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Supplementary materials for

Yansong CAO, Yutong WANG, Jing YANG, Yonglin TIAN, Jiangong WANG, Fei-Yue WANG, 2025. AOI-OPEN: federated operation and control for DAO-based trustworthy and intelligent AOI ecology. *Front Inform Technol Electron Eng*, 26(7):1209-1221. https://doi.org/10.1631/FITEE.2400975

1 Federated operations in AOI-OPEN

Member flow: The roles and relationships of different entities in AOI-OPEN are shown in the upper part of Fig. S1. Software providers design the machine vision algorithms and package the models for hardware manufacturers. Hardware manufacturers design the mechanical structures and optical systems and embed machine vision software into automated optical inspection (AOI) machines. Factories use AOI machines to inspect potential defects in their products. To gather these entities, we build AOI-DAO, a distributed online community, to connect the stakeholders and adopt an artificial identification mechanism for access control. With artificial identification methods, qualified physical entities will be permitted to enter and be members of the online community. Entities with potential threats will be denied to protect the stability of the community. In addition, members can also be expelled once they have been recorded with a certain number of malicious behaviors. Members can also quit the community whenever they wish.

What makes the community in AOI-OPEN attractive to different AOI-related entities lies in the co-operation mechanism that benefits all the members. For software providers, the most valuable thing is the massive and diverse data provided by other members in the ecology, which helps them develop high-performance models. For hardware manufacturers and factories, AOI-OPEN provides opportunities where they can maximize the value of the data they have. Data discarded and neglected previously have now become a new asset.

Information flow: Information flow denotes the process of construction of AI models for intelligent inspection. Considering that the constraints of AOI systems development lie in the lack of data resources,

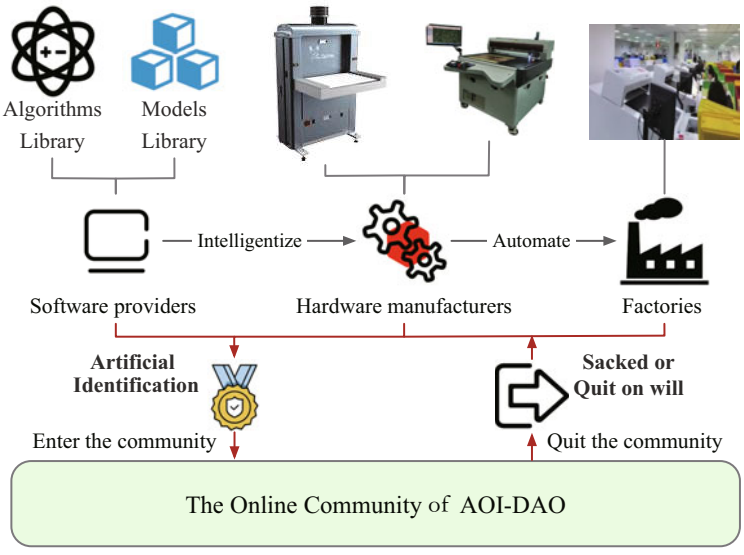

Fig. S1 Member flow in AOI-OPEN

we designed a pipeline of data generation as shown in Fig. S2. It begins with small-scale real data, and produces large-scale big data with generative methods. These data are finally used to develop big models applied for various tasks. Due to the rarity of defect data, the collected data are usually class-imbalanced. In such situations, parallel data methods can be used to enlarge the scale of defect data with model-based or data-driven methods by constructing metaverses. Both the raw data and generated data will be kept locally by each member to protect their privacy. Then, big models can be trained in an unsupervised manner with federated learning methods. Big models are shared globally and can be transformed into small local models according to the requirements of different members by transfer learning or knowledge distillation approaches.

The information contained in the data is first mined and used to generate large-scale and diverse data, which transforms small data into big data. Then, hidden patterns in the dataset are learned by task-agnostic training procedures. General knowledge about the characteristics of the dataset is extracted from large-capacity models. Finally, for specific applications, the information contained in big models is released and fine-tuned to adapt to different tasks.

