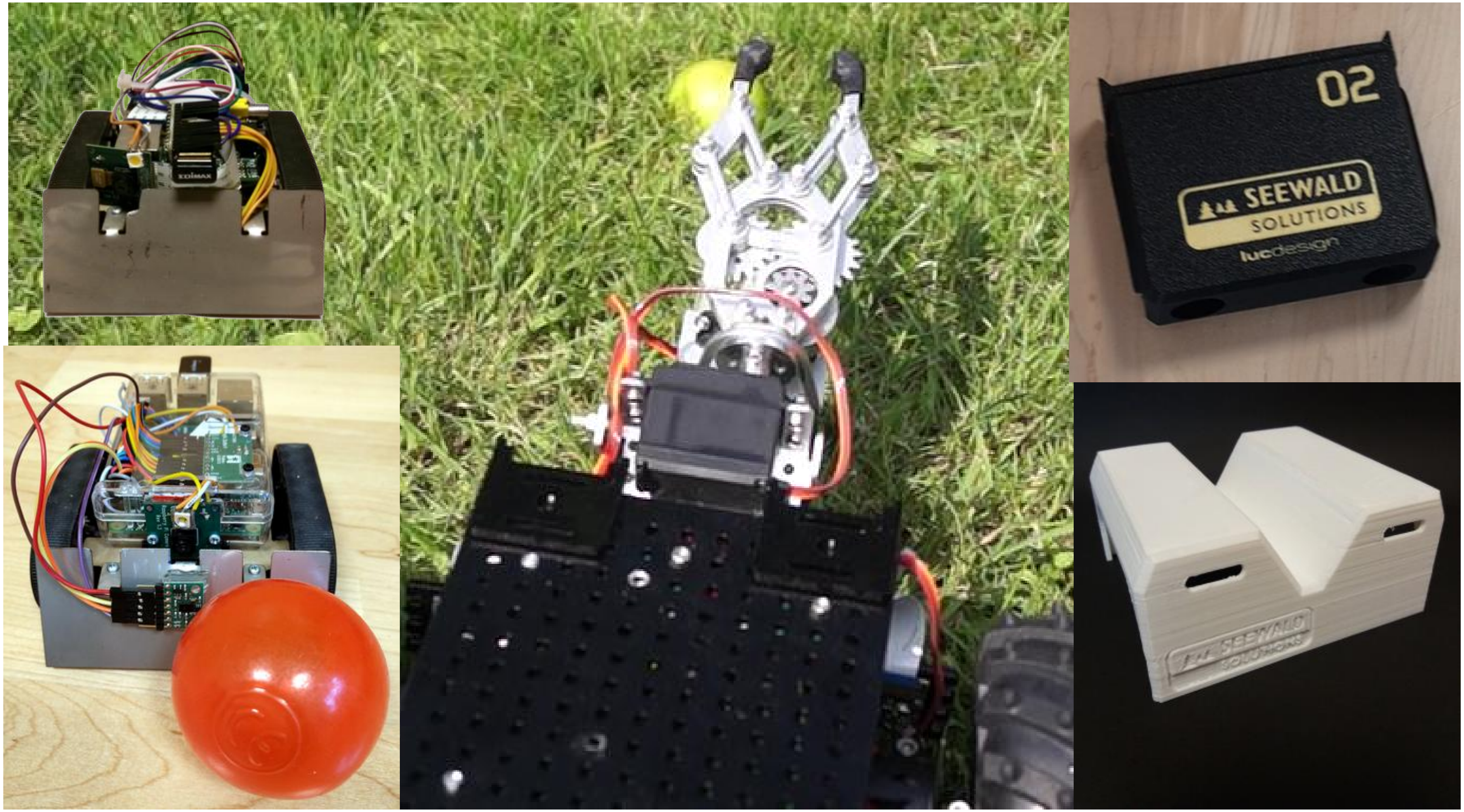
ToyCollect



An Open Source Robotic Platform

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What is ToyCollect?

