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University of Agriculture in Kraków

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REVIEW

of the doctoral dissertation by MSc Sunil Khatiwada entitled: “Exploring social complexity and the benefits of social relationships in domestic pigs”, carried out at the Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences, under the supervision of Dr hab. Irene Camerlink and Dr Simon P. Turner.

The basis for the review of the doctoral dissertation by MSc Sunil Khatiwada is a letter from Prof. dr hab. Agnieszka Wierzbicka - Director of the Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences in Poland, dated 9 February 2026.

Candidate Information

Mr Sunil Khatiwada, according to the academic CV, obtained a BSc degree in 2013 at Tri-Chandra Campus, Kathmandu, Nepal. In 2020, he was awarded an MSc degree at Tribhuvan University, Kathmandu, Nepal, and, as stated in his CV, in the same year he was also awarded an MSc degree at the University of North Carolina at Chapel Hill, North Carolina, USA. According to his academic CV, Mr Sunil Khatiwada is a doctoral candidate at the Doctoral School of the Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences (IGBZ PAN), Jastrzębiec, Poland.

Information on whether the Candidate has previously applied for the doctoral degree

The declaration submitted by MSc Sunil Khatiwada indicates that the doctoral dissertation presented for review has not previously been used in any procedure for awarding the academic doctor degree.

Formal aspects, including the structure of the doctoral dissertation

The doctoral dissertation submitted for evaluation, entitled: “*Exploring social complexity and the benefits of social relationships in domestic pigs*”, consists of a thematically coherent series of four scientific publications together with a very detailed manuscript of 76 pages, in which the key issues contained in the publications forming the basis for applying for the doctoral degree are presented in an integrated manner. In addition, copies of the four scientific articles constituting the core of the doctoral dissertation were included.

I assess the structure of the doctoral dissertation submitted for evaluation, in the form of scientific publications accompanied by a manuscript – describing these publications, as correct; however, in my opinion the manuscript - summary itself is excessively extensive.

The following four thematically related scientific publications published in international peer-reviewed scientific journals constitute the basis on which MSc Sunil Khatiwada applies for the doctoral degree in the discipline of animal science and fisheries:

1. **Sunil Khatiwada**, Victoria E. Lee, Simon P. Turner, Irene Camerlink: Trade-offs between proximity and physical contact during group integration in pigs (*Sus scrofa domesticus*), *Current Zoology*, 2025, <https://doi.org/10.1093/cz/zoaf056>
2. **Sunil Khatiwada**, Victoria E. Lee, Simon P. Turner, Irene Camerlink: Temporal social network structures based on snout contact during group integration in pigs, *Applied Animal Behaviour Science*, 2025, <https://doi.org/10.1016/j.applanim.2025.106838>
3. **Sunil Khatiwada**, Simon P. Turner, Marianne Farish, Irene Camerlink: Leadership amongst pigs when faced with a novel situation, *Behavioural Processes*, 2024, <https://doi.org/10.1016/j.beproc.2024.105099>.
4. **Sunil Khatiwada**, Piero Seddaiu, Aneta Jaszczuk, Irene Camerlink: Is social support mediated by social relationship strength in pigs? *Animal*, 2025, <https://doi.org/10.1016/j.animal.2025.101693>.

The cumulative impact factor of the above-mentioned publications forming the basis for the doctoral degree application is 9.8, and the number of MNiSW (Polish Ministry of Science and Higher Education) points is 470. These indicators, as is commonly accepted, are important in proceedings concerning academic degrees. For the development of the discipline of animal science and fisheries, however, in my opinion greater weight should be attached to the novelty of the ideas presented within the doctoral dissertation, the real expansion of the existing state of knowledge, and the research methods applied in order to obtain the results of the studies conducted; therefore, I shall base my review primarily on these three pillars.

It is worth emphasising that the research for this thesis was conducted at the Animal Behaviour and Welfare Department, Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences, Jastrzębiec, Poland, and at Scotland's Rural College (SRUC), Easter Howgate, UK. The research was conducted within the project entitled: The importance of social relationships and social bonds for animals' behavioural expression, health and fitness - pigs as a model to explore the underlying physiological mechanism, funded by the National Science Centre (NCN), Poland, project number 2020/39/B/NZ8/02508.

