Intelligent Return Processing: Machine Vision (MV) with SAP BTP in Reverse Logistics

Arun Chinnannan Balasubramanian

Verizon communications,
Basking Ridge, USA

Abstract
Reverse logistics(RL) plays a pivotal role in managing the lifecycle of products, encompassing returns, repairs, and recycling. By integrating Machine Vision (MV) technologies with SAP's Business Technology Platform (BTP), industries can redefine return processing workflows, achieving improved accuracy, efficiency, and automation. This paper explores the technical intricacies of MV camera systems and their possible seamless integration with SAP BTP that aid the reverse logistics dispositioning. A methodology is provided, along with an examination of challenges, solutions, and potential impacts in industrial scenarios. The framework presented herein addresses pressing challenges in reverse logistics while paving the way for advanced engineering.

Keywords: MVS, Reverse Logistics inspection, Machine vision, Disposition automation, SAP BTP, Event mesh, Integration suite

1. Introduction

Reverse logistics involves the systematic handling of returned products, focusing on inspections, repairs, and recycling. Traditional methods, dominated by manual inspections, are prone to errors and inefficiencies, especially under high-volume processing. The emergence of Machine Vision (MV) technologies, coupled with SAP's Business Technology Platform (BTP), provides transformative opportunities. Through automation, real-time analytics, and predictive capabilities, this integration enables industries to optimize return processes, reducing costs and enhancing decision-making accuracy. This paper delves into these advancements, presenting an exhaustive technical exploration and a robust framework for implementation.

2. Literature Review

2.1 Machine Vision and Its Types

Machine Vision Systems(MVS) utilize cameras and sophisticated computational algorithms to automate the process of visual inspection, ensuring consistency and precision in industrial applications. Key camera types include:

1. *1D Cameras*: These systems specialize in line-based scanning, capturing sequential data to decode barcodes or validate printed text at high speeds. They are integral in industries such as logistics and packaging, where rapid identification of items on conveyor belts is essential.
2. *2D Cameras*: Capable of capturing flat, high-resolution images, these cameras excel in defect detection, character recognition, and verifying spatial arrangements of components. Advanced algorithms enable them to identify surface anomalies such as scratches or discoloration, making them invaluable in quality control.

3. *3D Cameras*: Designed for volumetric analysis, 3D cameras deploy techniques like structured light projection, stereo imaging, and time-of-flight (ToF) sensing. They create depth maps to measure dimensions, inspect geometries, and guide robotic systems for precise assembly or packaging tasks.
4. *X-ray Cameras*: These provide non-invasive insights into the internal structures of objects, detecting voids, fractures, or assembly errors. Widely used in aerospace and electronics, X-ray imaging is critical for ensuring the integrity of high-value components.

These systems collectively cater to a diverse array of inspection requirements, ensuring precision, speed, and reliability in varied industrial settings [1][2][3].

Fig 1 is the conventional MVS system with camera(which can be varied based on the intention), image processor library, illuminator and its software[11]. Modern systems come with software that can signal events for which a business transaction can be triggered. In our case for Ex- if an unboxed object is detected, a put-away process can be sent to the warehouse location system or ERP like SAP S/4. One dimensional and two dimensional MVS have a wide range of applications such as measurement, surface and depth inspection, thermal inspection and robot vision. Each kind of application has its own characteristic equipment with different image gathering source, such as photoelectric sensor, lasers, cameras and so on[5].

