Friedrich-Alexander-Universität Erlangen-Nürnberg
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Research Internship in Science and Engineering (RISE)

Experimental Analysis of Particle Source Localization in Branched Vessel Networks

Research Question: Branched vessel networks (BVNs), consisting of interconnected vessel segments that transport fluids, are vital in nature, engineering, and medicine. Examples include the cardiovascular system (CVS) [1], water distribution systems, and sewage networks [2, 3, 4].

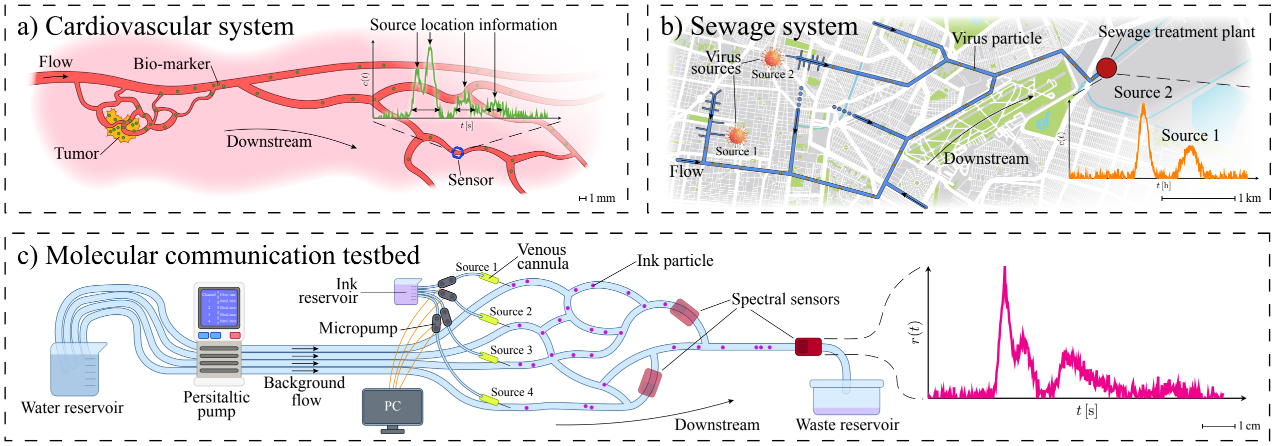

Figure 1: Particle source localization in BVNs across different scales. a) Inside the CVS, localization enables early tumor treatment. b) In sewage systems, infectious diseases can be traced back to their source, facilitating targeted countermeasures. c) MC testbeds can model source localization in real-world systems of different scales.

Across the varying scales of these applications, a central concern is understanding particle propagation through the network. This understanding is crucial for *particle source localization*, which involves estimating the position of a particle source (or sources) in the network based on distributed downstream sensor measurements [4]. For instance, in the CVS, this approach allows for the localization of tumors emitting bio-markers by estimating the position of the bio-marker source, see Fig. 1a). In sewage networks, virus particles contained in human excretions can be traced back to their host, see Fig. 1b), aiding in efficiently containing disease outbreaks [2, 3, 4].

Mathematically, particle propagation and source localization in BVNs can be described using tools from *molecular communications (MC)* [1], a sub-paradigm of communications engineering focused on the transmission of information via molecules. This is achieved by treating sources as transmitters (TXs), the BVN as the channel, the particles as the signal, and the sensors as receivers (RXs). To date, MC remains predominantly theoretical, with only limited experimental research available, especially for particle propagation and source localization *in BVNs*.

Recently, our research group has conducted extensive research on BVNs. Alongside this effort, in this research internship, we aim to *develop and test a branched mesofluidic MC testbed*, specifically for the purpose of source localization, see Fig. 1c). In particular, a simple single-pipe testbed using ink particles and spectral sensors (originally proposed in [5]) is already set up in our lab. You will get to extend this setup to include a branched topology as well as multiple particle sources and RXs. Besides addressing the gap in experimental MC research, we aim to explore whether the small-scale lab setup can accurately reflect the localization dynamics of larger systems, such as sewage networks.

Your Contribution: During this internship, you will explore the core principles of both theoretical and experimental MC, with a strong emphasis on lab work and designing experiments:

- You will extend the testbed in [5] from a simple single-pipe setup to a branched network topology with multiple particle injection sites and RXs, see Fig. 1c). The single-pipe testbed will already have been set up in the lab upon your arrival.
- Utilizing the testbed, you will conduct time-series measurements of the ink concentration received at the spectral sensors. In this context, you can decide on the number and placement of particle sources and sensors as well as the network topology.
- Finally, you get to prepare the experimental data to facilitate future evaluation of various particle source localization techniques, which will be developed by others in another project.

During your stay, you will be closely supervised by two doctoral researchers with expertise in theoretical modeling of particle propagation, experimental MC testbeds, and localization algorithms. At the end of your internship, you will have the opportunity to present your results to the entire institute. Because you will perform experiments with a testbed in our institute, a virtual internship is *not* possible.

Your Workplace: You will be hosted at the *Institute for Digital Communications (IDC)* at *Friedrich-Alexander-Universität Erlangen-Nürnberg*. IDC is one of the leading research groups in communications engineering in general and in MC in particular. Thus, you will be surrounded by experts in both theoretical modeling of MC systems as well as experts in building experiments. We are located in Erlangen, a city of about 110,000 people, in the south of Germany. Erlangen not only has a very vibrant student life but is also ideally located for day trips into the nearby countryside or to Munich, for example. And, of course, *Berg*, one of Germany's oldest and most famous fairs, will take place in Erlangen in June 2025, which is definitely worth a visit.

Questions? If you have any questions about the internship, please don't hesitate to reach out to us! You can find our contact information below:

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References

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