Evaluation of the dissertation

1. Evaluation of research hypotheses and objectives

In the summary of the publications, hypotheses and objectives were presented separately for each publication; however, when reading the publications themselves, it is difficult to find explicit research hypotheses in them. Was presenting them in the manuscript describing the publications therefore necessary? In my subjective view, this is somewhat excessive and not entirely needed. On the other hand, their use in order to emphasise the purposefulness of the studies conducted during the discussion of the results appears justified and necessary. Nevertheless, it must be stated unequivocally that the research hypotheses presented were formulated correctly and that the objectives correspond to those contained in the publications. The research objectives were also presented by the candidate in a correct, logical and justified manner. It is worth emphasising that the research objectives adopted by the

PhD candidate are innovative. Research on hierarchical relationships in domestic pigs has thus far most often been reduced in practice almost exclusively to fights, their duration, frequency of occurrence, or, at most, the length of time fights lasted from the moment a new group of pigs was formed. The doctoral candidate, however, clearly goes beyond these well-worn patterns by setting the following objectives, characterised by a new perspective on the issue of relationships between individual pigs. In Publication 1, the aim of the study was to determine how frequently close snout proximity and direct snout contact occur in pigs during social interactions, and what potential benefits may arise from these behaviours for individual animals. In Publication 2, the aim of the study was to investigate how pigs rebuild social relationships after being re-grouped, with particular emphasis on social preferences and patterns of subtle social interactions in this context. In Publication 3, the aim was to analyse the occurrence of leadership in domestic pigs and the factors associated with it in a potentially stressful situation. In Publication 4, the aim of the study was to examine whether the behavioural and physiological responses of pigs exposed to a stressor depend on the strength of the social bond with the partner present during the event. All the above research objectives are united by a distinctly new and original approach to the subject matter. In my opinion, all of them are extremely interesting; however, what deserves particular recognition in my view is the attempt to identify leadership traits in pigs, especially in the context of the fact that we too often forget about the origin of pigs and, in many cases, fail to remember that the domestication of the wild boar has not brought about major changes in the behaviour of the domestic pig as compared with its ancestor, the wild boar.

To sum up, I assess this part very highly. In the case of the publications presented, conceptualisation was not solely the work of the doctoral candidate; however, at this stage of scientific development this is absolutely not required. Personally, I somewhat regret that, in the course of such extensive and modern research, no objective was set to analyse the phenomenon of altruism in pigs, but perhaps this is an idea for future interesting studies by the doctoral candidate and the entire team.

2. Evaluation of the research methods applied

The “Materials and Methods” chapter of the manuscript, presents a high level of detail and covers a broad spectrum of experimental procedures and statistical analyses. The complexity and technical correctness of the research methods applied deserve emphasis. Certain inconsistencies and omissions arise primarily from the fact that the doctoral dissertation is based on four publications rather than being a monograph in which all studies were planned to be carried out in the same research facility. Nevertheless, in writing the summary the doctoral candidate demonstrated a good command of experimental methods and statistical analyses. Coherence between the research assumptions and the methods applied is evident. As mentioned earlier, some inconsistencies concern primarily the non-uniformity of methods between experiments; however, on the other hand, this cannot be regarded as an error, because the aims of the studies presented in the individual publications were different. The implementation of the studies and the acquisition of data at different centres (SRUC vs IGBZ PAN), the conduct of the studies in different years, and the variability of pig crosses (different crossing schemes in different publications) - Large White x Landrace sows x Danish Duroc boars - publication 1; Large White x Landrace sows x American Hampshire boars - publication 2; (Large White x Landrace) x American Hampshire - publication 3; and Puławska breed - publication 4 - may raise certain concerns. In my opinion, however, if we state that, in general, the behaviour of domestic pigs and wild boar does not differ significantly, it may be assumed that the use of different domestic pig breeds in behavioural research does not constitute a substantial error preventing correct inference, especially as the aims of the studies in the individual publications were different. I assess very highly the methods applied for observing animal behaviour, as well

