FAARV –

Feasibility of testing relevant **A**DAS and AD scenarios

in an **A**ugmented **R**eality **V**ehicle

Public report

Project within FFI - Elektronik, mjukvara och kommunikation

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Content

1. Summary

For certain ADAS and AD test scenarios, a test platform which retains the precision and repeatability of the driving simulator, but at the same time allows for fully realistic (rather than scaled down) vehicle dynamics, is required to properly test and verify function performance with drivers in the loop. The aim of FAARV was to assess whether an Augmented Reality Vehicle (ARV) can provide such a test platform for those ADAS and AD test scenarios which are judged to be the relevant ones within the next 4-5 years.

The project had two work packages. WP1 was tasked with defining the ADAS relevant test scenarios for the next 4-5 years. Work in WP2 was targeted to determine for which of the WP1 scenarios a current state-of-the art Augmented Reality Vehicle provides a suitable test bed, and which future technical challenges such a platform needs to meet to fully cover all scenarios. WP2 performed it’s work through a series of workshops in collaboration with Swedish stakeholders, represented by SAFER partners, and the Japanese Automobile Research Institute (JARI), who has a world leading position in Augmented Reality Vehicle development.

The project has generated two outcomes. The first is an in-depth assessment and understanding of for which conflict scenarios an ARV can be used to test ADAS influence on driver behaviour with naïve subjects. The second is a strengthened collaboration with JARI, resulting in a planned future collaborative effort where both JARI and Swedish stakeholders apply to their respective funding institutions to develop an ARV platform for ADAS/AD testing that can be used in NCAP-type scenarios with naïve drivers in the loop.

2. Sammanfattning på svenska

Syftet med FAARV var att utreda om det är möjligt att använda ett Augmented Reality Vehicle (ARV) för att utvärdera förarrespons och upplevelse i kritiska trafiksituationer där fordonsdynamiken är av avgörande betydelse för hur situationen utvecklas, utan att utsätta förarna för någon verklig fysisk fara.

Projektet har haft två arbetspaket. Arbetspaket 1 har tagit fram specifikationer på de ADAS /AD test scenarier som är aktuella för provning inom de närmaste 4-5 åren. Arbetspaket 2 har sen genom ett antal workshops tillsammans med Japanese Automobile Research Institute (JARI, världsledande på den här typen av testplattform), arbetat vidare med att svara på frågan för vilka av dem ett ARV är möjligt att använda, givet att man strävar efter trovärdiga experimentresultat vid försök med testpersoner som inte arbetar

med fordonsutveckling. Arbetspaket 2 har även tittat på vilken vidare teknisk utveckling som krävs för att få plattformen att räcka till i alla scenarier.

Projektet har lett till två resultat. Det första är en grundlig analys av vilka möjligheter en ARV har som testplattform för ADAS/AD scenarier, och en tydlig kravspecifikation på vad en vidareutvecklad version av t.ex. JARIs implementation måste kunna klara av för att de scenarier som bedöms som relevanta inom de närmsta 4-5 åren ska kunna testas. Det andra resultatet är ett fördjupat samarbete med JARI. VCC planerar, tillsammans med andra svenska parter som är intresserade, att ansöka om ett FAARV 2projekt riktat mot ARV baserad ADAS provning med föraren i loopen i NCAP-typiska scenarier. JARI kommer att söka ett motsvarande forskningsprojekt i Japan, och båda projekten kommer att lyfta fram samarbetet Japan-Sverige som en tydlig styrka i respektive ansökan.

3. Background

It is generally believed that new and improved Advance Driving Assistance Systems (ADAS) will form a key part of the development required to reach vision Zero. For these systems to fulfil their full safety potential, robust validation and verification prior to deployment in the vehicle fleet is necessary.

However, something that currently is difficult to validate and verify, due to a lack of suitable test tools, is driver response to ADAS warnings and interventions in conflicts where vehicle dynamics play a key role for the outcome. This also holds true for test situations where the vehicle is under autonomous control, i.e. where one would like to study driver response and interactions when an AD vehicle gets into kinematically challenging situations.

