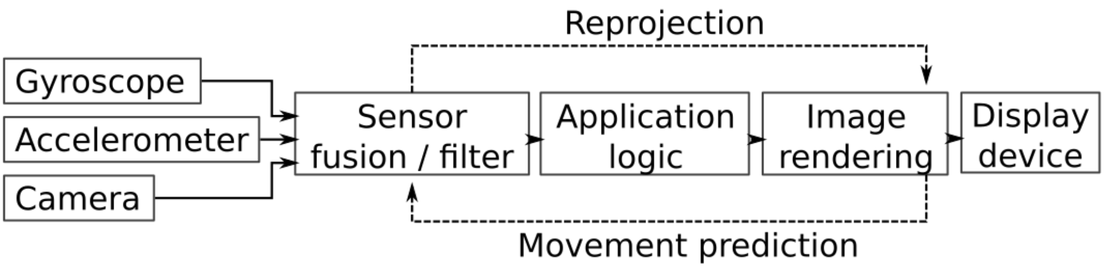
OPTOFIDELITY

Unpredictable movement performance of Virtual Reality headsets

1. Introduction

Virtual Reality headsets use a combination of sensors to track the orientation of the headset, in order to move the displayed image correspondingly. Sensors typically used include gyroscopes, accelerometers and optical sensors, such as cameras.

To reduce problems with motion sickness, it is desirable to minimize the delay from physical movement to the movement of the image, also called Motion-to-Photon (M2P) latency. The delay is caused by multiple factors: sensor sampling, data filtering and image rendering.



There are two main methods to reducing the M2P latency: reprojection and movement prediction. Reprojection works by taking the latest sensor data at the end of image rendering, and moving and distorting the already rendered image by small amounts. This eliminates most of the delay caused by application logic and image rendering.

Movement prediction, on the other hand, attempts to estimate the delay caused by image rendering and the current movement of the headset. It then predicts where the headset will be when the rendering is complete, and uses this position instead of the actual latest measured position.

Ideally, movement prediction can bring the M2P latency for predictable movements down to 0 milliseconds. However, it does not improve the performance for unpredictable movements, such as user suddenly turning their head. Aggressive movement prediction can also cause overshoot, where the image moves too far when movement suddenly stops. In contrast, reprojection will reduce the latency even for sudden movements, but cannot completely eliminate it.

2. Test setup

Four off-the-shelf consumer VR headsets were tested using OptoFidelity VR Multimeter. The headsets were mounted on a plastic head on a rotary platform. Inside the head an optical flow camera measures movements of the image displayed on the headset, while an encoder in the rotary platform measures the actual position of the head.

Device	Platform	Display framerate	Sensor type
Google Pixel	Android	60 FPS	Gyro + Accel
Acer WMR	PC, WMR	90 FPS	Gyro + Accel + Camera
Samsung Odyssey	PC, WMR	90 FPS	Gyro + Accel + Camera
HTC Vive	PC	90 FPS	Gyro + Accel + Optical beacon