Series of robots we have been building since 2014

- Open Source Software & off-the-shelf hardware
- All plans also Open Source
- Self-assembly (some soldering required)
- Using (at least one) camera(s)
- Various control mechanisms

Based on Raspberry Pi

- cheap (~ 25-35US$) ARM device
- low power (~ 75-125mA)
- small (large matchbox)

First Use Case: Recover toys from under the couch

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ToyCollect Original Video (2014)

Video

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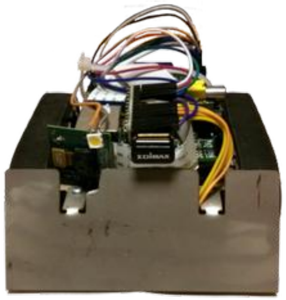
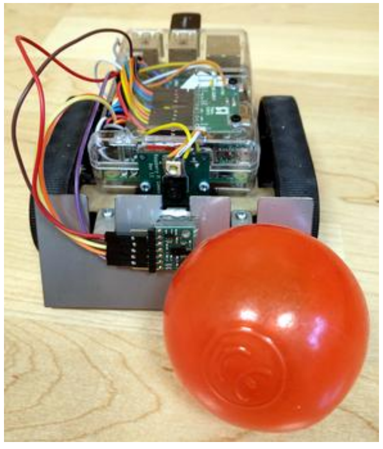
ToyCollect Generations (1)



v1.0 (2014)

- 2.4Ghz WLAN has choppy video under couch
- Camera is placed asymmetrically: hard to control
- LED too weak, range too small - too dark!



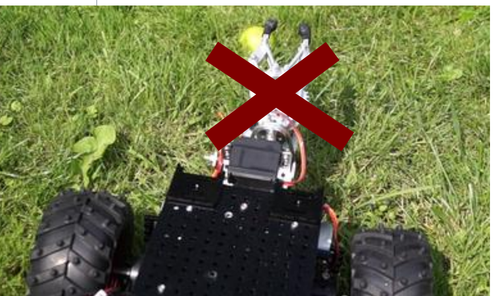
v1.1 (2016)

- 5.0Ghz WLAN - works perfectly under couch!
- Rechargable Batteries!
- New LED: now sufficient to work in darkness
- Center camera: 1.7x faster for benchmark task!
- 1.36min/toy for recovery (38min real-life test)

v2.0 (2016)

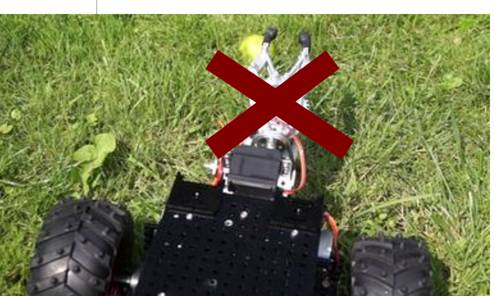
- Outdoor version for picking up fruit
- Compute module eval. kit with two camera ports
- Stereo cameras & robot arm
- Control via Google Cardboard & 2 Wii-Controllers

ToyCollect Generations (2)



v2.1 (2017)

- Removed robot arm
- New sensors: Ultrasound distance, GPS, accelerometer, magnetometer, gyroscope
- Depth camera (Asus Xtion)
- New remote controls: via head movements, bluetooth gaming controller and traditional driving wheel/gas/brake controller



v2.2 (*OUT*, 2018)

- Updated to Compute Module 3 (~ RPi 3B+)

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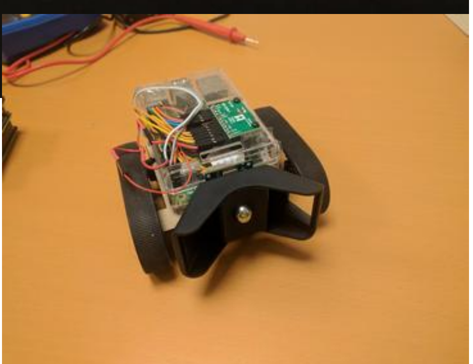
ToyCollect Generations (3)



v1.2 (2018)