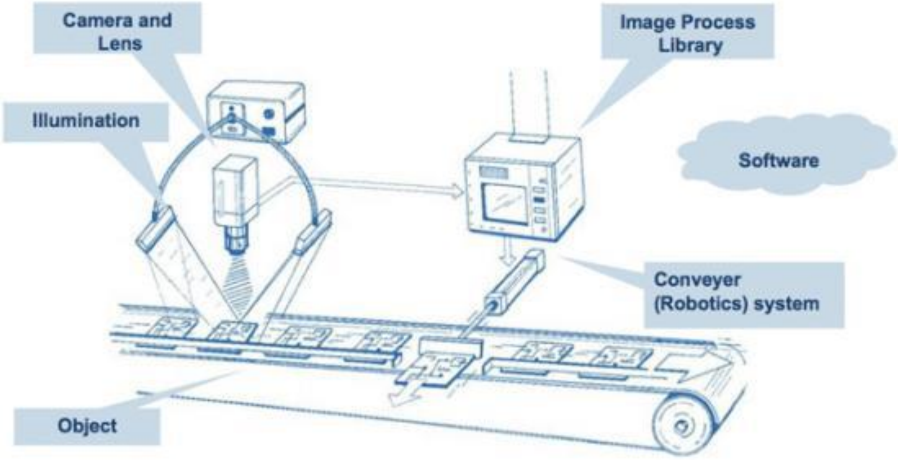

Fig 1: Conventional MVS systems, which can be integrated to modern systems [12]

Fig 2 is about industry evaluation of MVS systems in the automotive industry by a study[7]. Based on the usage and applications that are intended, a combination of these factors should be considered like adequate vision, considering system accuracy, working distance, image output, system advantages and limitations. New manufacturing systems propose simultaneous monitoring of physical processes while being controlled by digital technologies, being able to make smart decisions through real-time communication and interaction between humans, machines, or any smart device[4]. MVS systems now are IoT capable, also it can be integrated to ML/AI capable solutions on the findings. But for a deep learning and machine learning framework for MVS it is important to emphasize the need of an image knowledge database, which contains object features and quality criteria definitions, which may be used to assist and improve the current learning methods[10].

MVS TYPE	TYPE	PRECISION	WORKING DISTANCE	ADVANTAGES	CURRENT LIMITATIONS	AUTOMOTIVE INDUSTRY PERSPECTIVE
Traditional Camera System	2D	up to 0,1mm (*1)	18 mm up to 2m (*1)	Solutions are commercially available with customizable lenses and lighting accessories	Influenced by environment light conditions Object and Camera must be static Fewer image processing features which limits some defect type and object detection	Already in use (*3). AI applications under technical viability evalution
Photoeletric or Laser System	2D	(*2)	60mm up to 5m		Influenced by environment light conditions Object and Camera must be static	Already in use (*4)
Laser Triangulation	3D	(*2)	-		Influenced by environment light conditions	Under technical viability evalution
Time of Flight Triang.	3D	10mm	0,25m up to 3m	Independent of ambient light Static Object and Camera are not necessary	Low acurracy	Under technical viability evalution
Light Coding Imaging	3D	10mm	1m up to 3m	Static Object and Camera are not necessary	Low acurracy	Technology not evaluated yet
Structured Light	3D	34 µm up to 0,12mm	157mm up to 480mm	High Accuracy	Short working distance / Sensor can be quite large It may be influenced by ambient light depending on structured light type Static Object and Camera are needed	Technology not evaluated yet
Stereo Vision and Photogrammetry	3D	up to 50 µm	0,25m up to 3m	High Accuracy	Influenced by environment light conditions Physical marks necessary Point cloud density can be low Object and Camera must be static Intensive image processing required and it mat be time consuming	Under technical viability evalution
Projected Texture Stero Vision	3D	up to 0,1mm	0,25m up to 3m	No physical marks necess	Influenced by environment light conditions Object and Camera must be static Intensive image processing required and it mat be time consuming	Technology not evaluated yet

(*1) - Depend on Lens Selection, Camera Resolution, Working distance, object size and object tolerances
(*2) - Increasing working distance decreses inspection accuracy.
(*3) - Used for part detection, poka yoke - New process or process modification greatly affects its performance. New products may no be detected with the current
(*4) - Used for part detection and precision measurement

Fig 2: MachineVision Systems and usage capabilities. Courtesy from [7]

2.2 Variations and Applications

3D machine vision cameras are designed to capture dimensional data from multiple perspectives, generating a digital perspective of the model containing detailed information about position and shape. By incorporating depth data, these cameras overcome the 2D systems limitations. There are four primary types of 3D cameras, categorized as follows