as the statistical methods used. In both cases, appropriate knowledge and skills are required. All statistical analyses described in the publications and in the summary were carried out in the R statistical environment (Publications 1-2 and 4: R version 4.3.2; Publication 3: R version 4.1.3). In Publication 1, mixed modelling was applied. The statistical methods presented in Publication 2, in which social network analysis was conducted, deserve particular attention. The group of pigs was treated as a social network. Interactions between animals, for example snout contact, were analysed. At group level, the overall structure was examined: whether one pig dominated (centralisation) and whether subgroups were formed. At individual level, the position of a given pig was examined, including whether it initiated contact more often or received it, and, finally, whether it was “important” within the network. Within the research presented in Publication 2, data from live observations alone were compared with video observations. In the case of this publication as well, mixed models were used to examine the effect, *inter alia*, of housing conditions and sex on network position, number of contacts, and role (initiator vs recipient). The methods applied are very modern (for example, social network analysis is gradually becoming a standard in behavioural studies of gregarious animals), and the statistical approach used is robust (including, among others, GLMM and permutation tests). In Publication 3, the data analysis was conducted on two separate datasets. The first dataset included repeated measurements for individuals over three test days in order to assess the repeatability of leadership. The second dataset included individuals with a binary classification (leader/follower), obtained in the first test in which a leader was clearly identified ($n = 289$ individuals from 26 groups). Due to the lack of a clear leader, six groups were excluded from this dataset. In addition, a second model was applied in which the dependent variable was latency to touch the human. In this publication, the intention was to determine whether leadership in pigs is a stable trait and what it depends on (body weight, sex, temperament). In the summary of the publications, the methods used in Publication 4 appear to be described least thoroughly. The main criticism concerns the fact that not everything was explained in detail. This applies in particular to vocalisation analysis and analyses related to cortisol. In this case, however, it is helpful to consult the original publication, where full yet concise explanations that are easier to follow can be found. This is not a major criticism, just my subjective opinion. In conclusion, I find that the research methods applied were not only correct and adequate for achieving the research aims, but were also very modern and well suited to the behavioural nature of the doctoral dissertation.

3. Evaluation of the discussion of the research results

The discussion of the research results is a very strong and solidly developed part of the presentation of the findings obtained in the four publications, in the form of the summary. On the basis of the results obtained in Publication 1, the Author draws attention to the fact that different forms of nosing behaviour, such as snout proximity, snout-to-snout contact and snout-to-body contact, may serve different functions. It is interesting that similar observations have been made in elephants, where the shape of the trunk during contact is considered to convey different meanings. On the basis of the results obtained, snout proximity appears to be more strongly related to social recognition, whereas direct snout-to-snout contact may be more indicative of social affiliation. Time, and therefore also the age of the animals, constitutes a natural confounding factor in relation to social stability. However, social behaviours remain to a large extent independent of age in juvenile pigs.

The results obtained in Publication 2 are extremely interesting and valuable because of their very high level of detail. This publication was carried out in order to investigate how pigs rebuild their social relationships, including social preferences, after re-grouping, and what the pattern of linkages between subtle social interactions is in this context. When pigs were

regrouped into new social groups, this process was usually associated with the re-establishment of dominance relationships in order to achieve social stability and it affected several group-level indicators in social networks based on snout contact. These changes did not, however, significantly modify the overall network structure. The social network analysis conducted during the integration period, based on the frequency of snout contact, revealed several patterns at group level. Interactions appeared random, without a clear hierarchical organisation; the network was decentralised, and snout contact was distributed among individuals. Interactions were moderately outward-oriented, indicating a general motivation of individuals to engage in contact with others or to seek social information. Connections included all members of the group, creating indirect links, and the interactions were heterophilous, occurring more frequently between pigs originating from different litters and having different early-life experiences. In addition, at individual level, pigs showed a decrease over time in the number of social partners. Despite this decline in the number of social partners, the frequency of interactions increased at later stages, suggesting more frequent snout contact but with a smaller number of individuals. No lasting or strong partner preferences were observed at any stage of the integration process. It had been expected that snout contact would be frequent during pig regrouping, particularly as social stability increased, because of its potentially affiliative function. It was demonstrated that pigs formed strong social circles based on snout contact at the early stages of group integration, with interactions involving all group members. These interactions weakened somewhat as integration progressed.