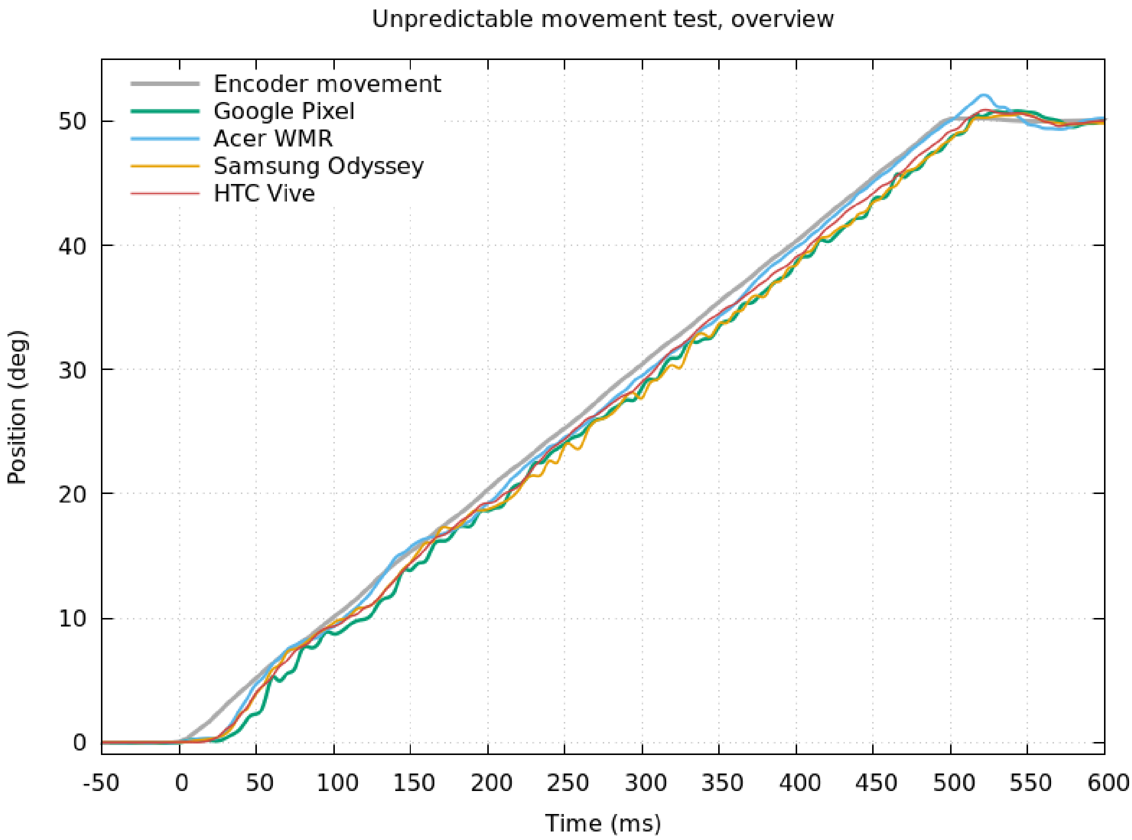
Encoder data was recorded at 1 ms intervals, while optical flow data was recorded synchronized to the display framerate, at either 11 ms or 17 ms intervals.

The rotary platform was set to 100 deg/s movement with 20 000 deg/s^2 acceleration. With these parameters, the top speed is achieved in just 5 milliseconds. For comparison, a test person was able to achieve up to 3 000 deg/s^2 acceleration with a lightweight headset. The higher acceleration in the test setup gives better resolution for the results.

With each headset 12 acceleration cycles were performed. The successful measurements were combined in a single graph, to provide a presentation of the average performance of each headset.

3. Overview of the results

All devices had an initial latency between 20 and 30 milliseconds. This represents the M2P latency when motion prediction is not effective. Final latency at the end of the movement was smaller for all headsets, varying between 2 and 11 ms. Because the movement in this test is easily predictable, the final latency tests how effective the movement prediction algorithm is at eliminating the rendering delay.