- *Structured Light Techniques:* These involve projecting known patterns onto an object's surface and analyzing distortions to generate 3D models. This approach is used in applications requiring fine geometrical inspections, such as automotive part analysis.
- *Stereo Vision Profilometry:* Employing dual-camera setups, this method captures and reconstructs the depth of objects, enabling its use in high-precision robotic arm guidance[6].
- *Time-of-Flight (ToF) Techniques:* Measuring the time taken by light to travel to and from a surface, ToF systems deliver rapid depth measurements, critical in dynamic environments like sorting facilities.
- *Laser triangulation:* It is a non-contact measurement technology that uses a laser beam and a camera to determine the position, shape, or dimensions of an object. By analyzing the angle of the reflected laser beam, the system calculates precise 3D coordinates, making it ideal for applications requiring high accuracy and resolution.

These functions can be applicable to several return merchandise inspection use cases.

2.3 SAP BTP Integration to MVS or any IOT systems

SAP BTP serves as a robust platform for integrating IoT-enabled devices, including MV systems, with enterprise workflows. Its technical capabilities include:

- *Seamless Device Integration:* SAP's IoT services offer built-in compatibility with diverse MV cameras, enabling real-time data acquisition and processing.
- *Scalable Cloud Infrastructure:* With SAP's high-capacity cloud solutions, large datasets generated by MV systems are efficiently stored, processed, and analyzed.
- *AI and Machine Learning Tools:* As an optional architecture, Advanced analytics tools support predictive maintenance, anomaly detection, and decision-making for quality assurance. It may take from 3 to 10 years for industries to achieve a concrete degree of maturity and obtain a fully operational system[8][9].
- *Extensibility and Customization:* The API-driven architecture of SAP BTP ensures adaptability to unique industrial scenarios, enabling bespoke solutions.

3. Methodology

3.1 Integration Framework

The proposed framework encompasses three distinct layers:

Hardware Layer: Includes MV cameras (1D, 2D, 3D) configured for specific use cases. High-resolution sensors capture detailed imagery for inspection. Also can send codes or signals that can classify binary values of each of the test cases.

Middleware Layer: Utilizes SAP Integration suite and event mesh to orchestrate the IoT services to normalize data formats, preprocess images, and ensure seamless communication between devices and enterprise systems.

Application Layer: Employs SAP AI Core to classify defects, automate disposition workflows, and generate actionable insights for logistics teams.

Flow of MVS event-to-business action framework with reference to Fig 3:

1. An application administrator logs into SAP BTP Extension application based on Events to Business Actions Framework via SAP Build Work Zone, advanced edition, to configure the business rules/decisions and the business actions that needs to be triggered in the business systems.
2. An event is triggered from source systems like Microsoft Azure/AWS/Telco IoT Platform (in the case of IoT scenario) or any other system.
3. These events are published on SAP Integration Suite, advanced Event mesh. As the processor module's (part of the Events-to-Business-Action framework) endpoint subscribes to advanced event mesh, the event is received.
4. Processor module (part of the Events-to-Business-Action framework) leverages the Decisions capability of SAP Build Process Automation to derive business action (for example, if the incoming signal from MVS a 'known recall product' a 'Out to Vendor' Transfer order creation in SAP S/4HANA is initiated) based on certain characteristics of incoming event.