An example would be emergency steering avoidance in a head-on conflict. While the development that leads up to such a conflict can be precisely created and reliably repeated in a driving simulator, not even the most sophisticated moving base driving simulators can fully reproduce the physical forces generated in a real vehicle during emergency steering manoeuvres, due to space and actuator constraints.

At the same time, staging a head-on conflict scenario on a test track with real vehicles poses a severe and unacceptable physical threat to test participants (ADAS are after all meant to address potentially life threatening situations), and also introduces undesired yet unavoidable variance in vehicle movements and positioning, weather, etc. Thus, to be able to study driver interactions with ADAS and AD under precisely repeatable conditions yet with full realism in terms of vehicle dynamics, there is a need for a test platform which retains the precision and repeatability of the driving simulator, but at the same time allows for realistic vehicle dynamics.

One way of realising such a platform is through virtual reality or augmented reality, where the visual and acoustic environment that is presented to the driver is either fully or partially computer generated. If such a visual and acoustic environment is realised in a real vehicle, scenarios similar to those found in driving simulators can be produced, but with real world vehicle dynamics.

The previous FFI project NG-TEST focused their efforts on developing and evaluating a Head Mounted display system for a virtual reality environment. Drivers were equipped with Occulus rift glasses and then drove a real vehicle while immersed in a simulated traffic environment. This project both established and answered many of the technical and practical questions associated with virtual reality based testing of ADAS (see e.g. the NG-TEST WP7 final report), so these will not be reiterated here. Instead, the focus here is on what can be perceived as complementary work to that performed in NG-TEST.

In driving simulator based ADAS testing, a common methodology is to make drivers perform a secondary task from time to time. This makes them take their eyes off the road for a couple of seconds, and that time window of visual inattention is then used to stage the ADAS relevant conflict scenario in front of the vehicle. When the driver looks back to the forward roadway again; the conflict is imminent. The same goes for AD related testing. A large portion of the attraction of AD is that it frees up time to do other things while the car is driving itself. To realize such test scenarios, the driver thus has to be able to engage in a multitude of possible secondary tasks, ranging from texting on their phones to eating and drinking or doing work on a computer.

Test driving with the NG-TEST system revealed that applying this type of secondary task protocol to studies which employ Virtual Reality displays gets complicated fast. First, in addition to the driving scenario having to be computer generated, a representation of the drivers body also has to be generated (looking down at an empty seat while driving is a rather uncanny experience). Also, the secondary task the driver is to perform has to be simulated. Whether the latter is a natural in-vehicle task, such as destination entry in a navigation system, or interaction with a portable device, that secondary task has to be computer generated graphically, and means for the driver to interact with it have to be provided, such as gloves with IR-reflective markers that can be tracked in 3D and then mapped in real-time onto the 3D-representation of the infotainment system. For some tasks, such as eating and drinking, a virtual representation is obviously not even meaningful.

These complexities are not trivial to resolve. FAARV was therefore conceived in order to explore the feasibility of developing and using Augmented Reality and a windshield mounted display system (as opposed to a head mounted, virtual reality, display system), for ADAS and AD testing. While technically more challenging to realise, it offers the advantage of realistic, real world, in-vehicle views and system interactions, i.e. all those things that would need extra soft- and hardware work to realise in s fully virtual reality system.

Of course, an alternative to the windshield mounted displays would be to use an optical, see-through, head mounted display system instead. In outdoor test conditions, these have so far suffered from severe enough brightness and contrast problems that they can be considered an invalid option for outdoor testing. However, new technologies are being launched this year, and so in a future FAARV 2 project; these should be revisited and assessed for suitability.

State of the art in ARVs

Another term used to describe a windshield mounted display systems is an Augmented Reality Vehicle (ARV). In an ARV, the driver is driving a real vehicle in a test track environment, where the visual input presented on the windshield mounted displays (i.e. the representation of the traffic environment) is generated from a mix of live forward facing camera feeds and computer generated objects superimposed on those camera feeds.