What especially deserves emphasis and attention is that the social network analysis presented in Publication 2 revealed different behavioural roles of males and females. Males initiated snout contact more frequently, which indicates a tendency actively to seek social interactions and increase the frequency of contacts. This is an excellent example of the fact that domestication and subsequent long-term breeding work have either not changed at all, or have changed only to a minor degree, the natural behaviour of pigs inherited from wild boar, in which under natural conditions young males usually leave the family group and lead a solitary life, joining groups only during reproductive periods, which places them under different social pressures than females. Females, by contrast, more often occupied central positions in snout-contact networks. This may reflect their tendency to live in sister groups and their ability to maintain strong social bonds. By connecting with well-linked individuals, females may gain access to social benefits such as reduced aggression or stress and better access to social information.

The results obtained in Publication 3 are equally interesting and at the same time very well discussed. The findings of this publication contribute to understanding behavioural traits associated with group living. Here, as well as in the Publication 2, attention was drawn to the important role of females. In the discussion of these results, the role of female domestic pigs was compared with the role of female lines in orcas and elephants, where they play a central role in group leadership, particularly during periods of resource shortage. Leadership is associated with taking risks, for example by being the first to engage in an unfamiliar situation. In the test used (Human Approach Test, HAT), pigs that had had little contact with humans manifested this by approaching an unfamiliar person, which is usually regarded as a risky situation. The latency data showed that many pigs postponed touching the human until the third exposure, which indicates that the situation was indeed perceived as risky. Individuals identified as leaders exhibited clearly shorter latency than follower individuals. However, leadership was only marginally stable, because only in 6 out of 26 groups did a single repeatable leader occur over the three test days. Publication 3 did not demonstrate any significant relationships between coping style and leadership, nor between body weight and leadership. Interestingly, females were observed in leadership roles more often than males. Although the pigs were still young (6 weeks of age), previous studies have shown that juvenile female wild boar may form social

groups even in the absence of adult females. The further discussion was carried out in an exemplary manner, as evidenced by statements allowing for different possibilities, for example that pigs may use distributed leadership, in which roles are shared among individuals rather than performed by a single leader, and that it is possible that leadership in young pigs is poorly developed. The most important observation in this part of the discussion of results is yet another confirmation that the pattern observed in the Author's own studies is consistent with wild populations, in which mature female wild boar usually lead small groups, whereas males lead a solitary life outside the breeding season, which may once again demonstrate that domestic pigs do not possess behaviour that departs from that of their ancestors, as is sometimes suggested by contemporary breeders to justify husbandry systems that are unfavourable to domestic pigs.

Publication 4 concerned the potential benefits arising from maintaining social relationships by examining whether behavioural and physiological responses to a stressor depended on the strength of the relationship between the focal pig and its companion. It was hypothesised that pairs with a strong social relationship, created by continuously housing siblings together, would show weaker stress responses than pairs with a weaker social relationship, created by separating siblings for at least two months. In this context, it would also seem worthwhile to ask questions about altruism in pigs. As the Candidate emphasises, it is known that pigs are sensitive to the emotional states of other individuals and may respond to a stressed companion with increased proximity or freezing-like behaviour, and, as he rightly notes on the basis of the literature review conducted, it is possible that more intense distress, such as that induced by electric shocks, is required to elicit stronger social-support responses. The discussion of the results obtained in Publication 4 should therefore also be regarded as correct. There can certainly be no doubt about the doctoral Candidate's ability to conduct discussion, compare the results of his own studies with those of others, and justify the results obtained. When assessing the summary, I would like to draw attention to the conclusions already appearing within the discussion of results itself as heading-like statements. I consider this procedure very interesting and necessary. I assess very highly the discussion of results both in the original constituent publications and in the summary manuscript itself.

4. Evaluation of the references used

The publications used by the PhD Candidate contributed to the preparation of the introduction in the form of a literature review, thereby leading to a justification of the research aims and, most importantly, to an exceptionally clear discussion rich in explanations. The dissertation uses 161 bibliographic references, the vast majority of which (138) are scientific articles, including several of the latest ones from 2025. I therefore assess the selection of references very highly. It is somewhat surprising that only one of the doctoral student's publications is cited in the self-presentation, while all four are described and discussed. Was this a deliberate approach or an omission?