Value flow: Value flow defines the incentive mechanism in AOI ecology that implements the rewards and punishments and stimulates the community to develop in a healthy direction. The embodiment of value is the token and gas of the system. Every member of AOI-OPEN will receive a digital wallet to store their tokens after the registration process. Actions or behaviors, including sharing insensitive data or feature resources, that contribute to the development of the global models and the mining in blockchains will be rewarded. Actions like data poisoning or providing corrupted models will be punished. There are also neutral actions, such as proposing a transaction or pools, that will consume ąřgasąś to settle the halting problems and require the proposers to deposit a specific number of tokens. The value flow is shown in Fig. S3.

Value flow is the circulation of the tokens and the increase or decrease of credits, where the token embodies the asset value and reputation states the signal value. Tokens are negotiable while reputation is not. Reputation is the proof of the contribution of members and reflects their social status, credit, impact, activity, and so on, and affords higher privileges to members who make significant contributions to the community and helps avoid election bribery.

Decision flow: The decision flow records the process of decision-making and decision deployment about the topics within the AOI ecology. Common topics, usually related to AOI data, intelligent models, and members, include the collection and generation of data, the evaluation of data quality, the benefits of data, usage of data and model resources, the protection of data privacy, and members, as well as the permission of data providers. AOI-OPEN adopts a distributed model to make decisions as shown in Fig. S4, among which data-related policies are the most prominent. Proposals about data provider permission, collection

