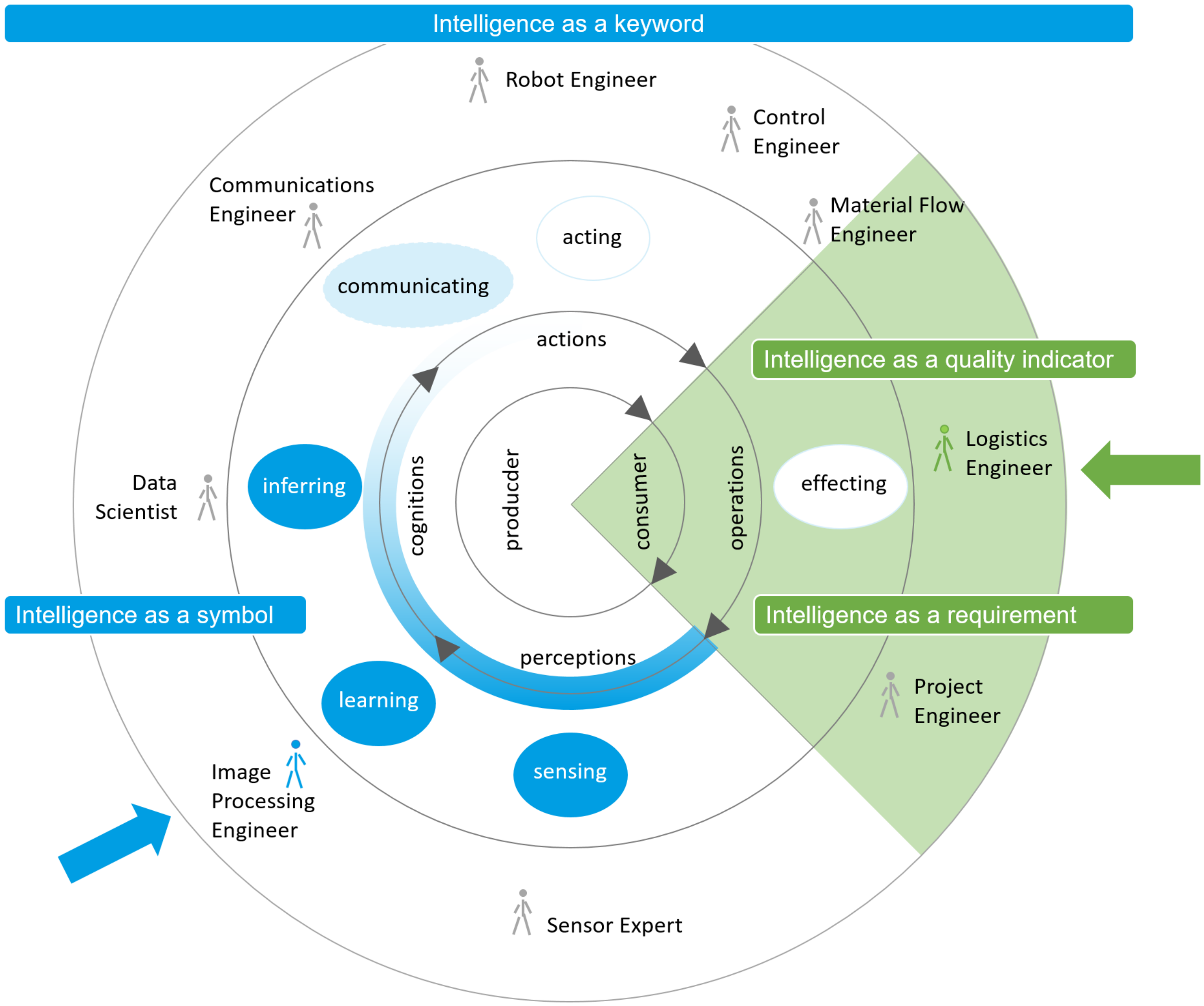

Fig. 4. Conceptual framework of intelligence. The blue and green arrows indicate the perspectives of image processing and logistics.

the degree of mechanical freedom of movement, the number of cameras used, the monitored area, the amount of data, or the bandwidth of communication. However, these parameters lack a reference to the goal orientation of intelligence. For this reason, it is more appropriate to assess intelligence in a goal-oriented manner:

- *Qualitative approach*: A technological component leads to a goal associated with the logistics process (e.g. efficiency, transparency, cost reduction, etc.)
- *Quantitative approach*: A technological component contributes to the "7+rights of logistics"

From a technological perspective, indicators such as the monitored area or the bandwidth of communication could act as low-level indicators of intelligence and could help to compare intelligence technically, e.g. "How intelligent is a specific operator?". The logistics perspective on intelligence, however, still forms the frame of reference for assessing the intelligence of the overall solution.

IV. Design and Implementation of Image Processing Components

After evolving a common understanding of what intelligence may mean from different perspectives and bringing it together to a conceptual framework, we want to briefly discuss how to design intelligent components based on image processing for logistics solutions. The principle design scheme is shown in Fig. 6. Many aspects of this design scheme result from the considerations in the previous sections, which is discussed below.