- 3D-plotted chassis
- 2x RPi Zero stereo camera setup
- Just connect cables and clip in RPis.... very fast to build

v1.21 (*R2X*, 2019)

- 3D-plotted chassis (improved version)

v1.3 (*K3D*, 2018, modified from v1.1)

- RPi 3B+ and Kula 3D (3D from one camera)
- Can run simple DeepLearning models locally (e.g. obstacle avoidance)

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ToyCollect Generations (4)

v1.4 (2024-25)

- 3D-plotted modular chassis
  (Baseplate, 2x Fahrwerk, Bumper, Deckel)
- StereoPi V1 w/ RPi 3B+ and cooling fans
  Can run simple deep learning models locally
- 2x Stereo Camera & depth camera
- Mechanical bumper w/ microswitches (left/right)
- Magnetic encoders on both motors
- On/Off Switch & Step-Up voltage converter
  runs 2h from a single 18650 LiIon battery

v1.5 (upcoming)

- StereoPi V2 w/ RPi 4 (maybe also RPi 5)

ToyCollect robots can be built by school kids!

Building times for prototypes until final version

- v1.0: 3 weeks (hardware & software & testing) by Georg,16yrs
- v1.1: 1 week (hardware & testing) by Diana, 17yrs
- v2.0: 2 weeks (hardware & testing) by Diana, 17yrs
- v1.2: 2-3 days (hardware & testing) by Miriam, 16yrs
- v1.3: 1 day (modified old v1.1) by Leonhard & Julian, 16yrs
- v1.4/v1.5: probably similar to v1.2 (not yet tested)

Funded by local research agency FFG under Talente 2014-2019, 2023-2024.

Received national award for excellent supervision in 2018 and 2024 & one of my students was used for a nationwide campaign

Feedback by builders

Hello! ToyCollect is really a nice Project. (*Maurizio*)

Anyways thanks for this great project my 4 year old loves to push toys out from under her bed with it (*Chad*)

Thank you for sharing your toycollect project. I really like the idea of the immediate feedback from the robot by video (*Sander*)

- **Also mentioned on the Raspberry Pi Blog**
- **Video viewed several thousand times in first week**