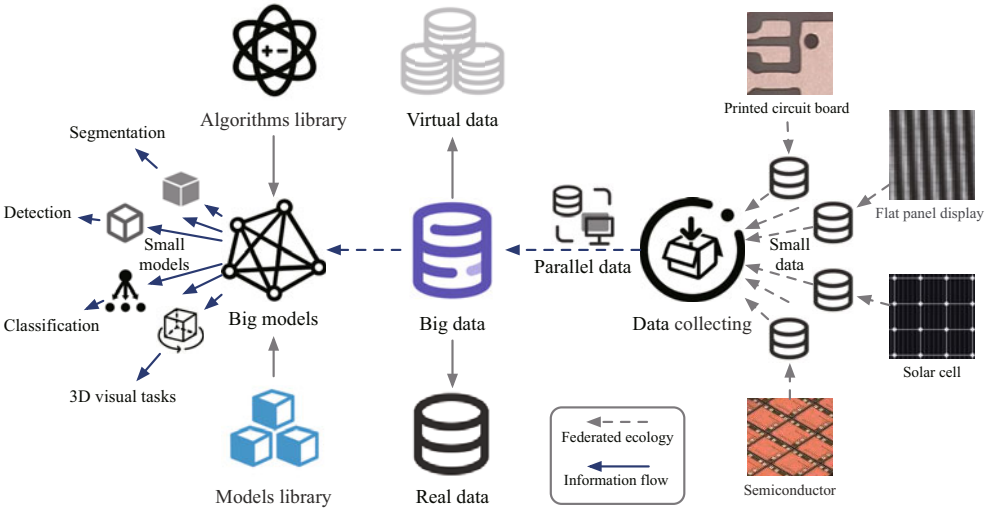

Fig. S2 Information flow in AOI-OPEN

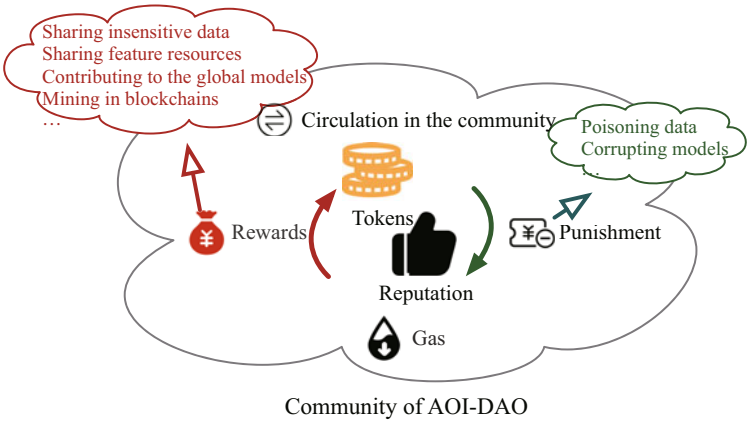

Fig. S3 Value flow in the AOI-OPEN community

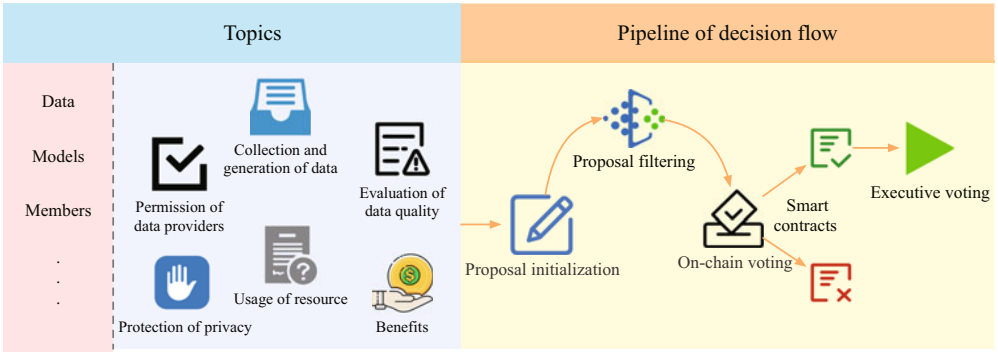

Fig. S4 Decision flow in the AOI-OPEN community

and generation of data, the evaluation of data quality, the protection of data privacy, and the usage of data resources as well as the benefits from data can be started by any member, and discussed among the community, passed when most of the members vote yes, and recorded by smart contracts.

The mechanism that allows every member to start proposals achieves fairness in the management of the community; however, it can also lead to low efficiency and bring potential threats. Designing the decision flow includes proposal initialization, proposal filtering, on-chain voting, and executive voting. To avoid malicious proposals, mechanisms like the governance security module proposed in Marker decentralized autonomous organization (DAO) are also necessary.

2 Evaluation of the trustworthy community

To evaluate the trustworthy community proposed in this paper, we invited 20 volunteers (10 employees from the AOI company and 10 students from universities) to act as the decision-makers of the printed circuit board (PCB) factories and gave them a basic introduction to AOI industry. Then, we designed a questionnaire to inquire about their willingness to join the AOI community by considering the five factors related to the trustworthiness of the community: concerns about data security and privacy, fairness of the compensation mechanism, convenience of data management, business benefits, and long-term sustainability. We provided two candidate frameworks of the AOI community, proposal A and proposal B. Proposal A allowed buyers and sellers to negotiate on pricing, with no consultation between communities. Proposal B used AOI-OPEN, which allows all participants to make recommendations and vote on decisions for running the community. The results of the questionnaire are shown in Fig. S5. As we can see, proposal B received more support, which shows that AOI-OPEN is more trustworthy than the traditional organization approach.