Currently, the JARI-ARV platform from JARI in Japan defines state of the art for ARV-based research in vehicle conflict situations. By mounting screens to create a 120 degree display on the bonnet of a real vehicle, and feeding those screens with a live video feed from cameras mounted in front, they have created a simulator with full dynamic realism. When the desired ADAS situations are to play out, the live video feed is overlaid with virtual, animated, objects which the driver then can interact with, even though they are not physically there. The setup is illustrated at JARI's ARV web page: http://www.jari.or.jp/tabid/139/Default.aspx .

JARI has done a lot of work with their ARV platform in lower speed scenarios, such as intersection conflicts. This is natural from the perspective of structural integrity issues that may arise at higher speeds and/or high G manoeuvres with a similar platform. It is also highly relevant from the perspective of display latency, a key issue for augmented display systems highlighted in the NG-TEST reporting. The merging of each live video feed frame with one or more simulated objects means there will be some form of delay before it can be displayed to the driver. Now, if there's a 100 ms latency in the graphics representation system, then at 30 kph a virtual object would "lag" about 0,4 m behind it's intended position. A key issue for the topic investigated in this project is how to deal with latency at higher speeds. While this probably could be ignored or compensated for in many scenarios, at 90 kph this becomes 1,25 m, which, especially in scenarios involving lateral displacement, probably must be dealt with in some way for the scenario to work out as intended.

4. Purpose, research questions and method

While augmented reality test platforms have been developed in several places, to our knowledge, no one had yet performed a full feasibility analysis regarding exactly for which of the currently relevant ADAS and AD scenarios a driver behaviour and interaction assessment can be performed using an ARV. The main objective of FAARV was therefore, in dialogue with JARI who kindly enough expressed an interest in having a dialogue about these issues with Volvo Cars, to fill this gap by describing which real world crash scenarios are possible stage and do ADAS and AD assessment of using ARV based methods and technology. FAARV also aimed to specify which improvements and developments would be required to ensure full scenario coverage. Thus, the two research questions to be addressed were:

1. For which kinematically challenging ADAS and AD assessment scenarios can a state of the art ARV be utilized?
2. Is further development of state of the art needed to make an ARV useful in all relevant ADAS and AD scenarios?

5. Objective

FAARV was formulated to deliver knowledge on to what extent an Augmented Reality Vehicle can be used to study driver interactions with ADAS, as well as drivers' perception of AD situational control, in critical scenarios where realistic vehicle dynamics are required to successfully predict and understand the situational outcome. Also, any technological gaps that need to be closed in order to extend the capabilities of the platform to cover relevant test scenarios were to be identified.

6. Results and deliverables

The project was carried out as a series of workshops in Sweden and Japan, with all workshop preparation work handled by VCC. The outcomes of these are shortly summarized below. For further information, see contact details at the end of this report.

Workshop 1 – SAFER, Sweden

The first workshop was held at SAFER in Gothenburg. All SAFER partners were invited to participate in the workshop, the aim of which was gauge interest for engaging in future, ARV based, research, and also to identify the set of relevant conflict scenarios that would form the basis for setting performance requirements on a future Swedish ARV platform.

In total, the first workshop had 17 participants, representing 10 different stakeholders from industry, academia and insurance companies. It was concluded that the proposed methodology was of interest almost all stakeholders. Furthermore, it was also concluded that intersection conflicts and oncoming vehicle conflicts were the key scenario drivers, and should be the focus of the technical assessment that was to take place in workshop 2 at JARI in Japan.

Workshop 2 – Jari, Japan

The second workshop was a two-day session held at JARI in Tsukuba, Japan. The aim of this workshop was to test drive the JARI-ARV and determine the technical feasibility of the intersection and oncoming scenarios specified in the first workshop at SAFER (i.e. to address research question 1 above). The focus was on discussing scenario setup criteria for intersection scenarios, as this is what JARI was generally able to demo based on previous work.

As it turned out, it was possible to identify several challenges for setting up a scenario where conditions are sufficiently similar to the real world to allow extrapolation of experimental results, yet which robustly lead to a surprising conflict detection and critical scenario response for the test person. This, by trying to answer research question 1 above, a number of answers to research question 2 were also formulated. These are described below.