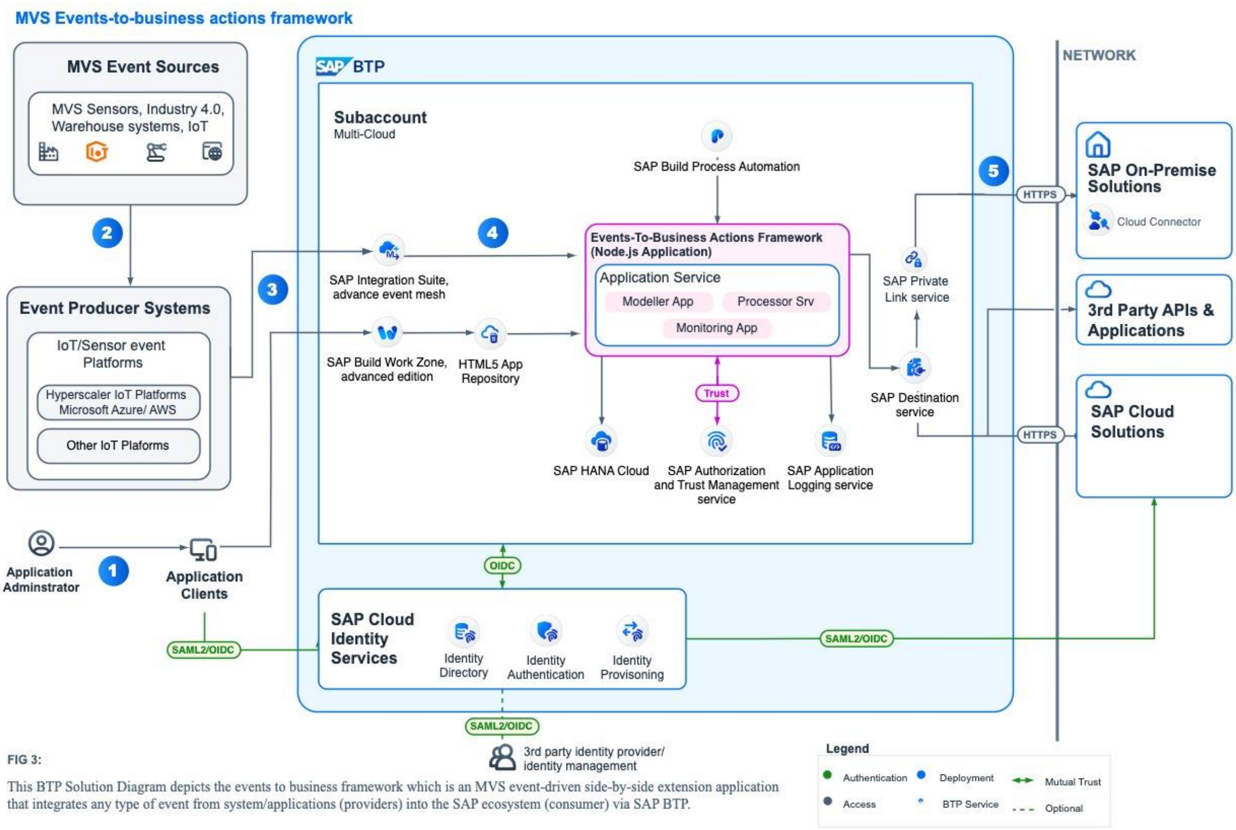

Fig 3: Architecture diagram for MVS based integrated system to SAP BTP and other ERP systems.

5. The defined action is triggered in SAP S/4HANA using the SAP Destination service and SAP Private Link service setup. In case SAP S/4HANA and SAP BTP are on the same hyperscaler, communication with SAP S/4HANA happens via SAP Private Link service.

Feature Scope for Event Mesh: SAP Event Mesh is a fully managed cloud service that allows applications to communicate through asynchronous events. Experience greater agility and scalability when you create responsive applications that work independently and participate in event-driven business processes across your business ecosystem[13].

Scoping for this paper, we take an example of an event that gets raised from MVS on possible action as a business event. Event mesh service provides the following key features:
Publish business events: Publish business events from SAP and non-SAP sources across hybrid landscapes from the digital core to extension applications through event-driven architecture.
Consume business events: Consume business events from SAP and non-SAP sources throughout SAP's event-driven ecosystem including SAP Extension Suite, SAP Integration Suite, and selected inbound enabled SAP back ends.
Connect Seamlessly: Provides reliable data transmission for extension and integration scenarios through decoupled communication[13].