5. Information concerning the practical application of the research results obtained

The doctoral Candidate's research focuses on subtle social behaviours in pigs, such as snout-to-snout contact, spatial proximity, and the dynamics of relationships within a group after it has been re-formed. The results obtained indicate in particular that social behaviours are not secondary, but constitute an important element regulating both the level of welfare and production efficiency.

The most important practical significance of the results presented for review concerns the way animal groups are organised. Traditionally, pig husbandry has focused mainly on factors such as stocking density, access to feed, or environmental conditions, treating social relationships as a side effect. The doctoral dissertation under review, shows that the way in which pigs interact after groups have been mixed is of key importance for social stability. As found, in the first phase after animals are brought together there is a clear trade-off between avoiding conflict and engaging in social contact. This means that animals regulate their behaviour depending on the risk of aggression. In practice, this leads to the conclusion that housing systems should be designed in such a way as to allow contacts to be established gradually, for example by increasing space or limiting forced direct interactions in the initial period. Of great practical importance is the PhD student's finding that slower-growing individuals, which may be more vulnerable to the costs of increased physical interactions, appear to adopt non-tactile behaviours, such as snout proximity, to avoid direct contact. In contrast, snout contact is associated with better growth outcomes.

A second important issue is the possibility of using behaviour, including the willingness to establish social relationships, as an indicator of the animals' condition. In practice, this means that observation of social behaviour may be used as a complement to classical production parameters and, in the future improvement of the welfare of pigs.

Another aspect concerns the approach to the social structure of herds. Research based on social network analysis shows that interactions between pigs do not create simple hierarchical systems dominated by single individuals. Instead, they are dispersed and dynamic in nature. In practice, this means a need to depart from the simplified dominance-based model of herd management. Housing systems should rather support the possibility of multidirectional social interactions, which may mean that group size, pen structure, or the way new animals are introduced need to be reconsidered.

The findings concerning so-called social support are also of considerable importance. The presence of another individual changes an animal's behaviour in a stressful situation, but does not always lead to a reduction in the level of physiological stress measured by cortisol concentration. The composition of groups may therefore require greater precision, particularly in potentially stressful situations such as transport or a change of environment. Research on leadership additionally challenges intuitive assumptions that have so far been applied in pig husbandry. No clear, stable leaders or simple predictors of their occurrence, such as body weight or coping style, were identified. In practice, this means that group management cannot be based on identifying “dominant” individuals, because their role is variable and context-dependent. This may lead to greater emphasis being placed on managing the whole social system rather than individual animals. Taking the strength of social relationships into account can improve both the validity of behavioural studies and the welfare of pigs in various housing systems.

For the development of the discipline of Animal Science and Fisheries in relation to behavioural research, the introduction of social network analysis into research may have practical significance. This means moving from a simple description of behaviour to quantitative modelling of relationships between individuals. In practice, this opens the way to the use of modern technologies, such as video monitoring and real-time data analysis, which in the future may enable automatic detection of problems in a herd before they become visible at production level.

To sum up, the Candidate's research results may lead to two kinds of practical change:
1. Social behaviour should cease to be treated as a secondary element and begin to be perceived

as one of the key factors affecting health, welfare and production efficiency. 2. A change in the perception of hierarchical relationships in pigs: attention should not be focused only on fights and on leaders - the winners of those fights - but greater attention should be paid to more subtle behaviours that contribute to the establishment of social relationships as well as to their stability. The results obtained therefore have not only important cognitive value, but also, and perhaps above all, utilitarian value.

6. Evaluation of whether the doctoral dissertation constitutes an original solution to a scientific problem, whether it presents the Candidate's general theoretical knowledge, and whether it demonstrates the ability to conduct independent scientific work. Assessment of the Candidate individual contribution.