Generation and Timing of visual obstructions in LTAP/OD scenarios (focus on turning driver)

The analysis of SHRP2 data in FAARV work package 1 (detailed scenario identification) showed that visual obstructions are present in 60 % of intersection conflicts. Also, the obstructing objects are basically always other traffic participants, not static road furniture (vegetation, signs, etc.). However, looking at the timeline for when the line of sight is blocked for the turning driver that crashes, it was clear that for the last 1,5-2,0 seconds before impact, the field of view was no longer blocked and the conflict vehicle clearly visible. Our hypothesis on why these drivers still crash is that the driver makes the decision to start the turn while the opponent vehicle still is not visible, and after that decision is made, the driver does not “update” the input used to make it.

Creating a test methodology protocol which robustly generates this decision to turn, and its corresponding lack of update due to a suddenly visible, clearly looming, vehicle, in test participants on a test track will probably be the major challenge for a FAARV 2 project. Also, a driver performance measure that is sensitive to this behavioural mechanism needs to be designed and used to measure implementation success.

Several techniques for setting up the scenario dynamics can be employed, including having a larger lead vehicle for the turning driver that may trigger “tag along” behaviour. One could also create highly salient and/or relevant events to the sides which may draw visual attention once the driver has started to turn, .e.g. a pedestrian on the left walking towards a pedestrian crossing which the driver will turn across, and hence somebody who the driver might need to stop for mid-turn. There is also the possibility to use kinemagics to hide the conflict vehicle as long as possible.

The above analysis puts the following requirements on the simulation used in a future FAARV 2 project:

- It must be possible to continuously control visual obstruction of the conflict vehicle by positioning other vehicles in front of the test subject vehicle at appropriate distances and angles
- It must be possible to apply kinemagic movement of the conflict vehicle (i.e. frame-by-frame repositioning that defies the laws of physics)
- It would be useful, but not required, to be able to trigger a conflict vehicle movement based on head/gaze tracking data in the subject vehicle. For example, only revealing the conflict vehicle when the drivers is looking to the side of the road to check e.g. a pedestrian.

Generating the real world view on the hood mounted displays

From the demo of the JARI-ARV, it was very clear that seeing the real world on screens led to a very high feeling of fidelity/immersion. The demo took place on a windy day in the fall, and seeing the tall grass sway on the road sides was very convincing. Also, the picture was generally good and stable. However, one thing that should be improved in a next generation would be to apply scaling/ warping layer software that compensates for the image skewing that naturally occurs with fixed lenses, to keep object size and proportions closer to what drivers naturally see.

Related to this, in recent work, JARI has found that while lateral control with and without the hood screens is similar, performance is less good when drivers are to make a controlled stop at a line or a cone. This is likely due to problems with scaling and warping, i.e. the line or cone does not have exactly the same visual properties on screen as in the real world, and hence is difficult to use for accurate stopping (at least when the outside world is the reference against which success is measured).

Also, if the vehicle is to be used for extended driving, e.g. 15-20 minutes before the critical scenario takes place, and if that driving is to involve turns rather than just going straight (a likely requirement for a LTAP/OD scenario, though less likely for a run-off-road or head-on conflict scenario), then the design of the field of view between A-pillars and B-pillars needs to be updated. First, unless the warping software works perfectly, the field-of-view on the screens probably needs to be extended all the way to the B-pillar. If not, when drivers look to the side to turn the same objects will be visible both at the edge of the screen and in the real world, but at different positions and with different proportions and contrasts. This really breaks the immersion, and should be avoided if possible.

Furthermore, to make a turn, the driver has to look down on the road and see the road markings. To integrate that view with the displays, one could have a low display as well, but that is probably not practical. Rather, some solution with a semi-permeable cloth could be applied, i.e. something which the driver can see the real lines through, but which reduces the difference in light between real world and screens to a sufficient degree.

The above analysis puts the following requirements on the simulation:

- Image warping that compensates for lens properties in relation to head position should be employed
- Extending FoV in the zone between A and B-pillar for tests which involve turning
- Reduce difference between screen and real world brightness in the zone between A and B-pillar where the driver needs to rely on lane markers to control vehicle in a turn

Generation of virtual vehicles overlaid on the real world camera views

The JARI rendering implementation of overlay of virtual objects on the real world was very fast, i.e. with lag times of max 50 ms and no perceptible delay. This speed should be strived for in a FAARV2 project.

