# Interactive Minimal Latency Laser Graphics Pipeline


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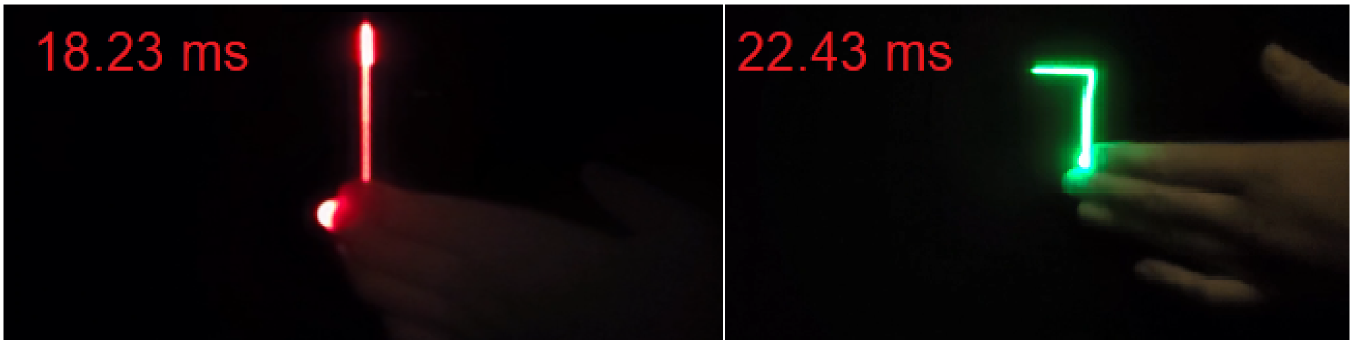


**Figure 1: Our system enables interaction with laser graphics on moving objects with an end-to-end latency of 4 ms.**


## ABSTRACT

We present the design and implementation of a "Laser Graphics Processing Unit" (LGPU) featuring a proposed re-configurable graphics pipeline capable of minimal latency interactive feedback, without the need of computer communication. This is a novel approach for creating interactive graphics where a simple program describes the interaction on a vertex. Similar in design to a geometry or fragment shader on a GPU, these programs are uploaded on initialisation and do not require input from any external micro-controller while running. The interaction shader takes input from a light sensor and updates the vertex and fragment shader, an operation that can be parallelised. Once loaded onto our prototype LGPU the pipeline can create laser graphics that react within 4 ms of interaction and can run without input from a computer. The pipeline achieves this low latency by having the interaction shader communicate with the geometry and vertex shaders that are also running on the LGPU. This enables the creation of low latency displays such as car counters, musical instrument interfaces, and non-touch projected widgets or buttons. From our testing we were able to achieve a reaction time of 4 ms and from a range of up to 15 m.



## CCS CONCEPTS

• **Hardware → Sensor applications and deployments**; **Emerging interfaces**.

## KEYWORDS

interaction shader, laser display, interactive projection, low latency feedback

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## 1 INTRODUCTION

We present the design and implementation of a pipeline for interactive laser graphics that can run with minimal latency. This pipeline runs on a prototype "Laser Graphics Processing Unit" (LGPU) which processes the uploaded geometry to display on a galvanometer based laser projector. The novel component of this system is the "interaction shader", which once loaded onto the LGPU can change the geometry and colour of the laser graphics in response to data from a photo-detector that is measuring the intensity of the back-scattered light. Since this occurs on the LGPU, it does not need commands or control from a computer or external system.

The LGPU is an update of Cassinelli and colleagues Laser Sensing Display [Cassinelli et al. 2010], [Cassinelli et al. 2012], which simultaneously projects laser light and detects changes in the intensity of the reflected light. Their system uses a carrier modulated scanning laser with a high speed photo-detector that can detect the intensity of the laser beam as it moves through its trajectory. Building upon their previous work, we implemented a prototype and then created a new re-configurable pipeline to run on it. This pipeline improves reaction time, robustness, and flexibility by implementing per point detection in the LGPU and can be parallelised.

There have been numerous works [Harrison et al. 2011], [Sand et al. 2020] that project interfaces onto surfaces. Since these systems use an external 30 fps depth camera and image processing they have a longer reaction time. We achieve an updated rate of over



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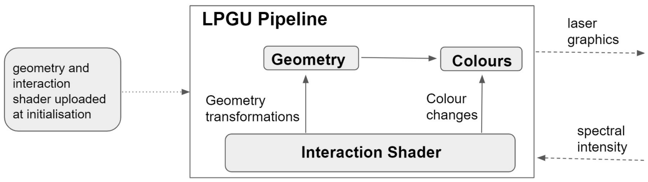


**Figure 2: Prototype hardware LPGU pipeline**

250 Hz by running our pipeline on the same micro-controller that controls the laser drawing. Other non camera based solutions such as PICOControl [Schmidt et al. 2012] require instrumentation of the surface. This reduces the flexibility of the system by requiring the projection surface to have a sensor at every point of interaction.