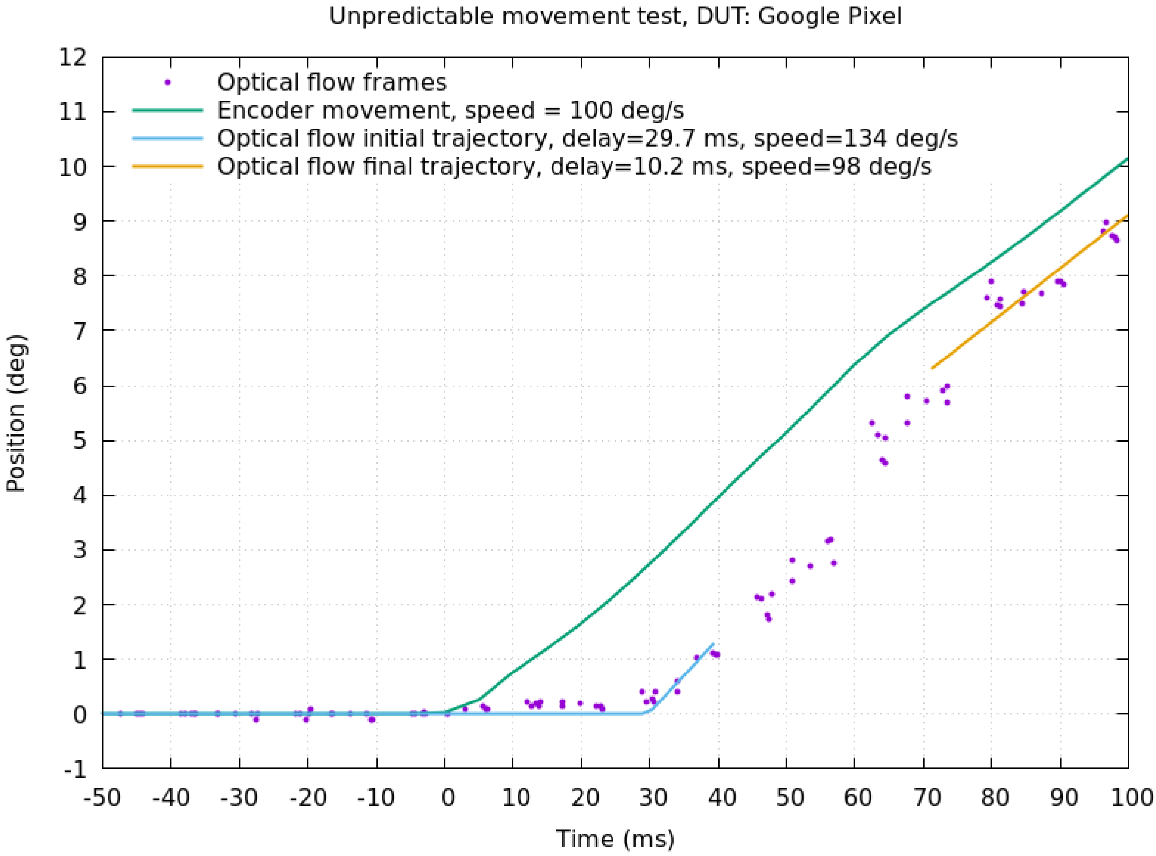


Device	Initial latency	Final latency	Overshoot
Google Pixel	29.7 ms	10.2 ms	0.8 deg
Acer WMR	25.7 ms	2.2 ms	2.1 deg
Samsung Odyssey	21.4 ms	5.2 ms	0.6 deg
HTC Vive	23.3 ms	11.3 ms	0.9 deg

It is important to note that the fast acceleration caused some vibrations in the test platform, which can contribute to the shape of the response and the amount of overshoot. Also, the weight of the headset and the firmness of its attachment to the head affects the response. There are small changes at t = 0 ms in the optical flow graphs for some devices, which is caused by movement of the headset relative to the head at the beginning of the movement.