The positioning of the virtual vehicles however needs to be approached in a new way to become fully robust. In the current setup, JARI relies on DGPS and digital maps to position all virtual objects relative to the test vehicle. However, at least in the JARI location, the DGPS signal has some noise in it. It is not much, but when the DGPS signal is used directly to position a virtual vehicle, that noise becomes visible as lateral flicker in the virtual vehicles (they kind of "vibrate"). The problem is most salient for virtual vehicles far away, and then decreases as one approaches (i.e. when the virtual vehicle increases in size, the ratio between noise error and object size shrinks). JARI has tried to address this by filtering the DGPS signal, but this introduced too large delays in the vehicle positioning.

Two possible approaches need to be investigated in a FAARV 2 project. One would be to create a noise free DGPS signal. The other would be to tie the subject and virtual vehicles to another positioning system that relies on DGPS for input but not for absolute positioning. For example, it could control the virtual vehicles according to a representation of the road network where the lateral component of vehicle movement is locked to a lane centric path, and thus cannot flicker laterally even if there is DGPS noise.

The above analysis puts the following requirements on the simulation:

- Delay due to rendering of virtual objects on real world images should be 50 ms or less
- Control of virtual vehicle position should be implemented such that its position is stable and does not flicker, even if there is noise in the DGPS (or other positioning means) input.
- See if virtual vehicle scaling can be improved, and increase the sense of realistic depth

Since the FFI project CHRONOS is dealing with the same issue, a FAARV 2 project should seek cooperation with CHRONOS to see what joint goals and requirements can be set and met.

Moreover, JARI indicated that while the current overlay rendering works very well, it is also quite old (3-4 years) and because computer graphics is a fast moving field, it would probably be worthwhile to redo the implementation with the new SW/HW tools that are available, for example by porting the setup to UNITY which is a flexible simulation platform on the rise.

Workshop 3 – SAFER, Sweden

The aim of the second workshop at SAFER was to, given outcome of WS1 at JARI, go through the identified challenges and assess if these could be resolved in a future FAARV 2 project. A second aim was also to find out who would be interested in joining a future FAARV 2 application for creating an ARV test bed at e.g. AstaZero.

The same set of stakeholders as for the first WS were invited to the workshop. Multiple stakeholder expressed their explicit interest in joining a future FAARV 2 project application; clearly the proposed methodology would fill a gap in most of the research institutes' test portfolio.

To further enable stakeholders to judge for themselves what an ARV platform can offer, it was also decided that for the second workshop at JARI; all who would be able to secure their own travel funds were most welcome to join the test driving and discussion of future collaborative efforts at JARI.

Workshop 4 - JARI, Japan

The second workshop at JARI on May 11th 2017 turned out to be a great learning and discussion opportunity. Beyond Volvo Cars, researchers from Autoliv, VTI and Chalmers were also present. The morning was spent test driving two intersection conflict scenarios in the JARI-ARV at the JARI test track. The afternoon was spent discussing how to set up a collaborative effort that can leverage the knowledge on ARV testing which JARI has gathered over the years into a FAARV 2 project, with the aim of building a similar vehicle and methodology at AstaZero, but where JARI still feel they are getting something worthwhile out of the collaboration, not just transferring their knowhow.

It became clear during discussions that JARI has decided to develop their ARV methodology in the direction of J-NCAP style testing of ADAS. The Swedish participants agreed that this would be a good direction to take also for a Swedish project in the same style. Euro-NCAP and J-NCAP have very similar test scenarios, so this should be doable at AstaZero. Moreover, since the scenarios are precisely defined, focus can be on how to make them work rather than on what they should be.

This focus also opens up a possibility for the Swedish partners to offer something that would benefit JARI in a collaborative project. Both Volvo and Autoliv have in-depth knowledge of current production ADAS; something which JARI has limited/no access to. Of course, the actual implementations are proprietary, and cannot be distributed as they are. However, it may well be possible to calculate/simulate their performance in a particular (NCAP) test situation, and then share this information on what the ADAS would do in exactly that situation within a collaborative project without violating IP and other agreements. This will of course need further investigation to make sure that it can work.