As outlined in the previous section, it is important for the design of intelligent logistics systems that the objectives to which the technical components with their intelligent functions should contribute are clearly defined. In this context, intelligence is implicitly requested to solve the problem and acts as a requirement of the solution. Based on the objectives, it should be verified, if a technology domain such as image processing can offer a solution. Due to the many perspectives and the interdisciplinary character of the design of intelligent systems (see Fig. 4), it would be helpful to support this step with a knowledge database containing applications of the certain technology (image processing) in the application domain of logistics. A first contribution towards such a knowledge database of image processing in logistics can be found in [35]. The knowledge database has to be developed and maintained on the basis of literature and market studies. When creating a knowledge database, however, the question arises how existing solutions can be indexed and categorized. In our experience process indicators, such as operators and operands [16] and task indicators, such as the 7+rights of logistics [19] are suitable features for classifying those applications. In this way, the principle suitability of a certain technology can be ensured and evidenced by reference applications. Subsequently, a request can be submitted to the technology domain such as image processing. This request can be answered with a solution concept that provides components with intelligent functions according to the requirements. In this context, intelligence acts as a common keyword and a symbol of the solution and refers to the use of methods, procedures, and technologies that are inspired by concepts of human intelligence, e.g. sensing, learning, inferring and communicating. From our point of view, it would also be helpful to support the solution design with a knowledge database. These should contain expert knowledge such as sensing devices, learning algorithms, inference hardware and their properties in order to support the selection of components. A further approach to the early evaluation of image-based components is virtual commissioning [36]. Here, technical components are emulated and the basic feasibility of the solution concept is evaluated (see Fig. 5).

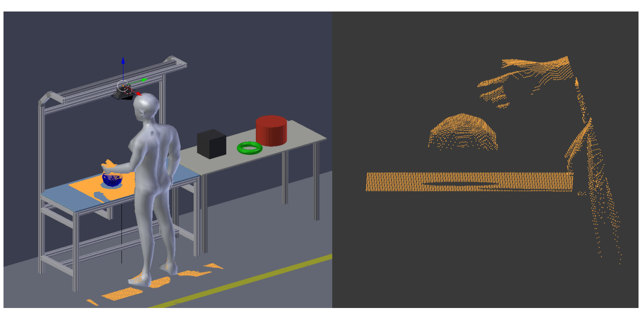

Fig. 5. Example of virtual commissioning of an image-based component.

As a result, one or more solutions variants form the feedback to the application domain. In this context, the intelligence generated by the technical components acts as a quality indicator of the solution. If no solutions in the field of image processing could be found according to the requirements, a reference should be made to other, related fields of technology, e.g. a radio-based positioning system instead of an image-based positioning system.

V. Conclusions

In this paper, we have examined the role of intelligence in the context of logistics solutions with components of image processing. We demonstrated that intelligence is an omnipresent term in everyday practice and is researched from many different perspectives and is thus attached with a variety of definitions and meanings. As a contribution, we proposed a conceptual framework that connects the technology domain image processing with the application domain logistics via the concept of intelligence. Here, different perspectives to intelligence with different sub-concepts, functions, and terms are organized and interrelated. After evolving a common understanding of what intelligence may mean from different perspectives, we discussed design and implementation aspects of image processing components for intelligent logistics solutions, with references to the conceptual framework and the different roles of intelligence within that.

In future work, we plan to support the design scheme with content (databases) and elaborate and evaluate it further on the basis of application scenarios. Moreover, it would be promising to examine the concept of virtual commissioning for evaluation of different variants of image processing components in the planning and implementation phase.

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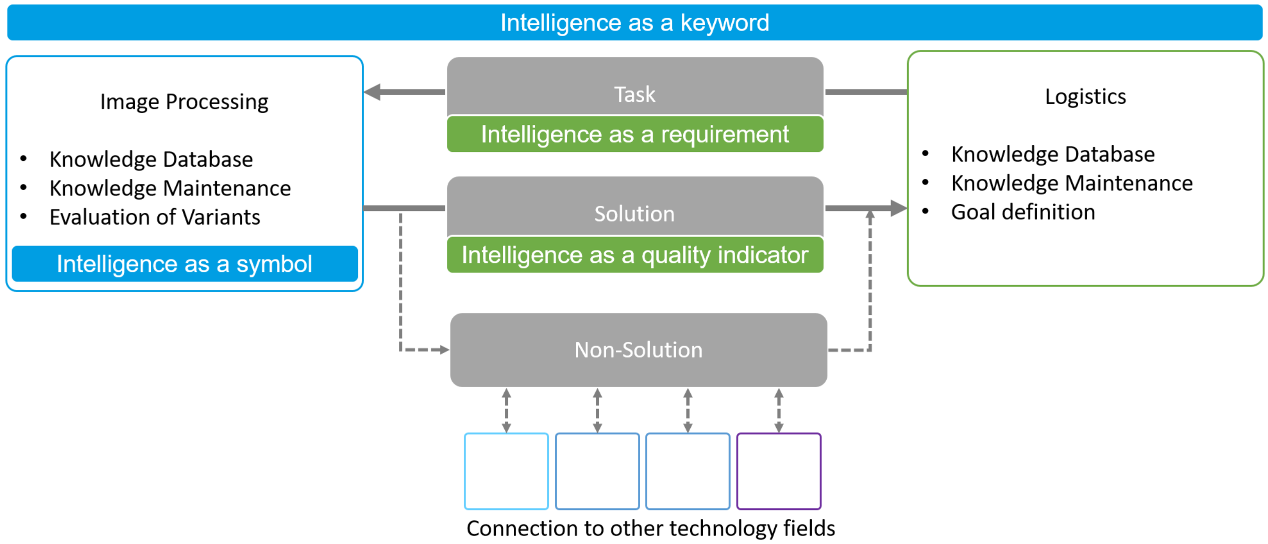

Fig. 6. Design Scheme for planning and developing "intelligent" components based on image processing for "intelligent" logistics solutions.

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