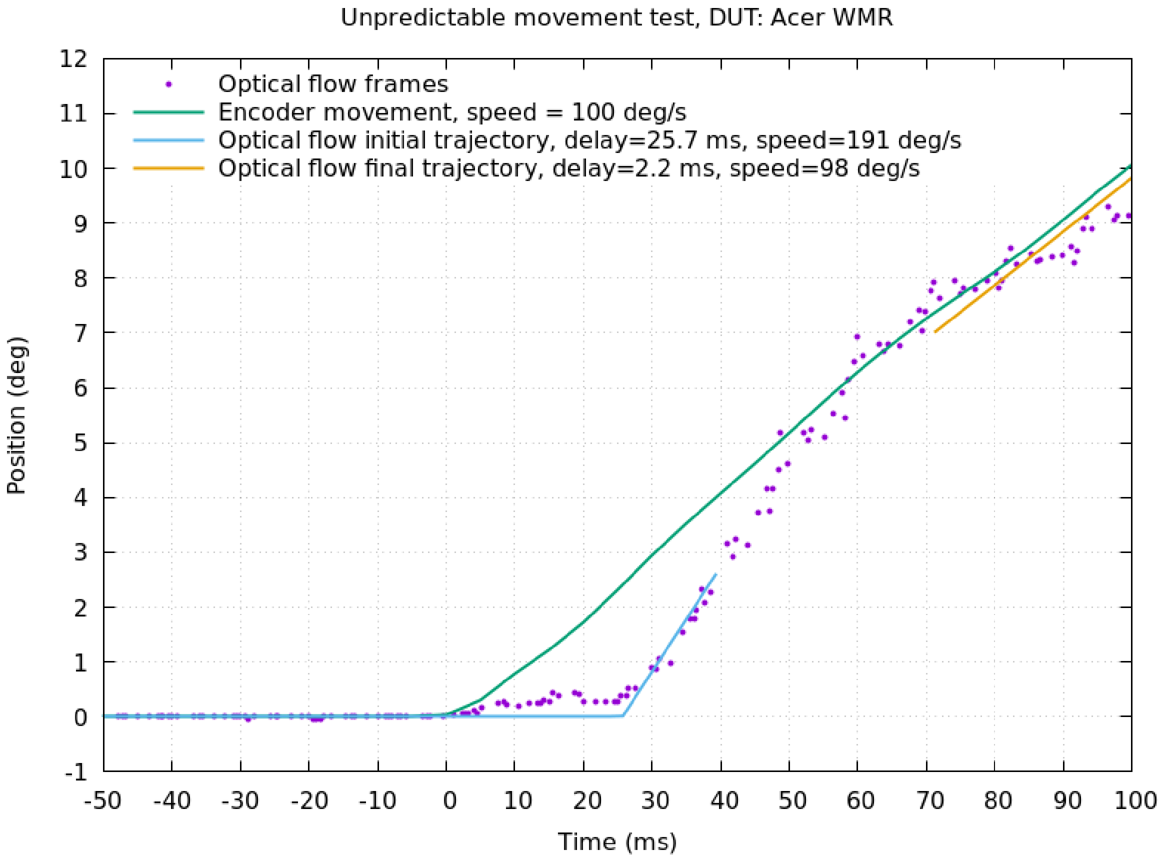
4. Results for Google Pixel

Unlike the other, dedicated headset devices, Google Pixel in an Android phone that is mounted in a VR headset holder. Its performance for unpredictable movements was the worst of this set of devices at nearly 30 ms latency, while its movement prediction brings latency down to 10 ms.