Other laser solutions [Xiao et al. 2018], [Jeon et al. 2013], overcome limitations of projector-based systems, but have a range of less than 0.6 m, compared with our system which is effective up to 15 m.

Our contribution in this work is a proposed interaction shader pipeline that enables responsive laser graphics and can be parallelised. This overcomes many of the aforementioned limitations of current interactive projection systems. Further benefits of our system include:

- Extremely low latency (4 ms response time)
- No instrumentation or calibration of surfaces
- Works on non-planar and irregular surfaces
- Works over large distances (further than 15.0 m in testing)
- Parallel architecture design

## 2 METHOD

The proposed pipeline runs on a hardware prototype LGPU, based on work by Cassinelli[Cassinelli et al. 2012]. The interaction shader is uploaded to the LGPU on initialisation and interacts directly with the geometry and colour drawing of the projected laser graphics. The projected laser beams intensity is detected by a photo-sensor which streams directly to the interaction shader. When this shader detects changes in intensity it can update the colour, modify the trajectory of the laser beam, and change the behaviour of the laser graphic displayed by the system. For example it can rotate the graphic when touched. These behaviours can be programmed directly into the interaction shader by detecting differences in intensity of the laser beam as it moves through it's trajectory and updating the graphics accordingly. This can be used to correct the image colour or disable the laser when there is some change on the projection surface, making the system safer to use in public spaces.

The interaction, vertex and fragment shaders are implemented in C++ on a Teensy micro-controller which calculates the trajectory, intensity and modulation of the projected laser image and outputs via an ILDA port to the laser. The laser outputs approximately 5 mW of power and since the beam is constantly moving at high frequency the time of exposure is low enough that it does not pose a danger to eyes.

## 3 APPLICATION SCENARIOS

Since the LGPU simultaneously displays and scans with a laser, it can augment the surface of objects. This enables the creation of interactive displays that require minimal setup. For example in a temporary retail or construction site, where it is impractical to install a permanent fixture. Since there is no instrumentation or disturbance to the projection surface this is beneficial in situations where the surface is fragile, such as historical or archaeological sites. This lack of physical contact can also prevent the spread of germs. Enabling safer interaction points such as elevator, pin code and door access buttons which can be a substitute for physical buttons in public spaces.

The low latency of the pipeline enables interfaces that simulate the responsiveness of real musical instruments which existing projected interfaces are unable to do. This low latency also enables the safer use of lasers in public spaces. Many lasers used in entertainment and industry exceed the "Maximum Permissible Exposure", our system can detect when something interrupts the laser beam and can then stop the beam very quickly as a safety mechanism.

## 4 CONCLUSIONS AND FUTURE WORK

We present a pipeline for interactive laser graphics that enables low latency interactive laser graphics with a reaction time of 4 ms. It addresses many limitations of previous interactive projected graphic systems by reducing the latency of reaction. We achieve this by using modulated laser light to simultaneously project graphics and detect their intensity with a photo-detector. This pipeline has many uses for interactive graphic displays, non-touch interfaces and interfaces where low latency feedback is necessary. Future development of the interaction shader architecture is to implement with raster graphics that can draw more complex images, fully implementing parallelisation of processing, and implementing the pipeline onto an integrated chip for use in wearables, phones or other portable devices.

## REFERENCES

Alvaro Cassinelli, Jussi Angesleva, Yoshihiro Watanabe, Gonzalo Frasca, and Masatoshi Ishikawa. 2012. Skin games. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces*. 323–326.

Álvaro Cassinelli, Yusaku Kuribara, Alexis Zerroug, Masatoshi Ishikawa, and Daito Manabe. 2010. scoreLight: Playing with a Human-Sized Laser Pick-Up.. In *NIME*, Vol. 10. 144–149.

Chris Harrison, Hrvoje Benko, and Andrew D. Wilson. 2011. OmniTouch: wearable multitouch interaction everywhere. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology*. 441–450.

Sungho Jeon, Hiroyuki Fujita, and Hiroshi Toshiyoshi. 2013. A MEMS interactive laser projection display with a built-in laser range finder. In *2013 International Conference on Optical MEMS and Nanophotonics (OMN)*. 15–16. https://doi.org/10.1109/OMN.2013.6659036 ISSN: 2160-5041.

Antti Sand, Vera Remizova, I. Scott MacKenzie, Oleg Spakov, Katariina Nieminen, Ismo Rakkolainen, Anneli Kylliäinen, Veikko Surakka, and Julia Kuosmanen. 2020. Tactile feedback on mid-air gestural interaction with a large fogscreen. In *Proceedings of the 23rd International Conference on Academic Mindtrek*. 161–164.

Dominik Schmidt, David Molyneaux, and Xiang Cao. 2012. PICOntrol: using a handheld projector for direct control of physical devices through visible light. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology*. 379–388.

Robert Xiao, Teng Cao, Ning Guo, Jun Zhuo, Yang Zhang, and Chris Harrison. 2018. LumiWatch: On-Arm Projected Graphics and Touch Input. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, Montreal QC, Canada, 1–11. https://doi.org/10.1145/3173574.3173669