Given the focus on NCAP and ADAS, it also follows that a key aspect of the collaborative work would be to solve how to represent ADAS functions in the ARV test environment. Very concretely, the virtual conflict objects have to be made visible to the system sensors. This is essentially the equivalent of target design for standard NCAP testing. Also, non-production functions might be interesting to study, and these then need a computational “home” where they can compute threat levels and trigger HMI/actuators. Resolving this in the best possible manner will require a lot of thought, and will form a significant portion of a collaborative project.

As for timing, JARI indicated that they will apply for Japanese research funding to start their journey toward ARV-based NCAP testing sometime in the fall of 2017, with a likely decision on project approval or not in early 2018. This would line up nicely with the writing of a FAARV 2 application, where a realistic submission date would be somewhere in November/December 2017, and a reply from evaluators in early 2018. It was agreed that we if possible should share our application drafts to harmonise problem descriptions and highlight gains which are to be had from the collaboration, to promote the impact and outreach of each respective project.

From Chalmers, it also became clear that a future FAARV 2 project ties in nicely with the ongoing DIV- project (divproject.eu), which currently is running with a similar goal and has an explicit NCAP focus. As DIV is expected to complete during the fall of 2017, the lessons learned there would form very valuable input to a FAARV2 application which most likely could be ready for submission in November/December 2017.

Contribution the FFI program - Elektronik, mjukvara och kommunikation

The program Electronics, Software and Communication aims to contribute to a global leadership in vehicle electronics and software, as well as increase competence in the areas of verification and development methods. In relation to these goals, FAARV has contributed by formulating a clear set of requirements which an Augmented Reality

Vehicle platform needs to meet to be useful for the of study driver interactions with ADAS, as well as driver perception of AD situational control, in critical scenarios where realistic vehicle dynamics are required to successfully predict and understand the situational outcome. A platform that can be used in this way does not exist in Sweden today, and FAARV has taken the first steps toward realising such a platform at a Swedish test centre, i.e. AstaZero.

As a result of FAARV, an in-depth collaboration with JARI has also come about, where the expertise of JARI will contribute to the development of a Swedish ARV platform. This is a very important part. The lessons learned and experiences gained at JARI during their 10 years of working on this concept will be invaluable and shorten development time on the Swedish side considerably.

Overall, the goals that FAARV set out to meet have been met. The prerequisites for developing an ARV in an AstaZero context have been identified, and it seems like the requirements which the identified conflict scenarios place on the platform can be met through technological development.

On an unexpected and positive side, the test drives at JARI proved to be even more valuable than initially thought. As reported by all who participated at the second workshop at JARI, it is very difficult to imagine what driving an ARV will be like. First-hand experience is both necessary and very useful input for those who are to formulate the next FAARV application.

On the negative side, it was not possible to publish a joint paper with JARI on the platform performance, as initially planned. The basic idea, which was to compare driving with and without the screens on the hood in place, had already just been done and published by JARI, so it was not possible to repeat that setup.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	
Be passed on to other advanced technological development projects	X	
Be passed on to product development projects		
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

It was not possible to publish a joint paper with JARI on the platform performance, as initially planned, so there are no publication from FAARV, except this final report.

8. Conclusions and future research

FAARV was principally setup as a first investigation into whether it would be worthwhile pursuing the idea of building an ARV in Sweden to be able to test ADAS and AD scenarios where proper vehicle dynamics are key to the outcome. The outcome of the project is a clear yes; it would be worthwhile, and while the technical challenges are non-trivial, they also seem surmountable. The next step is therefore to apply for a FAARV 2 project and start working toward such a realisation.

Also, while formally a vertical project under the FFI umbrella, the project has been largely cooperative with multiple other stakeholders than VCC contributing their time and input. Basically, when a topic is interesting enough, people commit to it. The vertical formal structure of the project has thus not been a hindrance (this was a potential issue that was brought up at project evaluation). Of course, with the new pre-study format offered by FFI, this is no longer an issue for any future, similar, efforts.

9. Participating parties and contact persons

FAARV was carried out by Volvo Car Corporation.

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