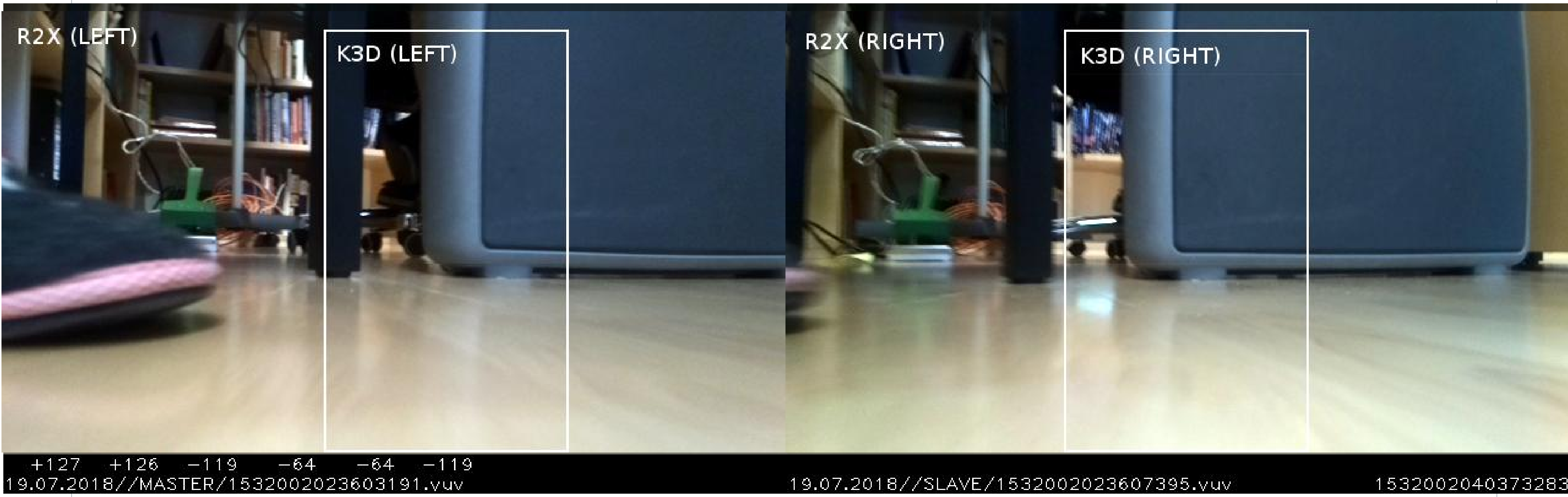
Milestones

Major milestones in ToyCollect development

- 07/2019: First autonomous obstacle avoiding robot v1.3/K3D with local deep learning model
- 12/2019: Streaming uncompressed low-res video via WiFi to a RPi 4 for v1.2/v1.21/R2X ~ around 4-8fps achievable
- 03/2020: Published a paper on our work at ICAART 2020, updated website and provided plans, models and source code.
- 03/2022: Published another theoretical paper on our work at ICAART 2022 (~ reanalyzing recorded data)
- 07/2024-08/2025: New 3D printed modular chassis which...
  - no longer needs Zumo robot platform w/ battery compartment
  - allows using a depth camera (Intel Realsense D410)
  - has mechanical bumper sensors & on/off switch
  - finally uses all the hardware we've already bought in 2017...

Field of View (FoV) - Stereo cameras

- Each stereo camera has 60° horizontal and 40° vertical FoV
- v1.3/K3D has a much smaller horizontal FoV - about one third - due to the double-periscope split of a single 60° camera



- Using two 120° cameras (e.g. RPi Camera Module 3 Wide) would also be an option to increase FoV

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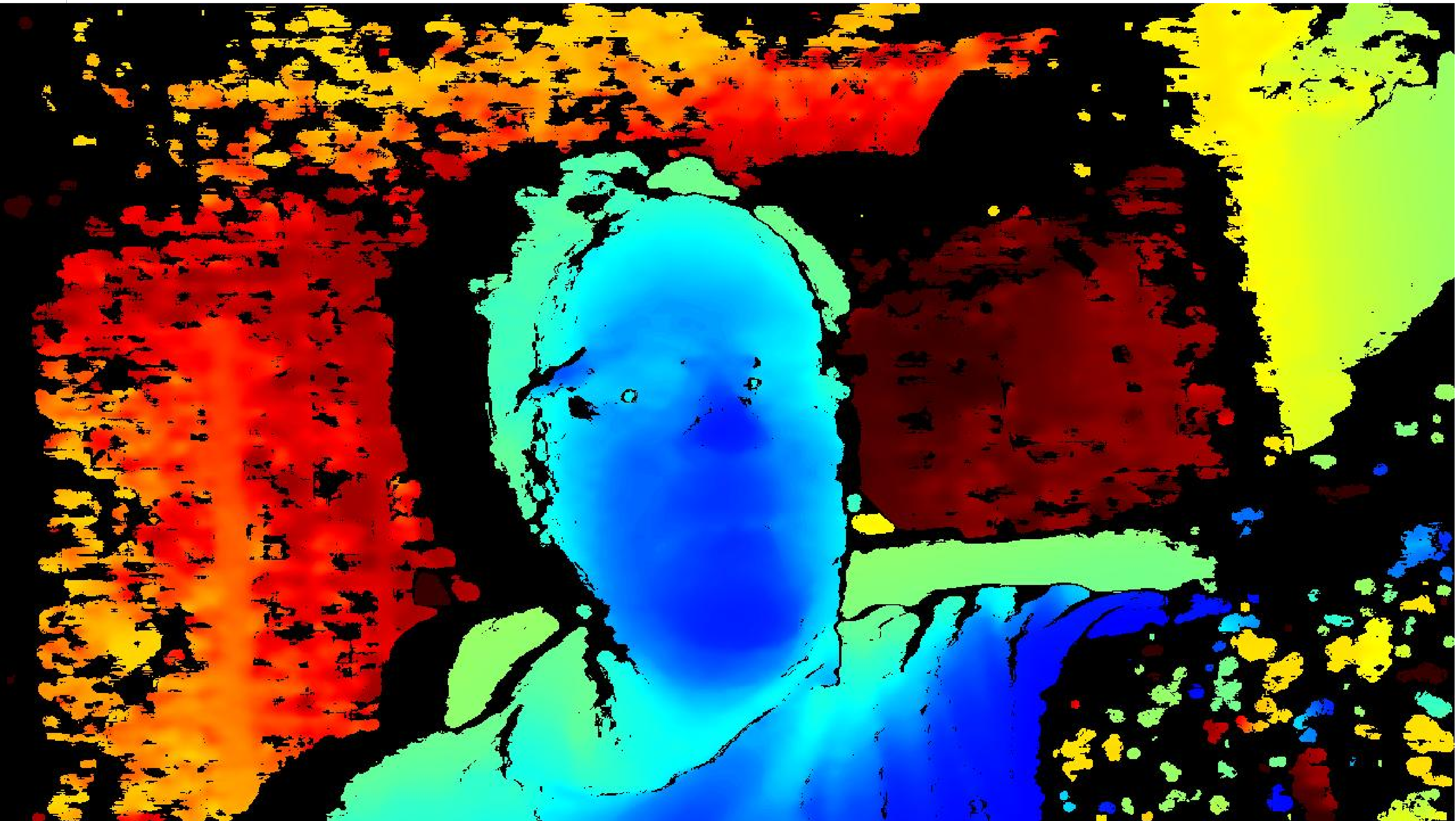
Field of View (FoV) - Depth camera