The innovativeness of the works constituting the doctoral dissertation of MSc Sunil Khatiwada may be assessed as clearly significant and as contributing to the development of modern animal science and applied ethology. The greatest value of the Candidate's assessed body of work lies in the skilful combination of several levels of analysis - from subtle social behaviours, through the structure of relationships within the group, to physiological and production consequences. In this case, the objectives of the individual scientific publications included in the doctoral dissertation were very well planned. There is no doubt that these articles are thematically convergent and mutually complementary. Such an integrated approach constitutes an important step forward in research on farm animals, because it makes it possible to move beyond the traditional, fragmentary description of behaviour and to view the functioning of the group as a dynamic system. As I emphasised earlier, particularly valuable is the consistent application of social network analysis, which in Mr Khatiwada's work does not serve merely as a statistical tool, but becomes a way of thinking about relationships between animals. Another major achievement is the demonstration that seemingly minor social interactions may have real biological and production significance. This opens up new perspectives for husbandry practice, suggesting that behaviour may be not only an indicator of welfare, but also a potential tool for herd management and the selection associated with that management. Such an approach has considerable application potential and fits into modern trends in precision agriculture. Equally important is the clarification of the role of social relationships in the context of stress and social support. The works of Mr Sunil Khatiwada make an important contribution to research on animal welfare, emphasising the need to take social structure and changes within it into account when designing housing systems and ways of dealing with pigs. Particularly important in the assessment of the series of four publications is the fact that carrying out such complex studies as those presented in the doctoral dissertation required enormous effort, skills, and also direct work with animals on the part of the Candidate. The multi-threaded character of the objectives necessitated many highly complex statistical analyses, and the very drafting of publications for renowned journals attests to the Doctoral Candidate's very good preparation for scientific work. Publishing studies that are thematically coherent yet address different aspects is sufficient evidence of the Candidate's scientific maturity. The publication of the main research threads in JCR-listed journals unquestionably attests to the Doctoral Candidate's high scientific level. This creates considerable opportunities for the publications forming part of the doctoral dissertation to be cited many times. Moreover, I would like to note that, according to the statements presented, in all four publications the Candidate played a leading role, which consisted primarily of the most important tasks: data collection, analysis and writing. This demonstrates the ability to conduct scientific research independently, as the result is the four publications discussed in this review.

The Candidate's contribution to the four publications constituting the doctoral dissertation was substantial. MSc Sunil Khatiwada was the first author of each of these

publications. He was responsible, among others, for data collection, curation, analysis, interpretation, and writing. There is no doubt that he played a leading role.

7. Reviewer's comments and questions

The doctoral dissertation is very extensive, and many complex statistical analysis methods were used to develop the research results. In the Candidate's opinion, were all of them absolutely necessary? Was there an excessive use of statistics? Many years ago, at the beginning of my research career, I was taught that the descriptions contained in the Materials and Methods chapter should be written in such a way that anyone reading the chapter could repeat the experiment. In the Candidate's opinion, does this principle still apply today and should it be followed? In the Candidate's opinion, could the use of different crossbreeding schemes in the reviewed publications have had any impact on the results achieved and, therefore, the overall conclusions drawn? The same question applies to the different locations of the research, and therefore the different housing systems, animal care methods, etc. Did this influence the final four conclusions presented in the doctoral dissertation? I partially answered these questions in my review, but I would like to hear the doctoral Candidate's opinion.

8. Conclusion

Taking into account all the issues discussed above and in particular the fact that novelty, research methods, and the real expansion of the existing state of knowledge I assess highly, I am authorized to state unequivocally that the doctoral dissertation submitted for review by MSc Sunil Khatiwada, entitled: "Exploring social complexity and the benefits of social relationships in domestic pigs", meets the requirements for doctoral dissertations as defined in art. 187 ustawy z dnia 20 lipca 2018 r. – Prawo o szkolnictwie wyższym i nauce (Dz.U. z 2018 r., poz. 1668, z późn. zm.).

Having regard to the points emphasised several times in the review - the innovativeness of the research conducted, including the much more detailed approach to social relationships in pigs, the very high methodological level of the studies carried out, the possibility of applying the results obtained both in practice (including the fact that pig behaviour can and should be perceived as a tool for herd management and the selection related to that management with respect to specific behavioural traits) and at the methodological level in order to improve the discipline of animal science and fisheries, which should make broader use of the advanced statistical analysis methods employed by the Doctoral Candidate, as well as the fact that the publications forming part of the doctoral dissertation were published in renowned scientific journals (and had previously been subject to separate reviews) - I hereby request the Scientific Council of the Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences in Jastrzębiec to award distinction to the doctoral dissertation of MSc Sunil Khatiwada.

Jacek Nowicki