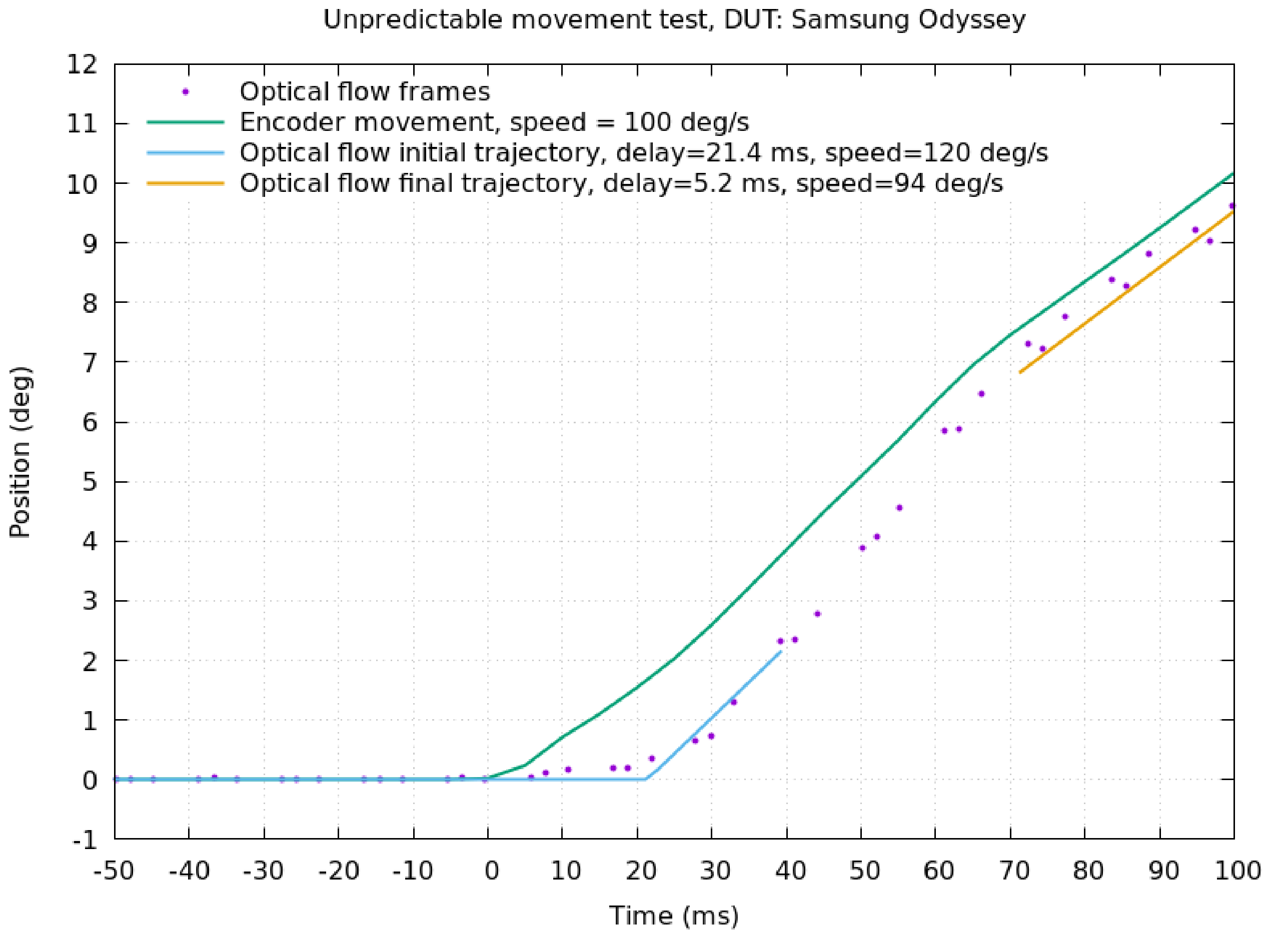
5. Results for Acer WMR

Acer's initial latency was midway in this test, while its movement prediction is clearly the strongest of these devices. It effectively eliminates the M2P latency, bringing delay down to just 2.2 milliseconds, but also causes the highest overshoot at the end of the movement.



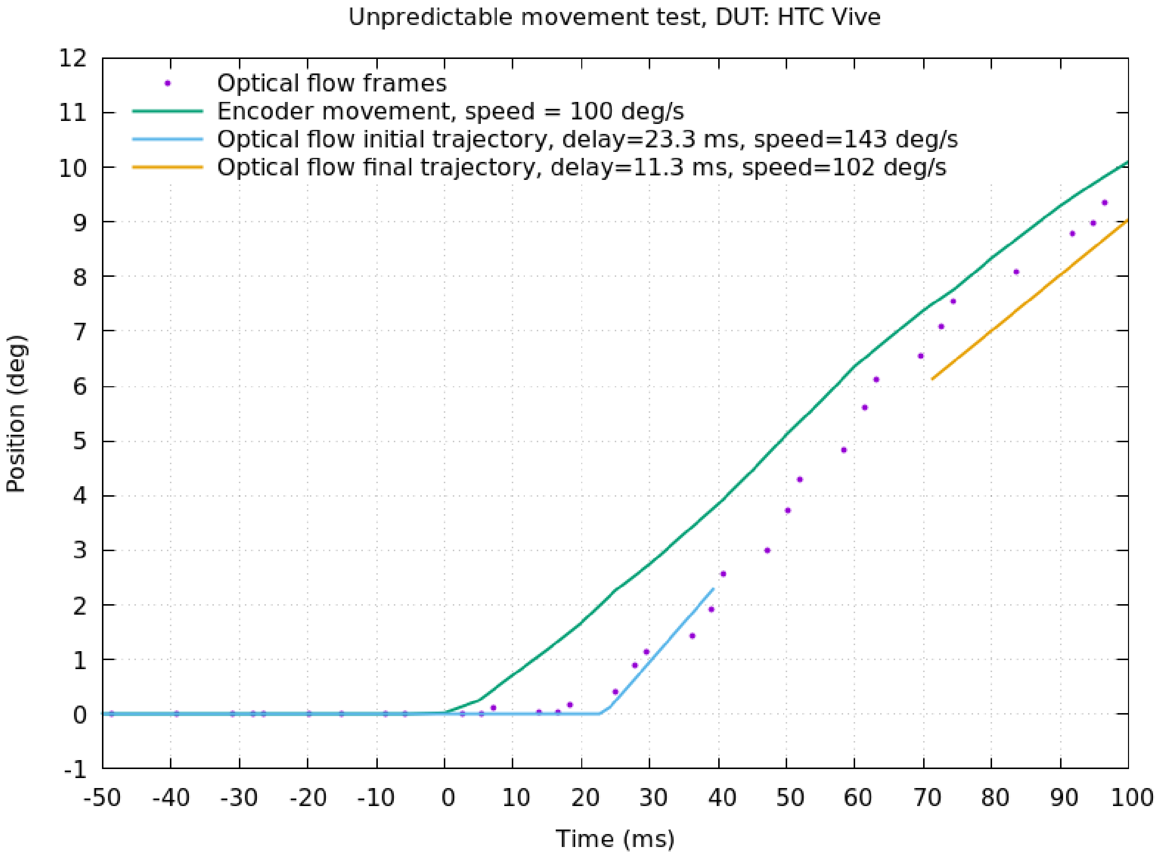
6. Results for Samsung Odyssey

Samsung Odyssey is the second Windows Mixed Reality headset in this test. Compared to Acer, its initial latency is lowest in this test and this is combined with less aggressive movement prediction. This provides a good balance between M2P latency and overshoot.