- The depth camera (D410) has a FoV of 65° horizontal and 40° vertical - about the same as one of the stereo cameras
- Centered between stereo cameras to maximize overlap



Using ToyCollect in Research

Seewald, A. (2020). *Revisiting End-to-end Deep Learning for Obstacle Avoidance: Replication and Open Issues*. In Proceedings of the 12th International Conference on Agents and Artificial Intelligence - Volume 2, ISBN 978-989-758-395-7, ISSN 2184-433X, pages 652-659. DOI: 10.5220/0008979706520659
https://www.seewald.at/de/02/2020/revisiting_end_to_end_deep_learning_for_obstacle

Seewald, A. (2022). *Evaluating Two Ways for Mobile Robot Obstacle Avoidance with Stereo Cameras: Stereo View Algorithms and End-to-End Trained Disparity-sensitive Networks.* In Proceedings of the 14th International Conference on Agents and Artificial Intelligence - Volume 3, ISBN 978-989-758-547-0, ISSN 2184-433X, pages 663-672. DOI: 10.5220/0010878500003116
https://www.seewald.at/de/02/2022/evaluating_two_ways_for_mobile_robot_obstacle

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Datasets

Name	Coll.by robot	Size	DL Train?	Qual. Eval?	Comments
Mixed	R2X	557,640	No	Yes	Indoors and outdoors near houses
Outside	OUT	51,735	No	Yes	Outdoors, fields, forests, small streets, walkways and trails
R2X_Train	R2X	70,745	Yes	No	Curated subset of *Mixed* and recorded on a single robot, includes only indoor scenes.
OUT_Train	OUT	27,368	Yes	No	Curated subset of *Outside*
K3D_Train	R2X	70,745	Yes	No	*R2X_Train* dataset restricted to field-of-view of K3D robot (see Fig. 2)

- Recorded directly on the different robots (except K3D)

- Consistent obstacle avoidance behaviour at same distance
- Straight runs and left/right avoidance equally represented

- Different environments and lighting conditions
- Large continuous sequences with minimal postprocessing