Event Mesh can integrate seamlessly with an IoT camera sensor to enable event-driven communication. When the MVS camera sensor detects an event, such as an ' product', it posts the event to SAP Event Mesh using protocols like MQTT or HTTP. Event Mesh then distributes this event to subscribed systems or applications within the SAP ecosystem or custom applications. This setup ensures real-time REST based event processing and enables scalable, decoupled integration between IoT devices and business systems[13].

3.2 Automation of Disposition Processes

After inspection, SAP BTP automates decision-making for returns. For the scope of the study, we take a few return quality inspection scenarios, so that the MVS and BTP platform can be modelled for automated/aided decision making.

- ***Recalled product model from the vendor:*** This once detected, assuring the packages are intact, serial numbers can be scanned for verification of that in the 'Recall list' from the supplier/vendor. Inspection can be auto completed with recall codes & mark this serial number for 'Out-To-Vendor' orders. If the warehouse bin/pallet is ready, transfer order can be initiated in the warehouse to put-away process. This can be from the backend SAP S/4 HANA system or if the Extended warehouse management(EWM) is in place. Workflows can be modelled to keep that put-away process.
- ***Identifying a Merchandise kit components:*** A box can be inspected to look for all components it's supposed to have. MVS systems can be trained to look for the components for that merchandise, if that is opened and repacked by the customer. Sensors can detect and look for counts in a pack, like 10-in-a-box is expected and only 8 is there. It can be sent for re-kitting or refurbishing the merchandise. The decision will be learnt and trained over the time and it matures by its detection. Here once trained an automated refurbishment order is created with details to manually repack and disposition it to 'Pre-owned' product. Here most decisions are automated. Identifying missing components, sending the instruction of re-kitting, disposition to 'Pre-owned' is all automated. Thus driving the value of merchandise quickly back to the sales shelf.

4. Challenges and Limitations

1. *Lighting Variability:* Uneven or fluctuating lighting conditions can affect MV accuracy. Solutions include deploying adaptive lighting systems or advanced image processing algorithms.
2. *Data Standardization:* Different camera systems output data in diverse formats, complicating integration. Middleware solutions must harmonize these discrepancies.
3. *Scalability Issues:* As return volumes increase, maintaining system performance becomes critical. Scalable cloud and edge computing architectures mitigate this challenge.

5. Conclusion

Harnessing Machine Vision with SAP BTP in Reverse Logistics: The integration of Machine Vision (MV) technology with SAP's Business Technology Platform (BTP) transforms reverse logistics processes, driving efficiency, precision, and scalability. This paper illustrates how industries can leverage these advanced capabilities to overcome traditional challenges in return processing while setting the foundation for innovation and continuous improvement. Key Benefits of Integrating MV and SAP BTP architecture.

Enhanced Accuracy and Automation

Automates the inspection of returned merchandise, reducing reliance on error-prone manual processes. Machine learning capabilities ensure continuous improvement in detecting and classifying defects or anomalies. Real-time event-driven processing via SAP Event Mesh enables quick and informed decision-making, optimizing workflows.

Streamlined Return Disposition

Automates complex workflows such as recall verification, re-kitting, or refurbishing processes for example. Integrates seamlessly with SAP S/4HANA and Extended Warehouse Management (EWM) systems to streamline inventory management and return logistics. Reduces operational bottlenecks by enabling predictive decision-making and efficient disposition actions.

Scalable and Resilient Architecture

Combines cloud scalability and edge computing to handle large volumes of return data in real time. Ensures robust data processing and integration across diverse IoT-enabled devices through SAP BTP's flexible middleware solutions. Supports future growth and adaptability with extensible APIs and customizable workflows.

Driving Innovation and Sustainability

The fusion of MV technology and SAP BTP not only enhances operational efficiency but also aligns with sustainability goals. By automating and optimizing return processes, businesses can reduce waste, extend product life cycles, and improve resource utilization. Future advancements in AI adaptability and industrial applications will further solidify this integration as a cornerstone for global supply chain innovation with SAP BTP as a platform for technology foundation.

Through its transformative potential, this integrated framework equips organizations with the tools needed to redefine reverse logistics, meeting the demands of modern business landscapes while paving the way for smarter, greener operations.

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