Low-Cost Motion Capture

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Infrared-based motion capture systems represent the state of the art for tracking movement in a predetermined, three-dimensional space. The technology offers high tracking accuracy and a high sampling rate. However, commercial solutions are prohibitively expensive. The goal of this thesis is to develop a low-cost, open-source infrared-based motion capture system as an alternative to the proprietary solutions currently dominating the market.

Outset

Infrared-based motion capture systems work by using multiple cameras to observe reflective markers, which are worn by the tracking subject. An infrared light source illuminates the markers, which then appear as bright spots in the image feed. An image processing algorithm detects the two-dimensional positions of all markers in each camera's frame. A central system then collects the two-dimensional positions of all detected markers and triangulates their three-dimensional position in physical space.
Although infrared-based motion capture technology is mature, commercial systems are expensive and often suffer from vendor lock-in. There is a lack of affordable, open-source, high-precision, and low-latency infrared-based solutions. Most openly developed systems rely on machine learning and do not use physical trackers to capture motion data, often at the expense of tracking accuracy, flexibility, robustness, and sampling rate. An alternative to the commercial offerings is to be developed in this thesis.

Methods

To accelerate processing, an image-processing pipeline was implemented on a field-programmable gate array (FPGA). The pipeline receives a high frame-rate video feed from a global shutter camera, its output is a list of all detected two-dimensional marker positions for each frame.
A custom PCB, powered by a Power over Ethernet (PoE) module, was developed. The PCB drives an infrared light source, which illuminates the reflective markers. Additionally, the PCB hosts a microcontroller which receives the markers detected by the FPGA (transmitted over SPI) and forwards them over UDP to a central system in real time. This system consisting of a camera, infrared light source, micro-controller, and FPGA, is refereed to as a maker detection unit (seen in the figure to the right).
Python server software was developed, which receives the two-dimensional marker positions over UDP and triangulates their three-dimensional position in space. Finally, the marker's three-dimensional positions are rendered in real time in a simple scatter plot.
Additionally, a GUI was designed and implemented, which is used to configure and calibrate the marker detection unit.

Results and Conclusion

For less than 2'000 CHF, an infrared based motion capture system consisting of 6 cameras was built. The marker detection unit is capable of tracking over 100 markers at 72 frames per second at a resolution of 1280 x 800 pixels. The python server software can currently only triangulate the position of a single marker.

All source files needed to build and deploy the system are freely available. The tooling requires no licensing fees, allowing anyone to build a system at cost.

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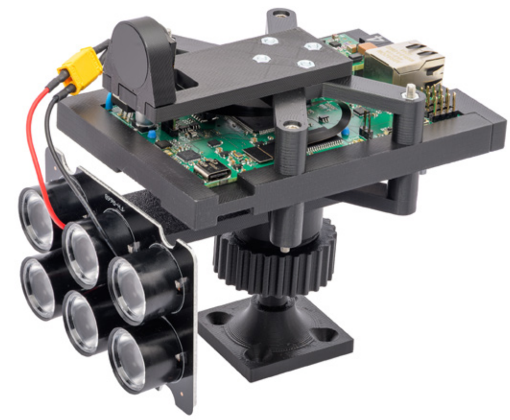

Marker Detection Unit