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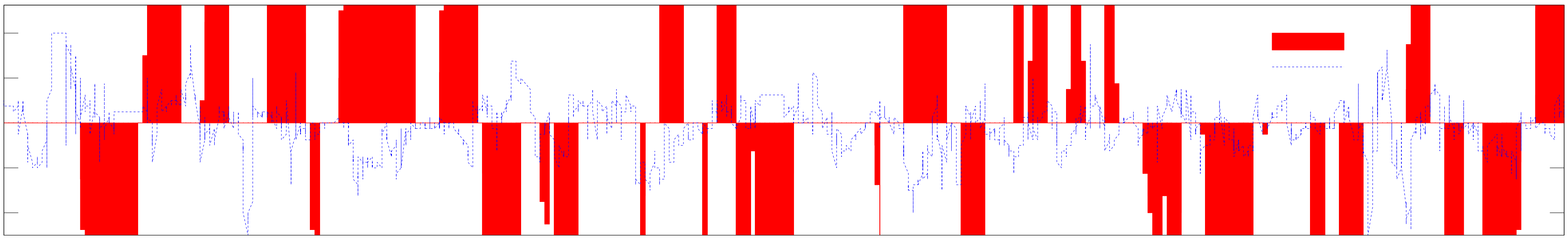
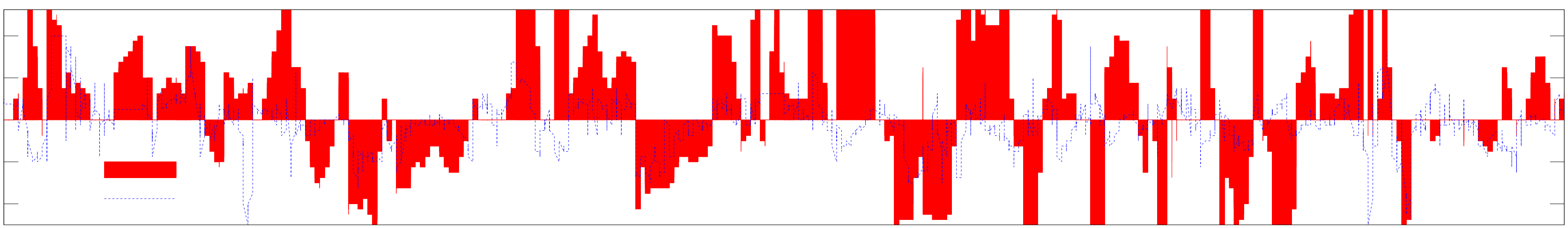
Deep Learning Stereo Camera Avoidance Model



Indoor / R2X

- Angles mostly follow human driver, but sometimes too small or in opposite direction (direction to evade *may* be arbitrary)



Outdoor / OUT

- Same as R2X, but much more diverse steering angles in outdoor setting, may be responsible for better performance

Qualitative Evaluation of Stereo Algorithms (1)

Table 3: Results of qualitative evaluation. Mixed: 56, Outside: 52 stereo views were randomly selected and manually analyzed by visual inspection. For definition of category labels see text. Last column: proportion of non-bad stereo views.

Stereo Alg.	**Dataset**	**bad**	**med.**	**good**	**Prop. ¬bad**
GC	Mixed	48	8	0	14.28%
BM	Mixed	51	5	0	8.92%
SGBM	Mixed	46	10	0	17.85%
SGBM	Outside	39	13	0	25.00%
HITnet	Mixed	25	29	2	55.35%
HITnet	Outside	19	32	1	63.46%

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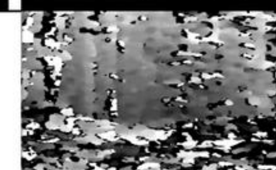
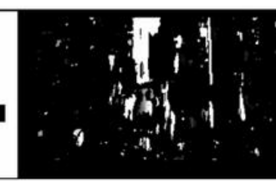
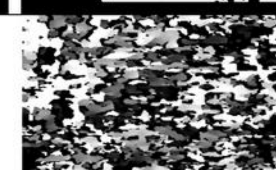
Qualitative Evaluation of Stereo Algorithms (2)

Table 4: Sample images for the three categories bad, mediocre and good.