7. Results for HTC Vive

HTC Vive has a low initial latency, but its movement prediction does not seem particularly effective. This results in the highest M2P latency during the final part of the movement in this test. On the other hand, it does have the smallest difference between initial and final latency, which could allow human brain to better adapt to the delay and make the movement feel smoother.



8. Conclusions and future development

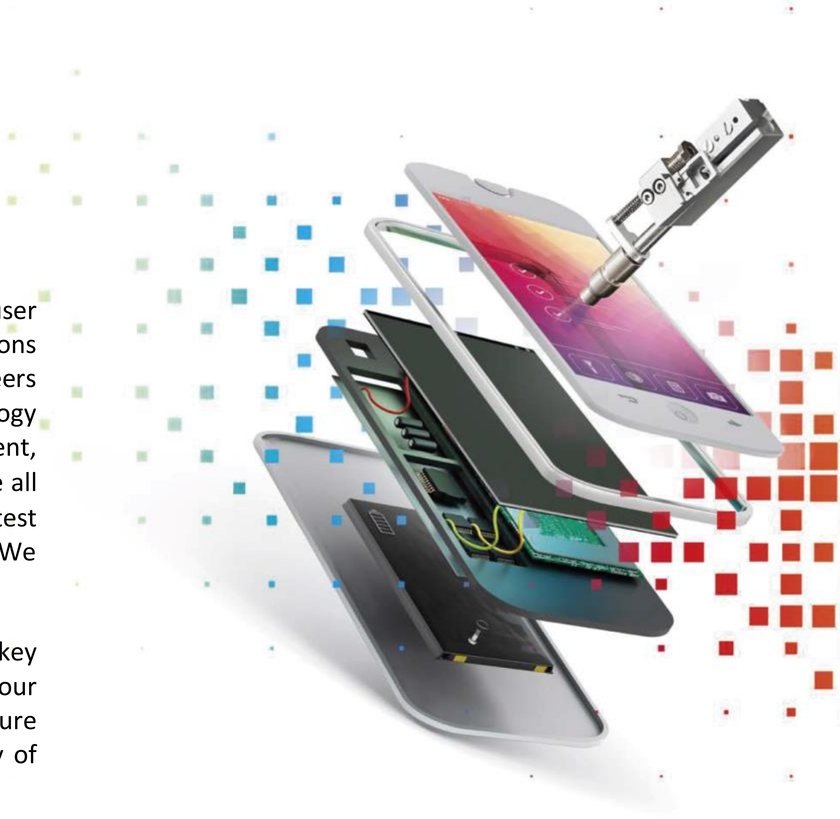
M2P latency in predictable movements has been studied extensively for several years now, and motion prediction algorithms have brought it to sub-10 ms values in most devices. Meanwhile, latency for unpredictable movements has been more difficult to measure and cannot be eliminated using software methods. Instead, reducing the initial latency will require improvements in sensor technology, combined with efficient software design and good re-projection implementation.

The main metric for predictable movements has been M2P latency measured in milliseconds. This is typically determined by cross-correlation of physical and image movement graphs. Latency for unpredictable movements could be measured similarly, but restricting the measurement for the first ~40 milliseconds after the start of the movement.

Other possible metrics include the area between the two movement curves, measured in millisecond-degrees, and movement percentage after N milliseconds. However, these metrics lack the intuitiveness that a simple millisecond value has.

OPTOFIDELITY

Who We Are



At OptoFidelity we thrive for the ultimate user experience by simulating and testing user interactions for smart devices. We are globally recognized pioneers in testing, and our humanlike robot assisted technology platforms are widely used in product development, production and quality assurance. Our products are all equipped with easy-to-use SW tools for test parametrizing, results analysis and reporting tools. We work with the world's largest device manufacturers.

Tight and loyal cooperation with our customers is a key to successful test system delivery. We enable our customers to focus on their own expertise, and ensure the ultimate performance, quality and functionality of their products.

Our People

We are a team of multitalented professionals in the fields of test automation, robotics, machine vision, signal processing and software development. 90% of our people have an engineering degree, and 100% of our people have a hands-on, problem-solving oriented mindset.

CONTACT US

WHAT IS YOUR TESTING MISSION?

WE'D LOVE TO HEAR IT!

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