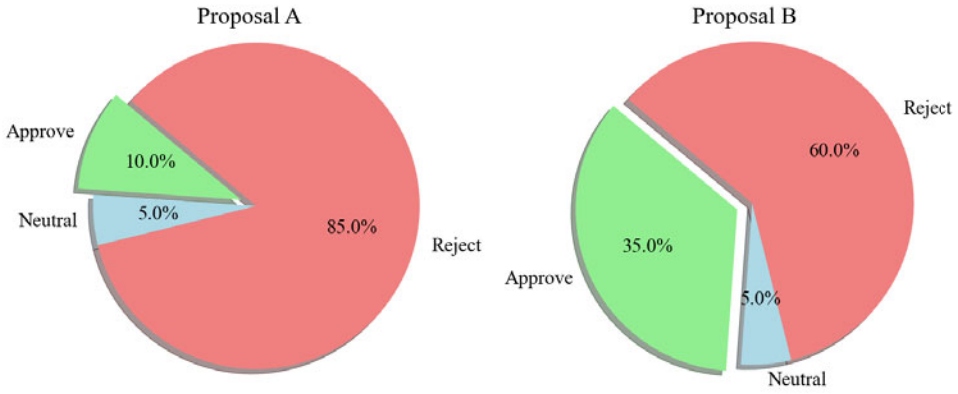

Fig. S5 Voting results on proposals A and B

3 Discussions on AOI-OPEN

The experiment results demonstrated that AOI-OPEN has the potential to break through isolated data islands within the AOI industry, even in the low- or zero-trust environment, and build a secure, collaborative, and trustworthy AOI ecology for high-performance optical inspection. However, there are still some challenges to overcome for the realization of AOI-OPEN.

- Data distribution: AOI-OPEN operates under the assumption that the data across various factories within the community exhibits a relatively consistent distribution. In reality, however, factories may generate data that significantly varies in type and style. This variability poses challenges for the application of federated learning, which relies on the assumption of similar data distributions. To tackle this issue in future work, we will investigate federated learning methods designed to accommodate heterogeneous data distributions. Specifically, we plan to implement distribution adaptation techniques to facilitate effective learning from diverse data types. Additionally, we will explore a two-phase training approach: first, we will train a general foundational network, followed by a second phase where we specialize the model through transfer learning tailored to the unique characteristics of different datasets. This strategy aims to mitigate the impact of distribution discrepancies and enhance the overall performance of AOI-OPEN in various real-world scenarios.

- Computing capabilities: In reality, participants may vary widely in computing capabilities, from powerful servers to less capable edge devices, potentially leading to inefficiencies in the cooperative training process. To address this, AOI-OPEN can incorporate a pre-assessment mechanism to evaluate the computing capabilities of participating nodes. This approach would exclude nodes with insufficient computing power while also employing a partial-model strategy to allocate different partial model sizes based on each node's capabilities. In this way, AOI-OPEN can achieve collaborative training of the model, even at the cost of some efficiency.

- Participant organization: Forming a data alliance across an industry's supply chain is challenging. Leveraging suppliers that connect all production stages is crucial. AOI's unique position in quality inspection enables it to engage both upstream manufacturers and downstream users, and create opportunities for collaboration. To enhance participant organization, targeted outreach about the benefits of AOI-OPEN is essential, along with building trust through transparent communication and shared goals.

- Consensus formation: Establishing an effective consensus mechanism is critical for AOI-OPEN's success. This involves creating fair incentive structures, privacy protections, and transparent data evaluation systems. Engaging stakeholders in the consensus process will help identify their needs, leading

to accepted governance models. Additionally, a dynamic reward system that adjusts to participant contributions can enhance engagement and commitment.

- Technical support: Equitable execution of agreements is vital for AOI-OPEN's functionality. Recent advancements in DAO and blockchain technologies support secure decision-making processes, which reinforce trust. Smart contracts can automate compliance and ensure that members adhere to rules. These technologies collectively enhance transparency and efficiency within the AOI-OPEN framework.

Furthermore, we believe that DAO and metaverse-based management like AOI-OPEN will have a profound impact not only on industrial management but also on social governance such as finance, education, and medical care. It can reduce the risk of power concentration in a few individuals through decentralized management and harness collective wisdom and consciousness to transcend the limitations of individual capabilities. Ultimately, we will move toward a "6S" society: Safe in physical spaces, Secure in cyberspaces, Sustainable in ecology, Sensitive in individual privacy and rights, Service for all, and Smartness of all.