Distributed fault detection

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Networked robots have been object of widespread research in the latest years. This is motivated by their wide application domain, as well as by their flexibility, potential robustness to faults and capacity to accomplish complex tasks alternatively impossible for a single unit. Despite their clear advantages, networked robots pose challenging problems due to the interaction among control, communication and perception. When dealing with the control of networked robots, a decentralized control strategy is a desirable feature and, sometime, the only one possible; indeed, in most challenging applications, a central control unit represents a weak point of the system and the communication with all the robots could be impossible in the case of vehicles with short communication range capabilities. However, the complexity of controlling multi-robot systems rapidly grows when a central unit able to coordinate the team is lacking. In such a case, despite the need to cooperate in order to achieve a common *global* task, each unit is required to be able to compute its own control input based on *local* information coming from on-board sensors and/or communicated by a subset of its teammates, usually named *neighbors*.

Graph theoretical methods, that allow extracting analytical properties of the system on the base of the connectivity properties of the communication network formed by the agents, are often used to the aim. In this context, one of the most popular problem is the consensus, that consists in reaching an agreement regarding a specific variable, exogenous or depending on the state of the single robots, without using all-to-all communication [3].

The intrinsic redundancy of networked robots may allow to accomplish the assigned mission also in the case of failure of one or more teammates. Nevertheless, when dealing with distributed control of multi-robot systems aimed at achieving a global task, this feature, without the explicit adoption of a suitable Fault Detection and Isolation (FDI) schema, is only potential and the fault of one robot may jeopardize the proper execution of the task.

While several FDI approaches have been presented in the last decades for single unit systems, very few works addressed the FDI for networked robots. In these works, a necessary condition for the distributed detection of the fault on a robot by a healthy one is that the two robots are either able to directly communicate or sense each other. This is, obviously, a limitation in the case the control law depends on the state of all the vehicles in the team and not only from the direct neighbours. Such a case requires to develop a distributed FDI algorithm for networked robots that allows each robot to detect faults of any other robot in the team, even if not directly connected. A possible strategy consists in designing a distributed observers that allows each agent to estimate the collective state of the system. This observer has to make use only of information from the robot itself and its direct neighbours.

Building on this observer, it is possible to define proper residuals vectors relative to the teammates to monitor their healthy state. The FDI schema proposed in this paper is based on the following steps:

- Each robot runs a local observer (a modification of what presented in [1], [2]), that uses only local information and a suitable vector received from neighbour robots to estimate the overall system state (i.e., the positions of all the robots);
- Each robot computes a motion control law that uses a locally available estimate of the overall system state to track desired time varying trajectories of global task functions (team centroid and formation in our case);

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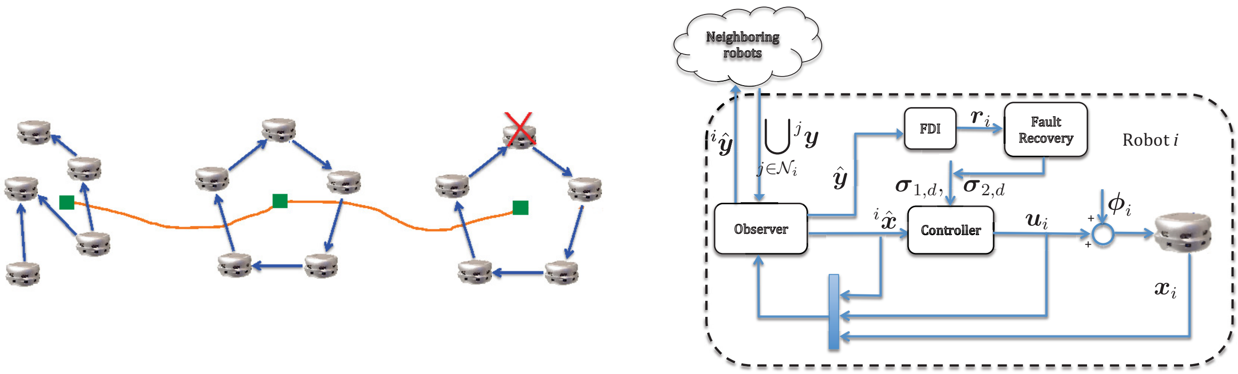
- Using the same local information and information received from neighbours gained for the observer-controller schema, each robot computes residual vectors relative to the teammates to monitor their healthy state;
- The residual dynamics are analytically investigated both in the presence and in the absence of faults. Thus, to detect and isolate faults of any other robot in the team, the residual vectors are compared to adaptive thresholds designed on the base of residual dynamics, the presence of likely non-zero initial observer estimation errors, measurement noise and model uncertainties.

A possible realization of this observer-controller-FDI strategy relative to the i th robot is shown in the figure below. The global state, $\boldsymbol{x}$, is not available to the robots, therefore, robot i makes an estimation



The Observer-Controller-FDI architecture.

of it ($^i\hat{\boldsymbol{x}}$). The block *Observer* allows to obtain such an estimation. The state estimate is used by the *Controller* block to calculate the estimated global input to achieve the global task. In parallel to them, the *FDI* and *FDI Recovery* blocks are respectively in charge of monitoring the healty of robots in the network and run a proper recovery strategy.

References

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