Cat.	Dataset	Stereo views	GC	BM	SGBM	HITnet
good	*Mixed*					
good	*Outside*					
mediocre	*Mixed*					
mediocre	*Outside*					
bad	*Mixed*					
bad	*Outside*					

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Conclusions

- Performance of trained obstacle avoidance model not competitive to SLAM or specialized sensors

- State-of-the-art stereo view algorithms do not yet create useful depth maps for obstacle avoidance (~ 50% of frames not bad, only 3% good)

So we added a depth camera, mechanical bumper sensors and magnetic motor encoders to have three alternative ways to detect obstacles!

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Which robots can be built? (1)

Plans already available (on tc.seewald.at)

- **v1.0:** Zumo robot platform, RPi board mounted directly
  However camera is non-centred... please do not build!
- **v1.1,v1.3:** Chassis no longer available, must be replaced with a similarily-sized one that has outlets at the right positions. For RPi 3B+ and above cooling fan is essential!
- **v1.2:** No mounting screw connecting chassis to robot platform, so camera positions change on each collision... do not build!
- **v1.21:** Needs two RPi Zero W (or W 2) with angled back pins
  no heatsinks or active cooling; synchronization of stereo cameras suboptimal (+/- 50ms); motor controller obsolete

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Which robots can be built? (2)

Plans on request

- **v2.0:** The robot arm makes the chassis front-weighted, must compensate with lead counterweight; must use newer evaluation board for Compute Module (but any should work); needs Dagu robotics platform, lots of screws and **self-locking** nuts in different sizes (mostly M2.5, M2)

- **v2.1/v2.2:** Less front-weight problems, but additional weights are still recommended - the platform is so light it easily tumbles and flips. Using 4x2 ribbon cables for I2C ultrasound sensors works well but the sensors sometimes get lost in collisions...

Which robots can be built? (3)

No plans yet (upcoming <= 02/2026)

- **v1.4:** practically finished, **v1.5:** not well tested yet
  STLs and preliminary plans available upon request

Bumper microswitches

Magnetic springs

Depth camera

Flexible interposer cable (Alibaba.com)

Magnetic springs

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~~Future~~Finished Work

- ~~Integrate disparity computation into the DL network, enabling more complex correlation functions and optimizing patch size.~~

- Make R2X robot chassis fronts for common depth cameras and add one to enable quantative evaluations next year
  - ~~Sensible use for Jetson Nano (has only one camera port)~~
  - Can combine with StereoPi to get stereo cameras as well

- Add bumper ~~and acceleration sensors~~ to automate the generation of obstacle detection training data

- Use StereoPi for R2X Robot
  - Allows running local Deep Learning models on R2X
  - Allows using 120° wide-angle cameras without redesign

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Future Work

Automatically learn obstacle avoidance by self-training

- Using bumpers, stereo- and depth-camera, motor encoders

Write a paper on it and update all documentations

Additional brightness I2C sensor on top to finally solve the original "clean-up-under-couch" problem!

1) **Drive around randomly** until dark, then switch on LEDs
2) **DL model w/ camera(s):** movable and non-movable objects (could be trained using acceleration sensor)
   non-movable: avoid as obstacles ~ bumper
   movable: drive against them until bright again, then reverse
3) **until** certain amount of time has passed w/o movable objects (SLAM would be more elegant, but this should work ;-)

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Future Future Work

Switch from AutoDesk Fusion to FreeCAD

- It's the only software we use that's not Open Source...

Switching to Open Hardware as well?

- Motor controllers actually exist!
- Voltage converters are going to be tricky
- Electrical motors are going to be extremely hard

Baseplate variants for other depth cameras and platforms

- Intel Realsense D405 (but no active sensing)
- Jetson Nano

Prusa XL 3D Printer: Design print-head using conductive ink

- Get rid of (most) cables
- Create robot (almost) automatically in one single step

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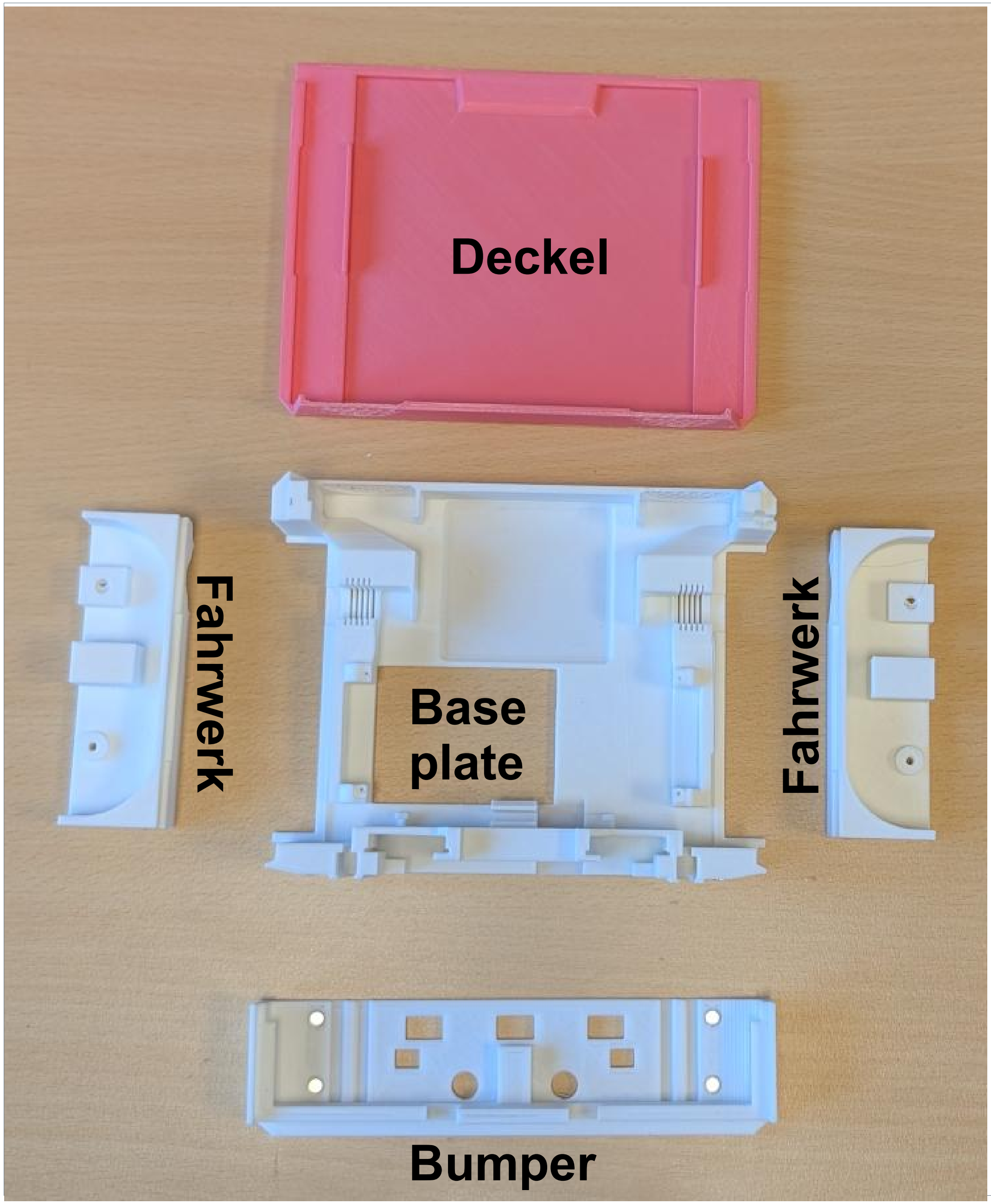
v1.4/v1.5 Modular Chassis & Live Robot Demo



Live Robot Demo

- Deep stereo-camera obstacle avoidance model (from 2020 paper)
- Fallback bumper sensors
- Fallback stalled motors
- Simple randomized avoidance behaviour

Any kind of collaboration is welcome!

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